EPRI

Electrostatic Precipitator Maintenance Guide

Volume 1 of a Two-Volume Set (E213676)

Technical Report

Plant Maintenance Support

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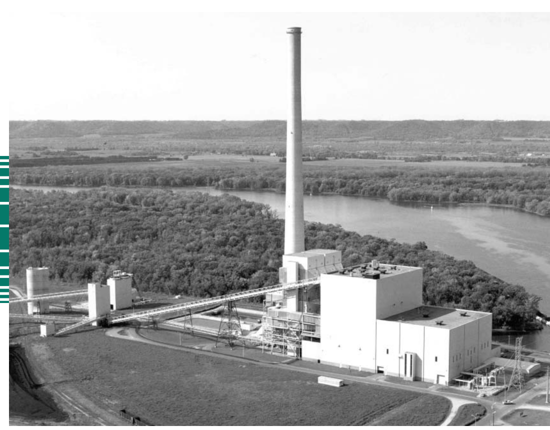

FMAC

Electrostatic Precipitator Maintenance Guide

Volume 1 of a Two-Volume Set (E213676)

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Final Report, February 2003

EPRI Project Manager
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REPORT SUMMARY

The *Electrostatic Precipitator Maintenance Guide* is directed towards electrical and maintenance personnel who have to maintain the precipitator and troubleshoot problems that occur during operation. The intent of this guide is to give the plant personnel guidelines for maintaining an electrostatic precipitator (ESP) for reliable operation.

Background
With increased restrictions on emission requirements and cutbacks in personnel that have been shown in the industry over the past several years, more responsibility of daily operation and maintenance of the precipitator falls into the hands of electrical and maintenance personnel. These personnel therefore need a better understating of the precipitator system and how its operation affects the entire plant.

Objectives
- To give a basic understanding of the fundamental theory and principles of electrostatic precipitation
- To provide guidelines on routine maintenance to maintain and improve the reliability and performance of the precipitator system
- To have a quick and easy reference for plant personnel on the maintenance requirements for each component of the system
- To give a basic understanding of how system changes can affect precipitator operation

Approach
The content of this guide mainly came from practical experience from the writer and associates, as well as from available guides that include past EPRI publications. A survey was sent to Fossil Maintenance Applications Center (FMAC) members to have them identify specific ESP maintenance issues experienced at their plant/utility. The results of this survey helped determine which issues were important to discuss in the guide.

Results
The guide includes information on the following topics:

- Background of ESPs
- ESP components and terms
- ESP theory
- Process effects on ESPs

- Maintenance practices
- On-line diagnostics
- Off-line diagnostics
- ESP components
- Control and instrumentation
- Penthouse/weather enclosure area components
- Hopper area
- Ductwork and casing
- ESP internals
- Safety system
- ESP maintenance program
- Outage maintenance planning
- Safety
- Effects of boiler system equipment and system modifications

Volume 1 ((1007436) of this two-volume set (E213676) contains Sections 1-4. Volume 2 (1007690) contains Sections 5 and 6 and the appendices.

EPRI Perspective
Providing plant personnel with accurate information concerning the maintenance of ESPs and the operational effects on them may prevent unneeded maintenance or forced outages from occurring on the equipment. The primary objective of the guide is to aid plant personnel in maintaining the ESP and all its associated components/systems. The guide focuses on providing detailed operational, testing, maintenance practices, and troubleshooting techniques on ESPs.

Keywords
Process variables
ESP controls
ESP maintenance
ESP components
ESP troubleshooting

ABSTRACT

A precipitator is used to remove all particles that are created in processes that occur at a fossil station. With increasingly strict emission requirements, the responsibility for daily operation and maintenance on a precipitator has gone to electrical and maintenance personnel.

The EPRI focus in this guide is predictive, preventive, and corrective maintenance aspects of the precipitator and its components with proper operation and troubleshooting. The information contained in this guide was gathered from the knowledge of the writer and the available literature, including past EPRI publications.

A survey was sent to FMAC members with precipitator systems, soliciting plant data to identify specific ESP maintenance issues experienced by the plant/utility. Eleven plants participated, and the information that was provided was used to analyze problems that various plants are experiencing.

The material presented in this guide will provide maintenance personnel with a better overall understanding of the precipitation process and a practical approach to maintenance of the precipitator and the auxiliary equipment.

Volume 1 of this two-volume set (E213676) contains Sections 1-4. Volume 2 contains Sections 5 and 6 and the appendices.

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1 INTRODUCTION

Much of the literature available on the subject of electrostatic precipitators (ESPs) is geared towards plant engineers and operators. The content of this guide is directed towards electrical and maintenance personnel who must maintain the precipitator and troubleshoot problems that develop during operation. With the increasingly more stringent emissions requirements and cutbacks in personnel that have characterized the utility industry in recent years, now more than ever, responsibility for the daily operation and maintenance of the precipitator falls to electrical and maintenance personnel. The intent of this guide is to provide these plant personnel with guidelines for maintaining an ESP for reliable operation.

The focus of the guide is primarily on the predictive, preventive, and corrective maintenance aspects of the precipitator and its components, including discussion of proper operation and problem diagnostics. Because the precipitator is part of a synergistic system, there is also discussion of basic ESP theory and factors that can or do affect ESP operation. Although not completely necessary to perform maintenance, some understanding of these issues will enhance the maintenance person's ability to evaluate precipitator operation. If the reader wishes to pursue these subjects in more detail, there are numerous publications available. References are included for this purpose.

The content of this guide was largely derived from the practical experience of the writers and their associates, and from the available literature on the subject, including past EPRI publications. There was no attempt made to reinvent the wheel. Where applicable, some of the materials were taken verbatim from previous EPRI ESP guides/manuals. In some instances, there may be information presented in this guide that differs from that found in previous EPRI ESP guides/manuals. As in most fields, there are differences of opinion and variations in approach. The information and recommendations presented in this guide represent the opinions of the writers.

1.1 Organization and Overview of This Guide

Section 2 is intended to provide maintenance personnel with a basic understanding of the fundamental theory and principles of electrostatic precipitation. It includes discussions of common precipitator designs and their components, and factors that affect precipitator performance (process and chemistry, design, environment). Efforts have been made to cover basic concepts and theory with limited use of mathematical derivations in order to save the reader time and enhance the utility of the guide. While the information in this section is important to understanding the precipitator system, maintenance of the precipitator can be performed without this knowledge. References are included if the reader desires to pursue a more comprehensive study of precipitator design and the precipitator process.

Section 3 includes a discussion of the two basic types of maintenance procedures in use today: *preventive* and *corrective*. Guidelines and techniques for evaluating precipitator systems, both on-line and off-line, are covered in detail. Where applicable, suggestions are made for corrective actions that can be taken to maintain and/or improve reliability and performance of the precipitator system. Start-up and shutdown procedures, and clean and dirty inspection procedures are also covered.

Section 4 discusses the components of the precipitator in detail, describing their function, maintenance requirements, operating procedures, and safety considerations. Also discussed, as applicable, are inspecting, evaluating operation, typical problems and modes of failure, troubleshooting and repair methodology, recommended spare parts, upgrade options, performance enhancements, and tips. The intent of this section is to provide maintenance personnel with quick and easy reference to information on the maintenance requirements of the individual components of the precipitator system.

Section 5 provides guidelines for routine maintenance in order to maintain and/or improve reliability and performance of the precipitator system. The guidelines are general in nature because of variations in equipment and design, control schemes, and process streams from plant site to plant site. However, they provide a framework for establishing good site-specific maintenance programs and practices. The important components of an effective maintenance program, planning for scheduled and unscheduled outages, and precipitator safety are discussed.

Section 6 provides brief discussions of how various boiler system equipment, process conditions, precipitator design, and modifications to them, can influence system operation, precipitator performance, and maintenance practices and procedures. Many of these changes and modifications are the result of the need to meet changing regulatory requirements. Also discussed are considerations for and when upgrading and/or rebuilding the precipitator. Although much of the discussion is not maintenance related, maintenance personnel should have at least a basic understanding of how system changes can affect precipitator operation.

Appendix A includes:

- The EPRI/FMAC Electrostatic Precipitator Maintenance Survey
- Results of the EPRI/FMAC Electrostatic Maintenance Survey that was sent to FMAC members in order to identify specific ESP maintenance issues experienced by the Plant / Utility

Appendix B includes:

- Examples of blank typical forms used for maintenance purposes
- Examples of field maps used for recording the location of potential problems
- Megger testing procedures

Appendix C includes:

- Troubleshooting table
- Troubleshooting flow chart

Appendix D includes:

- Examples of drawings of different manufacturers' designs

Appendix E includes:

- Examples of typical ESP problems and failures, including photographs

Appendix F includes:

- List of abbreviations used in this guide
- Glossary of ESP-related terms

Appendix G includes:

- List of reference materials, including those used in preparation of this manual, general ESP reference material, websites, and software

Appendix H includes:

- Table to assist in converting from English to metric units

Appendix I includes:

- Summary of the "Key Points" contained within this guide

1.2 Overview of Other Related EPRI Manuals and Guides

The following EPRI manuals, guides, and computer models on the subject of ESPs are also available.

1.2.1 Manuals and Guides

Electrostatic Precipitator Reference Manual. January 1983. CS-2809, RP-1402-4 [1].

The manual was written as an aid to utility engineers involved in the design, specification, purchasing, project management, and operation/maintenance of ESPs. The report summarizes the history and theory of electrostatic precipitation and contains an outline of steam boilers and their production of fly ash. The chemical and physical properties of fly ash are discussed in-depth with emphasis upon the affects of these properties upon ESP performance. Practical guides for the selection of ESP design and size are given, along with examples of commercial and technical aspects of equipment specifications. Sections are included covering the construction, operation, and maintenance of ESPs. Special attention is given to operating and performance problem diagnostics (troubleshooting). The report concludes with a discussion of future trends in the design and application of ESPs to electric generating plants.

Electrostatic Precipitator Guidelines, Volumes 1 – 3. June 1987. CS-5198, RP-2243-1 [2].

Volume 1 - Design Specifications

Volume 1 provides information to assist the utility engineer in the preparation of specifications to procure electrostatic precipitators. Further, the manual is intended to provide a framework within which the utility engineer can evaluate precipitator proposals. The manual includes discussions of ESP design principles; process parameter calculations; size selection; mechanical and electrical / control features; operation and maintenance related systems; specification preparation; inquiry, proposal evaluation, and contract administration; fuels other than coal; and the effects of dry scrubbers on precipitators.

Volume 2 - Operation and Maintenance

Volume 2 contains general guidelines for the operation and maintenance of ESPs that are used to collect the fly ash produced by electric utility steam boilers.

Volume 3 - Troubleshooting

Volume 3 is designed to provide troubleshooting assistance by identifying the types of problems that may be anticipated and developing procedures for evaluating possible alternative causes for a problem.

Guidelines for Upgrading Electrostatic Precipitator Performance, Volumes 1 and 2. 1999. TR-113582-V1 & -V2 [3].

Volume 1 - Optimizing an Existing Electrostatic Precipitator

Volume 1 of this two-volume set presents a systematic procedure to optimize a chronically under-performing ESP without conducting a major upgrade. The guide focuses on ESPs that require only moderate improvements to achieve their emissions goals. The objective of the guide is to provide plant operators and engineers with a systematic method for: (1) determining whether emissions limits can be achieved with an existing ESP or whether an upgrade will be necessary; and (2) diagnosing the cause(s) of ESP under-performance and identifying the best corrective actions.

Volume 2 - Electrostatic Precipitator Upgrade Options

Volume 2 assumes that the Volume 1 diagnostics reveal that the existing ESP, even when optimized, is still not capable of meeting reduced emission requirements. This volume presents more extensive and costly measures to meeting emission goals such as rebuilding the ESP (perhaps with additional plate area), adding a polishing device, or adding a new ESP or fabric filter, either in lieu of the existing ESP, in parallel, or in series. Volume 2 also discusses three simpler measures that were touched upon in Volume 1:

- Gas flow optimization
- Flue gas conditioning
- Replacing the power supply controls

1.2.2 EPRI Computer Models

ESPert ™ Electrostatic Precipitator Performance Diagnostic Model, Version R4.2. December 1994. AP-104690, SW-23359 [4].

ESPM™ Electrostatic Precipitator Performance Model. November 1993. AP-101592, RP 1402-59 [5].

There are several versions of the leading computer model for simulating the performance of an ESP. This model was initially developed by the Southern Research Institute (SRI) in the late 1960s; subsequent evolution to its current form was funded, in part, by the U. S. Environmental Protection Agency (EPA) and EPRI.

EPRI offers two ESP modeling packages, ESPM and ESPert, which are both built around the same core SRI-EPA-EPRI model, but differ from the original model and from each other in data entry routine. ESPM was designed to be more *user friendly* than the original model and places less of a requirement on the user to have a thorough, detailed knowledge of ESP theory and practice. ESPM uses approximations to replace some of the more detailed calculations included in the original version. Tests comparing ESPM with the original model show that the data developed by either model are suitable for analyzing the behavior of any ESP system and for predicting the effects of many optimization and upgrade options.

ESPert is designed for use as a data-monitoring package that works with the power plant data gathering system. Like ESPM, ESPert can be used to evaluate *what if* changes in plant/fuel parameters and ESP operation. In addition, ESPert serves as a useful tool for monitoring ESP operation and alerting plant personnel to potential problems. However, for conducting the optimization analysis in the Guidelines for Upgrading Electrostatic Precipitator Performance [3], EPRI recommends using ESPM due to its straightforward simplicity, unless you have experience using one of the other versions of the model.

The core SRI-EPA-EPRI model is based on the Deutsch-Anderson equation (discussed in Section 2.3), which describes the behavior of a particle with a known value of electrical charge in a given electric field being collected from a gas stream with fully developed turbulent flow, assuming an idealized uniform flow field. Empirical correction factors have been added to the model to account for the non-ideal conditions. These correction factors address non-uniform gas flow, gas *sneakage* around the treatment zone, through hoppers and the space above the collecting electrode assembly, and rapping re-entrainment (rapping re-entrainment correction factors were developed independently for hot-side and cold-side units). The correction factors were developed on the basis of particle size and loading measurements on several operating ESP units. The model has been validated through many measurements from operating full-scale and pilot-scale precipitators.

1.3 Highlighting of Key Points

Throughout this guide, key information is summarized in *Pop Outs*. Pop Outs are bold lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Pop Out is to emphasize information that will allow individuals to take action for the benefit of their plant. NMAC personnel and the consultants and utility personnel who prepared and reviewed this guide selected the information included in these Pop Outs.

The Pop Outs are organized according to the three categories: O&M Costs, Technical, and Human Performance. Each category has an identifying icon, as shown below, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point

Emphasizes information that will result in overall reduced costs and/or increase in revenue through additional or restored energy production.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent personal injury, equipment damage and/or improve the efficiency and effectiveness of the task.

Appendix I contains a listing of all key points in each category. The listing restates each key point and provides reference to its location in the body of the report. By reviewing this listing, users of this guide can determine if they have taken advantage of key information that the writers of this guide believe would benefit their plants.

1.4 How to Best Use This Guide

This guide was designed to be read in its entirety, yet still allow maintenance personnel to focus on specific subjects, particularly in regard to the discussions relating to individual components of the precipitator and their operation and maintenance. For instance, if problems are known or suspected to exist with the rapping system, it may be appropriate to go directly to that section of the manual. The component basis format results in some inherent redundancy between related topics. Knowledge of the material presented in the guide will provide maintenance personnel with a better overall understanding of the precipitation process and a practical approach to maintenance of the precipitator and auxiliary equipment.

The reader is encouraged to refer to the glossary in Appendix F of this manual for an explanation of terms that may be unfamiliar.

Note that since specific collecting surface area (SCA) is an industry standard term, no attempt has been made in this report to provide the SI conversions. To convert SCAs to the metric equivalent, multiply the SCA value by 0.197.

2
ESP FUNDAMENTALS

The section is intended to provide maintenance personnel with a basic understanding of the fundamental theory and principles of electrostatic precipitation. It includes discussions of common precipitator designs and their components, and factors that affect precipitator performance (process and chemistry, design, and environment). Efforts have been made to cover basic concepts and theory with limited use of mathematical derivations in order to save the reader time and enhance the utility of the guide. While the information in this section is important to understanding the precipitator system, maintenance of the precipitator can be performed without this knowledge. References are included if the reader desires to pursue a more comprehensive study of precipitator design and the precipitator process.

2.1 History of the Electrostatic Precipitator

The application of the ESP for the utility power plant has provided a fascinating journey over the last 80 years. Changes in the ESP equipment and process mirrored the growth of the pulverized coal-fired boiler in its complexity.

While much effort has been expanded toward understanding the complex theories of precipitation, a look back at history often points out that it is the simple ideas that consistently work well. These simple concepts on how to cope with the ESP will be stressed in the following sections.

2.1.1 The Early Years

Soon after the pulverized coal-fired boiler arrived, the first ESP was installed on this process (early 1920s). Precipitation had only been in existence for about 15 years in primarily the chemical and cement industries.

The early boiler houses, prior to about 1950, were relatively small and were often found in metropolitan areas. Since the boiler steaming rates were low, the sizes of ESPs during this era were also small enough to be placed either on the upper floor or roof of the building.

As a rule, the ESP was split into two fields and energized by two power supplies. These early power plant installations also had a number of common factors that helped provide a satisfactory collection performance in the 80 to 90% range.

- Exit flue gas temperatures from the boiler normally ranged between 350 to 450°F (178 to 230°C), which matched well with the higher sulfur coals of the era.
- The smaller size of sturdy internal components helped minimize mechanical failures in the ESP. Hopper difficulties were also minimized at the higher temperatures.
- But more importantly, the quality of coal, which came from deep mines, produced a smaller quantity of ash with characteristics conducive for acceptable electrical operation of the ESP.

An interesting development for these early precipitators was that the lack of ESP theory actually forced the field servicemen to study the process itself for help in the adjustment of performance. Thus, they became quite knowledgeable about the combustion process and how it affected the ESP. This knowledge, passed down among servicemen in the field, helped solve many performance problems in later.

2.1.2 The Golden Years

Probably the most interesting and challenging years for ESPs in the utility industry occurred between 1950 and 1960. Things began to speed up after World War II with a spurt in power plant construction in order to meet electrical demand. At the same time, research and development efforts to understand and improve the ESP were initiated, in major part by Dr. Harry White and his group at Research, Corp. (later known as Research-Cottrell). New manufacturers of ESPs also got started within the United States in an industry previously dominated by two companies: Research-Cottrell and Western Precipitation (later a part of Joy Manufacturing, Co.).

As boiler sizes grew during this decade, the ESPs kept in step with collection efficiency designs of 94 to 98%. While two electrical fields deep were still the most common layout, the height and number of gas passages increased to meet this higher performance.

It was also during this period that a number of changes occurred in ESP apparatus.

- Solid-state rectifiers replaced the original mechanical rectifiers in power supplies. This allowed the oil-filled tank to house both the rectifier and high-voltage transformer.
- The first automatic devices were applied for the voltage control of the ESP.
- A new breed of electric rappers was applied with emphasis on a continuous rapping mode. Rapping of the high voltage components became standard for the fly ash application.
- Flat sheets of light gauge steel became the standard collecting surface in the ESP.

But two other process changes during this period helped produce major detrimental effects on the performance of the ESP.

- Large quantities of surface coal entered the market from strip mining operations in the mid-western part of the country. This began to occur soon after World War II and this quality of coal, with higher ash/lower sulfur characteristics, tended to produce a high resistivity condition that resulted in low levels of power in the ESP.
- New boilers coming on line in the 1950s began to show flue gas temperatures of 270 to 300°F (132 to 149°C) at the exit of the air heater. This was about 40 to 50°F (4 to 10°C) below the norm of the times. A major reduction of ash resistivity occurred at these reduced gas temperatures when moderate to higher sulfur coal was used. The performance of the ESP was often reduced appreciably under this condition.

The problem with both of these conditions surfacing close in time was that most of the efforts were concentrated on the higher resistivity problems. Based on the well-established theory that higher sulfur in coal produced higher ESP performance, it was difficult to accept the opposite concept. This paradox of resistivity led to an important criterion for the ESP: *nothing is etched in stone*. Additional details of this resistivity phenomenon can be found in Section 2.4.

The mechanical cyclone collector was widely used to collect fly ash from both the utility and industrial boiler prior to the use of the ESP. In fact, some of the power plants in rural areas continued to use the cyclones alone for years after World War II. The decade of the 1950s also saw the mechanical collector placed ahead of the ESP as a method to cope with some of the performance problems that began to surface.

It was thought that the 60 to 70% collection efficiency obtained in the cyclones would stabilize the efficiency of the combined system. In reality, the cyclone, by its removal of much of the desirable ash particles, often led to a deterioration of the electrical input in the ESP. The use of cyclones was phased out in later years at most installations.

2.1.3 The Years 1960 to 1970

This decade saw a new breed of large boilers coming on-line in the utility industry because of the economics of scale. Units of 100 to 150 MW capacities with boiler nominal steam flow rates of 1 million lb/hr (453,599 kg/hr) began in the 1950s. Within this decade, units began to reach 1000 MW levels along with the ESP trending toward 99 to 99.5% efficiencies.

The size of these new ESPs grew to a point where creative layouts had to be used for conservation of space. Piggyback installations were seen, but the Chevron design became common starting in the late 1960s. It was the Chevron layout that aggravated gas distribution and temperature patterns at the inlet face of the ESP, which further sensitized its performance. Some of these problems took years to correct.

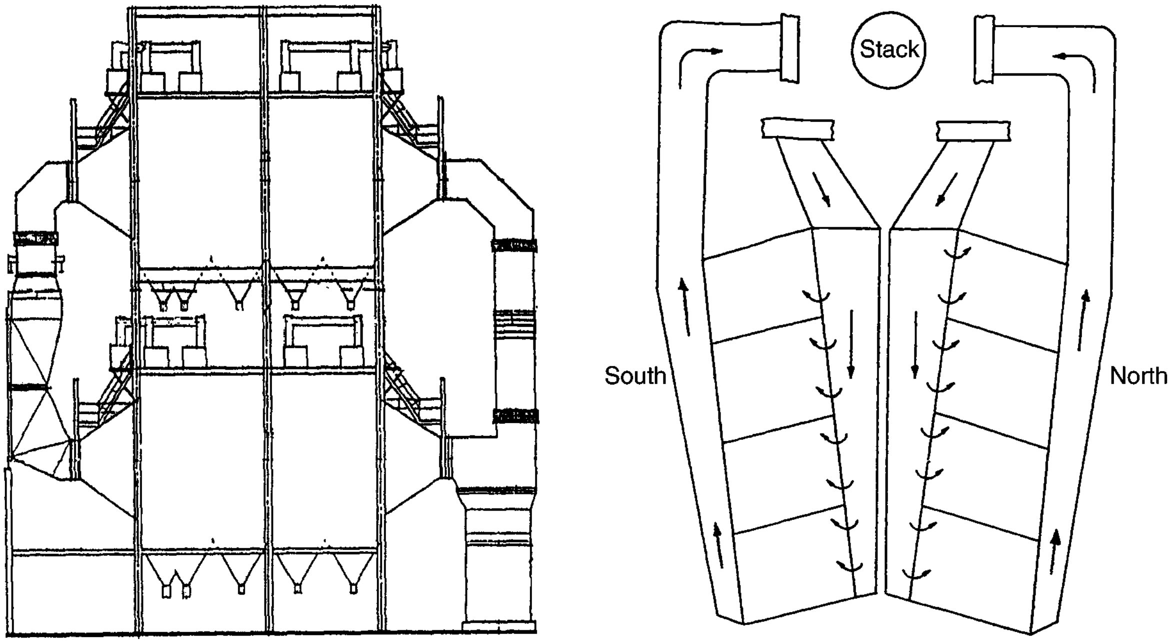

Figure 2-1
Typical Piggyback Layout (Left) and Chevron Layout (Right)

Moreover, the sheer growth in the physical size of the ESP allowed corollary difficulties to surface in hopper systems and with internal components. Economics of scale thus provided some disadvantages. Consider some of these problems:

- Internal inspections became more essential for success in ESP performance. However, the larger ESPs made optimum inspection activity that much more difficult to accomplish.
- The reliability of all its components had to also substantially improve as the ESP grew in size. Unfortunately, this was difficult to achieve with the rapid changes that were occurring in the field.
- The electrical integrity of a field or section of the ESP that is connected to a single power supply is only as good as its weakest spot. As the internal components grew in number, the statistical chance also grew for an electrical weak spot to occur.

Other areas of development during the 1960s involved larger transformer rectifiers in the power supplies, improved automatic voltage control, and a variety of flue gas conditioning techniques. To further complicate the realm of knowledge about the effects of ash characteristics on the ESP, the use of sub-bituminous and lignite coal from the western states opened up a new source of problems for the power plant operator.

2.1.4 The Decade of 1970 to 1980

The Federal Clean Air Act (CAA) of 1970 came into existence to really complicate things as the manufacturers and users of ESPs were trying to digest these higher efficiency designs of the late 1960s. After a controversy was resolved about what constituted particulate matter, the regulation called for stack emissions to be less than 0.2 lb (0.09 kg) of particulate matter for every

1 million Btu (1,055,060,000 J) input to the boiler. This emission goal generally required ESP efficiencies in the 99.2 to 99.5% range. At the same time, an opacity limit of 20% was applied on stacks, usually averaged over a 6-minute time period.

This would be a good time to place some numbers on the size of the ESP rather than refer to a small or large design. The early empirical method of design would tend to look at the flue gas velocity and subsequent time of treatment within the ESP box itself. Gas velocities of 8 to 10 ft/sec (2.4 to 3.1 m/sec) and treatment times of 1.5 to 2 seconds were not uncommon prior to 1950.

With the larger ESPs found in the late 1960s and during the early 1970s designed for the 99 to 99.5% range, it was not unusual to see gas velocities of 5 to 7 ft/s (1.5 to 2.1 m/s) and treatment times of 5 to 6 seconds. But then another parameter of size became the one of choice and that was specific collecting surface area (SCA). This value represents the collecting plate area of the ESP relative to the flue gas flow rate.

The state of the art at the time of the CAA of 1970 called for a SCA of about 220 ft^2 per 1000 actual cubic feet per minute (acfm) (43.3 m^2 per cubic meter/second) [m^2-s/m^3]). This number was based on prior experiences, and, unfortunately, was found to be marginal. However, some ESPs met the emission regulation at the 220 SCA level and some did not. Knowledge of how to control the variables and integrity of the apparatus was necessary for success, but this became difficult to achieve over time. So extra margins were included in new designs after about 1975 and SCAs in the 300 area were implemented to meet the 0.2 lb/million Btu (9×10^{-11} kg/J).

The latter part of the 1970s saw new emphasis on the size of the ESP to help solve performance problems, especially for collection of the fine particles of ash. This thinking doubled the ESP size over that seen earlier for the same collection efficiency. And then more restrictive government standards for new power plant units increased designs of ESPs to the 1000 SCA levels on some installations. Flue gas velocities through the ESP began to approach the 2 ft/s (0.6 m/s) range. Treatment time of 12 to 20 seconds was common.

Another major equipment change occurred in the early 1970s when several utility companies decided to purchase European ESP designs that did not use the weighed-wire discharge electrode. Failures of the wire electrode could not be tolerated under the new opacity and emission regulations. Since the latter part of the 1970s, new and retrofit ESPs would see little more of weighted wires for the fly ash application.

Nevertheless, there are still hundreds of ESPs using the weighted-wire design and performing well. It was primarily the design without shrouds at the top and bottom of the wires that led to frequent failures. Some ESPs could go through a year without a wire loss, but the trend toward its replacement was strong.

The American manufacturers responded with a rigid electrode replacement for the weighted-wire application. This new electrode design, fabricated in a variety of ways, was of sufficient metal construction so as to minimize the earlier problems experienced with the wires.

2.1.5 The Years 1980 to Date

In the last 20 years or so, the ESP industry has seen an evolution in equipment and process that the early practioners would have found overwhelming. Collection efficiencies in the 99.8 to 99.95% range produced gigantic ESP designs. The number of electrical fields in series approached 10 or more. Collector plates extended to 50 ft (15.2 m) high, and 96 hoppers were beginning to be seen. Enhanced automatic voltage controls and computerized recording of operating data from the ESP and boiler became common. Probably the more drastic changes began in the width of the gas passages in the ESP that almost doubled the distance between collector plates of the earlier weighted-wire designs (from 9 to 16 in. [228.6 to 406.4 mm]).

As the size of the ESPs grew much above the 220 SCA designs, the need to optimize the boiler operations to help the ESP was minimized. But exceptions occurred when ash characteristics were still important even with the large installations. For example, the hot-side ESP could not handle the low sodium make-up of some of the sub-bituminous coals of the West, and programs for conversion to cold-side ESPs were instituted in recent years.

Other complications with the boiler system and the ESP arose with the efforts to control oxides of sulfur and nitrogen by an assortment of techniques. Certainly the severe washing of coals and the use of low sulfur coals had an adverse effect on the electrical characteristics of the ash. There is no doubt that the control of NO_x and that effect on carbon carryover to the ESP will present a continuing challenge.

The use of selective catalytic reduction (SCRs) technology for NO_x control has required the upgrade and stiffening of the ESP casing to allow existing ESPs to operate at higher negative pressures. Future changes in regulations will likely see more combinations of systems, such as scrubbers or baghouses in series with the ESP, and more use of new technologies to help further reduce emissions, particularly on marginally sized ESPs. High frequency power supplies, biased gas flow distribution, and gas conditioning systems are all relatively new techniques that many end users will need to utilize to meet future regulations.

Table 2-1
Trends in ESP Designs and Sizes (Fly Ash Application)

Time Period	Trends
1923–1950	< 120 SCA 80–94% collection efficiency 2 fields 2 transformer rectifier (TR) sets Mechanical rectifiers
1950–1960	130–170 SCA 94–98% collection efficiency 2–3 fields 2–3 TR sets Vacuum tube TR sets First automatic controls
1960–1970	160–200 SCA 95–99% collection efficiency 2–6 fields 4–12 TR sets Silicon diode TR sets Improved auto controls
1970–1977 Clean Air Act	180–250 SCA 99.2–99.5% collection efficiency 3–5 fields 12–24 TR sets European designs Gas conditioning Improved controls
1977–1990	350–500 SCA 99.5–99.9% collection efficiency 4–6 fields 16–36 TR sets Microprocessor controls 12 in. (304.8 mm) plate spacing Rigid electrodes
1990–Present	350–800 SCA 99.5–99.99% collection efficiency 5–10 fields 16–48 TR sets High frequency TRs 16 in. (406.4 mm) plate spacing Combining of technologies

2.1.6 Summary

This brief review of the development of the fly ash ESP can be useful to the personnel of power plants if only a few of its simple concepts are heeded.

- Be alert to changes in the performance of the ESP by the continuous changes of boiler operation and fuel utilized. Learn how these variables can be controlled.
- Much of the success of the ESP lies in addressing the mechanical problems that arise. Often it is the effectiveness of the internal inspection that can have a significant input on the electrical performance of the ESP.
- Be aware that the ESP operates best when the plant personnel optimizes each of its critical parts, which tend to inter-react with each other. This manual will explore each of these parts in detail.
- An individual field in the ESP can only operate as well as its weakest point, which makes detailed and meticulous inspection and maintenance critical to good performance on all ESPs.

Key Technical Point

Be alert to changes in the performance of the ESP by the continuous changes of boiler operation and fuel utilized. Learn how these variables can be controlled.

Key Technical Point

Much of the success of the ESP lies in addressing the mechanical problems that arise. Often it is the effectiveness of the internal inspection that can have a significant input on the electrical performance of the ESP.

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Be aware that the ESP operates best when the plant personnel optimizes each of its critical parts, which tend to inter-react with each other. This manual will explore each of these parts in detail.

Key Technical Point

An individual field in the ESP can only operate as well as its weakest point, which makes detailed and meticulous inspection and maintenance critical to good performance on all ESPs.

2.2 Electrostatic Precipitator Components and Related Terms

An ESP consists of many components, each of which contributes to the successful operation of a total particulate removal system. This section describes the basic function and location of the most common components found in ESPs and some of the common terminology. All designs require the same fundamental components such as casing, hoppers collecting plates, discharge electrodes, rappers, and power supplies. The following list of components is common to all ESPs and each component is described in detail in Section 4.0 of this manual. Additionally a glossary of terms is included in the Appendix B.

- Ductwork
- Expansion joints
- Inlet and outlet nozzles/plenums
- Gas distribution media
- Casing
- Structural steel
- Insulation barrier
- Access doors
- Weather enclosure
- Penthouse/insulator compartments
- High voltage (HV) bus system (bus, bus duct, switches, insulators)
- HV support assembly and support insulators
- Insulator purge systems and heaters
- Hoppers
- Ash removal system
- Hopper level detectors
- Hopper heaters
- Collecting plates
- Discharge electrodes
- Anti-sway insulators
- Walkways
- Transformer rectifiers
- Automatic voltage controls (AVCs)
- Rappers controls
- Rappers (electric, mechanical, and pneumatic)

- Key interlock system
- Grounding system

In general, ESP designs are frequently referred to as *American* or *European*, with obvious reference to the origin of the design. Generally, this designation refers to differences in the physical arrangement of the precipitator. The distinctions between the designs were much clearer 20 years ago and today some manufacturers utilize a combination of the two designs described in Table 2-2.

Table 2-2
Summary of the Basic Differences Between American and European Designs

American	European
Casing / Structure	
Penthouse or insulator compartments	Insulator compartments
Collecting Surfaces	
Integral collecting surface using a single roll formed plate Panel plate assembly	Panel plate assembly
Discharge Electrodes and HV Support System	
Weighted wire rigid electrodes Two or four point HV frame suspension	Rigid mast frame - pipe frames with electrode fitted into the frames Four point HV frame suspension
Rappers	
External top rapping Electric/pneumatic impact and vibrator type Rappers Tumbling hammer top mounted	Internal rapping - rappers located internal to ESP in the gas stream Tumbling hammer located on bottoms, side, or tops

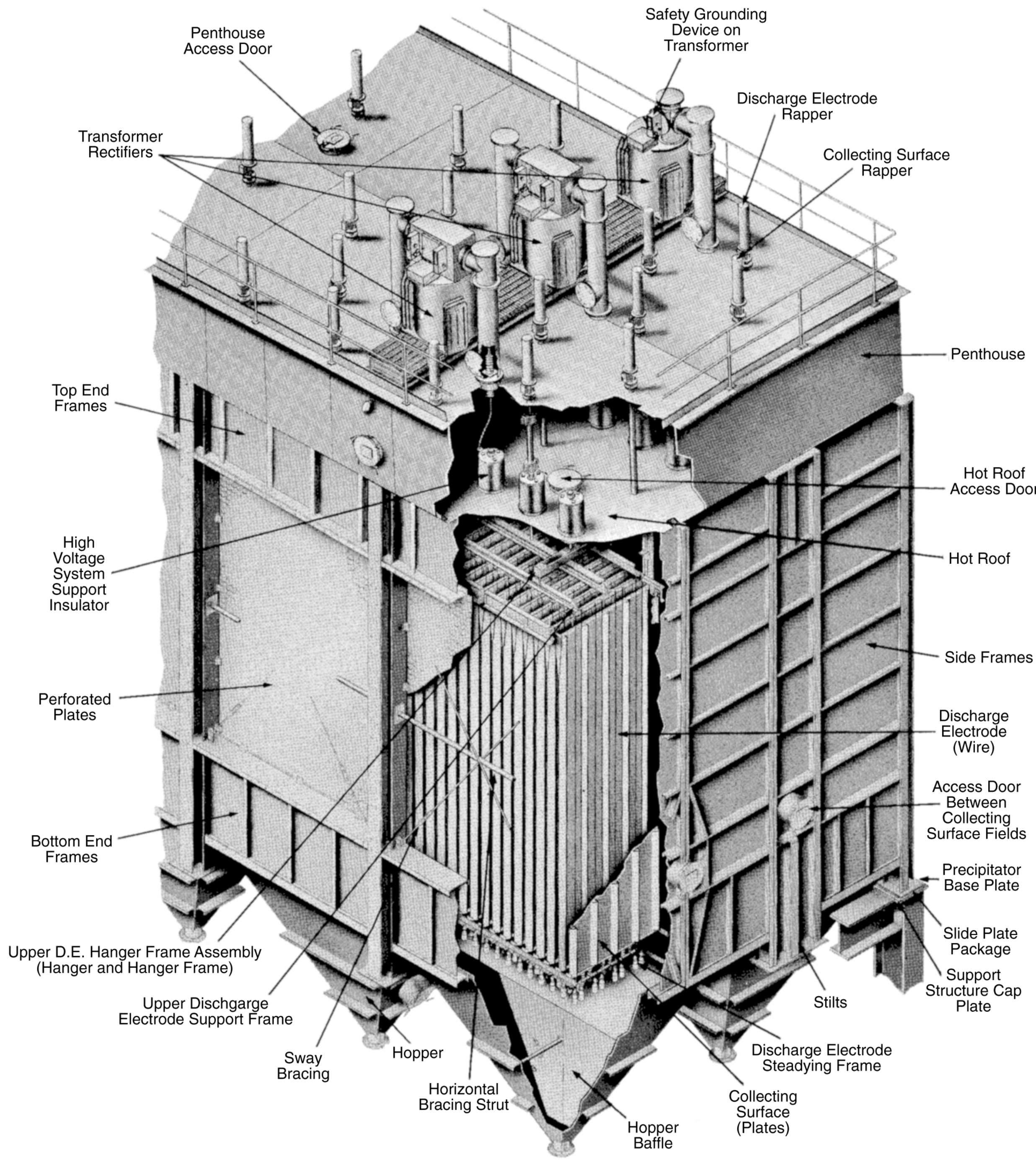


Figure 2-2
Typical American Design

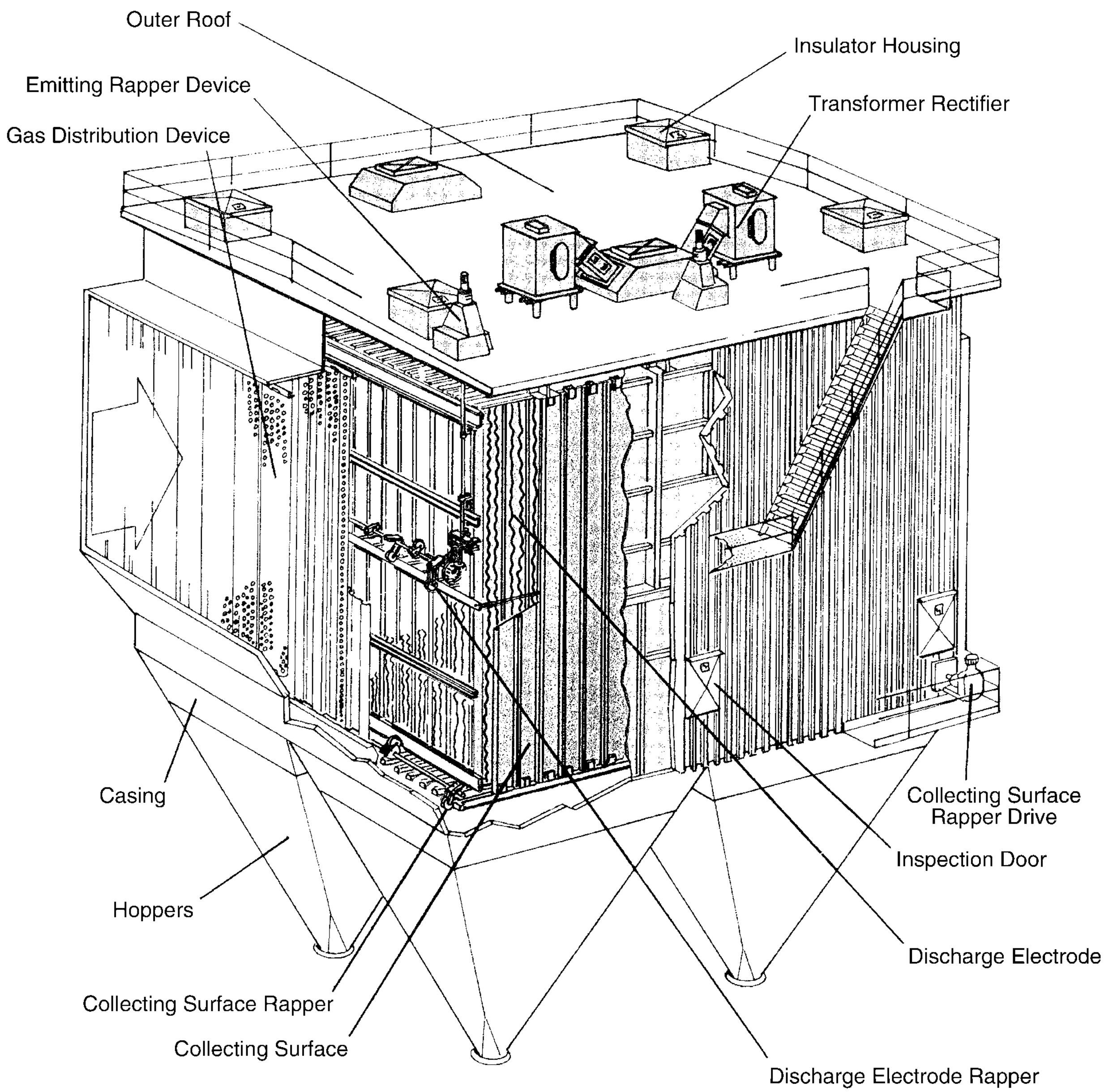


Figure 2-3
Typical European Design

ESP - A single precipitator is defined by all parts that are contained by an independent casing.

Casing - The precipitator shell or casing is designed to confine the flue gas within a specific collection zone. It must provide structural support for the discharge and collecting electrode systems, rapping systems, gas distribution system, and other precipitator components. The precipitator casing is usually constructed of fabricated steel panels fitted with external columns, beams, and stiffeners and is designed so that the final assembly provides a gas-tight unit able to withstand both internal and external loading. The precipitator casing includes *access doors* located in the sidewalls and on the roof that permit access to the precipitator interior. A *key interlock system* prevents opening the doors while the precipitator is energized. Access walkways, platforms, stairs, and ladders are attached to the casing at various internal and external locations.

Structural Steel - The precipitator casing is support by a structure steel system that is typically only tied to the ESP in one fixed location to allow the ESP casing to grow and expand independently during normal operation. The casing columns rest on a *slide plate* or *slide bearing* in all other areas.

Hoppers - Hoppers are located at the bottom of the precipitator casing and are used to collect ash that has fallen out of gas stream or ash that has been cleaned from the internal components. The typical hopper shape is pyramidal but some installation may use through type. The sides of each hopper are steeply sloped and the outlet opening should be sized so that fly ash may be easily be removed by the *ash removal system*. Baffles are usually placed in the hoppers. They extend below the dust level to minimize undesirable gas sneakage below the collection plates. Typically, hoppers are equipped with *level detectors* to alarm high levels and *hopper heaters* that are used to reduce condensation and corrosion and to keep the material fluidized. Hoppers are also equipped with access doors, strike plates for manually rapping the hopper walls, and poke holes to unclog the hopper throats.

Collecting Surface - Is the term for the sheet metal collector plate that serves as the point of deposition for the particulate that is negatively charged within the gas passage of the ESP. Collecting surface plate design differs between manufacturers but, all are secured to the shell of the ESP at ground potential and serve as the positive anode of the gas passage.

Discharge Electrode - Refers to the high voltage component that ionizes the process gases and creates the electric field. It is shaped to provide a corona discharge when the impressed voltage breaks the gas down at the electrode surface. This breakdown of the gas creates corona tufts on the discharge surface. Typically, voltage applied to the discharge electrode is of negative polarity. In many *weighted wire* designs, the discharge electrode is a smooth round wire slightly larger than 0.1 in. (2.5 mm) in diameter. Barbed wire is also frequently used in part, or all of the ESP, to enhance corona characteristics. Discharge electrodes of the *rigid* and *rigid frame* or *mast* variety are also widely available. They can vary widely in style and shape.

Rigid Discharge Electrode (RDE) Design - This term refers to precipitators utilizing rigid discharge electrodes, such as the pipe and spike variety, for its discharge electrode rather than a weighted wire type of high voltage system.

Rigid Frame Design - This term refers to precipitators utilizing rigid frames with tensioned discharge electrodes between supporting members. Frame shapes can vary from rectangular, tubular pipes with horizontal cross members to mast frames with a vertical primary support and horizontal cross members in a *T* configuration. Electrode styles and shapes can also vary widely. Rigid frame designs are almost exclusive to European design precipitators and are typically rapped by tumbling hammer rappers located within the gas stream.

Weighted Wire Design - This term refers to precipitators utilizing the wire and weight for its discharge electrode rather than a rigid type of high voltage system. The *weights* used are typically cast iron and are attached to the bottom of the wire discharge electrode to keep it taut, much like the effect of a plumb bob. These weights are about 20 to 35 lb (9.1 to 16.00 kg) for most installations. The weights are positioned and retained in a bottom guide frame for maintenance of wire alignment at the centerline of the gas passage.

Support Insulator - This term refers to the ceramic component that supports and isolates the high voltage frame from ground potential. Recent designs involve an alumina cylinder that also acts as a gas seal at the top frame locations. The surface of the insulator is sensitive to electrical leakage to ground if condensation or contamination is allowed to occur. *Purge air* and *heater application* are two methods used to minimize insulator failures.

Anti-sway Insulator - These insulators are used to prevent the bottom high voltage frames, which position and retain the discharge electrodes, from swinging or drifting out of alignment. The insulators are either a ceramic bar or a shaft type and are usually secured to the hopper wall. Some designs connect directly between the collecting plates and the lower high voltage frames.

Gas Passage - Is the passage formed by two adjacent collector plates, normally on 9 to 10 in. (228 to 254 mm) centers with *weighted wire* systems; 11 to 16 in. (280 to 400 mm) with *rigid discharge electrode* and *rigid frame* systems. The passage can be considered to consist of two capacitors with the negative *discharge electrode* at centerline and the positive ground collecting plates forming the other electrode. This passage is where the action takes place within the precipitator.

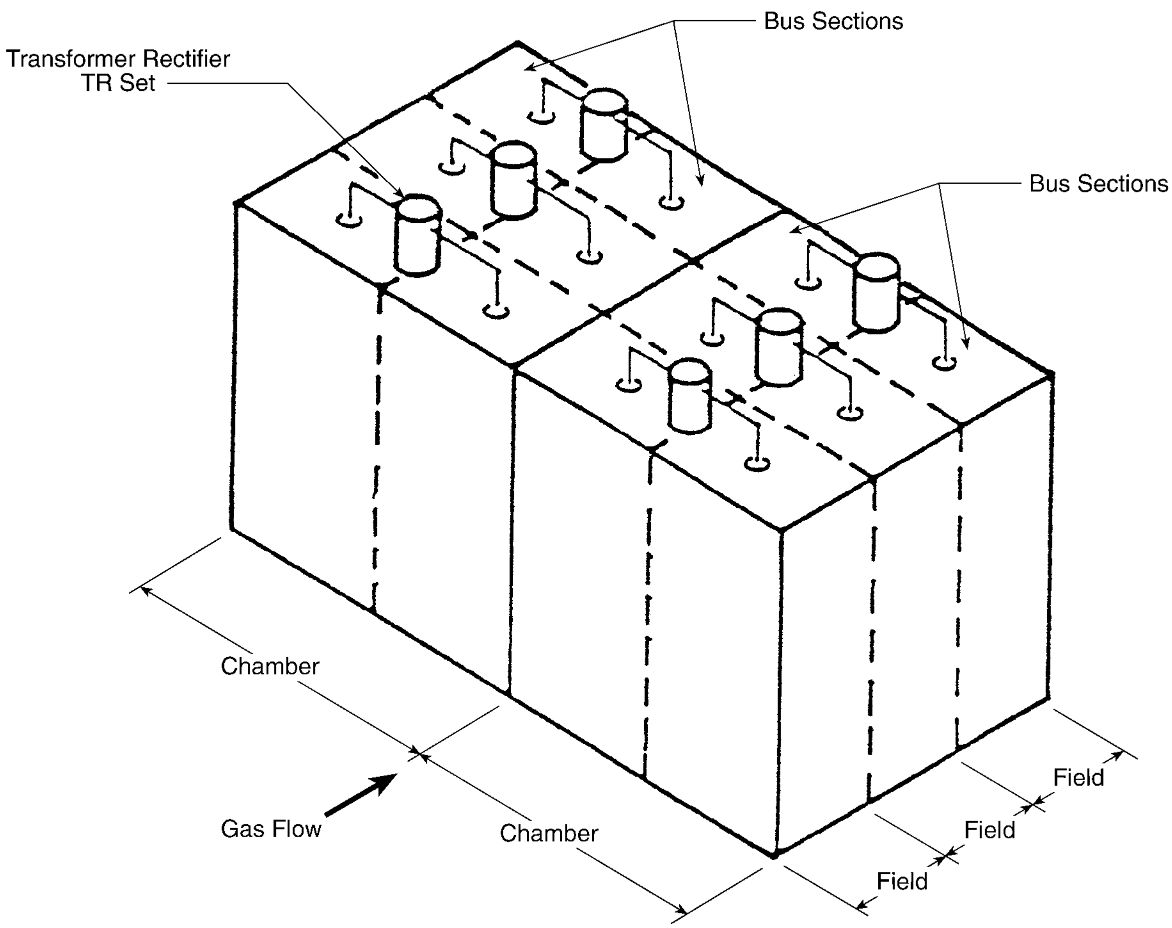


Figure 2-4
A Single Precipitator That Has 2 Chambers, 12 Bus Sections, 3 Fields, and 4 Cells. It Is Energized Using 6 Power Supplies (TRs).

Chamber - Refers to a gas-tight longitudinal subdivision of the precipitator (a precipitator without any internal dividing walls is a single chamber precipitator; a precipitator with a single internal dividing wall is a two chamber precipitator). Very wide precipitators may have non gas-tight load bearing walls that are used for structural purposes. Technically, these non gas-tight walls would not be considered as chamber dividing walls.

Bus Section - Is the smallest portion of high voltage structure, containing a fixed group of *discharge electrodes* that can be independently energized by a single TR. More than one bus section can be controlled through a TR either in parallel or series arrangement.

Field - Refers to an arrangement of one or more bus sections, oriented perpendicular to the direction of flue gas flow, which is energized by one *TR set*. The number of TR sets/power supplies positioned in series (parallel to the gas flow), each one controlling the collection of particles in a specific area, will typically identify the number of fields of a precipitator.

Cells - A cell is an arrangement of bus sections across the width of the ESP. Typically the number of cells times the number of fields equals the number of bus sections.

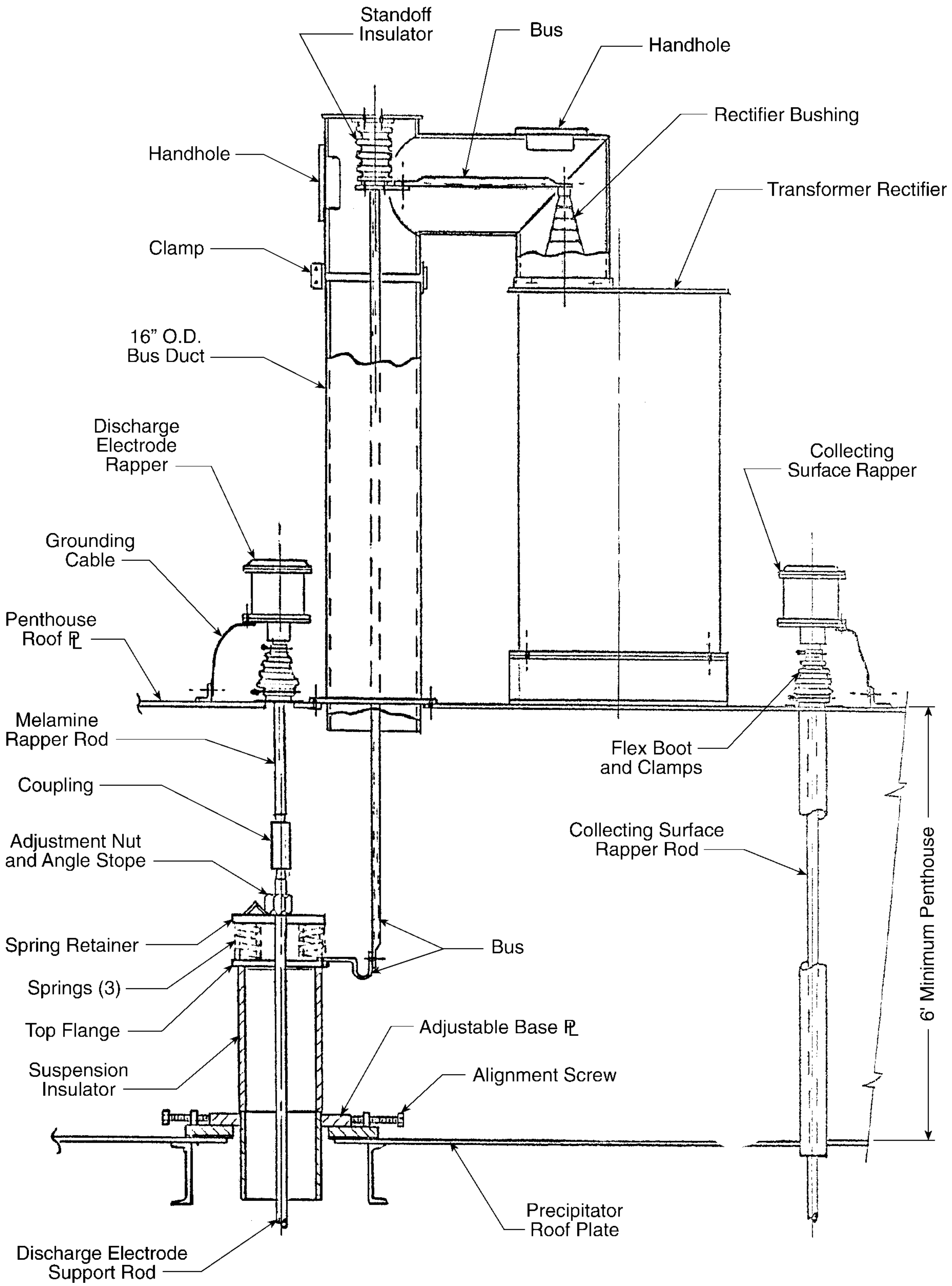


Figure 2-5
The TR Sets Are Connected to the Bus Section by a Bus Duct and Bus Bar Arrangement in the Insulator Compartment or Penthouse.

HV Bus System - The HV bus system is used to transfer power from the power supplies (transformer rectifiers) to the HV discharge electrode frames. The bus is the conductor and is usually made of pipe/bar, cable, or a combination of the two. Bus runs between the interlocked insulator compartments or penthouse are enclosed in watertight bus duct. The bus is supported with insulators, usually of the standoff/post insulator type. *Thru-bushing* insulators may or may not be used at the insulator compartment/penthouse and switch housing penetrations. Ground and/or disconnect switches may be part of the HV bus arrangement.

HV Selector Switch - Is the means to selectively energize a separate bus section when more than one bus is controlled by a TR set. There are several methods of HV isolation, but all must be accomplished with the TR set shut down and properly locked out. One type of switch is internal to the transformer and immersed in the same oil as the transformer winding. Another type of switch, external to the TR tank, isolates the HV circuit with a blade mechanism by withdrawing a blade from a clip or pan disc. A third mode of isolation on the HV side involves actual disconnection of a flexible lead from one TR output bushing and physically placing a jumper between the two bushings (if one is not already in place).

Rappers: Collecting Surfaces - These are devices, generally located at the top of the ESP or bottom of the collecting plates, which periodically impart a shock to the collecting surfaces to help dislodge the collected material into the hopper system. The final collection efficiency of the precipitator is often determined by how well this process is conducted. The object is to dislodge the material from the collector surface in small clumps or patches without building excessive dust layer thicknesses. This is a complex part of precipitation, but it is more important to know that reliability of rapper operation holds priority over timing, impact force, and other aspects of this system.

Rappers: HV - These rapper devices impart a vibration or shock to the HV frame supporting the discharge electrodes. The object is to keep the buildups on these electrodes from affecting the corona discharge pattern. The discharge electrodes will generally exhibit irregular coatings of various size and shape. Whether the buildups observed during outage inspections are detrimental can usually be determined by an analysis of electrical readings during periods of operation. It is usually better to operate with some buildup than employ excessive rapping forces that can result in failure of the *discharge electrodes*.

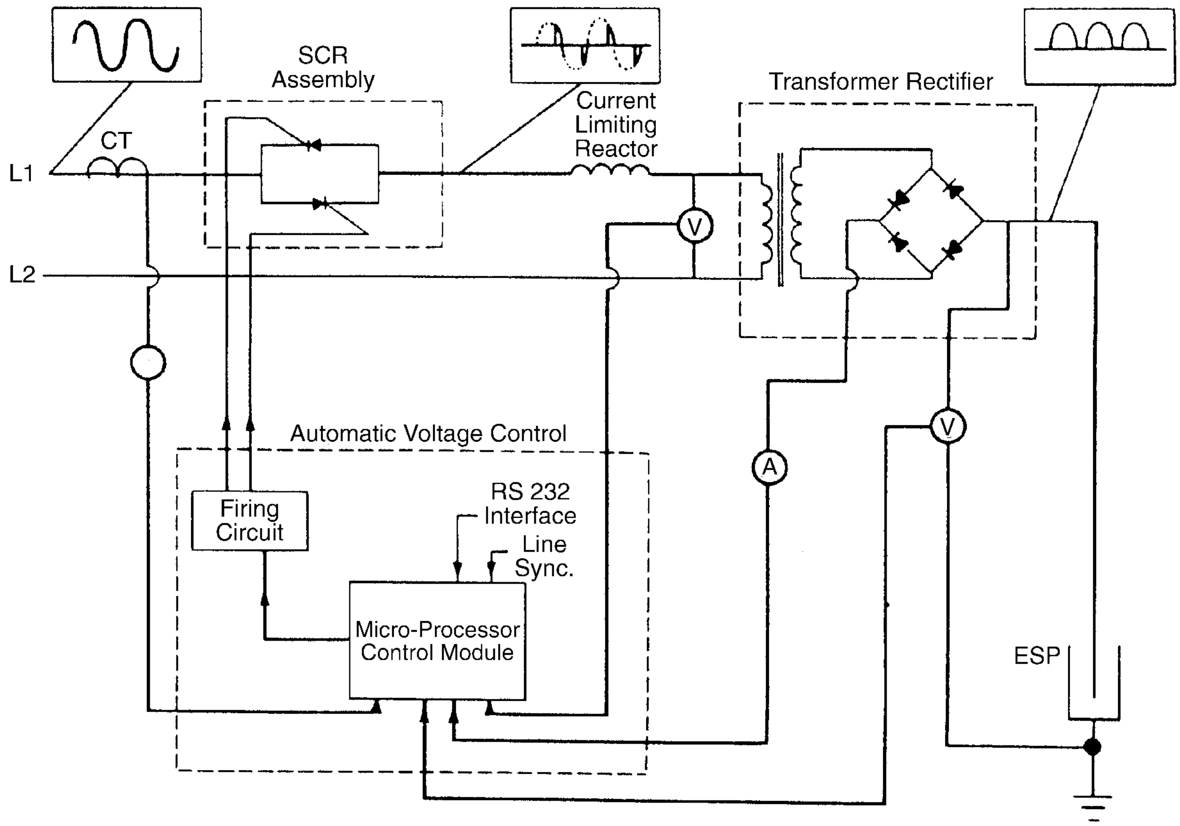


Figure 2-6
Typical AVC Control Circuit

Control Cabinet - This cabinet contains the control and monitor apparatus of the power supply. Features mainly involve low voltage breaker, overload controls, metering, and the AVC components.

Automatic Voltage Control (AVC) - The normal method of controlling the amount of secondary current to the ESP is by controlling the magnitude of voltage on the primary winding of the TR set. This is accomplished by detecting the transient disruption in the electrical circuitry caused by spark over, or an arc, in the ESP. A feedback circuit then adjusts the gate signal of an SCR (thyristor) so as to provide a level of voltage necessary to maintain the desired spark-over rate.

Current Limiting Reactor (CLR) - This is primarily a ballast of inductance placed in the low voltage circuit to provide current limiting ability under spark over in the ESP. Another major advantage of a properly sized reactor is to better shape the waveform of the input voltage to the TR set thereby gaining a greater conduction angle of secondary current flow. This feature has benefits for ash or dust layers that exhibit high resistivity characteristics.

Silicon-Controlled Rectifier (SCR) Controls - SCRs are the most extensively used method of voltage control in recent years, and consists of two silicon rectifiers mounted in an inverse parallel fashion in the primary ac circuit of the TR set. Thyristors are also used instead of silicon diodes, but the principle is basically identical. These devices are normally open in both directions until a small gate signal is applied which allows the SCR to conduct in one direction. The output is controlled by the strength of the current flow in the gate circuit that receives its signal from either the *automatic* or *manual* mode operation of the voltage controller.

Primary Ammeter - This meter measures the current flow through the low voltage primary winding of the TR set in alternating current amperes. The meter normally receives its signal from a current transformer in the primary circuit. Dividing this indicated current by the turns-ratio of the TR set will provide the level of ac current in the secondary winding.

Primary Voltmeter - This meter measures the voltage drop across the primary winding of the high voltage transformer in the TR set. The voltage can be measured in various manners, but the object is not to include any other equipment or apparatus within the measurement point located at the main power cables going directly to the TR set. With recent SCR controls, the true value of this voltage varies with the waveform at different levels of load current.

Secondary Ammeter - This meter measures the average dc secondary current, which is actually the precipitator corona current passing through the ground path on its return to the rectifier connection of the TR set so as to complete the electrical circuit. This meter has a low resistance movement and the scale reads in milliamperes or amps depending on the size of the TR set. The secondary current waveform can usually be observed by connecting an oscilloscope across the meter. There is usually a shorting device or surge arrester across the meter for protection. Under no circumstance should the leads be removed from this type of meter with the TR set energized. Another method generally used is a meter measuring a voltage across a resistor and calibrated as a current meter.

Secondary Voltmeter - This measurement is made between the rectifier output and the outlet bushing of the TR set by use of a voltage divider installed inside the tank. With older TR sets, it is possible to obtain the average precipitator voltage, usually read as average dc kilovolts, by installation of a retrofit voltage divider at the outlet bushing of the TR set. The indicated voltage represents the voltage from the discharge electrode to ground, comprising both the voltage drop across the gas space as well as the ash layer on the collecting surface. It actually is a measurement of the dielectric resistance and represents all the characteristics of the precipitator load.

Sparkmeter - This meter attempts to represent the number of sparks per minute by integrating these transient surges by some type of capacitance circuit. In most locations where sparkmeters still exist, replacement of the AVCs will discontinue its use. In all cases, representation of the ESP spark over by a meter can be misleading. For all practical purposes, it is recommended that a visual count or evaluation of the flicks of the voltmeter needle be made on a per minute basis to better gauge the spark rate. Spark rates as high as 60 to 70 per minute can be easily observed. This is generally at the higher range that should exist on most modern installations. At this higher spark-over level, the meter needle must still come to rest many times during any given minute.

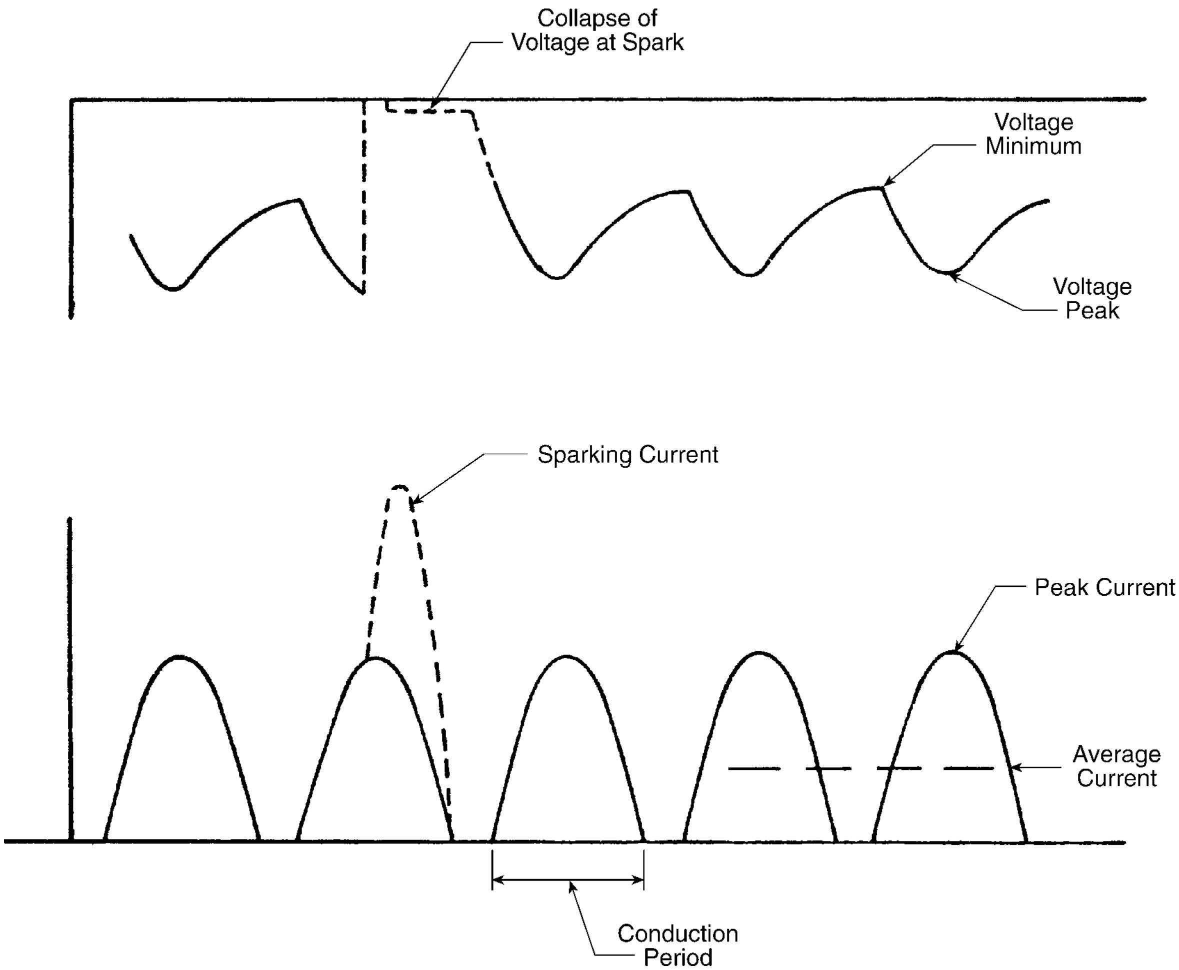
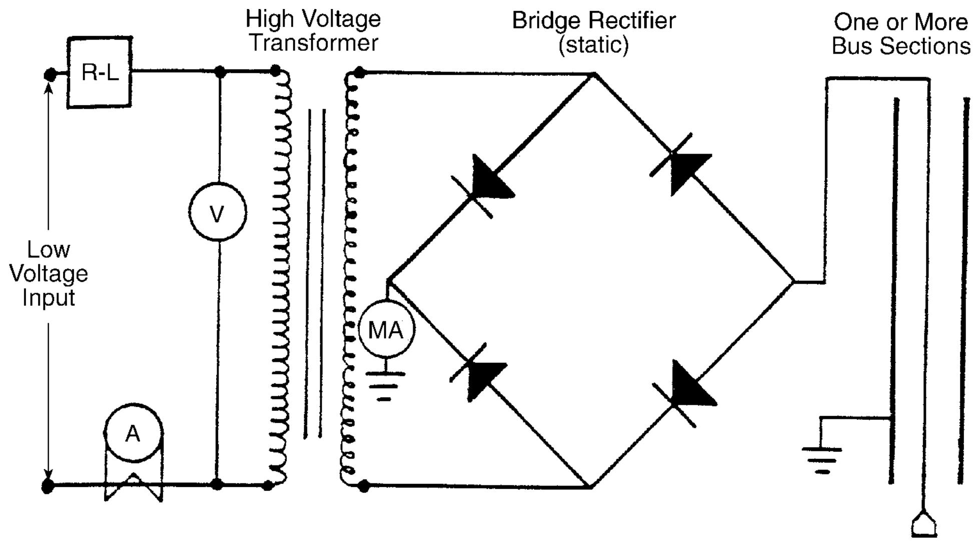
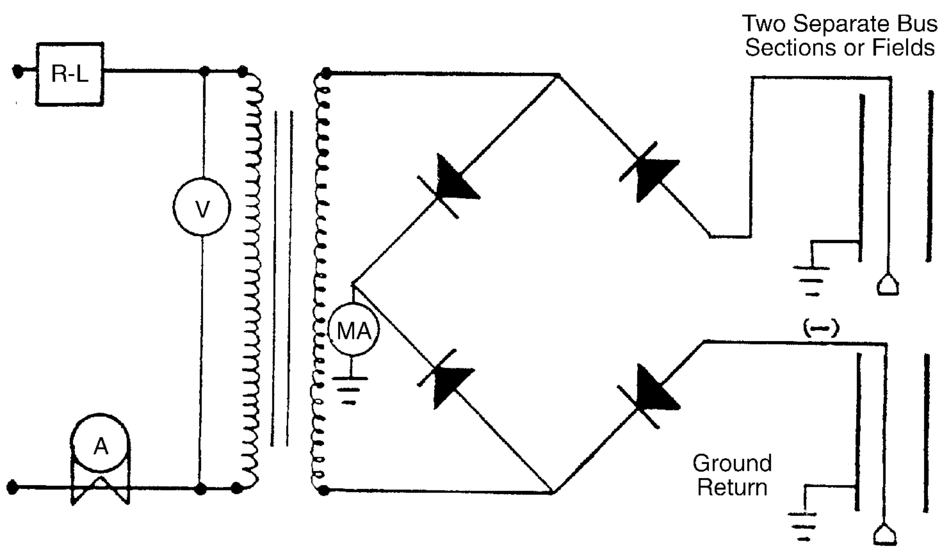


Figure 2-7
Waveforms of Precipitator Voltage and Corona Current Showing the Effect of Spark Over.

Spark Over - Is a localized electrical breakdown in the gas space between the HV system and ground. This generally occurs between the *discharge electrode* and the *collecting surface*. This breakdown, or flashover, can occur when the physical clearance has been reduced so that the operating voltage is greater than the space will allow. More often, spark over will occur when the resistivity of the ash layer on the collecting surface reaches critical levels. Premature spark over at extreme low levels of voltage can often be observed with a combination of higher resistivity and internal difficulties such as reduced electrical clearances. During a significant spark over, the basic collapse of the *voltage field* occurs which should always cause a downward flick of the *voltmeter* needles. The majority of sparks are self-extinguishing but some can promote into a sustained arc-over that can damage equipment. Automatic controls try to operate at the spark-over voltage (the maximum voltage for the internal conditions), reducing power quickly to prevent arcing from developing.



Full-Wave Circuit Schematic



Double-Wave Circuit Schematic

Two Possible Rectifier Circuits for an Electrostatic Precipitator
Are a F-W or Double H-W Energization Arrangement.

Figure 2-8
(HW and FW) TR Layout

TR Set - Is the term for the high voltage transformer rectifier that provides the electrical energy for a given precipitator area. These components involve a specially wound transformer that supplies a root mean squared (RMS) secondary voltage sized on the basis of *gas passage* spacing and discharge electrode design. An RMS secondary voltage of about 53,500 volts ac (45 kV dc average) is utilized for the 9 in. (228 mm) wide *gas passage* of most weighted wire precipitators; 77,300 volts ac (65 kV dc average) for most of the 12 in. (300 mm) wide *gas passage* of rigid electrode precipitators.

This ac voltage is usually rectified through a silicon diode bridge circuit in most existing TR sets. Rated dc voltages are usually specified at the 45,000 to 50,000 volt level for 9 to 10 in. (228 to 254 mm) plate spacing; the 55,000 to 65,000 volt level for 11 to 12 in. (280 to 300 mm) plate spacing; the 70,000 to 90,000 volt level for 15 to 16 in. (380 to 400 mm) plate spacing. Other pertinent data can be observed on the metal nameplate of each tank. While the voltages are generally similar between TR sets, the current ratings vary greatly based on the anticipated load requirements of the particular *ESP field*. While the kVA rating is used, it is also common practice to specify the size of the TR set by its corona current rating in milliamperes.

Transformer Rectifier (TR) Rating - The TR should be sized to supply sufficient current for the area of the precipitator to which it is connected. The nameplate shows a kVA size, primary and secondary voltage ratings, and primary and secondary current ratings. These values are of the most interest. The nameplate should show whether the primary winding is tapped for more than one voltage connection. A key point here is that the actual electrical performance of the ESP may in no way resemble any of the values shown on the nameplate.

Silicon Diode Bridge - The diode assembly converts the high voltage ac to dc voltage. These bridges are normally made up of individual diodes connected in series. The number of diodes used will vary by manufacturer from twenty to several hundred.

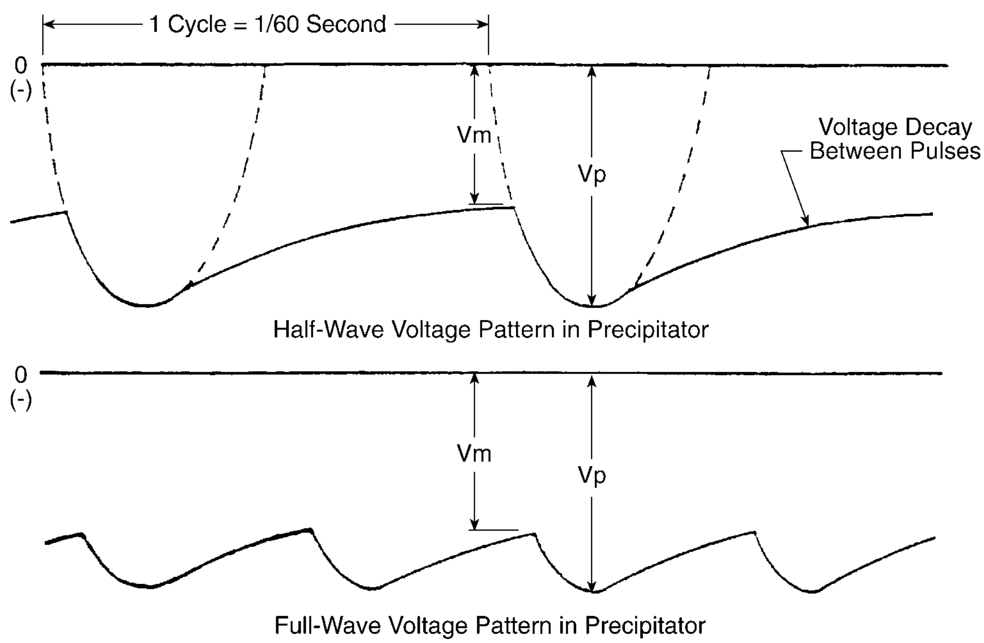


Figure 2-9
Typical kV Waveforms

Full Wave - This electrical term means that the 7200 rectified half-cycles per minute are fed into the full precipitator area energized or controlled by one TR set.

Half Wave - This term means the TR set is energizing more than one *bus section* and that these separate areas of the precipitator are receiving alternate pulses or 3600 rectified half-cycles per minute. The TR set will always have two outlet bushings with this mode of hook-up. Even though each bus section operates electrically independent, the overall operating level of the TR set is controlled by the weakest point of the areas controlled. On balance, with the larger TR sets in use today, the half-wave mode is not generally recommended.

Cycle - Generally refers to an alternating current of 60 cycles per second that is the standard energizing mode of the TR sets. This means that 3600 alternating cycles per minute are rectified into 7200 half-cycles per minute and are fed into the area of the precipitator controlled by one TR set.

Resistivity - This term is most critical for the fly ash precipitator because it normally directly controls the levels of voltage and current observed at most installations. Resistivity refers to the electrical resistance of the ash layer after it forms on the positive ground-collecting *surface*. If the resistance level is high, the corona current passing through the ash layer must be generally reduced or a *back corona* effect will reduce performance of the ESP. The range of resistivity is primarily affected by the chemistry of the ash, moisture in the flue gas, levels of sulfur trioxide, and flue gas temperature. Resistivity effects are generally observed by the occurrence of *spark over* on most ESP fields at some reduced level of voltage and current. Operation in a good zone of resistivity allows the ash layer on the collector plate to bond sufficiently for optimum ESP performance and helps to reduce *reentrainment*.

When resistivity drops to low levels, the ash layer on the collecting surface allows current to flow through it without restriction and it is easily reentrained back into the gas stream. This condition is generally characterized by high corona current levels without the occurrence of spark over.

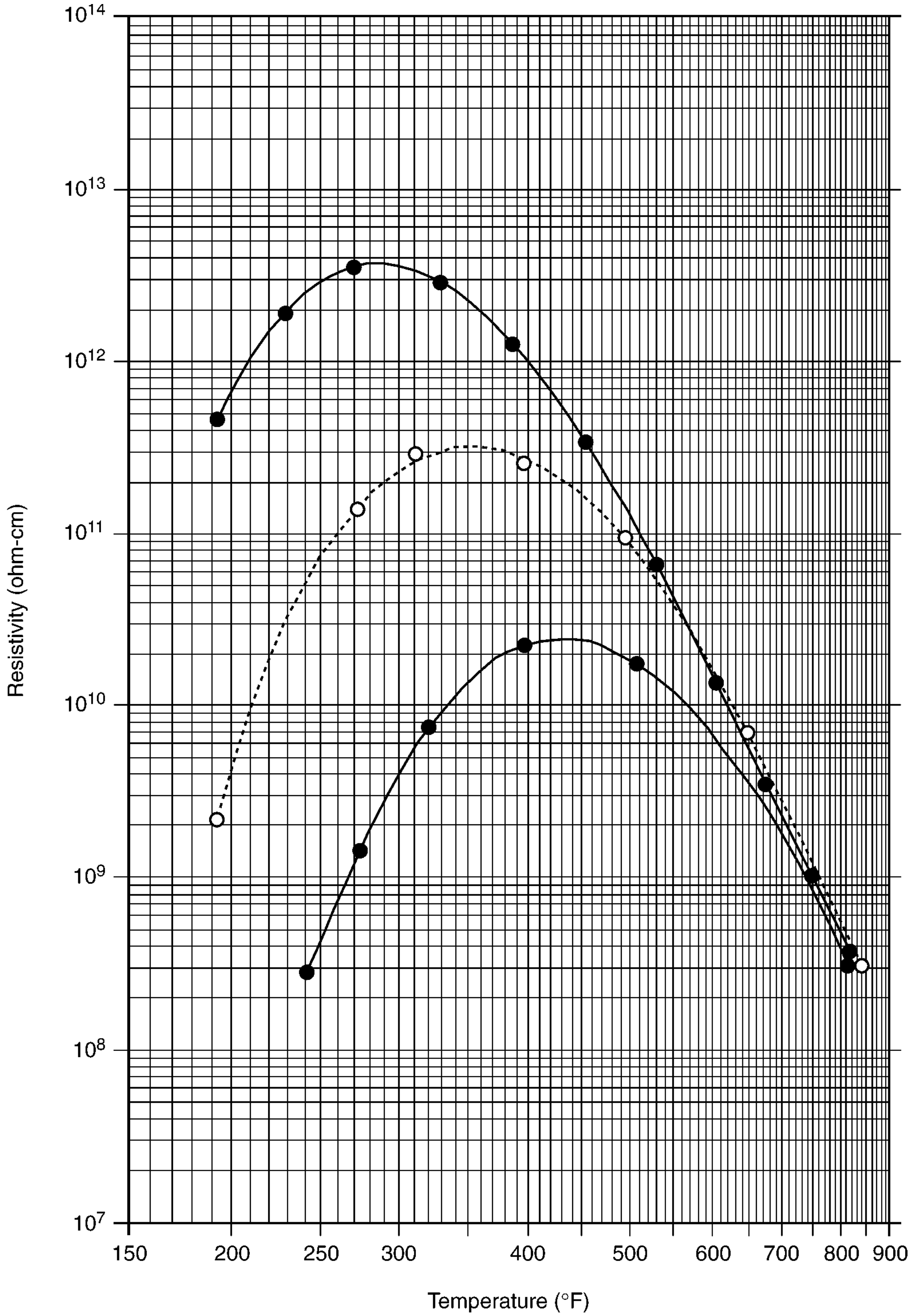


Figure 2-10
Examples of Typical Resistivity Curves for Different Types of Fly Ash

2.3 Basic ESP Theory

The word *simplicity* might come to mind if one just looks at the mechanical parts of the ESP and hears that it performs somewhat on the principle of *opposites attract*. But to anyone with experience with this collecting device, *simplicity* is soon replaced by the term *complexity*. There are certainly a number of developments that have occurred over the years that made it difficult to understand how the ESP system should be best designed, operated, and maintained.

One of the main reasons for this dilemma is that there is always a tendency to believe that if it sounds too simple, something must be wrong. For example, one might ask how ESPs work and get a complex answer that describes what occurs between electrons, gas molecules, and ash particles in the space between the discharge and collecting electrode. A simple answer might just say that ESPs work best when the highest voltage occurs between the two electrode systems throughout the structure.

So an effort will be made in the following sections to stress the basic ideas on how to cope with the precipitation process. Typically, the most successful ESP applications have implemented fundamental ideas and concepts to optimize ESP performance. Each manufacturer of ESPs works on the same basic principles to try to achieve the optimum charging and collection of ash particles. The physical parts from each manufacturer may look a little different, but the ESP should adhere to some simple concepts of design.

2.3.1 Particle Charging

The ESP is a relatively simple electrical device where a high voltage field spans the space between two electrodes. Since a mode of direct current is used, the two electrodes become the cathode and anode of the circuit, almost analogous to an automotive battery. Early experiments deemed that the use of negative polarity on the discharge electrode produced the best circuit stability that allowed higher voltages to exist before an electrical breakdown would occur between the electrodes. So, all manufacturers of ESPs for the collection of fly ash use this basic method of energization, although positive polarity on the discharge electrode has been infrequently used in other industrial applications and has been experimented with on-hot-side ESPs.

The negative high voltage is placed on the discharge electrode, which is the cathode, while the anode collecting surface becomes the positive side of the circuit at ground potential. Therefore, the flow of electrons is from the discharge electrode, through the space into the collecting surface, and then returns to the high voltage source through ground so as to complete the electrical circuit. This basic circuit is represented below.

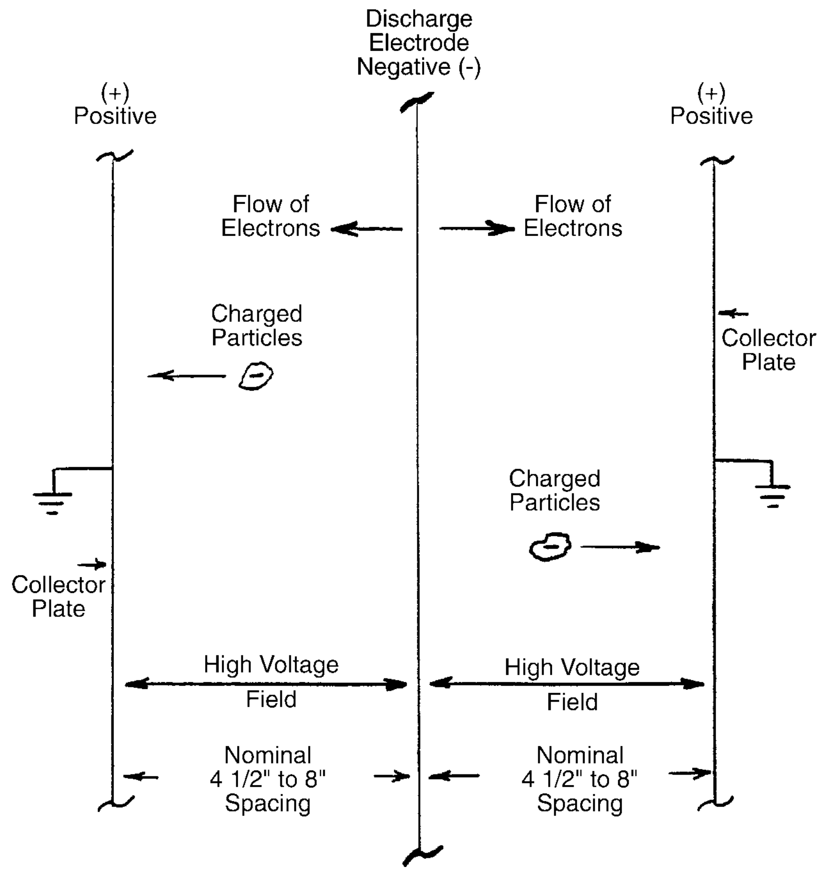


Figure 2-11
Elevation Cut View of the Gas Passage

It is important to know that some minimal level of voltage is needed on the discharge electrode so as to produce a breakdown of the flue gas at its surface. This breakdown of gas, called a *corona discharge*, initiates the electron activity that eventually leads to a stable current flow through the space. As the impressed voltage rises between the cathode and anode, corona current flow usually increases substantially.

In essence, it is this voltage and the resultant electronic current flow to ground that constitutes the charging mechanism of the ESP. Stated simply, the discrete particles of ash will acquire a negative charge by some complex phenomena as they pass through the electrode zone. Once charged, these particles will gravitate toward the positive collecting surface by the force of the applied voltage between the discharge electrode and the collecting plate surface.

Simply, voltage is the driving force of the ESP while the corona current is a measure of the overall resistance of the circuit. Each of these electrical values, observed on the meters of the power supply circuit, are measures of what is happening inside the electrode zone and thus your way of simply judging what is happening between the discharge and collecting electrodes. Understanding the basic patterns and language of the precipitator voltage and current levels is the first step to understanding how an ESP operates and what effect system changes can have on it. This basic technique will be discussed in many locations in this manual.

Key Technical Point

Simply, voltage is the driving force of the ESP while the corona current is a measure of the overall resistance of the circuit. Each of these electrical values, observed on the meters of the power supply circuit, are measures of what is happening inside the electrode zone and thus your way of simply judging what is happening between the discharge and collecting electrodes.

2.3.2 Particle Collection

Once the particles of ash acquire the negative charge from the electronic action in the space between electrodes, they soon will reach the positive surface of the ESP. It is conceivable that once the particle touches the collecting plate, it could loose its charge to ground and actually get repelled back into the gas stream. If that were to happen, the success of the precipitation process would cease. But in practically all cases, the charged particles begin to form a layer on the collector, lose a good portion of their electron charge to ground (but typically not all of it), while becoming part of the electric circuit between the electrodes. In other words, this layer of particles on the collecting plates is not only necessary for successful particle collection to occur in the ESP, but its ability to transfer the electric current flow to ground (its resistance) becomes a key factor in the successful performance of the ESP.

This layer begins to form as new particles of ash touch particles that were previously deposited. The tangent point of contact becomes the way the electrons are transferred from particle to particle throughout the layer to ground. Because there is a wide spectrum of size in the formation of fly ash from the combustion process, the layer itself develops a porosity based on this size differential. Even though the ash layer looks solid to the eye, it basically is full of holes of varying dimensions. Layer thicknesses will vary greatly between installations and even within any one ESP. It is not unusual to observe a layer of ash that can range from a thin coating to upwards of 1 in. (25.4 mm) thick in isolated cases.

What holds these fly ash particles together, attached to the collecting surface, is mostly tied to electrical forces along with some secondary mechanical and chemical reactions. The complexity and mystery of this layer of ash is tougher to understand than the theories of the gas space itself. The bonding of these particles can be strong or weak, and this will determine in large measure the ability of the rapping system to shed portions of the layer into the hoppers of the ESP.

Of practical use for plant personnel is the fact that the complex nature of the ash layer can be judged somewhat by the electrical readings of the ESP. The earlier statement that the voltage observed between the negative and positive electrodes is a measure of the degree of charging is still valid. But once the ash layer forms, that voltage value now represents two voltages in series. The voltage field applied from the discharge electrode to the surface of the layer across the space (V_S) is now added to the voltage drop across the ash layer (V_D). The voltage drop across the ash layer keeps changing in magnitude, even at stable boiler loads, as ash and flue gas conditions change. So the combined voltage is influenced to a great degree by what happens in the ash layer. We now have the ability to judge both the level of particle charging and particle collection phases of the ESP by using the precipitator voltage and current as an indicator. Different techniques using these two feedbacks will be discussed in detail later in this manual.

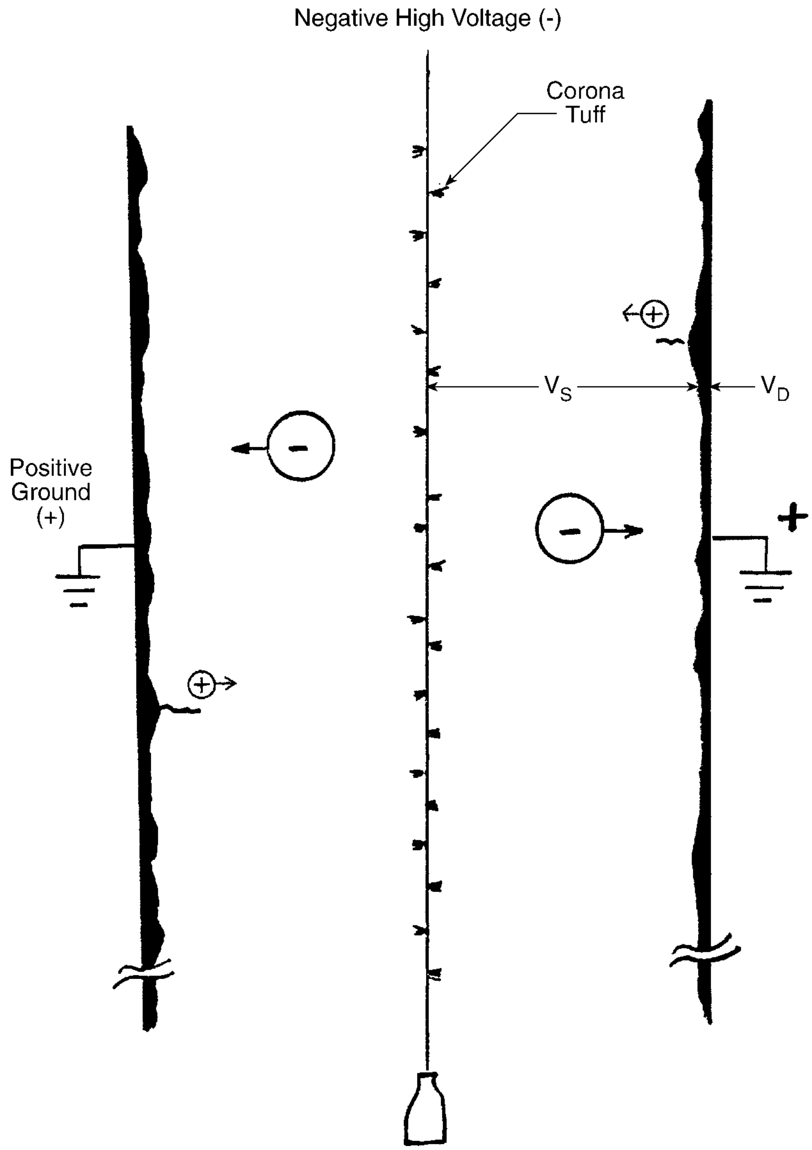


Figure 2-12
Gas Passage View Showing the Corona Discharge

2.3.3 Corona Discharge

The electric process of the ESP initiates at the surface of the discharge electrode. The manufacturer usually designs this electrode so that the threshold breakdown of gas occurs when a nominal 15 to 25 kV level is reached on TR set. The sharpness of the surface will help start a corona breakdown at the lower end of the range, for example, with the points off a barbed-wire or a pointed rigid electrode. Threshold coronas will tend to occur at higher voltages on round wires (nominal 0.1 in. [2.5 mm] diameter) where the curvature of radius is critical for this breakdown of gas.

The width of the gas space between the negative and positive electrode will also affect the starting voltage: the smaller the distance, the lower the onset corona voltage. Of course, a reduced clearance between one discharge electrode and ground could initiate a localized corona discharge much before the rest of the section's electrodes.

Consider an ESP section where the same distances exist between all the electrodes of opposite polarity. The start of corona current (corona onset) could be observed when the needle first moves on the analog dc secondary amp meter (newer controls that offer only digital metering displays do not provide the diagnostic tools offered by analog meters). At that point, there are only a few places where the corona breakdown has occurred. For an active corona to occur on all the discharge electrodes with uniformity requires a significant rise in voltage over that of the threshold level. For example, if the first sign of current shows up at 20 kV, it might take another 7 to 10 kV between electrodes to acquire ample distribution of corona from all the discharge electrodes.

On electrodes such as the barbed-wire (not commonly used on fly ash applications) or the rigid electrodes utilizing pins or fabricated sharp edges, the corona discharge shows up as blue corona tufts on each of the spaced points or edges. The smooth round wire, normally used in weighted-wire designs, on the other hand will develop corona at different spacings on its surface, depending on the level of voltage and current. Operating at the TR and CLR current limits will often place the corona tufts within 0.5 in. (12.7 mm) of each other throughout the length of each wire, creating a uniform corona distribution. The spacing of the tufts may be 4 in. (101.6 mm) or more apart on the wire when operating at low levels of current that can distort or promote poor distribution of the corona current. Poor corona distribution can also occur in rigid systems operating at a low percentage of design current level because the close clearance point will discharge first. This will be more pronounced in a field with poor alignment or localized close clearances.

The use of the discharge electrode as the cathode of the system has long-term implications for the ESP. The loss of metal occurs from the cathode surface in a direct current electrical circuit. Therefore, the sharp edges or pins of a rigid electrode will tend to lose their sharpness over time and thus require a higher voltage to initiate the corona. It is possible to create a non-uniform pattern of charging at low levels of current flow if this metal loss is not uniform over the electrode system. A non-uniform pattern of particle charging could also occur with the round wire electrodes if localized electrical activity (sparking) causes selective wire damage. In this case, the corona onset will occur at a lower voltage at the point of wire thinning.

Two basic concepts used to improve ESP operations are based on this knowledge of electrode damage.

1. Do not selectively replace a failed or damaged discharge electrode in an existing ESP.
2. Use the internal inspection to weed out defective electrodes by closely checking for localized damage and thinning of the electrodes, or bent or damaged pins or points on a rigid design.

Both of these concepts will help improve the uniformity of the charging process and desensitize the ESP from changes in the process.

Key Human Performance Point

Two basic concepts used to improve ESP operations are based on this knowledge of electrode damage.

1. **Do not selectively replace a failed or damaged discharge electrode in an existing ESP.**
2. **Use the internal inspection to weed out defective electrodes by closely checking for localized damage and thinning of the electrodes, or bent or damaged pins or points on a rigid design.**

Both of these concepts will help improve the uniformity of the charging process and desensitize the ESP from changes in the process.

2.3.4 Deutsch-Anderson Equation

Probably the best way to gain an insight into the process of precipitation is to become familiar with the terms of an equation developed around the year 1920. This equation (Eq. 2-1) was generated independently by two men: Anderson by experimental means; and Deutsch by mathematical deduction. In its simplest form, the Deutsch-Anderson (D-A) equation relates a number of factors that, when viewed together, tend to make some sense and help explain the collection efficiency of the ESP.

Although the ESP and the process are affected by many more factors than are included in the D-A equation, it is the basis for manufacturers' designs and present day modeling software. It is important to understand how these factors work together for the fly ash ESP. Let's break the equation down into its simplest parts:

Collection efficiency $$N = 1 - e^{-(A/V)w} \times 100$$ **Eq. 2-1**

where:

A = Effective collecting electrode area of the precipitator (ft^2) (m^2)

V = Gas flow rate through the precipitator (acf/s) (m^3/s)

e = Base of natural logarithm = 2.718

w = Migration velocity (ft/s) (cm/s)

The fractional collection efficiency represented by *N*, in a practical sense, usually means the overall ESP. But, it could mean any portion or even a single gas passage of the collector. Since the number of particles decreases in an exponential manner throughout the ESP, it makes sense for the base of the natural logarithm to be included in the equation, as represented by *e*.

From the mathematics of log relationships, an increase in the value of the negative exponent will cause the whole log term to decrease to a much smaller number. Subtracting this smaller number from 1.0 will result in an improved collection efficiency of the ESP. So it is important to understand what is involved in the exponent and how to increase its value.

The value of *A* represents the effective collecting surface area of the ESP, while the *V* number refers to the flue gas flow rate through this area. It is reasonable to judge that the performance of the ESP will improve if you make it larger, or conversely, reduce the amount of the flue gas flowing through it. In fact, the ratio *A/V* represents the common SCA term used to identify the physical design of the ESP relative to a collection goal.

Since the negative exponent of the D-A equation is made up of two components, the product of these two numbers really determines the end result. If, for example, the ratio *A/V* is fairly fixed for an existing ESP, then the ability to raise the value of the *W* component will generally improve its overall collection performance. Marginal sized ESPs would require higher values of *W* to counteract the size limitations.

The term *W*, known as the migration velocity, actually represents how fast the charged ash particle moves toward the collecting surface under the influence of the electric field (measured in ft/sec or cm/sec). While this term might be considered as more an indicator than an actual velocity, it does have a finite value that can be used for comparison purposes. This migration velocity is made up of the following components:

$$W = \frac{a\,E_o\,E_p}{2\pi\theta} \qquad \textbf{Eq. 2-2}$$

where:

a = Particle radius (microns)

E_o = Strength of the field in which the particles are charged (stat-volts/cm, represented by the peak voltage)

E_p = Strength of the field in which the particles are collected (stat-volts/cm, normally the field close to the collecting plates)

θ = Viscosity or frictional resistance coefficient of the gas (poises)

Aside from the mathematical 2π part of the component, the other three parts of the migration number present some interesting bits of precipitation knowledge for the field person.

2.3.4.1 Particle Size Factor (a)

One thing known in the electrical precipitation process is that larger particles of material within the voltage field will acquire a higher negative charge, which is proportional to their surface area. The higher charge makes the particle move more easily and quickly towards the grounded surface. Therefore the larger the particle, the easier it is to collect. The size distribution of the ash particles coming into the ESP tends to change, which means the value of a representative particle size is difficult to pin down over the life of the ESP. Particles in the 0.2 to 0.4 micron (micrometers) diameter range are the most difficult to collect because in this size range the fundamental field charging mechanism gives way to diffusion charging by thermal ions (random collisions) as a charging mechanism for very small particles. Figure 2-13 is an example of the effect particle size has on collection efficiency. While the designer may have had a limited size distribution in mind, the end user could face a completely different range of particle size. The ability to assign the particle size, as a factor in day-to-day operations, is so complex that it is best left alone other than to recognize its existence and evaluate its gross effect on ESP performance.

Key Technical Point

One thing known in the electrical precipitation process is that larger particles of material within the voltage field will acquire a higher negative charge, which is proportional to their surface area. The higher charge makes the particle move more easily and quickly towards the grounded surface. Therefore, the larger the particle, the easier it is to collect.

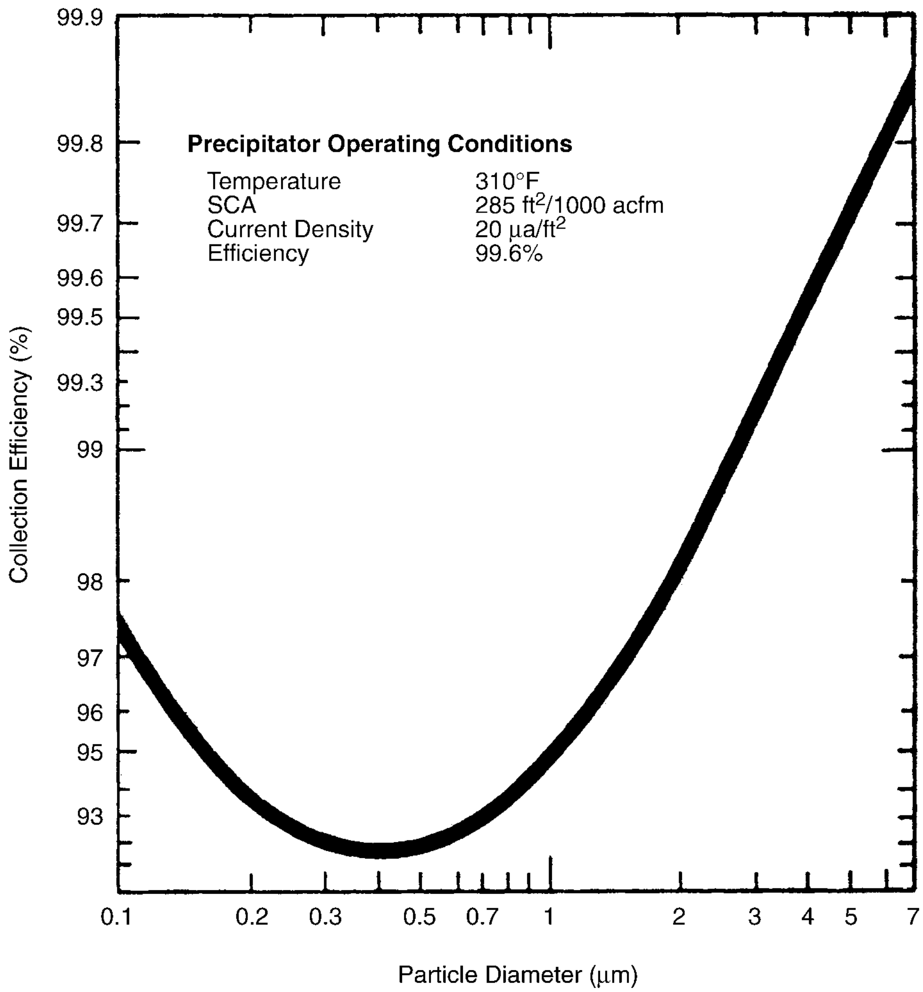


Figure 2-13
Typical Curve Showing the Efficiency as a Function of Particle Size for an ESP Collecting Fly Ash

Plant personnel must be alert to any major equipment or fuel change that could place an additional burden on the ESP. The normal wear and tear on the mills will change coal particle size somewhat. But more importantly, a change in fuel could result in a finer or courser material in the ESP. For example, a replacement of an eastern bituminous coal with a western sub-bituminous grade could result in a substantial increase of fine-sized particles. Modification of burners or the mills could also alter the particle size distribution and effect combustion.

Maybe even more important than the identification of the median size or distribution range of the fly ash is to ascertain the make-up of the large size portion. As you will see, many of the large particles finding their way to the ESP will be comprised of unburned carbon. High levels of unburned carbon typically monitored as loss on ignition (LOI) in the ESP, can dramatically affect ESP performance. This will be the parameter that should be continually monitored in the boiler effluent.

2.3.4.2 Voltage Field Factor

Optimum performance in an ESP is primarily produced by achieving the highest level of the voltage field between the two sets of electrodes. This factor was recognized by Deutsch and Anderson, so its influence on how fast to remove a particle out of the gas stream was given a double emphasis. Thus you see the ESP voltages E_o and E_p in the numerator of the migration velocity term. Each of these voltages does represent different numbers, but plant personnel should be more concerned about just working toward a higher voltage and knowing that any rise achieved will have at least a doubling benefit on the ESP.

This concept works even better when you find yourself operating at low levels of voltage. Just the ability to increase the voltage field by 5 to 10% when in some ESP performance difficulty will often work wonders. Out of all the components in the D-A equation, optimum voltage levels are the key to performance success.

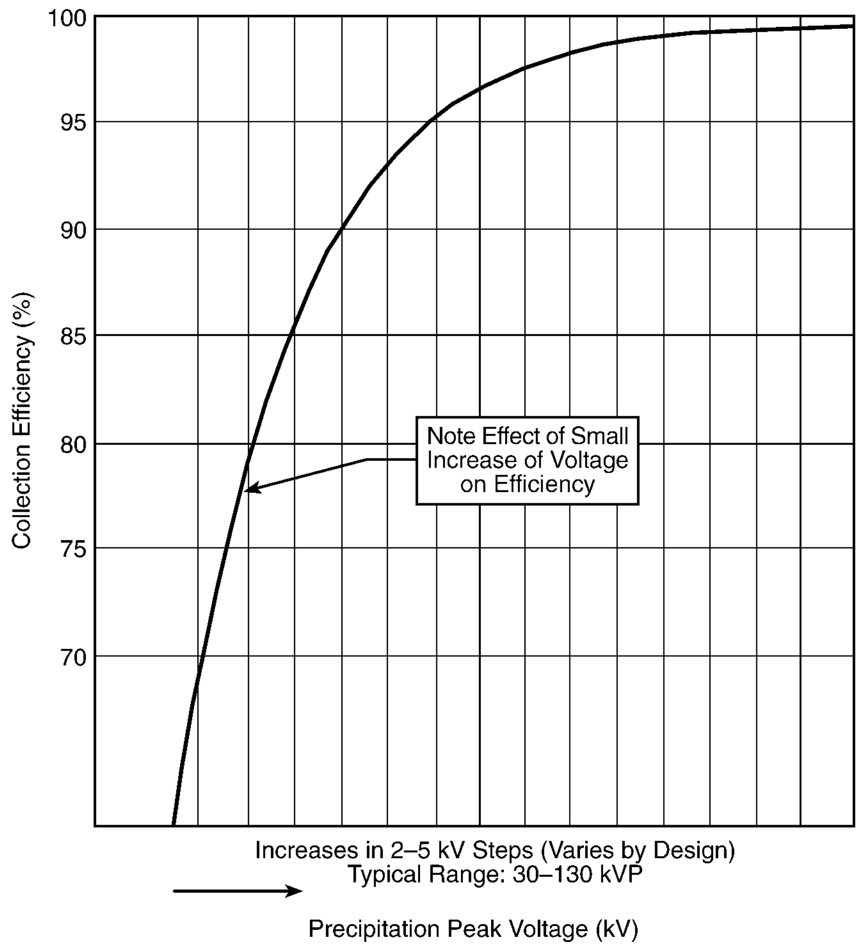


Figure 2-14
A Typical ESP Peak Voltage Versus Ash Collection Efficiency Curve Shows How Efficiency Increases with Voltage.

2.3.4.3 Gas Viscosity

Flue gas viscosity can change appreciably by major changes in temperature and pressure. The component θ in the denominator of the W term will make its effect opposite to that of particle size and voltage. For example, an increase in viscosity will work to decrease the migration velocity while a reduction in viscosity will be beneficial. Viscosity is normally considered in the design phase when looking at the application and location, typical operating temperature, static pressure, and elevations will be considered. For example, an ESP operating at 5000 ft (152.4 m) elevation in Denver will need to be sized larger than one running on the same size boiler at sea level. There usually are only minor changes in gas viscosity on a day-to-day basis at any given installation. However, major benefits would accrue for an installation where a hot-side ESP was converted to a cold-side unit.

2.3.5 Modification and Exception to D-A

The D-A equation can be used well under stable and good operating conditions. However, there are times when system changes contrary to the equation actually improve ESP efficiency. The primary reason is that the boiler and ESP system is very complex and the formula does not account for changes in resistivity, treatment zone bypass, or reentrainment losses, all of which can dramatically reduce overall efficiencies.

For example, the *A/V ratio* is used for the guarantee of the collection efficiency for new designs relative to the flue gas flow rate. However, there are fly ash ESPs where the efficiency will improve when more gas flows through the ESP. This typically will occur when the higher gas flow from the combustion process improves the electrical characteristics of the ESP. The higher excess air could increase SO_3 production or raise gas temperature levels to overcome low resistivity conditions. Or the increase O_2 levels may reduce LOI levels in the ESP reducing reentrainment losses as a result. So do not make the A/V ratio or SCA one of those *etched in stone* concepts.

The D-A equation has much merit for the designer as well as the end user, but its use should be weighed carefully. It would be better to use it as an indicator or tool rather than accept it on face value. In recent years, changes have also been implemented by a number of the manufacturers by raising the negative exponent to a fractional power. This was done to better the accuracy of the D-A equation for efficiencies greater than 99.0% and compensate for anticipated changes in fuels, chemistry, or other operating and design conditions that the manufacturer feels might affect ESP performance. Therefore, each manufacturer would have a different correction factor for different applications and different fuels specifications. This can dramatically affect ESP sizing. For example, a fly ash ESP would basically double in size for the same 99.5% efficiency if the exponent was raised to the 0.5 power (K) in the D-A equation.

Modified collection efficiency $$N = 1 - e^{-((A/V)w)^K} \times 100$$ **Eq. 2-3**

where:

K factor is a modification developed by Matts-Ohnfeldt.

It is of tremendous credit to Deutsch and Anderson that their efforts to explain precipitation has lasted over 80 years in one form or another. But the last 50 years has seen enough changes in the fly ash application of ESPs that requires a better understanding of how to cope with this collector. Real success in maintaining and improving ESPs will come from understanding of how the process, distributions, and internal integrity of the electrode systems interacts together so as to achieve the optimum voltage and current in each part of the ESP. These efforts can make the D-A equation an even better tool for predicting performance.

2.3.6 Collection Versus Field Location

After the input data of a specification is analyzed, the manufacturer will determine the physical layout of the ESP to best meet the collection goal. All designers are limited by the mechanical and electrical limitations of their design and the equipment available at the time on the market. As the size of ESPs has grown, the number of separate mechanical sections, usually called bus sections, both in parallel and in series, also has grown in number. More TR sets are required to meet this increased sectionalization. The designer might use a TR set on an individual or multiple bus sections depending on a multitude of design factors. In any case, it will be the number of TR sets placed on the bus sections located in series that constitutes the definition of the number of electrical fields in the ESP.

The size of each field and/or the sectionalization of the designs can vary greatly as is readily apparent between the European and American ESP layouts. For example, a European ESP might have two fields of 16 ft (4.9 m) depth compared to four fields of 9 ft (2.7 m) depth in an American design, while both are designed to achieve the same performance. For a 99.2% efficiency goal, the two-field layout would design for about 91% ash collection per field, while the four-field American concept would design for 70% ash collection per field.

As efficiencies have risen in recent years, both types of designs (with the rigid electrode replacement for the wire type) have increased the number of fields in about the same ratio. It is not unusual to now see two- to six-field European style rigid frame designs and eight- to ten-field American design ESPs. Regardless of the wide disparity of designs, it is of comfort to the purchaser of the ESP that they would all perform well if the ESP is sized properly, the internal components are reliable, and the operating conditions are controlled correctly.

2.3.7 How Collection Occurs

How well the ESP performs is based on a number of factors, but the user must become aware of how to judge this performance even though all the factors are difficult to define. It really boils down to an ability to collect and then deposit the ash material into hoppers. Even though the physical layout of the ESP may not be based on an exact science, it still adheres to a pattern of collection based on an exponential theory. The knowledge of this expected pattern is useful to the plant personnel, so lets consider a hypothetical four-field ESP to help explain some of its design and operating parameters. If it was determined by the manufacturer that four fields of equal mechanical size would suffice to achieve a 99.2% overall collection efficiency, then this sets the collection efficiency of each field.

On a theoretical basis, each field would have to collect 70% of the ash entering its zone and discharge what ash remains in the gas stream into the next field in series. The exponential theory of precipitation is clearly seen in the reduction of particles from field to field. The exact design of the fields to achieve this collection efficiency would come from a database that would define the ESP area, and capacities of the TR sets. Of course, the boiler operating parameters and coal specifications would also be considered in the final design.

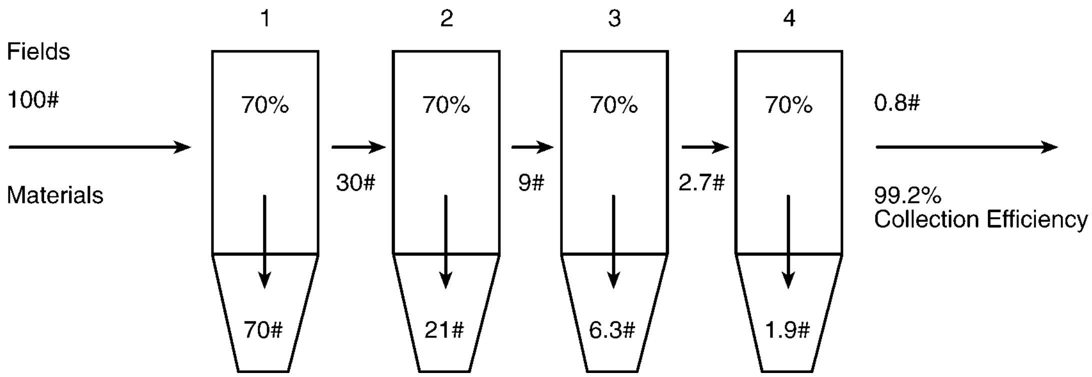


Figure 2-15
Effect of Collection on a Field-by-Field Basis

In Figure 2-15, it can be seen that for every 100 lb (45.4 kg) of fly ash entering Field #1, 70 lb (31.8 kg) are collected and deposited in the hopper of the field. That leaves 30 lb (13.6 kg) of ash left in the gas that is to be collected at the 70% rate in Field #2. So 21 lb (9.5 kg) are deposited in its hopper. That leaves 9 lb (4.1 kg) to enter Field #3. If the 70% collection holds, then 6.3 lb (2.9 kg) is retained in Field #3 with 2.7 lb (1.22 kg) entering Field #4. Again, at 70% collection 1.9 lb (0.9 kg) out of the 2.7 lb (1.2 kg) is retained. This leaves 0.8 lb (0.4 kg) exiting the outlet Field #4 so as to satisfy the guarantee of 99.2% efficiency.

There are a number of conditions that tend to alter the optimum field-to-field relationship shown above. Of benefit is the fact that some of the things that can go wrong with the ESP have already been built into the empirical database of the manufacturer. That is why sensitive ESPs can be made to work much better than the expected design efficiency when needed corrections are implemented. Sensitive and poorly performing ESPs exist because of their deviation from the theoretical pattern of collection shown in the example. The following list describes some of the concerns in the ESP that need to be recognized or addressed to develop a good pattern of collection in the ESP.

- The inlet field is the key to successful precipitation. So extra care is needed to insure satisfactory patterns of velocity and temperature into this field. This also means more attention to the mechanical integrity of the inlet field during internal inspections.
- Reentrainment of ash from the collecting surface of the inlet field sets the pattern throughout the ESP. Proper resistivity and voltage in the inlet field is of paramount value.
- Keeping a high level of collection in the front half of the ESP will help desensitize the whole installation. For example, any boiler disturbance will affect the ESP and allow ash to be dislodged from the collecting surfaces. The more ash in the latter half will cause greater losses from the ESP.

- The rapping pattern, both frequency and intensity, should match the quantity of ash from inlet to outlet of the ESP.
- The large variation of ash collection that should occur from inlet to outlet can develop some inherent difficulties for ash removal systems. The hoppers under the inlet fields are especially sensitive to blockage when a marginal or large ash removal system exists. The hoppers should not be considered as a storage area and the ash removal system (not the hoppers) should be designed with extra capacity to handle changes in fuels (higher ash content) and system malfunctions.

Probably the best way to analyze and work toward a desirable pattern of ash collection is to be able to understand the voltage and current readings of the TR sets. These electrical characteristics should provide a useful indicator of what is happening in every part of the ESP.

2.3.8 Voltage and Current Relationship

Since the ESP is an electrical device, its performance should be evaluated by its electrical characteristics. The electrical readings on the TR set meters provide a language that explains both the good and bad symptoms of the ESP. Unfortunately, this language has not been used effectively in many installations because of a lack of attention to simple concepts. Let's look at how the plant personnel should understand these electrical signs.

2.3.8.1 Basic Inputs

Before starting, however, there is need to collect some elementary bits of information and some procedures that should be followed and understood in doing so:

- The voltage and current limits of each TR set must be known, for both the primary and secondary sides. Observed measurements should be weighed against these limits.
- At least three electrical measurements are needed to help pin down the internal conditions of the ESP. They are one voltage and one current, either primary or secondary readings will suffice, and whether the energized area has spark over or not. If spark over does not exist, then the limit of the TR set should be reached. If the readings observed are below the limit of the TR set, this condition should be noted.
- Learn to use the patterns of electrical readings from TR set to TR set rather than worry about just the absolute values of the measurements. Of course, the aim of good precipitation is to work toward the optimum levels of voltage and current (which normally accrues at the highest achievable voltage).

- Record all voltages and currents at the point the needles of the analog meters come to rest. With modern controls, this usually occurs at the high point of the meter readings. If the needles do not come to rest, spark over is too excessive. If digital meters are being used, they should be set to indicate the values at spark over and provide an average reading to minimize the oscillation that is typically seen on a sparking ESP.
- Always record the electrical readings from inlet to outlet and by chambers or bays of the ESP to help identify patterns. Do not record readings by cabinet layout, since most cabinets are laid out to help balance the three-phase load in the motor control center (MCC).

2.3.8.2 General Concepts

Much of the emphasis in the industry has been placed in the wrong area in an effort to simplify the ESP operation. This has been done in an attempt to analyze or evaluate the performance level of the ESP on a continuous basis using one indicator. Part of the problem is that much of the emphasis has been placed on using power (as watts), and even the corona current as the sole evaluation tool. This limited input can be misleading and result in improper evaluation of or reaction to perceived problem conditions. The following is a list of key points to remember when analyzing ESP operation.

- There are many factors that can change the voltage and current relationship and their patterns in the ESP. *Space charge* and *ash resistivity* are the two main factors that affect the voltage in the space and the voltage across the ash layer. The space charge effect is normally fairly stable and typically changes only with fuel changes. Resistivity on the other hand can change quickly and is normally varying throughout a 24-hour period. The relationship and pattern of voltage and current levels in the ESP should be used as an indicator of the effect ash resistivity has on your ESP. The effect changes in resistivity can have on ESP performance is difficult to quantify because of differences between manufacturers' designs, mechanical integrating of the electrodes (alignment, damages, etc.), differences in process equipment, operator technique, and many other factors. As a result, it is quite common to have two identical boiler and ESP systems, built at the same time, burning the same fuels, which will operate quite differently. At times, it even seems as if your ESPs will develop a personality of their own. It is important that operations and maintenance personnel use the stack opacity and voltage and current feedbacks correctly to interpret the likes and dislikes of your ESP and to understand what is required to make it work better and to prevent damage and problems from occurring.
- Since the pattern of voltage values relative to the electric current values provides a useful message, then multiplying these two values together helps destroy that message. That is why the use of watts for the analysis of the ESP has disadvantages. The relationship of power versus collection efficiency works well for other industrial applications and even at times for the fly ash collector. But there are too many times the relationship does not hold up well and, since the product of the voltage and current loses the ability for judging performance trends, it is not recommended for long term success on smaller or marginally sized ESPs.
- Since the voltage across the space between the discharge electrode and the grounded plate represents a driving force for the removal of ash particles, the higher its value usually means better performance for the ESP. The D-A equation indicated its importance by doubling the effect of voltage on collection efficiency. As a general rule, it is wise to work toward the

highest voltage field in the ESP, but always remember that it is made up of both space and ash layer components. It is the voltage component across the layer that looms very important in critical ESPs. Still, there must be a minimum current density and corona distribution in the ESP to create the proper voltage drop across the dust layer. This is especially important in the inlet fields since ion flow is one of the main charging mechanisms.

- Either the kV meter across the load of the ESP or the voltmeter across the primary winding of the TR set can represent the variation of voltage conditions inside the collector. The kV meter reads the average of the peak and minimum voltage in the ESP and can be fairly accurate for typical ESP conditions. However, in extreme cases where the minimum and peak kV values are very close, the kV meter can be misleading. The primary voltmeter, which is on the alternating current side of the circuit, can also provide some problems with correct voltage readings at low operating levels because of the way the voltage is controlled (using SCRs). However, the primary voltmeter is a better indicator of secondary peak voltage levels and, in some cases, is a better monitoring point than secondary voltage. Low voltages on the primary side, relative to the rated voltage, easily points out problem areas that need to be addressed. Moreover, the primary voltmeter turns out to have long-term reliability when compared to the signal for the kV meter. Any TR set operating with a primary voltmeter reading less than 65 to75% of the TR rating would tend to trigger some concern.

2.3.9 Patterns of Readings

It will be the number of TR sets that exist in a sectionalized ESP that helps in the analysis of collection performance. Up to a practical limit, the more fields in series and the more parallel cells, each energized by a TR set, allows patterns to develop within the voltage and current relationships of the ESP. Each pattern of electrical readings may be primarily affected by a single condition, while other patterns will have two or three different conditions contributing their distinct inputs on the electrical results.

Even though most TR circuits will have two voltmeters and two ammeters, only one of each would be sufficient to help determine trouble in the ESP areas. There is nothing wrong with taking readings from all the control panel meters in a continuous monitor program. But, aside from the time factor when large numbers of TR sets are involved, patterns become difficult to visually discern with too many entries. Nevertheless, it still is a good idea to record all meter values on a periodic basis for a long-term database. In some cases, spark meters will exist, but it is prudent to learn how to judge the number of sparks per minute by a visual check. One problem in recent years has occurred with the replacement of the analog control panel meters with digital meters. The analog meters have advantages for pinpointing spark points as well as identifying some of the internal difficulties that show up in the ESP. Therefore, their use is certainly recommended. It is also important to note that as data logging and trending becomes more common, more and more information is being collected which is good. But most of the data is being averaged over 6 to 60 minutes, and some is being recorded at discrete increments (10 to 30 seconds, not continuously). Since the ESP power levels can fluctuate dramatically (from 0 to 100% on a sparking ESP), this data can become meaningless. Additionally, the data is only as good as the calibration and control setup that, in many cases, deteriorates over time for a variety of reasons. Therefore, it is important to remember that your evaluation is only as good as the data gathered.

2.3.9.1 By Reduction of Particle Count

If nothing exists to upset the major reduction of particles from field to field, a pattern of voltage and current will develop based on the collection pattern of the ESP. This is typically referred to as a reduction of *space charge particles* or *space charge effect*. This pattern can be judged to be caused by the effective change of the space charge between the cathode and anode electrodes and, as such, be considered a good representation of ideal collection efficiency in the ESP.

Table 2-3
Examples of Ideal Voltage and Current Readings Created by the Reduction of Space Charge in the ESP

Field	Primary ac Volts	Secondary dc Milliamperes (mA)
Inlet	360	250
2nd	330	500
3rd	310	750
Outlet	300	1000

The taper off of voltage from inlet to the outlet field reflects the high particle count in the inlet and relatively few particles in the outlet. Conversely, the corona current is seen to rise from inlet to outlet in nearly a straight-line relationship. It is this rapid rise of current that should be remembered as the pattern to shoot for in any installation. While this desirable pattern of voltage and current is not often observed in fly ash ESPs that have to cope with the grades of coal used today, it still remains the benchmark of good precipitation.

Key Technical Point

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2.3.9.2 By Resistivity Effect

What tends to alter the TR set patterns of electrical readings drastically from the above space charge pattern would be the effect from the resistivity factor. Coping with the continuous changes of resistivity in a fly ash ESP poses the greatest challenge for power plant personnel. The best way to evaluate and overcome a resistivity problem is by utilizing the ESP as the prime monitor of its severity.

When resistivity makes its impact on an ESP, the pattern that will surface will affect most, if not all, of the TR set electrical readings. It is wise to think of resistivity as having two bad zones with a relatively large good zone about half way between the two, which would then present a good operating area for most ESPs. Table 2-4 shows how these three zones would tend to affect the electrical reading of a four-field collector (the chemical conditions that cause these resistivity zones are explained in sections 2.4 and 6.2 in greater detail).

Table 2-4
Typical Patterns of Electrical Readings Under Varying Resistivity Levels

Fields →		Inlet	2nd	3rd	Outlet
Bad Zone Low Resistivity	**Volts**	290	280	279	275
	mA	1000	1000	1000	1000
	SPM*	0	0	0	0
Good Zone Moderate Resistivity	**Volts**	300	320	310	300
	mA	500	700	950	1000
	SPM	30	20	10	0
Bad Zone High Resistivity	**Volts**	200	195	200	205
	mA	70	75	80	110
	SPM	60	30	20	10

* = Sparks per minute

Conditions:
1. All fields are of equal size.
2. All TR set ratings are 400 V–1000 mA.
3. All readings are taken at same boiler load.

Low resistivity and high resistivity are the two areas that typically cause low ESP efficiencies.

Key Technical Point

Low resistivity and high resistivity are the two areas that typically cause low ESP efficiencies.

The pattern of readings shown at the top zone represent a low resistivity condition that will generally result in good ash collection, but which is negated by excessive reentrainment of ash. Its characteristics include the absence of spark over, and voltage values that show minimal differences from inlet to outlet with full TR rated current limits. This zone of operation should be avoided if at all possible. It is important to note that the pattern of very low resistivity is somewhat similar to the pattern observed when a condition called severe back corona exists. They both help to destroy the expected performance of the ESP, but for opposite reasons. Note that this pattern deviates from the space charge pattern that clearly shows the collection of ash occurring from field to field (with voltage decreasing and current increasing from the inlet to the outlet of the ESP).

Another pattern to avoid is shown as the high resistivity condition where low voltage and low corona current readings exist throughout the ESP. The ash layer initiates spark over at low voltage levels and this tends to repeat field to field. The low spark-over voltage will prevent the ash from being collected, resulting in low collection efficiencies. One problem area that tends to amplify this situation is when large capacity TR sets have to operate at a low percentage of their rating. Improper matching of the TR set to the load further sensitizes the field and can result in a spark-over condition at lower voltages. Additionally, as a result of the mismatched TRs, the ESP performance suffers from minimal current conduction times and poor corona distribution.

The moderate level of resistivity, shown by the middle pattern, provides benefits for most fly ash ESPs, especially sized 300 SCA or less. Good signs include relatively high voltages, even though its pattern does not follow the classic ideal space charge one because the inlet field voltage might be at a lower value than for the next field in service. In all cases, spark over should be present, especially in the front half of the ESP. This would show evidence of good bonding in the ash layers. The strong rise of corona current (from the front to back of the ESP) is the best sign of optimum ash collection.

2.3.9.3 By Internal Problems

Precipitation has been shown to have some rhyme and reason for its pattern of ash collection. There should be some ability to connect voltages and currents from field to field by a straight-line or curved relationship. Some explanation must be made for any set of TR readings that deviate greatly from this accepted pattern. See Table 2-5. It can be seen that a saw-tooth pattern exists that works counter to that expected from a uniform reduction of ash particles. A mechanical or electrical defect is most likely the cause of this observation. This type of superimposed difficulty in a specific area of the ESP will show up better when operating in the moderate zone of resistivity. Internal problems are less visible in the electrical readings when operating in a low resistivity zone since sparking may not occur even with major defects on the ground surface (for example jagged holes, torn plates, bolts threads, welding burrs). The effect of internal problems will probably more easily be seen during high resistivity conditions. The ability of the plant personnel to pick out areas of internal difficulty during periods of operation allows corrective action to be taken during outages. The more regularly power readings are taken, along with simultaneous recording of opacity and process parameters, the easier the analysis will be.

Table 2-5
Pattern of the Electrical Readings of a Four-Field ESP That Shows Difficulty in Field #3. Note the Deviation from an Expected Rise in Current in the Direction of Gas Flow Through the ESP.

Field of ESP	Primary ac Volts	Secondary dc mA	Sparks per Minute
Inlet	300	500	10
2nd	320	700	10
3rd	260	250	10
Outlet	310	900	1

Conditions: 1. All fields are of equal size.
2. All TR set ratings are 400 V–1000 mA.

2.3.9.4 By Parallel Cells

Large boiler systems with a large ESP located after the air pre-heater can present a multitude of different patterns, mostly related to the flue gas temperature differential. Parallel chambers could show a low resistivity pattern coexisting with a moderate resistivity pattern side by side. All this is perfectly normal under the situation, but it should be identified and understood. Whether it is corrected depends in large measure on the performance of the ESP.

Of course, multiple parallel chambers or cells with their TR sets allows evaluations to be made of inlet to inlet field characteristics, 2nd field to 2nd field, and so on throughout the ESP.

2.3.9.5 By Size of Field or Electrode Geometry

Be aware that patterns could be adversely affected by differences in the collection areas that are connected to the TR sets. Some ESPs have designs with unequal sizes of field area. In this case, patterns would be developed on a current density per area basis rather than using the readings directly from the TR set (mA/ft^2 [mA/m^2]). Bus sections that are isolated and removed from the collection process will also cause some electrical effect to occur on adjacent sections.

It is possible to also have an ESP designed with variation in plate spacing from field-to-field, or with different electrode geometry (for example wire size diameter, more pins on electrodes, or more aggressive points are all possibilities). These can result in different voltage and current levels that need to be understood by plant personnel when evaluating readings.

2.3.9.6 By Other Factors

While the above conditions are the prime causes of the most common patterns of electrical readings that are observed, other inputs tend to alter these patterns. As noted before, high levels of fine sized particles will affect the inlet field to a greater degree. Buildup of ash on the discharge electrode and collecting surface, aside from its effect on the resistivity, can also influence the voltage and current values observed on meters. In some cases, certain ash coatings on the high voltage component can elevate the voltage, but this is not a common problem for most fly ash units. Excessive collector plate buildup would tend to elevate the current and lower the voltage reading of a section when operating in a low resistivity zone. This might be observed when the rapper of that area has failed.

An interesting observation might occur with an ESP that uses over six fields in series. It would be possible to swing from one resistivity mode to another as the selective collection of particles leaves a much different chemistry of ash in the latter fields (finer particles and/or higher resistivity ash). In most cases, if this does occur, the characteristics observed would show a spark controlled resistivity convert to a severe back corona condition in the outlet.

The knowledge of the patterns of voltage, current, and spark over provide the key for successful analysis of the ESP performance. Even more important, how these patterns form will often point the way for the corrective steps that can be taken to improve performance. While these patterns will prove most useful for the ESPs less than 300 SCA in size, benefits will occur for even the large ESPs, but to a much lesser degree. In fact, an ESP design with at least twice the area needed to meet the collection goal would minimize the need for any analysis of most patterns. Designing oversized ESPs, adding gas-conditioning systems, and other major upgrade options are all an expensive direction to take. If plant personnel learn how to properly interpret ESP voltage and current levels, and utilize the proper techniques to manipulate the process and ESP equipment to optimize the performance, then even small ESPs can be made to work well.

2.4 Effect of Process and Other Systems Factors on the ESP

What conditions exist in the space between the discharge electrode and the collecting surface primarily determines the level of collection success of the ESP. Since the combustion process of the boiler system is continually changing, then the collection performance of the ESP will also tend to vary somewhat by this process change. The recognition of this intertwined relationship between the boiler system and the ESP becomes the hallmark of success at many power plant installations.

There is no need for the person responsible for the ESP to become an expert on the combustion process, but there has to be an awareness of which parts of the system exhibits the greatest influence on the ESP performance. Once known, these components of the combustion system and boiler equipment actually should be evaluated as important parts of the ESP system.

Another way to look at this relationship between the ESP and the boiler is that they need each other to a large degree. In most cases, the ESP reacts favorably to improvements in the combustion process and even becomes a sensitive monitor when things go wrong in the boiler.

The most important process factors influencing ESP performance are the chemical composition of the ash and flue gas, the operating temperature, and how certain boiler parameters and equipment influence these inputs to the ESP. The relationship is complex, but the goal is to apply simple ESP fundamental principles to evaluate cause and effect relationships, and to solve problems.

Key Technical Point

The most important process factors influencing ESP performance are the chemical composition of the ash and flue gas, the operating temperature, and how certain boiler parameters and equipment influence these inputs to the ESP. The relationship is complex, but the goal is to apply simple ESP fundamental principles to evaluate cause and effect relationships, and to solve problems.

Typically, the major factors that influence the ESP operations can be categorized in the following areas:

- Ash resistivity
- Gas temperature
- Boiler operations
- Air flow rate
- Distribution

2.4.1 Ash Resistivity

The term resistivity is almost synonymous with the fly ash application of the ESP. Even though much has been researched on this phase of precipitation, especially during the last 50 years, there still exists an element of uncertainty and misconceptions for the people working with the ESP.

One of the prime reasons for this continuing confusion with resistivity is that it keeps changing. Some of these changes might be seen every 10 to 20 minutes at certain sites while at others it might take hours. Fortunately, it is the very knowledge of this changing characteristic of resistivity that provides the best chance for its successful control and manipulation to improve ESP operations. A discussion of resistivity and factors influencing it follows.

2.4.1.1 What is Resistivity?

The individual particles of ash in the flue gas, whether of resistive or conductive material, do not affect the resistivity condition until they are removed from the gas stream and start forming a layer on the collecting surface. It is the resistance of this ash layer to the flow of electric current that develops the voltage drop that was previously discussed in the last section. Think of this phenomenon as a form of *Ohms Law* (volts = current × resistance), and the voltage that occurs will be of different values across the whole area of the ESP, depending on the localized conditions of the ash layer. Typically, the current flow through the dust layers can take two conduction paths: one through the material (*volume conduction*) and one along the surface of each individual particle (*surface conduction*). Which mechanisms are used is dependent on the temperature of the ash.

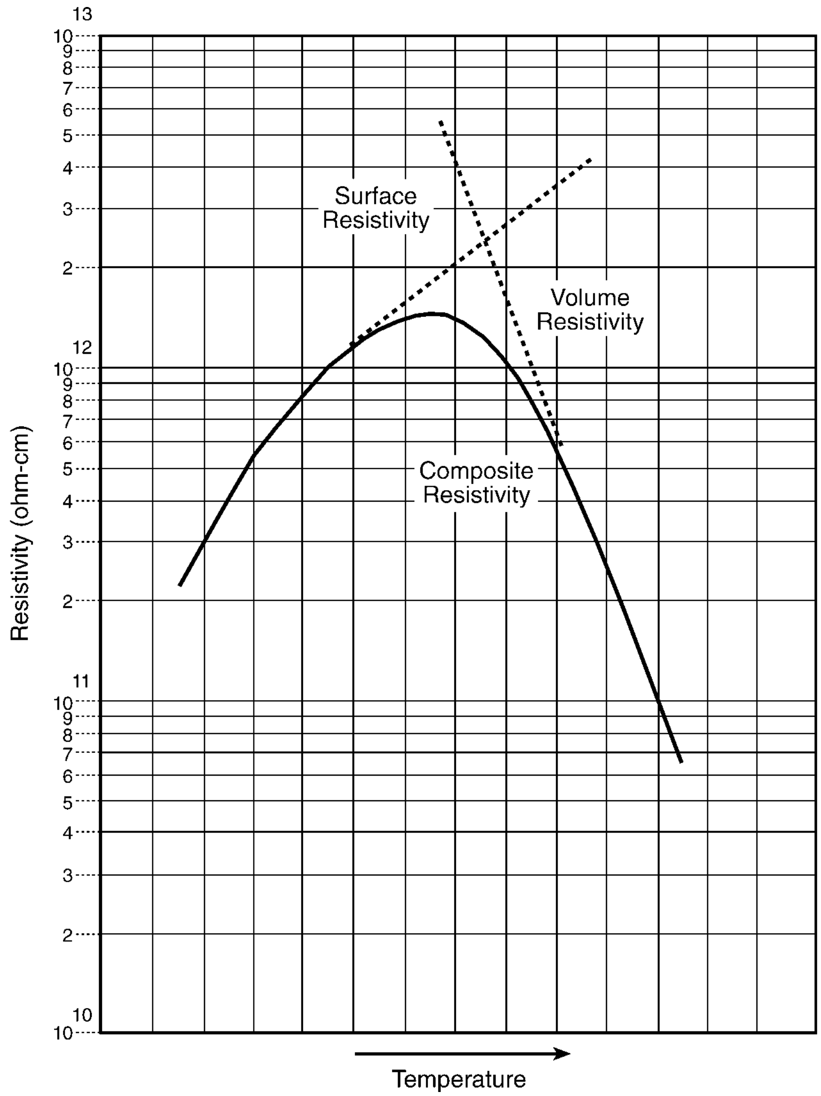

Figure 2-16
Fly Ash Resistivity as a Function of Temperature

It is this resistance of the layer, or resistivity, that can either help or be detrimental to the collection efficiency of the ESP. For example, the cohesion of the particles in the layer will improve with rising resistivity levels. Conversely, excessive ash losses from the layer will occur as resistivity drops below a certain level. But the main impact of resistivity on the performance of the ESP will be seen in its effect on the electrical characteristics, both good and bad.

2.4.1.2 The Three Faces of Resistivity

As discussed in the last section, typically, ash resistivity is broken up into three categories:

- Low resistivity
- Moderate resistivity
- High resistivity

High Resistivity (10^{12} ohm-cm or Higher)

There is still a little confusion on what the term high resistivity really signifies when it is discussed. Severe resistivity conditions are often mentioned as *back corona* or *severe back corona*. This occurs when the resistance of the ash layer on the anode (collecting plate) is so high that large numbers of positive ions are channeled back into the gas stream. This condition neutralizes the negative space charge of the voltage field to a point where the precipitation process is effectively diminished.

While this severe back corona condition is widely referred to, its existence is relatively infrequent for most cold-side installations across the country. However, it has surfaced more in recent years when sub-bituminous, lignite, or any coal with under a 1% sulfur content by weight that are used with the wrong set of flue gas conditions. It is also more commonly seen in the outlet field of oversized ESPs and in some 16 in. (400 mm) plate spacing units. Additionally, many hot-side ESPs have developed severe back corona as a result of sodium depletion of the ash particles that are in contact with or adjacent to the plate surface.

More commonly observed in the fly ash ESP is a high resistivity condition characterized by spark over. This form of resistivity is also initiated by localized back corona, where the number of positive ions produced is small compared to the severe back corona case, creating a localized spark over. The source of these positive ions comes from sporadic gas breakdowns in the pores of the ash layer.

For this condition to occur, the voltage drop across the depth of the layer on the positive surface, at a specific spot, must reach a critical level. This sets up a voltage differential between the resistive particles that form a pore or open space in the layer. If this voltage is greater than the small space can handle, a spark bridges the space between the ash particles. Figure 2-17 shows how the charged ash particles form a porous ash layer.

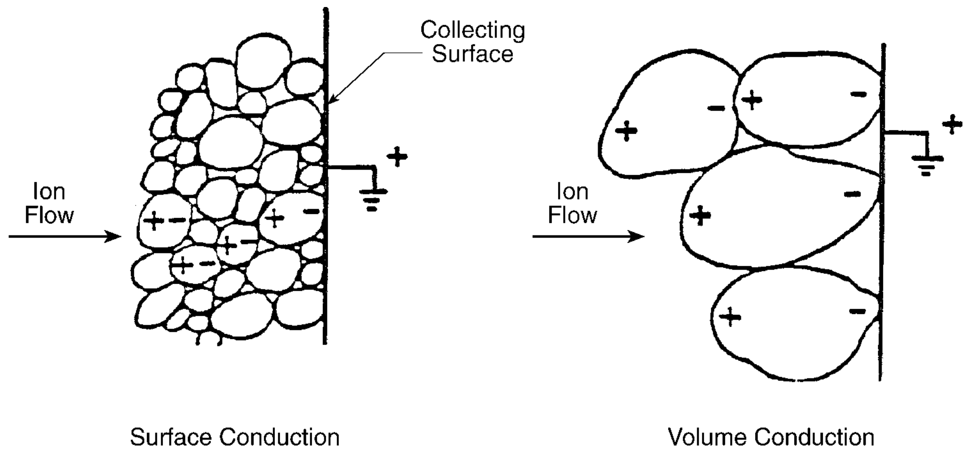

Figure 2-17
How the Charged Ash Particles Form a Porous Ash Layer

These small gaseous breakdowns will produce both negative and positive gas ions. The negative ions head toward ground and the positive ions want to head back toward the negative discharge electrode. What appears to happen on the surface of the layer is for the positive charges to concentrate on the highest and sharpest edges and send a positive streamer outward toward the negative electrode. The negative discharge electrode then bridges the space with a flashover or spark to the strongest positive streamer present on the anode.

Once the spark over occurs to one positive streamer, another streamer will cause a spark over to occur at a different location in the ESP. This breakdown process continues at a frequency, usually at a sparks-per-minute rate, that is set by the controls of the TR power supply. In fact, modern day automatic voltage controls are designed for the spark-over mode of resistivity. The control is usually set for a desired spark rate and the voltage of the TR set is raised or lowered so as to maintain this spark rate. As the voltage changes, the electric current passing through the ash layer will change so as to achieve the required voltage drop across the ash layer. Remember it is this voltage drop across the layer that will control how much back corona (positive streamers) that will form.

The spark over, actually a momentary short circuit, is not unlike what happens in a thunderstorm atmosphere. The earth being positive becomes highly charged in a storm. Any object that is conspicuous to its surrounding area, such as a tree, lightning rod, church steeple, or even a golfer on a fairway, becomes the emitter of highly charged positive streamers. A discharge, or lightning strike, occurs between the negative high voltage cloud and the most aggressive positive streamer. Only the magnitude is different from that which occurs in the ESP.

Moderate Resistivity (10^9–10^{11} ohm-cm)

The moderate resistivity condition typically includes sparking similar to the high resistivity condition explained above. The difference is the severity is less and the amount of positive ion steamer created is less. This allows higher voltage levels to be achieved before a spark over occurs. These relatively low energy spark overs can almost be considered a normal condition of the precipitator because good, effective collection is possible when it exists. In fact, the smaller, higher gas velocity ESPs need this normal moderate resistivity condition to function well. Spark over would indicate that the ash layer is resistive enough to form a tightly bonded ash layer that will resist reentrainment losses associated with high gas velocities.

Low Resistivity (10^8 ohm-cm or Lower)

The third resistivity condition, comprising the low levels of resistance, actually produces an opposite effect than the back corona cases. In fact, it might better be called a conductivity problem because the ash layer exhibits little resistance to the electric current flow. The low voltage drop across the layer is reflected in the lower voltages and high current observed on the meters. In a low resistivity condition material is collected well, but a large amount of material can be reentrained during rapping.

2.4.1.3 How Ash Resistivity is Measured

It is natural to want to place some number on the different levels of the ash layer resistance so as to help identify the zone of resistivity during operation. So a resistance measurement has been developed in ohm-centimeter terms. Numbers normally found in practice might extend from a 10^4 to 10^{13} value. Low resistivity conditions would be represented at the low end of the range, while severe back corona might be seen near the high end of the measurement.

Even though these numbers are valid for representing the resistivity levels to some degree, it is difficult to use this measurement in any practical way at a specific installation. A measurement obtained one day may not be meaningful a week later. Moreover, the resistivity of the ash layer exhibits a sliding pattern of numbers during any one operating day. It can even be completely different from area to area of an ESP at any given point in time, therefore, it is best to refer to zones of resistivity relative to their effect on the ESP. Table 2-6 might be considered typical for most ESPs.

Table 2-6
Typical Resistivity Levels

Resistivity Range	Effect
10^4 to 10^7 ohm-cm	Usually highly conductive material - hard to retain - low voltage fields present.
10^8 to 10^9 ohm-cm	Sensitive stage where lack of resistive characteristics can sometimes hurt ESP.
10^{10} to 10^{11} ohm-cm	Appears to be the best range to shoot for, should show spark over.
10^{12} to 10^{13} ohm-cm	Range usually associated with < 1% sulfur coals, reduced power in all fields can exist from sparking, difficult range for ESP.
Over 10^{13} ohm-cm	Can produce severe electrical disturbances, or severe back corona.

There is large amount of historical data of resistivity values in the utility industry, so it pays to understand how these values are obtained, as well as their limitations. The normal method used is to take a bulk sample of ash from the ESP or inlet ductwork and have the sample measured in a controlled laboratory environment. The classic curves of resistivity numbers versus changes in temperature are developed from this type of test. Getting a valid sample of ash to the lab is an art in itself, and this can cause some problems using the data generated by these test. To get the best results a bulk sample should be pulled directly from the gas stream through a test train. In an effort to overcome some of the problems of the lab measurement, an *in situ* device was developed in order to obtain a resistivity number directly from the flue gas stream at the ESP site. This number is generated by recording the values of voltage and current across a layer of ash that is collected in the device. Since this measurement is obtained at the gas conditions existing in the flue, it appears to have more validity than the laboratory result. However, be aware that these are single point measurements that may not be representative of the whole area of the flue. Some questions arise about the way the layer forms between that of the *in situ* cell and the actual deposition of material on the collecting surface of the ESP.

Computer modeling is another approach that has been used. The ultimate ash analysis is typically input into the software to produce a curve. EPRI's ESPM and ESPERT programs (as well as others) can produce these types of curves. Most of these programs are capable of evaluating changes in SO_3 injection rates and other chemical constituents. These programs should be used in conjunction with lab and *in situ* data to better determine in which resistivity zones the ESP might operate.

Be aware of the problems associated with the identification of the resistivity level by any one number. For example, if tests or model results indicate a resistivity of 10^7 ohm-cm (indicating a low resistivity condition), and the ESP exhibits spark over in most of its sections, it would be prudent to believe your eyes rather than the test numbers. Conversely, if a resistivity measurement generates a 10^{11} ohm-cm number (usually denoting a spark-over condition), and spark over is nowhere to be seen, believe your eyes. The actual changes in resistivity are better understood by daily observations of all the signs given off by the ESP power levels. This is more the norm than the exception of when fuel blending, fuel switching, and/or a gas conditioning system are being used.

2.4.1.4 How to Evaluate Resistivity

As previously discussed, the patterns of electrical readings of the TR sets provide the prime way to identify the working zone of resistivity that exists at any given time. There are also some other indicators that can help identify resistivity conditions that are covered in Section 4.2 (such as opacity trending, oscilloscope waveforms, and V-I curves).

An important point to optimizing ESP performance is for the plant personnel to recognize where the ESP is operating relative to the peak of the resistivity curve. That is more useful than knowing the value of resistivity at the peak. For example, the left-hand side of the curve shows a decreasing resistivity as the temperature drops. If low spark-over voltages were the dominant limit on the cold-side ESP, than that would suggest that a reduction in temperature would adjust the resistivity to a better level. Conversely, if a low resistivity condition exists on a cold-side ESP, a rise in temperature could be an effective corrective step.

How this relationship works to alter the electrical characteristics of the ESP may be seen in Table 2-7. As temperatures rises in the cold-side ESP in the case of the 2.8% sulfur coal, the resistivity changes from a low level to the spark-over mode rather quickly. Note how the voltage observed on the meter rises even before the onset of sparking. This is the sign of an increasing voltage drop across the ash layer. In this example, the best operating level of the ESP might be in the 295 to 300°F (146 to 149°C) range. This ESP is clearly operating on the left hand side of the resistivity peak.

Table 2-7
Effects of Temperature on Power Readings

ESP Electrical Readings Flue Gas Temperature Versus Coal Characteristics						
Average Flue Gas Temperature Exit Air Heater °F	2.8% Sul. Coal (High ppm of SO_3)			0.7% Sul. Coal (Low ppm of SO_3)		
	Primary Volts	Sec. mA	Sparks Per Min.	Primary Volts	Sec. mA	Sparks Per Min.
270	290	1000	0	300	500	20
275	295	1000	0	290	400	20
280	300	1000	0	280	300	20
285	315	1000	Occasional	260	200	20
290	325	900	10	240	150	20
295	315	700	20	220	110	20
300	300	500	20	200	70	20

If 0.7% sulfur coal is used at the same installation, the best electrical operation for this ash occurs at the lowest temperature, 270°F (132°C). In this case, the resistivity characteristics definitely worsen as the temperature rises and voltages and currents are driven down in value. At the 295 to 300°F (146 to 149°C) range that worked well for the high sulfur ash, the low sulfur situation would cause an unsatisfactory performance of the ESP.

Even though both ashes of the above example exhibited similar resistivity trends relative to temperature, they are clearly working on two different curves. In the low sulfur case, the spark-over mode of resistivity exists throughout the 300°F (149°C) transition. The important observation of the high sulfur coal case is that a transfer from low resistivity to a spark-over mode occurred within about a 10 to 15°F (-12 to -9°C) change. The fly ash ESP must be continually monitored for this resistivity characteristic and, with some fuels, there is an optimum temperature zone for the ESP. On most ESPs, this effect on power readings can be seen as the boiler system heats up through the day: with low temperatures in the morning and higher temperatures in the afternoon.

Changes in resistivity that occur from the variation of temperature may not be quick. Be aware that the ESP is a large heat sink device and any change of temperature will take time to work its way throughout the ash layers and metal of the collector. The inlet field will be the first affected and, fortunately, that is where it is needed if the change is for the good.

The rate of change of resistivity versus the temperature will be different on both sides of the curve's peak. On the left side, the decrease of resistivity will change faster primarily due to condensation effects (of SO_3) on the surface of the ash particles. On the right side of the peak, as temperatures rise the decay of resistivity will be more gradual, but somewhere around the 700°F (371°C) level, most ash layers will exhibit favorable resistance values.

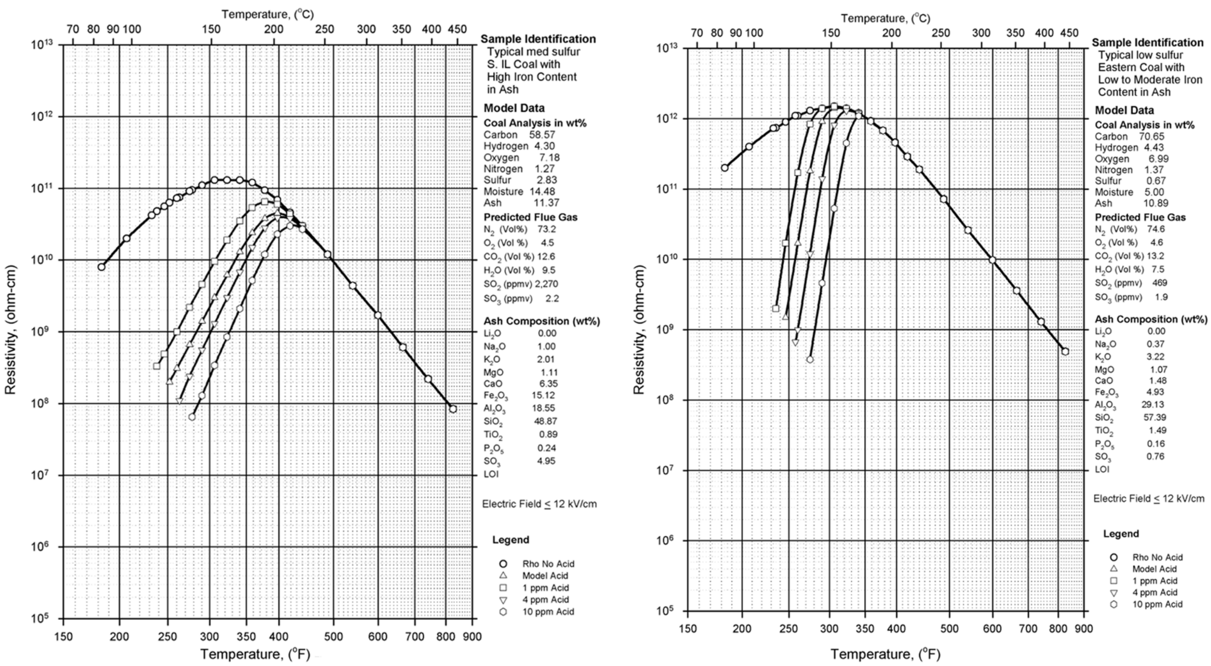

Figure 2-18
Examples of the Resistivity Curves for High and Low Sulfur Fuels

Note the difference in the peak of the curves. The curve on left is high sulfur (2.83% S) and the curve on the right is low sulfur (0.67% S).

Around the peak of the resistivity curve, the flow of the electric current over the surface of the ash particles is still the most dominant conduction mechanism. Somewhere over 400°F (204°C), the surface factor begins to diminish and the flow of current starts to use the body of the particles as its primary path through the ash layer to the grounded anode. As discussed earlier, this phenomenon is called volume conduction as opposed to the surface conduction method of passing the electrons from particle to particle. Evidently, small chemical ions, such as sodium and other alkalis, perform the task of carrying the electrons as the temperature rises. Just what temperature range provides the best performance of the ESP will depend on a number of the chemical constituents of both the ash and flue gas. The use of the hot-side ESP in the 700°F (371°C) temperature zone became an option when coal characteristics were deemed too poor for low temperature operation.

At what temperature the peak of resistivity occurs will vary from a multitude of inputs. As a general rule on cold-side ESPs though, a higher sulfur coal might find its peak occurring in the 330 to 350^{o}F (166 to 177^{o}C) range, while a low sulfur coal might produce its peak around the 310^{o}F (154^{o}C) level. As the chemistry of the ash reaches a poor zone for the ESP, peaks can easily occur below 300^{o}F (149^{o}C). In this case, operating the ESP at 220 to 230^{o}F (104 to 110^{o}C) could overcome adverse resistivity conditions but boiler systems normally are not designed to operate at this level and gas conditioning is a typical alternative solution. It is important to remember that operating at low temperatures or below acid dew points can accelerate corrosion and cause fouling of discharge electrodes.

2.4.1.5 Effects of Particle Size and Distribution on Resistivity

Most fly ash ESPs will see little effect from the particle size factor on the level of resistivity. Where some effect might occur is in the outlet fields of a large ESP with over six fields, where the fine-sized particles might consist of some sensitive chemical constituents. In this case, the latter fields might exhibit a high resistivity condition, even flashing into a severe back corona zone. This is further aggravated by the close packing of the fine-sized particles in the layer itself. Of course, high concentrations of fine-sized ash particles would play a major role in elevating the space charge of the inlet field.

Gas distribution patterns can affect how the larger size ash particles segregate in the flue gas stream ahead of the ESP. When the ductwork makes any kind of a severe turn without proper baffles, the large particles tend to concentrate in select channels. This is especially seen with the unburned coal particles entering the ESP. However, even with all this shifting of particles, it would still take an extremely sensitive resistivity condition for the ESP to be much affected from a poor particle distribution.

2.4.1.6 Effect of the Ash Layer on Sparking

The thickness of the ash layer tends to increase as the resistivity rises. And getting that layer to dislodge by rapping forces is no easy task because of the strong bond that develops between the particles. So there is always a strong tendency to believe that even harder rapper forces could reduce the spark-over problems by sufficiently reducing this layer of ash.

However, the surface layer continuity or uniformity can have a much greater effect on spark-over voltage. Instead of helping the situation, the extra rapping intensity sometimes affects the spark over adversely by causing sharper irregularities to occur on the surface of the layer of the anode (ash on the collecting plate). These sharper edges further promote the concentration points of the positive streamers that draw even more sparks. Even an increase in the frequency of the rapping cycle can be counter-productive. This does not mean that optimum rapping is not important. It is important to realize that rapping should not be viewed as a primary means of controlling resistivity.

As a general rule, other means should be used to reduce resistivity to a satisfactory level, such as temperature control or gas conditioning, and the rapper system should be set to match this resistivity level. This approach allows an existing rapper system to function well with little chance of mechanical damage to the ESP. Reduction of the resistivity in the layer will also allow a greater buildup to exist on the collecting surface with minimal electrical disturbances. On the other hand, let the resistivity go uncontrolled toward the higher levels, and just a thin ash layer will cause problems with the performance of the ESP.

Key Technical Point

It is important to realize that rapping should not be viewed as a primary means of controlling resistivity.

As a general rule, other means should be used to reduce resistivity to a satisfactory level, such as temperature control or gas conditioning, and the rapper system should be set to match this resistivity level.

2.4.1.7 Effect of Gas Composition on Resistivity

Only a few components of the flue gas might be evaluated regarding their effects on resistivity. The percentage of water vapor and oxygen in the gas stream at the ESP just helps pin down the dilution effect of excess air. There is not much water in the flue gas to begin with, and reducing that percentage even more aggravates the level of resistivity.

The trace amount of sulfur trioxide (SO_3) in the flue gas of the ESPs, located after the air pre-heater, has strong implications for resistivity. The value of SO_3 is often estimated to be 0.1 to 0.4% of the sulfur dioxide (SO_2) segment of the flue gas. An interesting facet of the SO_3 is its affect on the acid dew point. The greater the SO_3 content, the higher the temperature where sulfuric acid can form in the gas stream. This problem becomes apparent below 300^{o}F (149^{o}C) when high sulfur coals are used in the boiler, often producing the low resistivity condition in the ESP. The effect of SO_3 and water on the dust resistivity are covered in detail in Sections 6.2 and 6.5 with examples for different fuels and conditions.

2.4.2 Boiler Factors

There are some parts of the boiler and combustion system that have a sizable influence on the success of the fly ash ESP. Some of these areas can be monitored, some modified, but all of them should be understood as to their effect on the performance of the collector. A suggestion for anyone responsible for the ESP is to record pertinent operating parameters of the boiler system for any set of electrical readings of the TR sets that are retained. At a minimum, these should include:

- Steam flow rate
- Fuel feed rate (or pulverizer speeds)
- Air flow rate
- O_2 at economizer outlet
- Temperature at air pre-heater outlet (econ. outlet for hot-side ESP)
- Induced draft (I.D.) fan amps and damper setting

- Forced draft (F.D.) fan amps and damper setting
- Ambient air temperature
- Opacity readings, average and instantaneous valves

The object is not to download so much data as to be unwieldy, but yet enough to pin down the operating level as well as a few other key factors. If there are multiple readings of O_2 and temperature for the larger units, record all as separate data points. When major changes occur in the readings of the TR sets, expand the database for a historical record to include mill characteristics and additional temperature values across the whole system. At times like this, try to pin down the source of the coal being burned, even though it can be a difficult task at most sites.

2.4.2.1 Boiler System Exit Temperatures

The importance of temperature on the performance of the ESP should be well understood by now, but this value is an elusive number at any installation. From a practical standpoint, temperatures recorded in the boiler control room are used in relative ways, because attempts to obtain accurate temperatures at every point of the system can be quite difficult.

Consider what this means on a cold-side ESP with only one regenerative rotating air pre-heater. The average gas temperature at the exit of the air pre-heater might be recorded at 290^{O}F (143^{O}C) in the control room. If the diameter of the wheel is 36 ft (10.9 m), it is probably turning at one revolution per minute, which would produce about a 90^{O}F (32^{O}C) temperature range across the duct. The 290^{O}F (143^{O}C) temperature is recorded as an average but that actually represents flue gas temperatures that range from about 245^{O}F (118^{O}C) at one end of the air heater to about 335^{O}F (168^{O}C) at the other end.

Normally about eight thermocouples might be strung across the large area of the flue so even the 245^{O}F to 335^{O}F (118 to 168^{O}C) gradient measured might not actually reflect the actual gas temperature in the ESP. Many factors will affect the gas temperature between the air heater and the ESP. Air leakage at the seals of the air heater normally has the most significant effect. The distance of the ductwork form the air heater to the front of the ESP, length of ESP, air in-leakage into the ESP, condition of the insulation of the ductwork and the ESP, and the effect of radiant cooling will all alter the temperature profile in the ESP.

What this all means in a practical way is that the control room temperature becomes the benchmark for all the analysis of resistivity changes over a period of time. For example, at 290^{O}F (143^{O}C) certain patterns develop in the ESP. At 300^{O}F (149^{O}C), other changes may be seen. So the air pre-heater exit temperature is used as a barometer of all the temperatures that exist in the ESP, and it is used in this relative manner. One of the reasons the ambient air temperature is recorded is for its effect on some of these day-to-day temperature changes at the ESP. This has all worked pretty well over the years and the whole historical database of temperature versus ESP characteristics has been obtained this way in the field. In other words, each ESP develops its own relationship with the rest of the boiler system.

Every boiler system has a number of ways the flue gas temperature at the ESP can be varied. The cold-side ESP has more options than the hot-side collector. Just changes in the boiler load with its resultant fan operation will move temperatures up and down. Shifting the amount of air through each F.D. fan will vary the gas temperatures exiting the air pre-heaters if this is deemed helpful. Even at the same production rate, minor changes in the excess air, tilt position, or staging of the mill loads can shift combustion zones, effecting exit gas temperatures. In some systems there are by-pass air ducts around the air pre-heaters, and several methods for heating incoming air to the F.D. fans (typically steam pre-heater coils are used). Unfortunately, most of these available methods are for raising temperature, which is useful to counteract the low resistivity conditions, but of little benefit for the spark-over levels that need temperatures reduced.

Multiple air pre-heaters can create different exit temperatures in different sections of the ESP. This is usually caused by basket blockage and F.D. fan differences or air infiltration. If the temperature needs to be decreased, it is best to reduce the severity of the extreme temperature area. Speeding up the rotation of the apparatus, doubling the revolutions per minute will normally cut the temperature spread in half. If sufficient distance exists between the air pre-heater and the ESP, baffles can be installed to move large segments of the gas from one side to the other. Water or steam injection (biased to the gradient) has been used at some sites. All of these methods work but they have some drawbacks that could negatively effect ESP operation. Speeding up the air heater will increase the wear on the air heater seals and increase the tramp air in the system through the seals. The addition of baffles will increase the pressure drop in the system, requiring more fan capacity and increasing the tramp air where leaks are present. The addition of water conditioning can cause corrosion and buildup related problems. It is therefore important to look at the pros and cons of any system modifications.

Although the regenerative air pre-heater is the most commonly used heat exchanger, a tubular air heater has also been used in coal-fired installations. A key difference between the two devices is that the ESP receives a top to bottom variation in gas temperature from the tubular application as opposed to the side to side pattern from the rotating heat exchanger. Although the differential of temperature is less from the tubular device, it still could have a resistivity impact in critical ESPs.

Regardless of the average gas temperature obtained at the exit of the air pre-heater, it is safe to assume it will be quite a bit lower at the exit of the ESP. Efforts to help minimize a substantial loss of temperature will provide benefits, not only in performance but, in some cases, to prevent metal corrosion. The hot-side ESP might even need windbreaks and other enclosures for helping to contain heat within the ESP. This will be especially needed for northern locations. Emphasis on this phase of temperature evaluation and control will be more important as the sizes of the ESP get larger.

It is important to consider the correction of temperature differentials in the ESP even though exact measurements are difficult to obtain. An ESP with near perfect gas velocity and particle distribution may not cancel out the ill effects of a poor gas temperature pattern. Conversely, an optimum gas temperature across the ESP will overcome many ill effects from the poor gas flow distribution and ash particle segregation.

2.4.2.2 Coal Influence

For the people responsible for the performance of the ESP, the uniformity of the coal quality entering the combustion zone is of greater benefit than the knowledge of its composition. The ESP is basically a steady state collector, and the tools available such as temperature or other gas conditioning techniques work best on a uniform quality of coal. The smaller the SCA of the ESP, the greater importance should be extended as to how to achieve this condition.

Various coal blending methods can be employed if the quality of incoming coal sources differ greatly. This can be done at a separate site, but is more commonly tried at the boiler site. Alternating the unloading process, and even using the bunkers for effective mixing of different coals, is a useful method. The object is not to load all the bunkers equally with the same strata of coal. None of these methods are easy to accomplish, but at least should be considered based on the operating characteristics of the ESP.

The most common method of representing coal quality would be the proximate analysis on an *as received basis*. These figures include percentages of water content, ash fixed carbon, sulfur, and often included the volatile matter. The Btu/lb (J/kg) of coal, determined primarily from the above values, will basically set the quantity of coal required to reach the desired steam generation in a specific boiler. A general rule is that the higher the ash content, the lower the BTU content of the coal. This relationship presents a double hardship for the ESP, since a much higher amount of material must be handled by the collector system. An ultimate analysis will also be periodically performed to identify some other key chemical constituents.

The ash content of the coal becomes a significant factor in the successful operation of an ESP. The ash present in the flue gas entering the ESP is known as the top ash fraction (fly ash), and can represent rough outside limits from 60 to 85% of the total ash produced in the combustion process. Whether the boiler designation is either a dry or wet bottom will determine just how much top ash exists (and this fraction includes both the mineral and unburned carbon segments). The dry bottom boiler will trend toward the higher carryover of ash, and most commonly, show values between 70 to 80%. A value of 65% for the wet bottom design would be a fairly conservative estimate for top ash entering the ESP.

It is important that utility personnel gain an insight into what coal and ash characteristics best suit the performance of the ESP. There is a wealth of information available in published literature, contributed by Dr. R. E. Bickelhaupt and H. J. Hall among others, regarding the relationships of coal and ash characteristics. In Section 6.2 of this manual, there are several examples of different coals that are typically used in the United States. When evaluating the effect of the fuel there are some basic criteria to consider:

- As the ash content of the coal decreases, decreasing sulfur contents become less important. For example, a coal with an 8% ash content might work well with less than 1% sulfur by weight.
- How the sulfur content exists in the coal can be important. For example, benefits appear to occur when the pyretic portion is over 50% of the total sulfur content.
- Higher iron contents ($Fe_2\,O_3$) of the ash help convert more of the SO_2 to SO_3 in the gas stream.

- Sodium oxide (Na_2O) values of ash under 0.5% by weight becomes more critical for even the eastern bituminous coals with < 1% sulfur content.
- A CaO + MgO fraction above 15% by weight in the ash can increase ash resistivity.
- Low Na_2O below 0.5% by weight and Fe_2O_3 levels below about 4% by weight on western coals could point toward resistivity trouble.
- When the alumina-silicate portion is over 80% by weight of the ash analysis, the chance for resistivity problems increases.

Whether eastern bituminous, lignite, or sub-bituminous grades of coal are used, each with major differences of ash analysis, be alert to all the tools available to control their resistivity levels.

2.4.2.3 Coal Fineness

The *coal pulverizers*, or mills as they are commonly called, are the first components of the boiler system that can affect the performance of the ESP. Several designs exist but, in all cases, the object of these mills is to set an optimum range of size for the coal particles that are eventually burned in the combustion zone of the boiler.

The boiler manufacturer normally specifies a coal grind based on a sieve test that breaks the sample of coal leaving the mill into four segments of size. Sizes of the sieves are standardized as a 50-mesh, 100-mesh, and 200-mesh screen corresponding to 290-micron openings for the 50-mesh and 74-micron openings for the 200-mesh screen. The micron is a minute measurement and represents one thousandth of a millimeter. For practical purposes the amount of coal larger than 290 microns and passing the 74-micron sieve are of most interest. It is this plus 290-micron segment that gets the boiler and ESP into trouble. Coal fineness of over 0.5% retained on 50 mesh (99.5% through) or less than 80% through 200 mesh can cause increased carbon carry-over to the ESP. Some mill difficulties could jump this large size segment into the 2 to 4% by weight range, which would generally result in a large part of these large coal particles leaving the combustion zone in an unburned state. In most systems, some of this carryover from the boiler falls out in the economizer hoppers so it is important to keep them in service if carry-over is high.

The mills will determine the basic size distribution of the ash entering the ESP, as well as its composition to a large degree. How often mills are checked for their grinding efficiency will vary from plant to plant. With critical ESPs and other signs that indicate large coal carryover to the boiler, test sampling at the outlet of the mills should be done on a more frequent basis. Even this sampling is not a given for accuracy. The samples can be affected by where the sampling ports are located on the pipes leaving the mills. In large systems, a full traverse is needed through two ports placed 90^{o} apart. When taking the sample, it is also important to record pertinent mill data for comparison purposes. As boiler systems have increased in size, the number of mills in operation has increased and the whole problem of controlling the particle size of coal to the burners has worsened. Some of the larger mills might have four discharge pipes going to four different burners, which could bias the coal particle size to different burners.

Key Technical Point

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2.4.2.4 Particle Size of Ash

While the results of the mill grinding controls the basic size distribution of the particles of ash, some vaporizing and condensation action in the combustion zone does affect the number and size of the small segment of the ash that finds its way to the ESP. So here exists a range of particles from the sub-micron to a very large size, and made up of three different types of material. Not an easy situation for the ESP. However, an interesting point is that less change will occur in the size consistency on a day-to-day basis than the changes that might occur in the chemical constituents of the ash.

The size distribution of the top ash that is derived from coals with low moisture contents (usually less than 10% by weight) normally shows a sub-micron portion of about 2% by weight. About 45% by weight under 10 microns in diameter, and an unburned coal segment normally 3 to 5% by weight, at the higher end of the range. A perception of what the micron measurement represents is useful. The average diameter of a hair strand off one's head would be about 70 microns in diameter. An unaided eye would have a tough time focusing on a single particle of a 15- to 20-micron size.

Most of the sub-micron particles might be seen as hollow spheres that even appear glassy in appearance. They would be caused by the vaporization and then condensation of some of the mineral constituents in the combustion zone. There appears to be a melting process that also causes the formation of spheres, mostly solid, that might extend even beyond the 10-micron size. But most of the mineral ash residue of the coal particles, especially above the 10-micron level, takes various physical shapes other than spheres. The unburned coal particles, usually called the combustible fraction or percent LOI in the ash, tends to have spherical-like shapes with a jagged and porous surface. This develops from the burn off of the volatile matter from the coal particle, leaving the fixed carbon and ash, which is very much what occurs in the formation of coke particles.

There appears to be a significant increase in the number of fine-sized ash from the combustion of the lignite and sub-bituminous coals. This occurs because the high moisture embedded in the coal particles tends to flash into steam when the particles reach the combustion zone. This results in small explosions that break the coal particles into smaller fragments. The size segment of the resulting ash, below 1 micron, might increase to 3 to 5% by weight from this mechanism. The whole particle size curve would tend to shift with maybe 40 to 55% by weight below the 10-micron level.

The size characteristics of the fly ash particles entering the ESP are now known to consist of the very small (sub-micron) to the very large (in some cases over 300-micron effective diameter), of different shapes, of different chemistry, and even different density. For example, the small hollow particles as well as the large combustible particles are of much lower density than the solid particles of mineral constituents.

Fortunately, the ESP has the ability to effectively collect the whole spectrum of particle sizes that surface, providing the ESP is of sufficient size. Some of the fine-sized ash particles even attach themselves to the larger particles and are collected that way. But the primary collection of the small size segment requires operating at those optimum levels of voltage and current in the ESP. This is where most of the efforts have to be addressed by plant personnel rather than worrying too much about identifying the spectrum of particle size. In fact, just trying to obtain the accurate measurements of particle size is a monumental task in itself. However, the control of the large combustible loss on ignition (LOI) segment is one area that can and should be corrected, not only for its effect on the ESP performance, but on the boiler system as well.

2.4.2.5 Loss on Ignition

Since the introduction of the pulverized coal-fired boiler, a certain amount of unburned coal has been considered to be part of the top ash leaving the system. The boiler manufacturer even includes its existence into the heat balance design, often listing a 1 to 4% by weight fraction in the ash. In practice, it has varied from 1 to 30% by weight, which signifies the difficulty of controlling this part of the combustion process. This has been further complicated by NO_x control systems.

Aside from the grinding results of the mills, the air/fuel ratio at each burner, optimum mixing of air and coal in the burning zone, and how long the coal particle stays in the hot zone are some of the main contributors to the quantity of unburned coal observed in the gas stream. The higher values are usually seen when some mechanical defect surfaces in the burner box or mills.

The measurement of this LOI is usually performed in the plant's chemical lab utilizing an American Society of Testing and Materials (ASTM) test code. The purpose of this test is to measure the percent of combustibles in the ash. Normally, this represents partially unburned coal or carbon in the ash, and it also reflects a loss of chemical constituents in the ash that should be minimal compared to the carbon. In some extreme cases, the percent LOI may not match the percent carbon in the ash that means there are other chemicals present in the ash that can create some unexpected and unusual resistivity levels. This has become more common as plants switch fuels and utilize NO_x controls and conditioning systems. It is not a major concern but plant personnel should be aware that it could occur.

Getting the correct ash sample to the lab for an accurate test result is a sizable chore. An ash sample is usually obtained from the flue between the air pre-heater and ESP for the cold-side application. This location would provide a good representation of the top ash as long as a full-sampling traverse of the area was conducted under isokinetic conditions. For the boilers where the combustible problem appears frequent and critical, several methods are often used to shortcut the complexity and time of the comprehensive sampling test. A high volume sampling device, much like the cyclone type used for sampling coal from the mills, can be used to draw an ash sample from several spots in the flue. Less accurate would be the grab sample from the flow of ash in the evacuation system of the ESP hoppers, either in vacuum or pressure modes.

Sampling errors of 15 to 30% are possible with these crude methods, but this is acceptable if you are looking for a specific range of the combustible segment. For example, if the test results from one of these samples produces 3% LOI, then an error of 30% means it might actually be close to 4%, still an acceptable value. But if the sampling result shows 10% combustible, the variation caused by the sampling error becomes meaningless. The result is too high and further investigation is indicated.

A boiler operator can often see qualitative signs that combustible levels may be high. Various shades of color in the patterns of different burners, as well as haziness in the boiler, are two possible signs of combustion problems. The existence of sparklers in the upper tube sections of the boiler basically occurs from secondary combustion of some of the partially burned coal particles.

Somewhere around the 4% by weight of combustible particles there begins to be an area of concern for the ESP (and in some plants for ash sales). Every percentage point above 4% adds sensitivity to the ESP system. Around the 10% level would present performance difficulties for most of the ESPs in service. The basic size of these particles range from about 60 to over 300 microns in diameter, with the bulk of the combustible weight in the 150- to 300-micron segment. Their density is about 1.2 g/cm^3 (74.9 lb/ft^3), which is about ½ of the density of the solid mineral fraction of the ash. Its low density will let these coke-like particles rise to the top of any bulk sample of top ash, much like oil on water. This is one of the difficulties in obtaining a true representation of the quantity of this material. If the ash is left in the hopper or silo, the carbon will float to the top, making hopper samples less representative. Using this effect correctly in the ash silo can allow part of the ash to be separated and sold.

Even though the density is low, their very large size will cause this combustible fraction to display strong inertial forces that will concentrate these particles with every turn of the gas stream. The abrasive nature of the surface of these particles, as they group together, will cause severe metal loss in various parts of the boiler system. Erosion of boiler tubes and even excessive blade wear of I.D. fans are two areas that incur much of this damage. This inertial effect can even be seen within the ESP when baffles produce sharp turns in the gas just ahead of the collector. In these cases, some of the gas passages in the ESP can have two to three times the combustible content of adjacent passages.

The bulk of problems that occur in the ESP with high levels of combustibles (over 4%) are based both on its size and conductive features. High negative charges accrue on the large particles and they easily move to the collecting surface. But their conductivity allows the particles to lose their charge rapidly and bounce off the ash layer and return to the flue gas stream. A lot of this action continues all the way through the length of the ESP, even though a sizable percentage of the combustible does keep settling down into the hoppers. An unfortunate phase of this collection and repulsion action is that some of the ash previously collected tends to be shed off the layer by the large combustible particles. It is difficult to keep most of the ash in the front half of the ESP when this condition exists.

One of the signs that points to high combustible levels might be seen by excessive rapper spikes of opacity, even though the electrical readings indicate a moderate resistivity pattern. These rapper puffs would also contain significant levels of the combustible material. As the combustibles gravitate toward the rear of the ESP, the hopper catch of the outlet field would normally produce a higher LOI level and samples taken from the outlet hoppers would be the best single point indicator of change in LOI levels. This effect can be used to the plant's advantage to help ash sales. In some a cases, ash from the inlet half of the ESP may be acceptable for sale and only the back half of the ESP would need to be wasted.

Rather than reduce resistivity, these large porous combustible particles may even worsen conditions by absorbing a significant portion of the SO_3 component of the gas. However, a finer-sized carbon constituent throughout the ash layer could improve resistivity conditions. But, this is not the type of carbon particles that occur in the vast majority of installations. Furthermore, high combustible levels that coexist with low resistivity ash conditions would be highly detrimental to the performance of the ESP.

ESPs operating at an average 5 ft/s (152.4 cm/s) gas velocity or more will be more affected by high LOI. If gas velocities drop down toward the 1.5 to 2 ft/s (45.7 to 61.0 cm/s) level, the combustible effects will certainly diminish. But that is a costly way to attack the problem, which does not correct the metal erosion and loss of Btu in the boiler system. Increasing the levels of voltage, and especially current in the ESP, will also reduce the effect of the combustibles. But, there is an inherent limit to the benefits from this approach. Using ammonia conditioning to make the ash stickier is another approach that has worked well. In most systems, some of this carbon falls out in the economizer hoppers so it is important to keep them in service to reduce LOI levels in the ESP.

The art of controlling combustible particles in the combustion process has not lessened with the large boilers of recent decades. It is a continuous battle that is a fascinating part of connecting the operation parameters to the performance of the ESP. The new emphasis on NO_x reduction has added another dimension on this problem, which is discussed in depth in Section 6.3.

2.4.2.6 Excess Air

Keeping track of the O_2 reading at the economizer outlet is one of the chores of the personnel responsible for the ESP. It is a single measurement that combines the gas flow rate, gas temperature, and combustible formation, into one mix of factors that affect the ESP. The O_2 reading primarily represents the amount of excess air needed in the boiler combustion process. It would be economically ideal if all the pulverized coal could be burned completely without extra air, that is an O_2 reading of zero at the economizer and basically only CO_2 and N_2 exiting in the stack gases. However, for a multitude of reasons, not the least of which is the need to eliminate any carbon monoxide (CO) production and minimize combustible particles, most utility boilers will be seen to operate in the 1.5 to 4% range of O_2.

The most common number will hover around the 3% average level of O_2 at the economizer outlet. Just getting a true average O_2 reading at this location is extremely difficult. Most sizable boilers will split the flue gas into two separate sides; so two O_2 readings normally exist. There might only be two or four probes for areas as large as 600 ft^2 (55.7 m^2). Even though the average may show 3%, readings of O_2 across the economizer outlet might encompass a 1.5 to 6% range when combustion problems exist in the boiler.

One of the main reasons for operating at a higher average O_2 is to play it safe in a most complex combustion environment. As such, most boilers run at 16 to 20% average excess air at full load, as determined by the O_2 measurement that is carefully observed in the control room of the unit. And even though it may not represent a true average of O_2 at all times, it still provides a useful monitor of the changes in the flue gas.

From the viewpoint of the ESP, the O_2 measurement points toward some of the ways its performance can be altered briefly:

- Where dual O_2 readings exist between sides of the boiler, check that the two values are similar. But if a combustible problem arises in one side, shifting some of the secondary air toward that side will probably distort the O_2 readings, and that would be acceptable until the problem is corrected. This is apt to happen more with boilers utilizing wall burners.
- If a low resistivity problem surfaces, and other temperature controls are not available, raising the O_2 (excess air) and producing a little higher temperature to the ESP can be useful for a short-term correction.
- If a higher resistivity condition suddenly surfaces in the ESP, a slight reduction in O_2 might be helpful, providing combustible particles are not a problem in the boiler. Generally, no more than 0.5% moves in the O_2 percentage is changed at any one time. Always allow a 15 to 20 minute time period to lapse after a change of this magnitude so as to evaluate the effectiveness of the change.
- If the opacity trace or LOI test indicates the existence of a combustible problem, raising the total excess air might produce an overall improvement in the ESP, even though a higher gas velocity will result. Much depends on what mechanism is causing the combustible. This gas flow change can produce a short-term adverse effect on opacity, but stabilization will quickly occur.
- When a critical, high resistivity ESP exists, efforts to improve combustion conditions will allow a reduction in the O_2 operating level. In other words, the closer all O_2 readings at the economizer get to the average, the average can then be lowered with its resultant change in the flue gas flow. This is a win-win situation for the ESP and the boiler.

2.4.2.7 In-Leakage Air

In-leakage air from the boiler all the way through the ESP is one of those subtle problem areas that work against the collection performance of the system. This in-leakage can move a marginal ESP into a critical stage rather easily. Under a negative draft system, the ESP might have to handle as much as 15% more air flow than would be expected from the combustion process alone.

Key Technical Point

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The in-flow of air can start at the boiler walls, and this air is not usually detected by the O_2 meter system of the economizer. Air in-leakage at the seals of the rotating air pre-heater can produce a significant amount of air transfer from the F.D. fan system to the flue gas side controlled by the I.D. fan. Even with new seals, air leakage across the air pre-heater could reach 7 to 9% levels. Even the tubular air pre-heaters are not immune to air in-leakage through eroded tubes of the system.

Added to the air pre-heater source of in-leakage air are a number of other entry points that include expansion joints, cracks in the ductwork, gaskets at doors, through purge holes of insulators, and even hopper systems. The higher the negative draft, the more air is sucked in through all these possible spots. Aside from increasing the total gas flow rate through the ESP, this in-flow of cool air presents a number of localized problems.

The air being drawn into the ESP along the outer wall surfaces can condense moisture from the flue gas, creating up the potential for corrosion. Aside from this problem, the concentrated stream of air could cause localized electrical disturbances at select areas of the ESP. In reality, the ESP would be less affected if all the in-leakage air were equally distributed across the collector. But, absent this situation, this in-leakage air causes much more problems than its volume would normally justify.

For that reason, the plant personnel must continually inspect the whole system to correct any in-flow of air. The air pre-heater should be inspected during every outage opportunity for the condition of both sets of seals. Especially important is the inspection for any selective metal damage inside the ESP when air was known to have infiltrated during operation. In addition, periodic measurements of O_2 at the outlet of the ESP would be beneficial to detect any substantial change of air from the economizer to that point in the system. Most plants have the ability to monitor O_2 levels at the stack built into the new continuous emission monitoring (CEM) systems. If that indicator is not available in the control room, it should be added. The monitoring of air in-leakage in the ESP system is important and becomes more so with the use of SCRs. The level of air in-leakage will increase as system pressure increases. Installations that use SCRs for NO_x control will see the ESP's negative pressure increase 20 in. (508.0 mm) of water or more when the SCR is in service. This process change would require more emphasis be put on eliminating air in-leakage than has been given in the past at most plants.

2.4.2.8 Gas Distribution

The collecting efficiency of an ESP is the best that can be expected when the gas velocity distribution (and particle distribution) within the collecting zone is uniform. The Institute of Clean Air Companies (ICAC, formerly IGCI) has set guidelines for the appropriate gas velocity distribution in ESPs: 85% of the measured points should have velocities less than 1.15 times the average velocity, while 99% of the points should have velocities of no more than 1.40 times the average velocity. The ICAC standards are considered to be very good. If the gas velocity distribution in an ESP meets ICAC guidelines, further modifications to the gas flow distribution will provide very little, if any, incremental improvement in collection efficiency.

However, in practice, many ESPs do not meet these standards and exhibit undesirable gas flow characteristics that, when corrected, could significantly boost collection efficiency. Very poor gas velocity distributions can arise because a careful gas flow model study was not performed and implemented initially, or because events within the ESP or upstream of it are affecting the gas flow.

There has recently been interest in biasing flow from top to bottom with baffles and/or variations in diffuser plate porosities to improve collection efficiency in the ESP and reduce material reentrainment. This is somewhat of a departure from the ICAC standard and has worked well in older ESPs with high gas velocities, low resistivity ash or already poor gas distribution.

Maintenance personnel do not need to have a thorough enough understanding of gas distribution design to appreciate its importance to good ESP performance. What they should be aware of during inspection are indications of gross irregularities in uniformity from side to side and top to bottom, and missing or damaged media. Actual gas distribution in a precipitator can differ from the design model and can often be evaluated in the field by observations of dust patterns, or the lack thereof, at the inlet, the hopper area, and in the treatment zone of the precipitator. The absence of ash buildup and possible scouring of the steel indicate areas of high gas flow. Ash buildup may be excessive in areas of low gas flow. In many cases, the visual patterns show the direction of gas flow, and corrective modifications can be made on the basis of these observations. Actual measurements and modeling are sometimes necessary to identify a quantitative pattern to help implement solutions to poor gas distribution. Optimizing gas distribution in ESPs where it did not previously exist can help to improve precipitator performance. Results are most pronounced in marginally-sized ESPs.

3
ESP DIAGNOSTIC TOOLS

In this section, the two basic types of maintenance procedures used today (preventive and corrective) are discussed and defined. Guidelines and techniques for evaluating precipitator systems, both on-line and off-line, are covered in detail. Suggestions on corrective action, where applicable, are discuss to maintain and/or improve reliability and performance of the precipitator system. Startup and shutdown procedures, as well as clean and dirty inspection procedures are also covered.

3.1 Standard Maintenance Practices

The primary goal of any maintenance program is to protect the equipment from damage, while keeping the equipment in an operating condition that meets the plant's emission regulations. Personnel safety should be the first priority of any maintenance program. In the past, it was common to have two types of maintenance: preventive and corrective. Typically, preventative maintenance schedules are listed in the original equipment manufacturer's (OEM) manuals and include recommended routine maintenance on the ESP equipment. Corrective maintenance would normally consist of the repairs to the equipment due to damage caused by failures.

These two types of maintenance programs have worked well. However, in recent years, with cuts in staffing, reduced outage schedules, and smaller budgets, many of the traditional, periodic preventative maintenance programs have fallen short of their requirements. Also, plants have specified new ESPs with redundancies that are very large and can meet compliance with sections out of service or with equipment in poor condition. These trends have made it impractical for many maintenance departments to consider it cost effective to perform the standard OEM specified periodic preventative maintenance. As a result, some of these plants have made efforts to develop a predictive maintenance program to try to avoid serious damage to the equipment and to keep the equipment operating in compliance under the current budget and personnel limitations. A primary part of a predictive maintenance program is proper diagnostics of the equipment to determine the necessary maintenance required. Sections 3.2 and 3.3 discuss the tools available to diagnose the equipment, both on-line and off-line, to develop an effective preventative maintenance program. In Section 4, each component of the ESP is discussed in detail and suggestions for testing, analysis, and repair are made for each component. Section 5 discusses routine checks and inspections that are needed to develop a good maintenance program.

The key to all successful maintenance programs is record keeping, training, and routine inspection of the equipment. Each plant will need to develop their own maintenance program that fits their budget, available personnel, and needs.

The definitions of what qualifies as preventative and corrective maintenance can vary from plant to plant. EPRI's definitions of preventive and corrective maintenance are listed below in an effort to help clarify the different types.

Preventive Maintenance (PM) - This includes the actions that detect, preclude, or mitigate degradation of functional equipment to sustain or extend its useful life by controlling degradation and failures to an acceptable level. There are three types of preventive maintenance: periodic, predictive, and planned.

- *Periodic maintenance* is a form of preventive maintenance consisting of servicing, parts replacement, surveillance, or testing at predetermined intervals of calendar time, operating time, or number of cycles.
- *Predictive maintenance* is a form of preventive maintenance performed continuously, or at intervals governed by observed conditions to monitor, diagnose, or trend the equipment's functional or conditional indicators. Results indicate current and future functional ability or the nature and schedule for planned maintenance.
- *Planned maintenance* is a form of preventive maintenance consisting of refurbishment or replacement that is scheduled and performed prior to failure of the equipment.

Corrective Maintenance - This includes actions that restore (by repair, overhaul, or replacement) the capability of any failed equipment so it can function within acceptance criteria.

3.2 On-Line Diagnostics

To diagnose the cause(s) of poor ESP performance, begin by evaluating the key parameters while the unit is on-line. This chapter describes the diagnostic procedures that can be performed and the basic techniques used to evaluate the following areas:

- Basic operating data: opacity traces and voltage and current meter readings. Significant changes from previous measurements signal a likely problem area.
- Rapping performance: using visual opacity reading, opacity trending, and TR power readings.
- TR control operations: detailed electrical data taken during normal and abnormal operations (for example, secondary voltage vs. current curves and oscilloscope waveforms).

3.2.1 Retrieve Baseline Data: The ESP Logbook

Finding and understanding the problem(s) underlying poor ESP performance will be much easier if you have kept faithful records of ESP performance data. Such historical data provides a valuable baseline of ESP metrics when the unit is operating normally. Any discrepancies between current performance readings and historical norms signal a need for further investigation.

Ideally, your company will have kept an *ESP logbook*, beginning with data collected during ESP commissioning and maintaining continuity throughout the life of the unit. The logbook should include electrical readings from the power supply control cabinets, together with concurrent stack opacity readings and boiler process data. Secondary voltage verses current curves, and secondary voltage and current waveforms obtained with an oscilloscope are also useful if available.

This electrical information should be collected routinely. (If you have been suspecting a problem, you may have been recording meter readings daily several times on every shift and collecting voltage versus current (V-I) curves and voltage (V) and current (I) waveforms as often as weekly.) The logbook should contain data collected under partial load as well as full load operation. (Boiler load affects flue gas temperature, which in turn alters the electrical resistivity of the fly ash and therefore the electrical operating points and the appearance of V-I curves.) Ideally, voltage, current, process, and opacity data will have been collected concurrently with any inlet or outlet mass emissions tests, providing valuable reference data for the system diagnostics.

The logbook should also include any notes on opacity excursions or load ramp rate limitations caused by opacity, as well as notes on ash accumulation, hopper plugging, misalignment, and insulator failure, and any repair or replacement activities. Maintenance of an ESP logbook is described in detail in:

Electrostatic Precipitator Guidelines, Operation, and Maintenance, EPRI, Palo Alto, CA: June 1987. CS-5198-Vol. 2.

If, in addition to the basic ESP log, you have kept records of certain auxiliary data, you will be in a good position to begin diagnosing the problem(s) with your unit. These auxiliary data can be collected during routine regulatory compliance tests and include:

- Inlet and outlet mass loading.
- Particle size distribution - both inlet and outlet.
- Standard boiler, fuel, and fly ash data - load level (MW), heat rate, gas-flow rate, gas temperature, coal composition, fly ash resistivity, mills in service, excess O_2, and other data typically logged by the data acquisition system. Be sure to collect this data concurrent with the mass loading and particle size tests. This auxiliary information provides guidance about what may have caused test results to fall outside expected ranges. If there is a glitch in the test program, this data is very useful to determine what went awry.
- Coal proximate and ultimate analyses plus ash mineral analyses. This data can be used to determine if changes in coal and ash properties are affecting ESP performance.

As the repository of the unit's electrical, opacity, and general operating data history, the ESP logbook serves as the starting point and baseline reference for the ESP evaluating and diagnosing problems in the ESP.

3.2.2 How to Document Operating Data

Begin the data collection process by recording standard operating data on a data sheet on a regular basis or using a computer trend to record the data. Typical data would include:

- Opacity traces
- Secondary voltage
- Secondary current
- Spark rate
- Parameter that is limiting TR (current limit, voltage limit, sparking)
- Intermittent energization ratio or other special AVC features being used
- Auxiliary operational data such as
    - Flue gas temperature (ESP inlet), ^{o}F (^{o}C)
    - Flue gas oxygen (O_2 economizer outlet), %
    - Fuel feed rate, t/h (metric tons/h)
    - Steam flow rate, lb/hr (kg/hr)
    - Fuel sulfur content, % or SO_2 emissions, ppm
    - Fuel ash (coal, oil, etc), %, (type if known)
    - Fans speeds and/or gas-flow rates
    - Gas conditioning rates, ppm (if used)
    - Ambient air temperature and weather conditions

This data will typically be used to check against historic norms; variations may indicate a problem area. The auxiliary data is needed to determine if changes in the power readings and opacity are related to changes in process conditions. Detailed concurrent data is also useful for determining what happened in the plant during stack testing to allow the information to be used in modeling or other future analysis, if needed. When interpreting what happened during a poor stack test or period of high opacity, it is invaluable to know whether the apparent problem with the test or opacity was actually due to another event elsewhere in the power plant rather than with the ESP. Figure 3-1 is an example of a typical data sheet.

Electrostatic Precipitator
Shift and Daily Operation Record

Plant:	Unit #:	ESP:
Name:	Date/time:	Reviewed by:
Opacity:	Boiler load:	Fuel feed rate:
Steam flow rate:	Gas temp:	% O_2:
% moisture:	Fuel type:	Fuel sulfur %:
Fan speed:	Conditioning rate:	Ambient temp:

TR set	**Primary volts**	**Primary amps**	**Secondary volts (kV)**	**Secondary amps (mA)**	**Sparks per minute**	**Limit**

Remarks: Any upset conditions (for example, tube leaks, mill out, and the like)?

Inspection Item	**Checked By**	**Date**	**Condition** **Acceptable** **Unacceptable**		**Nature of Deficiency and Corrective Action Taken**
Take readings from TR cabinet meters and record opacity and process info.					
Check ventilation or A/C in control room					
Verify TR control cabinet vent fan operation					
Check for any abnormal arcing sounds in TR set or bus duct					
Verify operation of insulator compartment/penthouse purge air system					
Check other auxiliary equipment control cabinets and panels to verify operation					
Visually verify rappers are operating					
Check hopper levels and verify ash removal system operation					
Note any audible air in-leakage					

Figure 3-1
Typical ESP Data Sheet

3.2.3 How to Use Power Levels to Evaluate ESP Operations

The importance of using the ESP power readings as a barometer of the ESP performance and as a predictive maintenance tool is discussed in many sections of this manual. Later in this section the methods used to take the readings and to interpret the V-I curves are discussed. In Sections 2.4 and 6.8, the effects of process and dust resistivity are discussed. In Sections 4.1 and 4.2, using the meter readings to troubleshoot problems with the TR and controls is covered. This section will provide examples of how to evaluate changes from day-to-day.

The best evaluation is typically the most basic. Understanding the effect system changes have on voltage and current is the first step to interpreting ESP power readings. This is discussed in detail in many areas in this manual. The table below can be used as a basic guideline, but the there are many more possible causes for day-to-day changes in power readings than the ones listed below. Changes in voltage and current would normally occur slowly over a few days (that is, from a process change), but can occur within minutes in an event such as a component failure.

Table 3-1
Illustrates the Possible Causes for Changes in Voltage and Current

Change in Meter Readings	Possible Cause
Voltage ↑ Current ↓	Increase in ash loading Increased space charge Coating of ash on discharge electrodes Increase in dust resistivity (low to moderate)
Voltage ↓ Current ↑	Decrease in ash loading Decrease in space charge Improved rapping Decrease in dust resistivity (moderate to low) Severe back corona Tracking on the insulators or dust bridge in the hoppers
Voltage ↑ Current ↑	Decrease in total gas flow Decrease in ash loading Decrease in dust resistivity (high to moderate) Improved rapping Improvement in AVC control adjustment Decrease in LOI (large drop)
Voltage ↓ Current ↓	Increase in ash loading Increase buildup on plates Increase in dust resistivity (moderate to high) Mechanical damage in ESP Low AVC spark rates holding power down

The best time to evaluate ESP performance is before you have a problem. As you can see from Table 3.2 below there are many system parameters that can be changed to modify the ash resistivity. The effects on the ESP can be evaluated using the TR meter readings as feedback. When opacity is good and the load is stable is the time to experiment. Changing temperatures, pulling a mill out of service or changing the gas conditioning system should affect the dust resistivity or loading to the ESP, which in turn should affect power levels in a good or bad way. If power levels are not affected that can also point to a system condition that is over powering the ESP, such as over conditioning, carbon carry-over or poor distribution. The effects will also be much less visible if the ESP is oversized.

Table 3-2
Illustrates the Effect Process Changes Have on the ESP

Process Change	Typical Effect on ESP
↓ Ash loading ↓ Fine particles ↓ Gas volume (O_2 levels or fan speed)	Improves power levels Improves efficiency
For a Cold-Side ESP ↓ Temperature ↑ SO_3 ↑ Ammonium ↑ Moisture ↑ Iron/sodium ↑ Carbon (minor increase)	Lowers resistivity Reduces sparking
For a Hot-Side ESP ↑ Temperature ↑ Moisture ↑ Iron ↑ Sodium ↑ Carbon (minor increase)	Lowers resistivity Reduces sparking

The first step to analyzing the power levels is to prove that the operating theory described in Section 2.3 works at your site. This can be done easily by turning off a field and see what happens to the fields behind. The power readings below are a typical set of readings. If the first field is shut down the load to the downstream fields should increase. The second set of readings show the effect of the increased loading with the voltage increasing in 2nd and 3rd fields and the 4th field starting to spark, also the current has dropped in 2nd and 3rd fields.

Table 3-3
Normal Power Readings (Limits Are in Bold)

Field No.	Primary Voltage (V)	Primary Current (A)	Secondary Voltage (kV)	Secondary Current (mA)	Spark Rate (SPM)
1	335	55	47	280	**33**
2	325	80	44	420	**21**
3	315	140	41	800	**9**
4	305	**160**	39	**1000**	0

Table 3-4
Effect of One Field Out of Service (Limits Are in Bold)

Field No.	Primary Voltage (V)	Primary Current (A)	Secondary Voltage (kV)	Secondary Current (mA)	Spark Rate (SPM)
1	0	0	0	0	0
2	330	60	45	320	**30**
3	320	130	42	700	**15**
4	310	160	39	**1000**	**5**

If we increase temperature or reduce SO_3 conditioning, the effect would be to increase resistivity, which should increase resistance in the circuit, which would increase sparking and lower currents. The Table 3-5 represents the effect on readings.

Table 3-5
Effect of Increasing the Ash Resistivity (Limits Are in Bold)

Field No.	Primary Voltage (V)	Primary Current (A)	Secondary Voltage (kV)	Secondary Current (mA)	Spark Rate (SPM)
1	320	35	43	180	**60**
2	325	55	44	280	**30**
3	320	130	42	700	**15**
4	310	150	39	900	**5**

As seen in the readings in Table 3-6, the opposite effect would occur if the ash resistivity were lowered (from a moderate level to a low level) by either lowering the gas temperatures or increasing the SO_3 content in the flue gas.

Table 3-6
Effect of Decreasing the Ash Resistivity (Limits Are in Bold)

Field No.	Primary Voltage (V)	Primary Current (A)	Secondary Voltage (kV)	Secondary Current (mA)	Spark Rate (SPM)
1	325	**160**	44	**1000**	0
2	315	**160**	42	**1000**	0
3	300	**160**	40	**1000**	0
4	280	**160**	37	**1000**	0

This same type of analysis can be used when evaluating rapper program changes or the effects of boiler changes. For example, if the inlet field rappers program was changed for the better, reentrainment losses might be reduced. The increase in loading on the inlet field plates as a result of the change might increase sparking in that field, but the overall effect would be less material passed to the back fields of the ESP. That would mean lower opacity levels and higher current levels in the back fields. However, if the outlet field is already current limited, then the outlet field voltage will drop, indicating an increase in performance. If we were using kVA as the only indicator, we would actually see a drop in kVA with an increase in ESP performance. This is one example of why using kVA as an indicator of subtle changes in performance can be misleading.

Table 3-7
Effect of an Improved Rapper Program on Readings (Limits Are in Bold)

Field No.	Primary Voltage (V)	Primary Current (A)	Secondary Voltage (kV)	Secondary Current (mA)	Spark Rate (SPM)
1	320	35	43	180	**45**
2	330	100	45	480	**17**
3	315	140	41	900	**5**
4	290	**160**	37	**1000**	0

If the fuel was changed from Eastern to Western Powder River Basis (PRB) coal, then you might expect to see a change in the particle size entering the ESP, shifting the particle size to the finer side. This would normally increase voltage levels and decrease the current in the inlet fields as a result of the increase in space charge. See Table 3-8 for an example.

Table 3-8
Effects of Finer Ash Particles on Readings (Limits Are in Bold)

Field No.	Primary Voltage (V)	Primary Current (A)	Secondary Voltage (kV)	Secondary Current (mA)	Spark Rate (SPM)
1	360	35	**50**	180	**5**
2	335	70	47	360	**21**
3	315	130	42	700	**5**
4	310	**160**	39	**1000**	0

Evaluating the effects of gas conditioning can be complicated. If the systems are not biased for the air heater temperature gradient, the effect could be mixed with both high resistivity on the hot side of the ESP and low resistivity in the cold side of the ESP. Normally, the easiest ash to condition comes from medium sulfur, eastern fuels. The curve shown in Figure 3-2 would be considered a typical resistivity curve for these coals. (See Section 6.2 for an example and a discussion of other fuel types.)

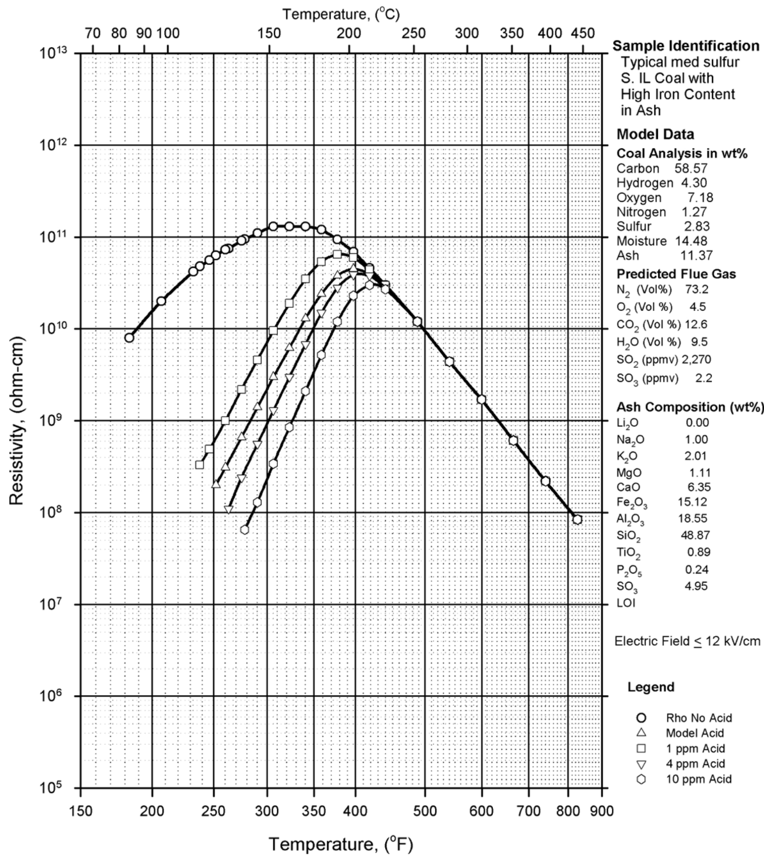


Figure 3-2
Typical Resistivity Curves for Medium Sulfur, Eastern Coals

The ESP could have the same power levels for different injection rates and temperature levels. The Tables 3-9 and 3-10 are examples of what might be observed for different injection rates of SO_3 and NH_3.

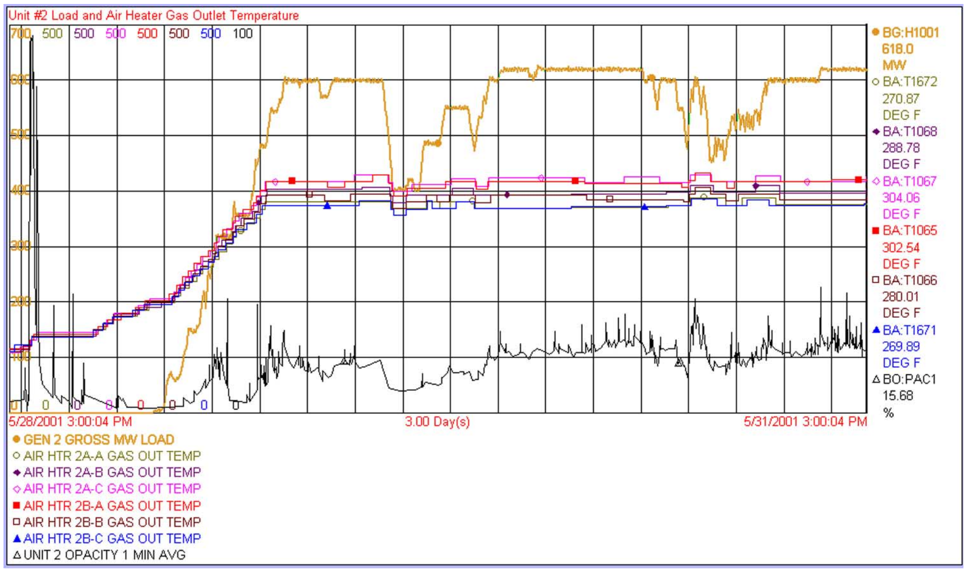
Table 3-9
Example of the Effects That SO_3 and Temperature Have on Power Readings and Opacity

Gas Temp.	Added SO_3		Field #1	Field #2	Field #3	Field #4	Opacity Base	Opacity Spike	Opacity Avg.
280°	0 ppm	kV	42	42	38	32			
300	5 ppm	mA	300	500	1000	1000	11%	20%	14%
320°	10 ppm	SPM	30	15	-	-			
260°	0 ppm	kV	42	41	36	33			
280°	5 ppm	mA	1000	1000	1000	1000	10%	60%	18%
300°	10 ppm	SPM	20	-	-	-			
300°	0 ppm	kV	40	42	41	36			
320°	5 ppm	mA	150	300	600	1000	13%	16%	14%
350°	10 ppm	SPM	30	30	10	2			
320°	0 ppm	kV	38	42	41	37			
350°	15 ppm	mA	100	200	500	800	16%	25%	22%
		SPM	45	30	10	10			
350°	0 ppm	kV	36	37	39	37			
		mA	100	100	200	500	25%	50%	30%
		SPM	60	45	20	10			

Table 3-10
Examples of the Effects That SO_3, NH_3, and Temperature Have on Power Readings and Opacity

Gas Temp.			Field #1	#2	#3	#4	Opacity Base	Spike	Avg.
320°		kV	38	42	41	37			
SO_3	0 ppm	mA	100	200	500	800	16%	25%	22%
NH_3	0 ppm	SPM	45	30	10	10			
320°		kV	40	42	41	36			
SO_3	5 ppm	mA	150	300	600	1000	13%	16%	14%
NH_3	0 ppm	SPM	30	30	10	2			
320°		kV	45	42	36	31			
SO_3	5 ppm	mA	500	700	1000	1000	10%	13%	12%
NH_3	3 ppm	SPM	20	15	-	-			
320°		kV	50	42	35	30			
SO_3	8 ppm	mA	700	1000	1000	1000	8%	10%	9%
NH_3	5 ppm	SPM	10	-	-	-			
350°		kV	45	45	41	40			
SO_3	10 ppm	mA	300	700	1000	1000	15%	20%	18%
NH_3	8 ppm	SPM	30	20	10	-			

All of the effects mentioned above can be observed using trending on either a data management system or the plant's digital control system (DCS). Normally, trending is limited to four to eight items per screen, so it is best to produce several trends showing different system parameters compared to opacity. Below you can see the effect that changes in temperature and boiler load have on the opacity.



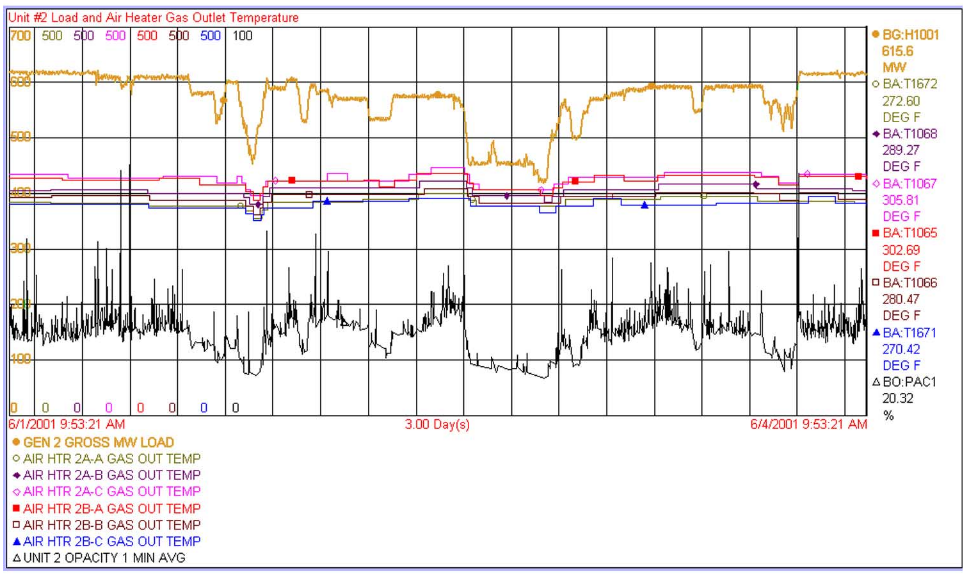


Figure 3-3
Typical Trending Available from the Plant's DCS or the ESP Data Management System (DMS). These Trends Show the Effect Load and Gas Temperature Have on Opacity.

3.2.4 Assessing the Rapping System

3.2.4.1 Inspecting Rapping Equipment

If your opacity traces are high and have many spikes, this would normally indicate non-optimal rapping. The first step is to inspect the general condition of the rapping system components, including auxiliary equipment such as drive motors and controls. This inspection should include a functional test, which entails manually sequencing through each group or row while an observer notes any abnormalities. For solenoid rappers, the weight drop height should be verified by measurement rather than relying on the sound of impact alone. This on-line inspection allows you to check all aspects of the rapper mechanical operation except for the proper transmission of rapping force, which requires observing rapping while standing inside a deenergized, dirty precipitator during shutdown.

The rapper condition should have been inspected periodically, providing a historical record in the ESP logbook against which you can compare results. Obviously, broken or defective equipment should be replaced. One of the keys to good ESP operation is to keep the rapper system 100% operational. If the ash resistivity is at a moderate to a high level, having one rapper out of service can affect the spark-over voltage dramatically of the associated TR set. With internal hammer-style ESPs, it is difficult to do this on-line check, but it is important to verify that all of the drives are operational.

3.2.4.2 Evaluating the Rapper System's Operation

Particle reentrainment during rapping is a leading factor in ESP outlet emissions, accounting for about 30 to 40% of the emissions from a high efficiency cold-side ESP, and as much as 50% from hot-side units (*normal* percentages will vary from plant to plant). This level of emissions is expected from well-designed and operated ESP systems in good condition. If the rapping system is poorly designed or improperly adjusted, even greater particle emissions from reentrainment would be expected.

For optimum collection efficiency, the frequency and intensity of rapping must be kept in balance. Insufficient rapping of the collecting plates may result in low, short-term opacity, but can ultimately increase the overall opacity due to large puffs. Conversely, excessive rapping can result in unacceptably high opacity due to excessive particle reentrainment. Excessive rapping also wastes energy and can lead to premature mechanical failure of the rappers and the discharge electrodes.

Key O&M Cost Point

For optimum collection efficiency, the frequency and intensity of rapping must be kept in balance. Insufficient rapping of the collecting plates may result in low, short-term opacity, but can ultimately increase the overall opacity due to large puffs. Conversely, excessive rapping can result in unacceptably high opacity due to excessive particle reentrainment. Excessive rapping also wastes energy and can lead to premature mechanical failure of the rappers and the discharge electrodes.

The good news is that, by and large, performance of the collecting plate rappers can be assessed and adjusted while the unit is in service although certain problems, such as improper transmission of rapping force, will require diagnosis via visual inspection inside the deenergized ESP.

3.2.4.3 Investigating Rapping Reentrainment

The first step to evaluate the contribution of rapping reentrainment to total outlet emissions is simply done by comparing outlet opacity with the rappers on and then off. First, observe the outlet opacity meter trace for a few hours while operating at a steady load. As shown in Figure 3-4, this trace will typically consist of a baseline trace with rapping spikes superimposed. After recording a representative trace, turn off the rappers for the last two fields. Just the outlet fields are adequate for this test, as the most significant reentrainment typically occurs from these fields. (Particles reentrained in the inlet fields are usually recollected by the downstream fields, whereas particles reentrained in the outlet fields can pass directly into the duct and on up the stack.)

Naturally, when the rappers are turned off, the rapping spikes on the opacity trace will disappear, as depicted in the right side portion of Figure 3-4. Estimate (by eye) the difference in the average opacity value with the rappers turned on and off. If the rappers' *on* value is more than about 1.4 times the rappers' *off* value for cold-side units, or more than 1.5 times the rappers' *off* value for hot-side units, reentrainment is likely excessive.

Key Technical Point

If the rappers' *on* value is more than about 1.4 times the rappers' *off* value for cold-side units, or more than 1.5 times the rappers' *off* value for hot-side units, reentrainment is likely excessive.

A word of caution: If the rappers are off for a long time, a significant rapping puff could occur when the rappers are placed back in service, ***which could create an opacity violation.*** In general, try to avoid leaving the rappers off for more than a few hours.

Key Human Performance Point

A word of caution: **If the rappers are off for a long time, a significant rapping puff could occur when the rappers are placed back in service, *which could create an opacity violation.* In general, try to avoid leaving the rappers off for more than a few hours.**

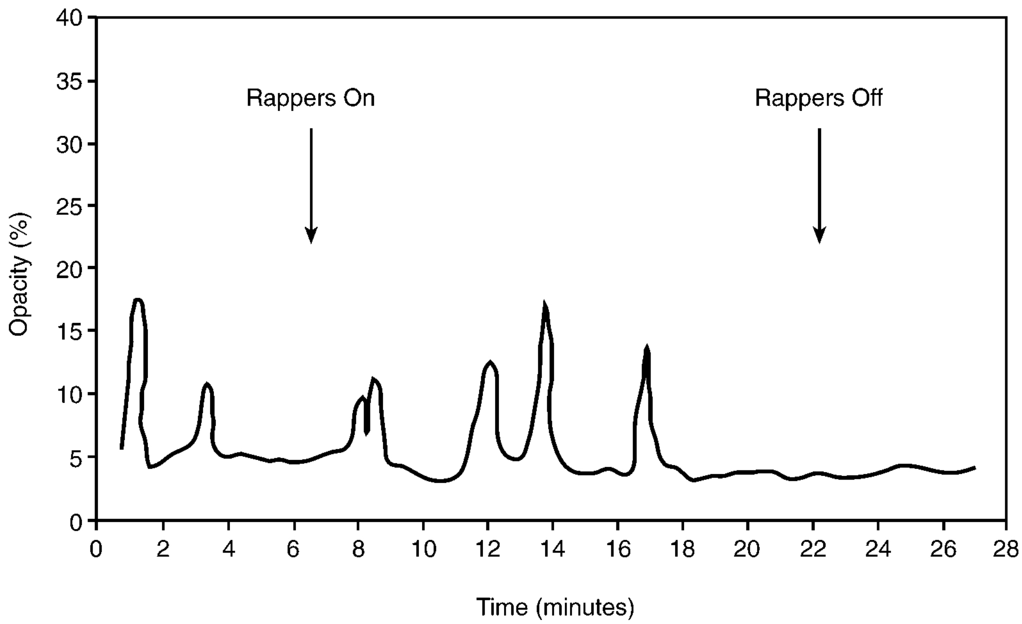


Figure 3-4
Opacity Traces Indicating Baseline Opacity Before and After Rappers Are Turned Off

3.2.4.4 Analyzing Reentrainment

Figure 3-5 illustrates a healthy rapping trace with moderate, average opacity and occasional rapping spikes low enough to avoid risk of an opacity violation. The ratio of base and peak opacities, or *opacity aspect ratio*, correlates rapping, instantaneous opacity, and 6-minute opacity. The values shown in Figure 3-5 are typical for standard precipitator and duct configurations for cold-side ESPs in good operating condition. Adjustments must be made if the physical distance between the opacity monitor and the precipitator increases, because of the potential for gas-flow mixing to reduce the peak opacity values.

Figures 3-6, 3-7, and 3-8, in contrast, indicate rapping problems requiring attention.

Figure 3-6 illustrates insufficient rapping: the rapping puffs (spikes in the trace) are excessively high compared with the base-level opacity. Rapping will need to be done more frequently and possibly more intensely to avoid the possibility of an opacity violation. Note that if prior rapping settings are no longer adequate and there has been no change of coal, there is some underlying problem, such as inadequate rapper force transmission or a change in gas-flow distribution, which warrants investigation during shutdown. This pattern could also be a result of a low resistivity condition caused by low bonding force on the dust layer and reentrainment of material from the inlet to the outlet fields, which loads up the outlet collecting plates. This would typically be associated with high current levels and no sparking on most of the TR sets and would require reducing rapping in all sections to reduce reentrainment losses while keeping power levels high.

Figure 3-7 depicts the opposite problem, over rapping. Here, rapping is so frequent and intense that the rapping puffs are very small, but the overall base level of reentrainment has risen from about 10% to about 15% (compare to Figure 3-5).

Figure 3-8 shows *uneven* rapping, with significant reentrainment occurring in a relatively small portion of the ESP. This could be a result of over rapping in a localized area, reentrainment caused by low temperature zones in the ESP, or high gas velocity zones. It is important to identify the specific rappers causing these spikes and try to determine the cause.

If your trace appears similar to 3-5, then rapper reentrainment is not a major concern. The general rule is that your typical opacity spikes should not exceed twice the percentage of your average baseline opacity. This is an extremely important rule to remember during compliance testing. The material released during reentrainment is normally very coarse, large, agglomerated particles which weigh a lot when compared to the resulting opacity averages. Large opacity spikes can dramatically increase the filter weight, making a test out of compliance, even if the 6-minute average was in compliances during the stack PM test. It is important to remember that the effect particle size has on the opacity versus its weight makes it difficult to correlate opacity (%) to emission rates (g/acfm). For the same weight of material, finer (light) particles will have higher opacities than large (heavy) particles.

Key Technical Point

The general rule is that your typical opacity spikes should not exceed twice the percentage of your average baseline opacity. This is an extremely important rule to remember during compliance testing. The material released during reentrainment is normally very coarse, large, agglomerated particles which weigh a lot when compared to the resulting opacity averages. Large opacity spikes can dramatically increase the filter weight, making a test out of compliance, even if the 6-minute average was in compliances during the stack PM test. It is important to remember that the effect particle size has on the opacity versus its weight makes it difficult to correlate opacity (%) to emission rates (g/acfm). For the same weight of material, finer (light) particles will have higher opacities than large (heavy) particles.

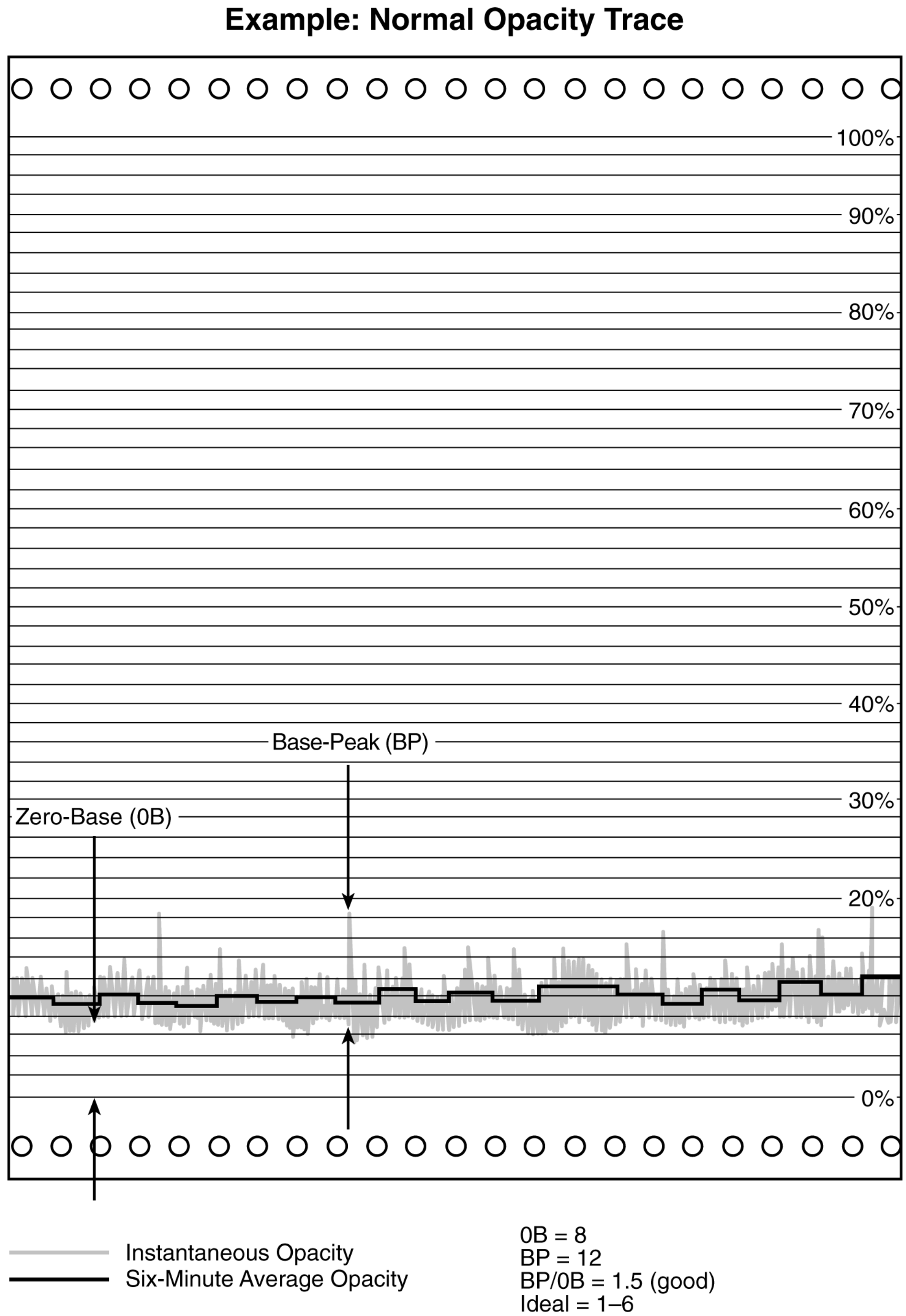


Figure 3-5
Opacity Trace Indicating Appropriate Levels of Rapping

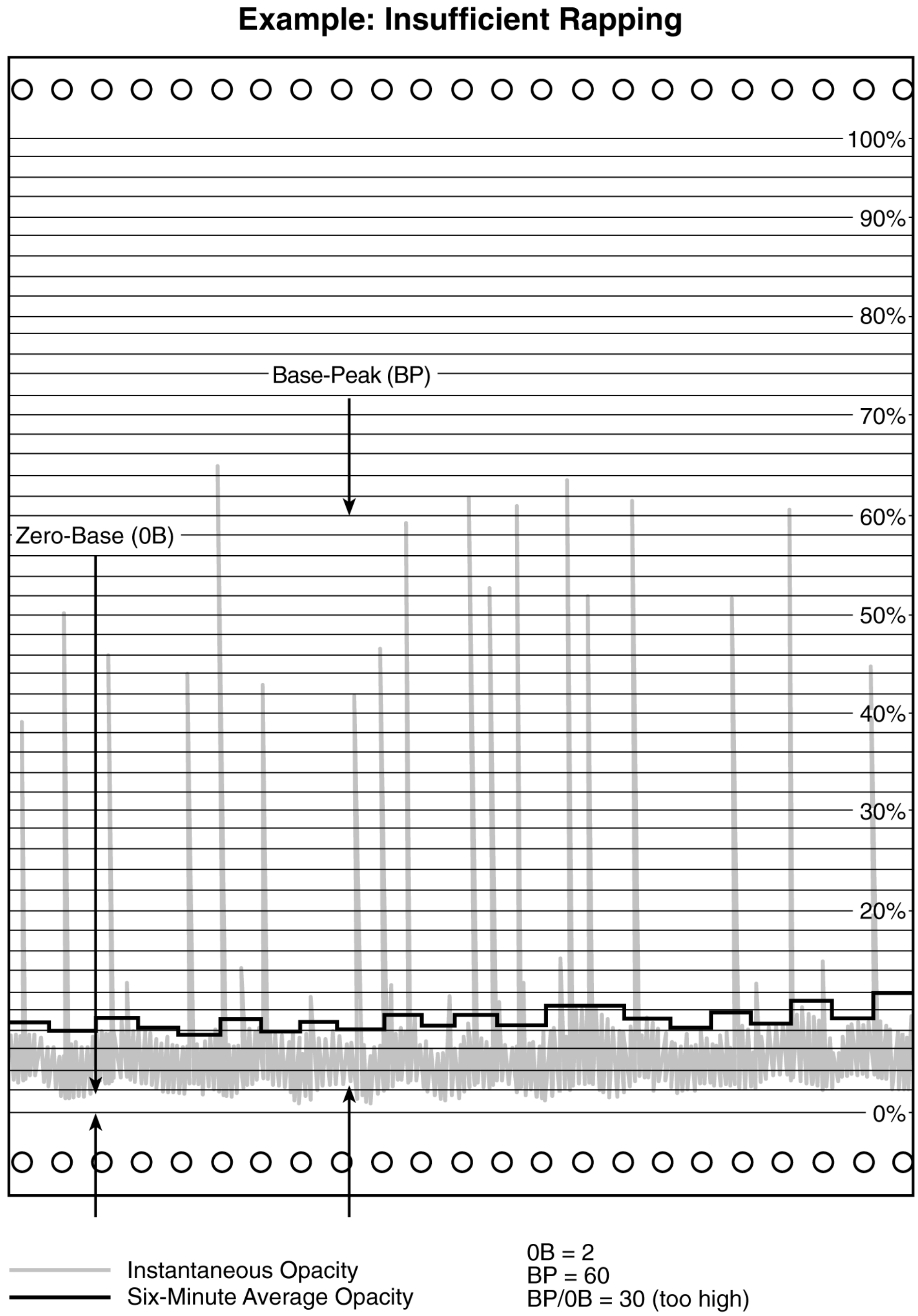


Figure 3-6
Opacity Trace Indicating Excessive Rapping Puffs

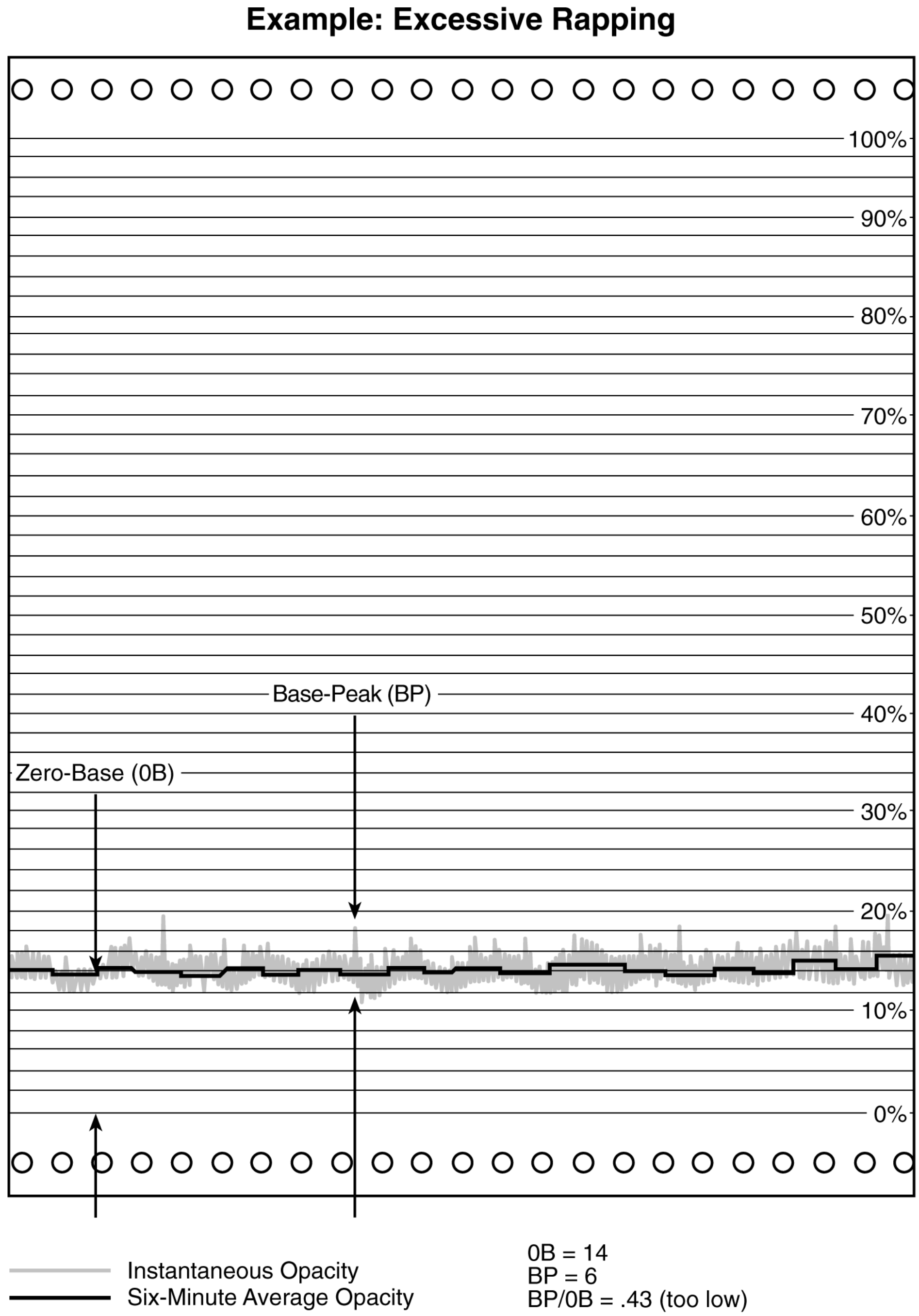


Figure 3-7
Opacity Trace Suggesting Excessive Rapping Forces Causing Rapping Reentrainment to Raise the Baseline Opacity

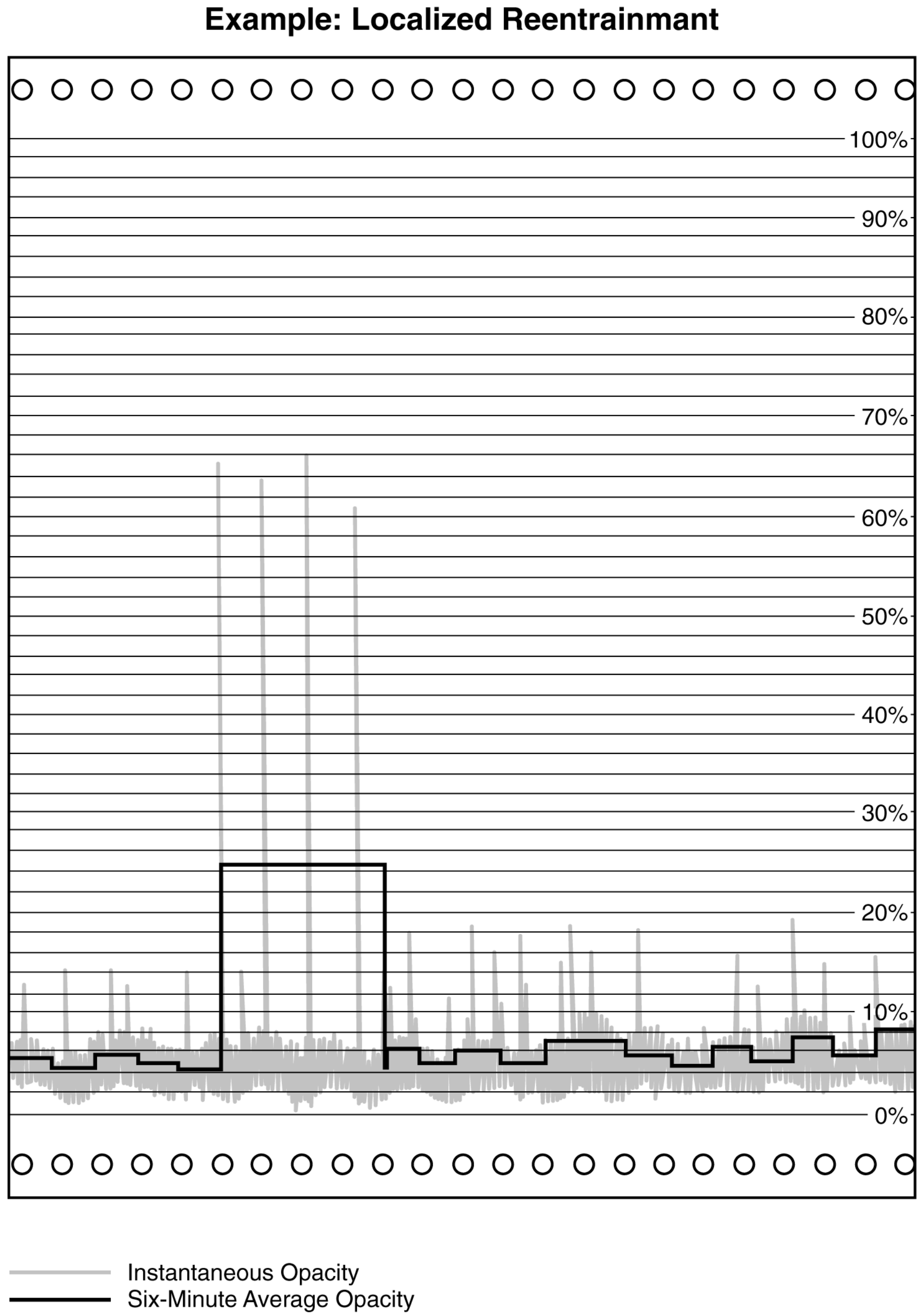


Figure 3-8
Opacity Trace Suggesting Localized Reentrainment from a Particular Region of the ESP

3.2.5 V-I Curves and Waveforms

3.2.5.1 Diagnostic Value

Electrical data (namely, 1. secondary voltage [V] vs. current curves [I] and 2. secondary voltage and current waveforms) are key tools for diagnosing problems with ESP operation. The remainder of this chapter focuses on collecting and interpreting these electrical data.

Note that this chapter will refer to straight V-I curves rather than voltage vs. current density (V-j) curves. V-j curves should be used in cases where different TR sets feed different collecting plate areas by normalizing all electrical sections for comparison purposes. If all your TR sets feed equal plate areas, you can simply plot straight V-I data without the extra step of calculating current density.

V-I data provides valuable insight into ESP operation. Variations in the shape of the secondary V-I curves or the secondary waveforms can indicate a variety of problems, including:

- Extreme misalignment of plates or discharge electrodes
- Electrical shorts (due, for example, to cracked insulators, carbon tracking on insulators, broken wires, or overly full hoppers)
- Abnormal sparking
- Back corona (severe back corona, discussed earlier sections, is an undesirable condition that contributes to significantly degraded ESP performance, cause by high resistivity ash)

3.2.5.2 How to Perform the Gas-load Test

Both V-I data and oscilloscope waveforms are obtained by conducting a *gas-load* test with the ESP in service. This test entails incrementally increasing the secondary voltage from 0.0 V to its limit (or to the commencement of multiple sparking or back corona) for each electrical section, one section at a time. At each increment, note the secondary current and corresponding voltage. Progressive data points furnish the V-I curve for each electrical section.

Key Technical Point

Because a gas-load test alters (and momentarily disables) the ESP operation section by section, it is possible to incur an opacity violation.

If you are not assured of a sufficient operating margin, you will need to obtain permission from your local air pollution control agency before conducting the test. If your regulator refuses, try to obtain approval for a test at part load. (Note that part load results will not be as accurate.) Failing that, you will have to settle for an air-load test during a plant shutdown, preferably under both dirty and clean conditions. If you must resort to a part load test or none at all, at least obtain oscilloscope waveforms at full load. These waveforms will indicate if you have a problem with back corona. On the hot-side ESPs, the back corona condition will worsen at partial load as temperature decreases and resistivity increases.

As stated above, a gas-load test entails incrementally increasing the secondary voltage until a limitation occurs (either the voltage limit, or the commencement of multiple sparking, or the commencement of back corona, whichever comes first). Conduct the test one electrical section at a time, *beginning with the outlet fields and working back toward the inlet.* This precaution ensures that ash layer disturbances caused by changing energization do not influence data from other fields. If the inlet field were tested first, dust cake released from the collecting plates as the operating voltage is reduced would be recollected on the downstream fields, creating an unrepresentative dust cake on those plates. This unrepresentative dust cake could skew test results by causing unrealistic current readings for a given voltage.

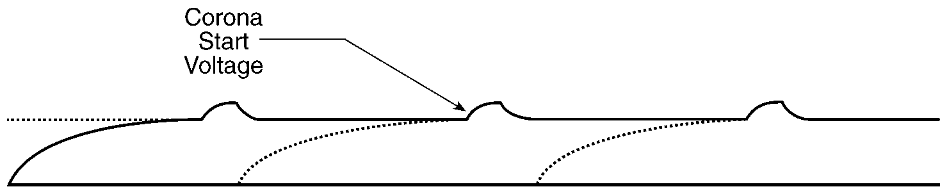
Throughout the V-I test, collect the plant operating data described earlier in Section 3.2. As discussed, this auxiliary information may be able to explain any unusual test results. Stepwise procedures for conducting the gas-load test are as follows.

1. **Record the following preliminary information for each electrical section.**
   - Total collecting plate surface area.
   - Pertinent mechanical design information, including plate design, discharge (corona) electrode configuration, and plate to plate spacing. Also note the diameter of the discharge electrode; its shape and size are important because electrodes that have sharp points or are very slender exhibit a lower corona starting voltage than electrodes with a larger radius of curvature.
   - Ambient temperature and barometric pressure.
   - Meter readings for primary and secondary operating voltage and current. Note that if the power supply controls are an older analog model, only average values of secondary voltages and currents are available. Some of the newer control sets indicate the peak, average, and trough (minimum) values of voltage for each value of current. If your controls provide such information, record it for this preliminary measure and all subsequent measurements throughout the gas-load test.

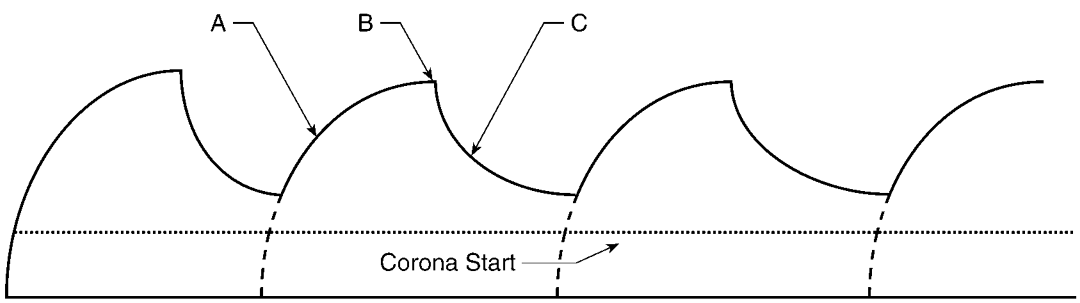
2. **Hook up an oscilloscope to obtain the secondary waveforms.** Record the operating waveforms before starting the gas-load test, and then record the waveform at key points throughout the test. These waveforms confirm the corona start voltage and the onset of sparking or arcing during the gas-load test. They also serve as diagnostic tools by indicating the presence of back corona.

   If you are not sure how to set up the oscilloscope for these readings, consult the power supply manufacturer. Normally the oscilloscope will be connected to a voltage of around 5 V that is proportional to the secondary voltage. If you install voltage dividers, remember that the actual voltage in the ESP, where the connection is made, is on the order of 50,000 V. If you do not have experience installing voltage dividers, it is important to obtain assistance.

3. **Record the corona onset voltage,** that is the secondary voltage at which the secondary current meter just moves off of zero, indicating the beginning of corona current flow. On an oscilloscope, the secondary voltage will appear as essentially pure dc until corona start, because the discharge and collecting electrode system provides sufficient distributed capacitance to filter and smooth the secondary voltage to a constant value until corona current begins to flow. The general shape of the secondary voltage as a function of time, at corona start, is shown as Curve 1 in Figure 3-9.



Curve 1: Secondary Voltage vs. Time at Corona Start



A = Current Flowing From Power Supply to Charge Distributed Capacitance of Electrode System and Provide Corona Current

B = Power Supply Effectively "Disconnected" by Back-Biased Diodes

C = Corona Current Provided by Drawdown of Energy Stored in Distributed Capacitance of Electrode System

Curve 2: Secondary Voltage vs. Time for Normal Operation

Figure 3-9
Secondary Voltage Waveforms for Normal Resistivity with No Back Corona (Note: kV Valves Have Inverted Positive)

4. **Incrementally increase the secondary voltage through its range** and record the corresponding current at each interval. In addition, record oscilloscope traces at key points of the test: near corona start, midway through the voltage range, and at the voltage limit (end of the test), or at whatever point sparking or back corona is detected.

   Increasing the secondary voltage can be accomplished by either: 1. increasing the conduction angle of the SCR in the power supply control; 2. increasing the secondary current limits; or 3. using the control microcomputer to run the power supply through its range.

Beginning at the corona-start voltage, measure the corresponding secondary voltages and currents at regular intervals of secondary current (that is adjust the applied voltage until you get a secondary current reading at a pre-designated current interval, then measure the corresponding secondary voltage). As is evident from the sample V-I curves below, the plot of secondary voltage vs. current changes curvature quite rapidly near corona start. Consequently, it is best to take frequent measurements at lower values to ensure enough data points to define the critical beginning part of the curve. Using incremental changes of either kV or mA is the easiest way to generate these curves as seen in Figure 3-10.

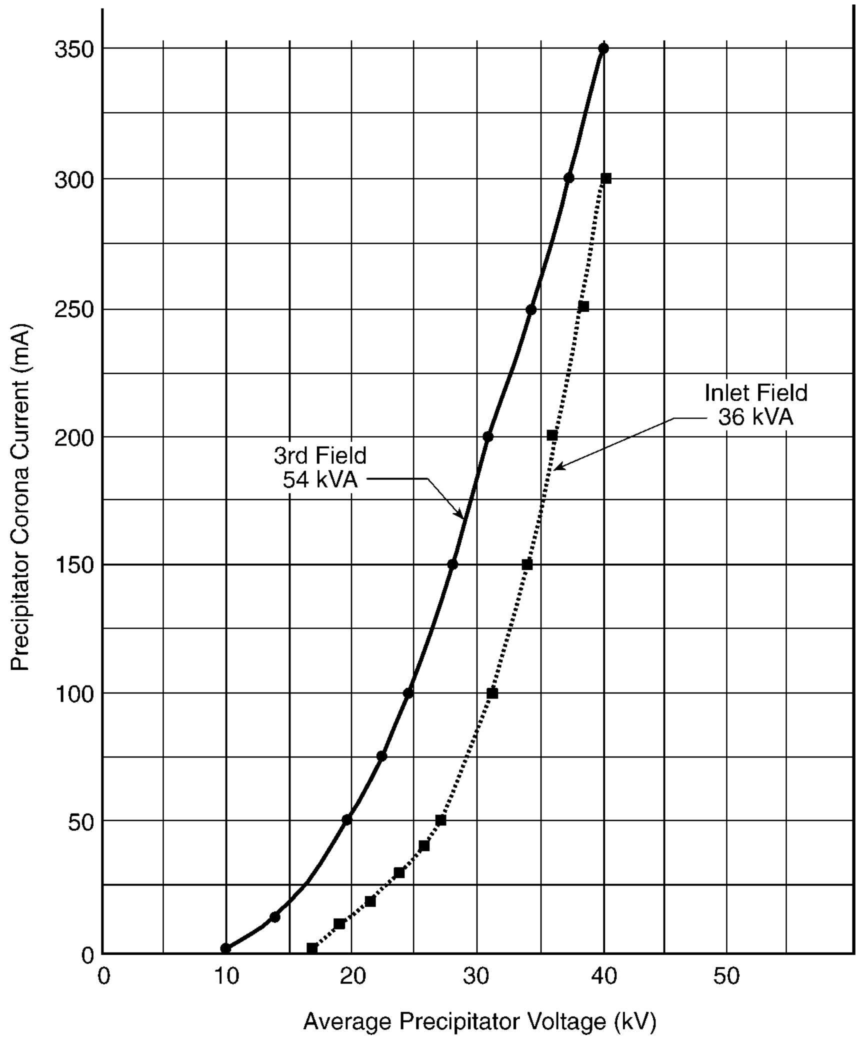


Figure 3-10
V-I Curve Showing Data Points

Note that each time you proceed to a new test point, it takes a minute or so for the ESP to stabilize. Wait for this steady state before recording the V-I data point. As stated earlier, if your controls provide peak and trough electrical readings, record them as well. The trough values provide the earliest indication of the onset of back corona.

As the secondary voltage is raised above corona start, its oscilloscope waveform changes in appearance to that indicated as Curve 2 in Figure 3-9. The rising portion of the waveform shows that the secondary voltage is increasing with the applied voltage until the ESP secondary voltage reaches the peak value of the applied voltage waveform. During this time, current is flowing from the power supply to charge the distributed capacitance of the ESP system and to supply the corona current that is flowing. The letter *A* on Curve 2 indicates this region.

As the input voltage from the power supply begins to fall below the voltage across the ESP electrode system, the back-biased diode stack in the transformer secondary effectively disconnects the power supply from the ESP electrodes until the next half-cycle of energization. This point is indicated as point *B* on Curve 2. During the remainder of this half-cycle of input from the power supply, the secondary voltage on the ESP decays as the corona current flow discharges the energy stored in the distributed capacitance of the electrode system. This decay in secondary voltage continues until the next half-cycle of energization arrives from the power supply. The decay in voltage from the stored energy is indicated as segment *C* on Curve 2.

5. **Continue increasing voltage until you reach a limitation.** This limitation may be the power supply voltage or current limit, electrical spark over, or back corona. If there is no problem with high resistivity ash, the voltage is usually limited by sparking.

   Spark over can be detected by the secondary meters and the oscilloscope waveforms (see Figure 3-19). Back corona can also be detected by meter readings (the current will continue to increase while the voltage will fail to increase commensurately, or even decrease), as well as oscilloscope waveforms (see Figure 3-20).

3.2.5.3 Plotting the V-I Curves

Plot the data for all electrical sections on linear graph paper as depicted in Figure 3-11. If all your ESP's sections have the same plate area, simple V-I plots will suffice. If your sections vary in plate area, it is necessary to normalize all ESP sections by dividing the secondary current readings for each electrical section by the collecting plate area for that section (thereby creating a V-j instead of a V-I plot).

Some digital power supplies automatically plot V-I or V-j results. However, many of the new controls *jump the gun* by logging the V-I values too soon (that is before the current has a chance to stabilize in response to each incremental voltage increase). Some systems allow you to specify the *wait* interval before taking a reading after a change in voltage or current. If you can set the wait for 1 to 2 minutes, then your automatic V-I plot should be reliable. If not, log the stabilized data points by hand and create your own graph.

The types of V-I curves that can be generated vary depending on the type and age of the power supply controls. Figure 3-11 shows V-I curves for a precipitator with old analog controls, which give only average values of secondary voltages and currents. Figure 3-12 shows a normal V-j curve from a newer digital control set, which can record peak and trough values as well. Both Figures 3-11 and 3-12 correspond to a normally operating ESP without any limitation imposed by high-resistivity ash.

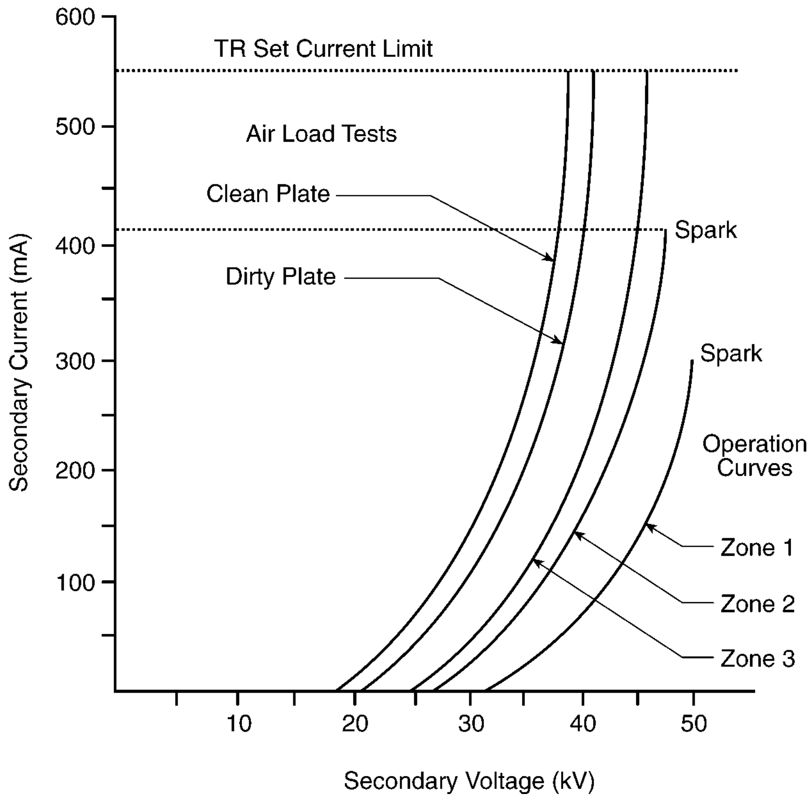


Figure 3-11
Normal Gas-Load V-I Curves for Healthy ESP

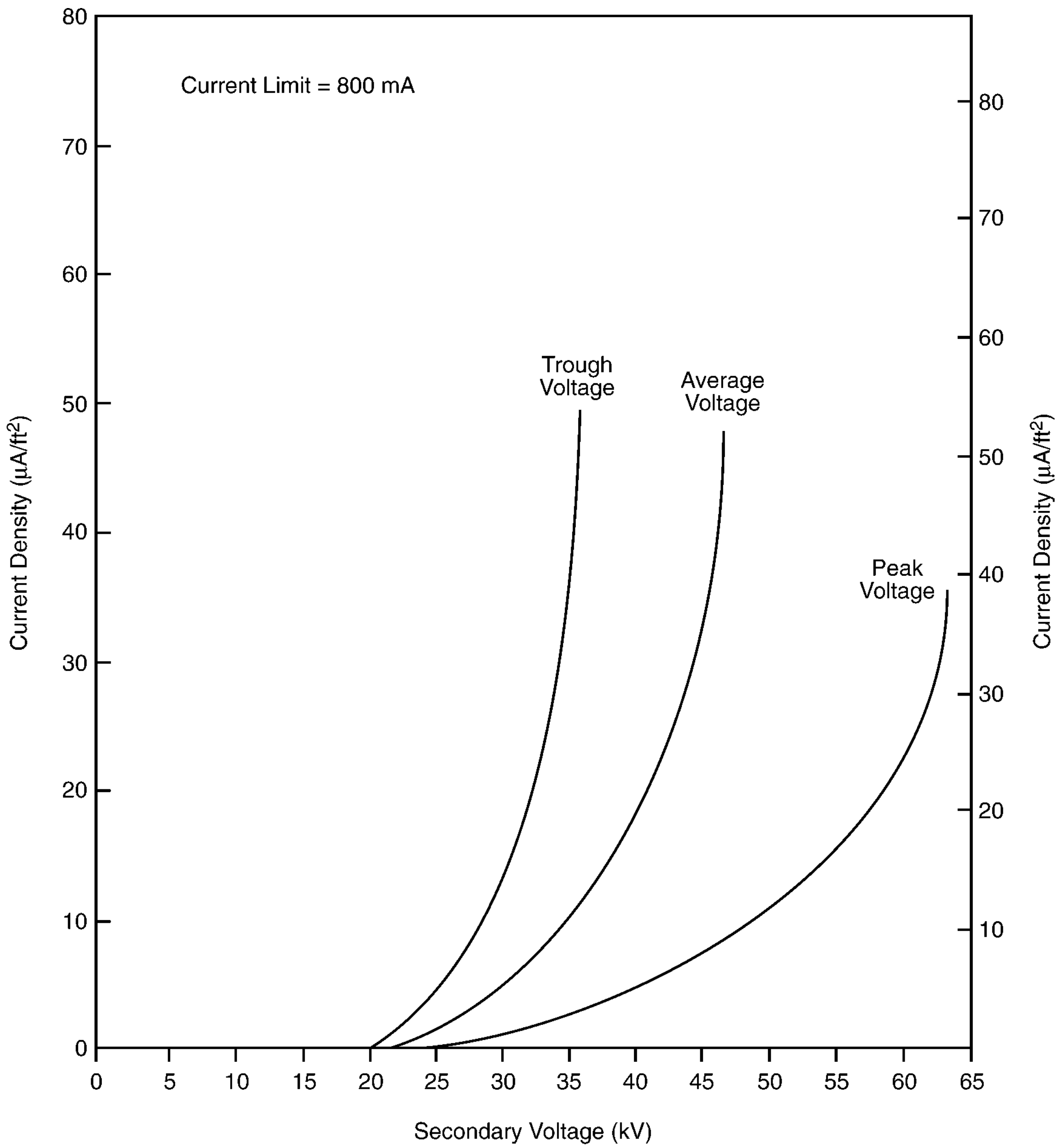


Figure 3-12
Normal V-j Curves of the kV Minimum, Average, and Peak from a Microprocessor Control

Notice that the corona onset voltage changes between zones. Zone 1 represents the inlet field and Zone 3 represents the 3rd field. The change in the corona onset voltage is a direct indicator of the amount of dust loading, and represents the effect that the space charge has on the electrodes and their corona generation capabilities. More dust loading, finer particles or coating of the discharge electrodes will increase the corona onset voltage. The amount of dust lessens in subsequent fields, reducing the corona onset voltage proportional to the dust removed. This makes the corona onset voltage a very useful tool to evaluate the amount of material that is removed from field to field. Comparing the pattern of the onset from inlet-to-outlet and chamber-to-chamber can be very useful, similar to the comparison of the power readings discussed earlier in this section. It is important to remember, on very large ESPs with more than 5 fields, there will be very little change in the V-I curves for the outlet fields since the dust loading barely changes from field to field.

Key Technical Point

The change in the corona onset voltage is a direct indicator of the amount of dust loading, and represents the effect that the space charge has on the electrodes and their corona generation capabilities. More dust loading, finer particles or coating of the discharge electrodes will increase the corona onset voltage. The amount of dust lessens in subsequent fields, reducing the corona onset voltage proportional to the dust removed. This makes the corona onset voltage a very useful tool to evaluate the amount of material that is removed from field to field. Comparing the pattern of the onset from inlet-to-outlet and chamber-to-chamber can be very useful, similar to the comparison of the power readings discussed earlier in this section.

3.2.6 Analyzing the Electrical Data

This section provides examples to assist in analyzing ESP electrical readings. The discussion first addresses interpreting individual meter readings, then oscilloscope waveforms, and finally the V-I curves obtained through gas-load testing.

3.2.6.1 Interpreting Meter Readings

The meters on the power supply controls provide a wealth of information about the ESP's operating conditions. Power supply controls operating conventionally act to maintain the average voltage on the ESP electrode system as high as possible. The controller raises the operating voltage from the high voltage rectifier until a spark over occurs between ground and the high voltage section. The secondary voltage is then reduced by a small amount (by reducing the conduction angle on the control SCR), and then increased again until the spark is repeated. This process repeats to maintain the average voltage near to spark over. The voltage ramp rate is controllable in most modern controls.

It is important to determine whether the operating currents are completely useful in charging and collecting particles. If excessive sparking or back corona is occurring, the measured currents will not be completely useful and may, in fact, be detrimental to ESP performance in the case of severe back corona.

3.2.6.1.1 Normal Meter Readings for an ESP in Good Condition

Figure 3-13 suggests typical meter readings for a healthy, four-field ESP with 9 or 10 in. (228.6 to 254.0 mm) plate spacing. Such an ESP, collecting pulverized coal fly ash with a resistivity of 5×10^{10} ohm-cm to 1×10^{11} ohm-cm, will have inlet sections operating at voltages of about 42 to 44 kV and current densities of about 15 microamperes per square foot (16 nanoamperes per square centimeter). The second field would likely operate at 38 to 42 kV with a current density of 25 $\mu A/ft^2$ (27 nA/cm^2). The third and fourth fields would operate with secondary voltages of 32 to 38 kV with current densities approaching 40 to 50 $\mu A/ft^2$ (43 to 54 nA/cm^2).

Note that the variation in electrical readings from field-to-field results from the material removal that is taking place inside of the ESP. The inlet field operates with a higher secondary voltage and lower current because of the greater amount of electrical space charge from the uncollected particles that have been charged. The fields further into the ESP operate with progressively higher currents and lower voltages as fewer charged particles remain uncollected.

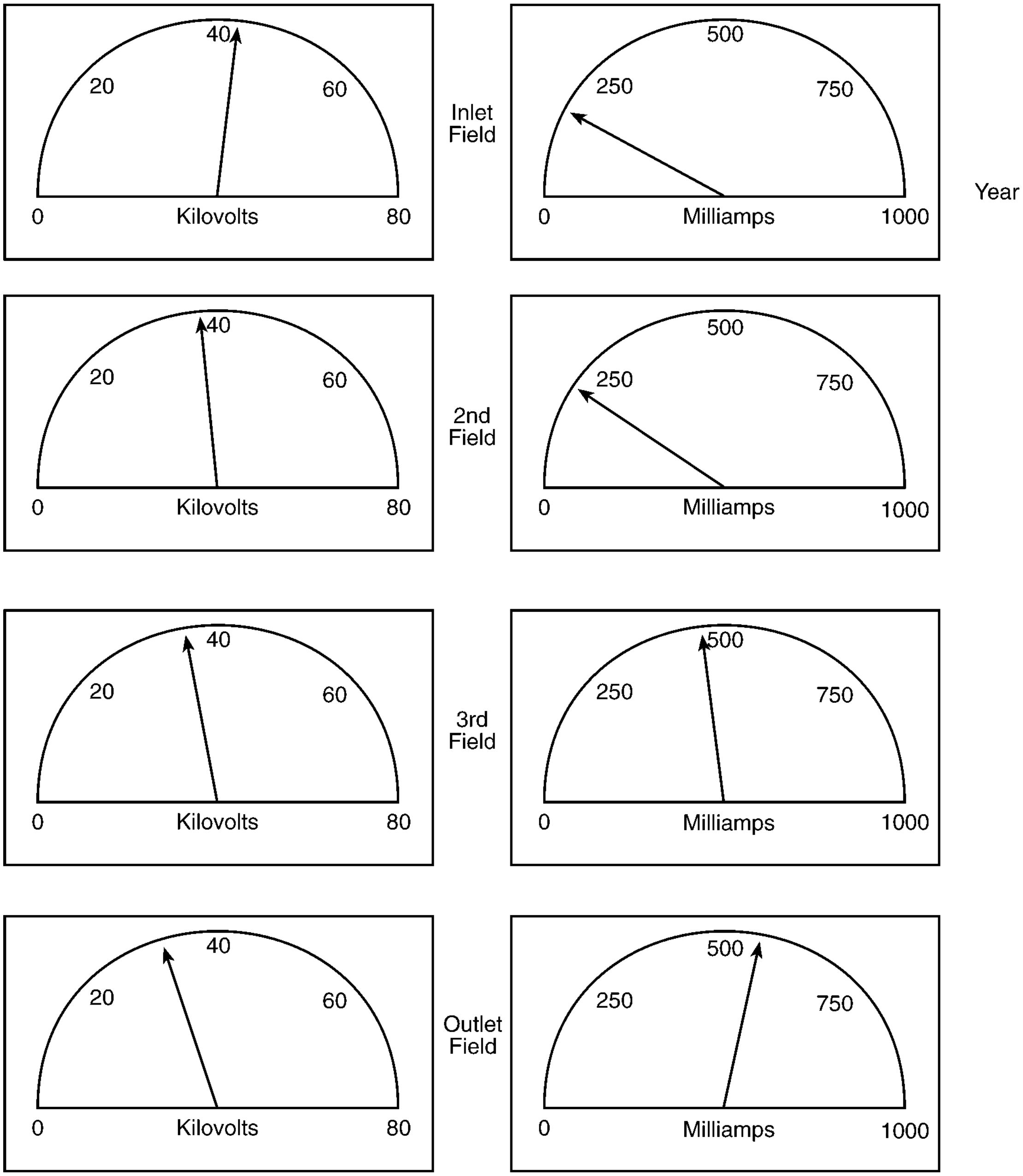


Figure 3-13
Examples of Secondary Meters for a Four-field ESP

Table 3-11 provides an example set of electrical data from another ESP in good condition. This unit is similar to the one whose readings are shown in Figure 3-13: four fields, 10 in. (254 mm) plate spacing, pulverized bituminous coal, and no ash resistivity limitation. Note that the values are quite different from those in Figure 3-13, but the trend in electrical readings from field-to-field is the same. This variation in voltage and current readings between these two normal ESPs, operating under similar conditions, underscores the importance of keeping a historical logbook so you can compare your unit's meter readings to their own norm, rather than to some generic ESP.

Table 3-11
Example Power Supply Readings for a Four-field ESP (Moderate Resistivity Conditions)

Field No.	Primary Voltage (V)	Primary Current (A)	Secondary Voltage (kV)	Secondary Current (mA)	Spark Rate (SPM)
1	335	55	47	280	33
2	325	80	44	420	21
3	315	110	41	600	9
4	310	130	39	700	0

To appreciate meter readings, a correlation can be made between the meter readings, oscilloscope waveforms, and the events occurring in the precipitator itself. Figures 3-14 through 3-21 each illustrate a different condition in the ESP. Each figure depicts the meter readings, the secondary voltage and current waveforms as they might appear on an oscilloscope, and a suggested picture of the activity in the ESP concurrent with these readings. Examples of meter readings caused by equipment failure can be found in ESP Components Section 4.1 and 4.2.

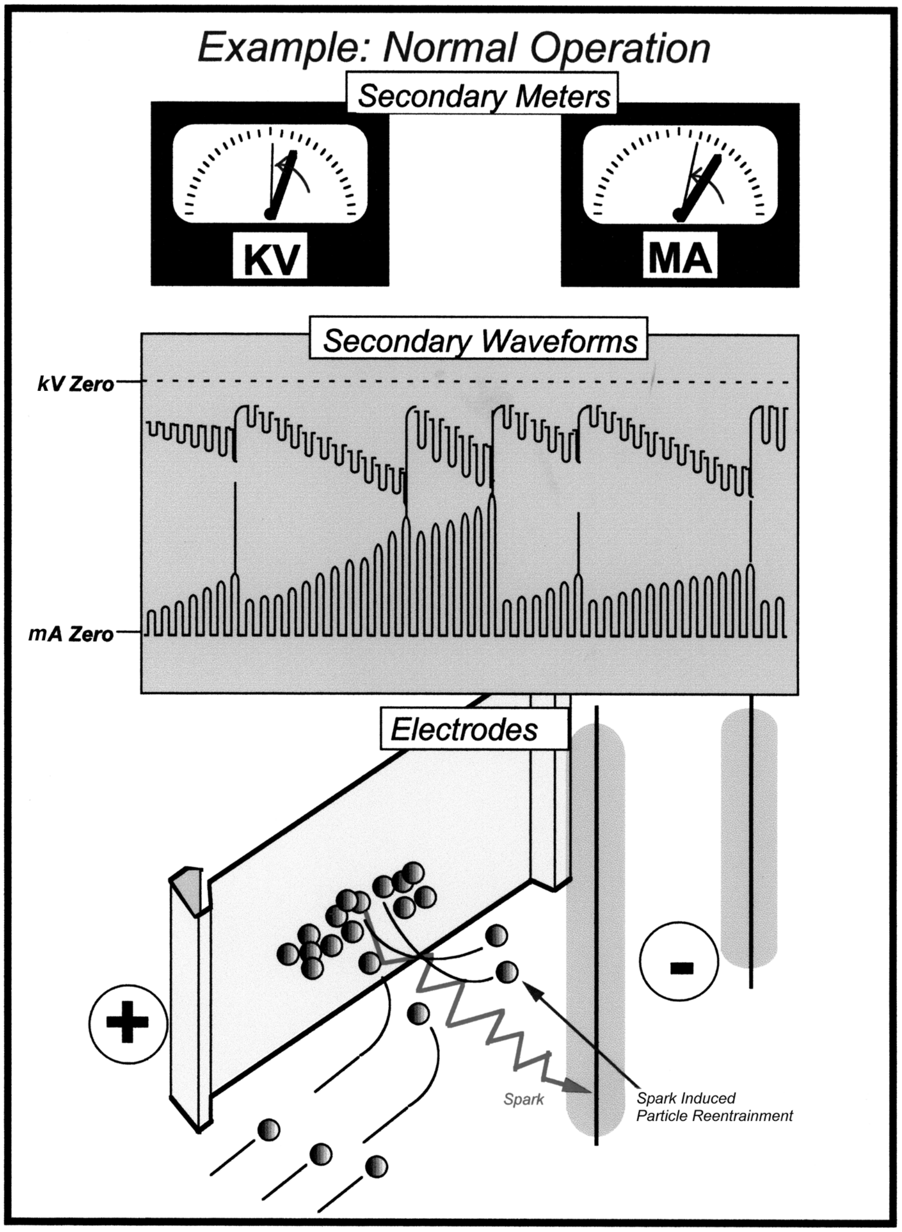


Figure 3-14
Depicts Normal Operation with a Modern Microprocessor Power Supply and Control System Cycling Through the Control Function. The Control Function Is Set to Regulate Power to the Section on the Basis of Spark Detection.

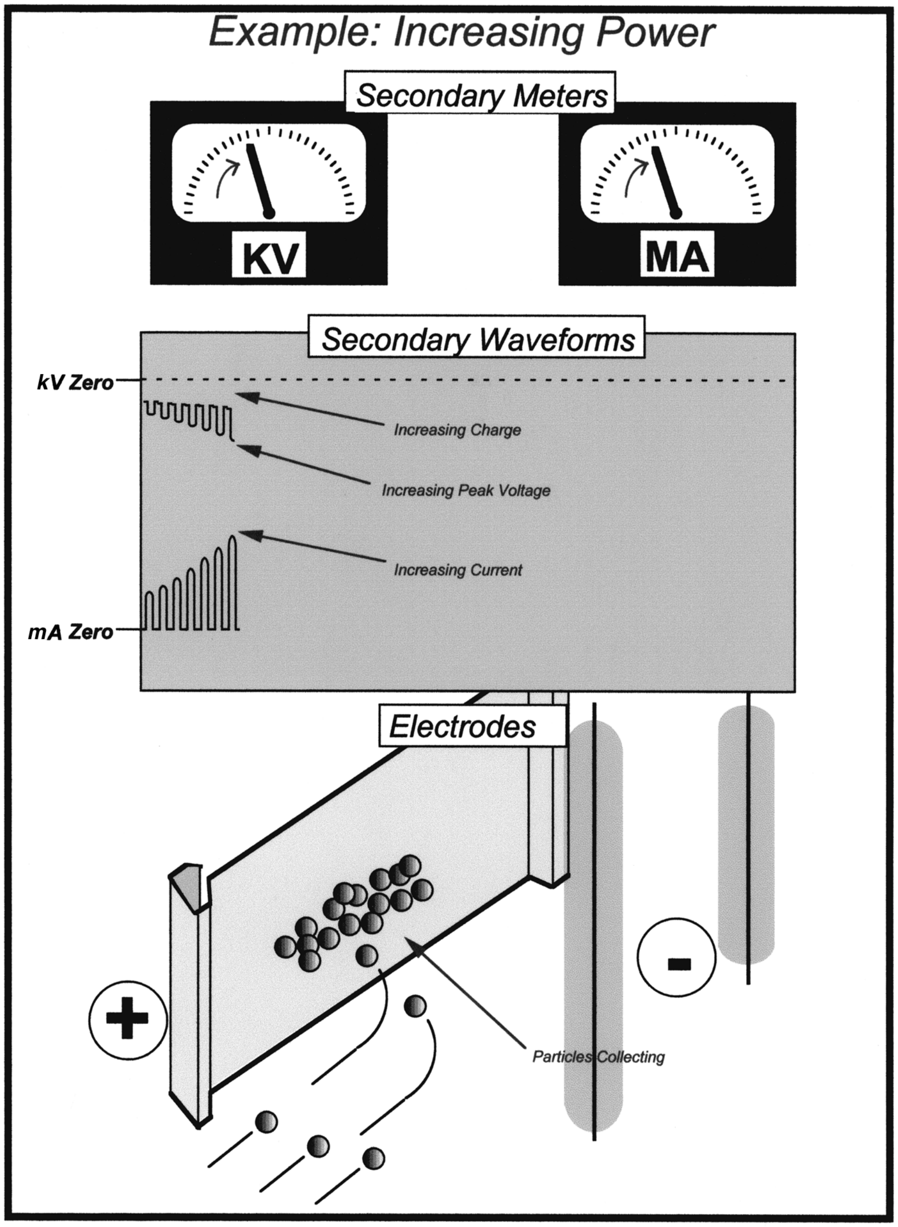


Figure 3-15
Shows the Condition Where Power Is Increasing After the Equipment Is Initially Energized or Is Recovering from a Normal Discharge Spark. The Meter Direction Arrows Suggest the Power Is Being Ramped Up to the Section.

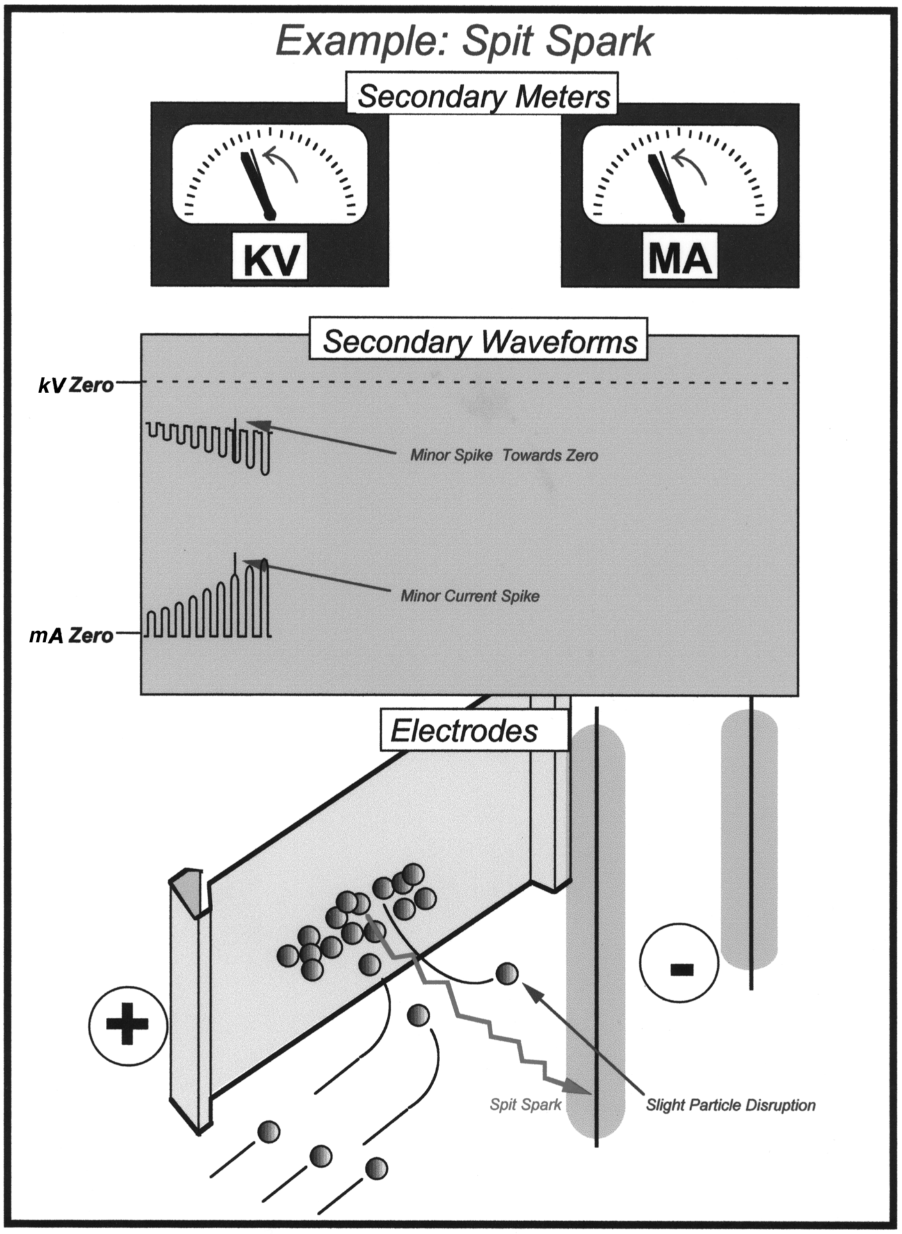


Figure 3-16
Shows a Minor Increase in Secondary Current Accompanied by a Minor Decrease in Secondary Voltage Associated with a Normal Light Spark (Referred to as a Spit Spark). The Decrease in Secondary Voltage Results from the Current Surge Discharging Some of the Electrical Energy Stored in the ESP Distributed Capacitance. The Control System Does Not Normally Respond to this Type of Discharge.

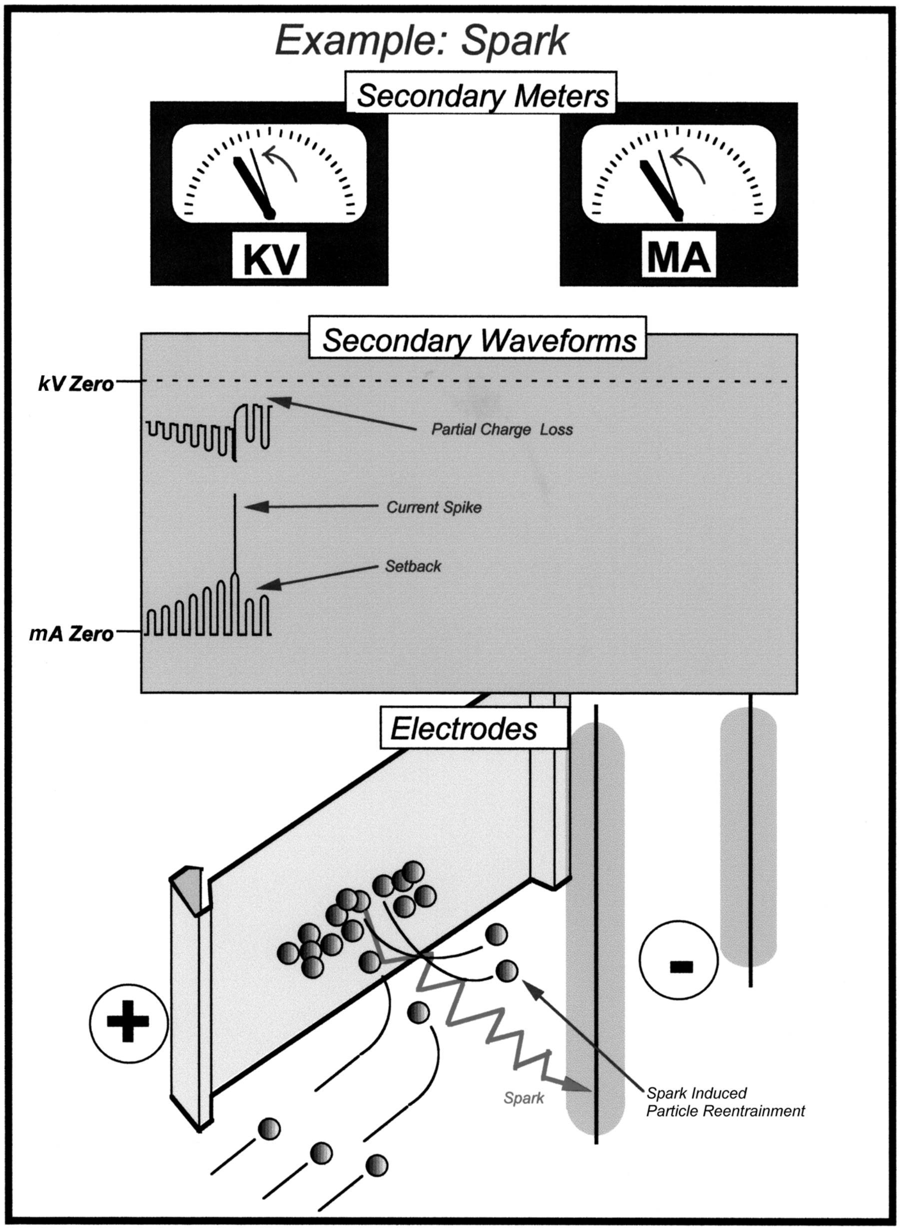


Figure 3-17
Represents the Response to a Somewhat Heavier Spark. This Condition Causes a Larger Increase in Current and Reduction in Voltage. In This Case, the Control System Responds by Setting the Voltage Back Slightly to Prevent the Occurrence of a Spark Re-strike. The Rate of Sparking Should Be Measured with Spark Rate Meters. Acceptable Levels of Sparking Are in the Range of 10 to 60 Sparks per Minute.

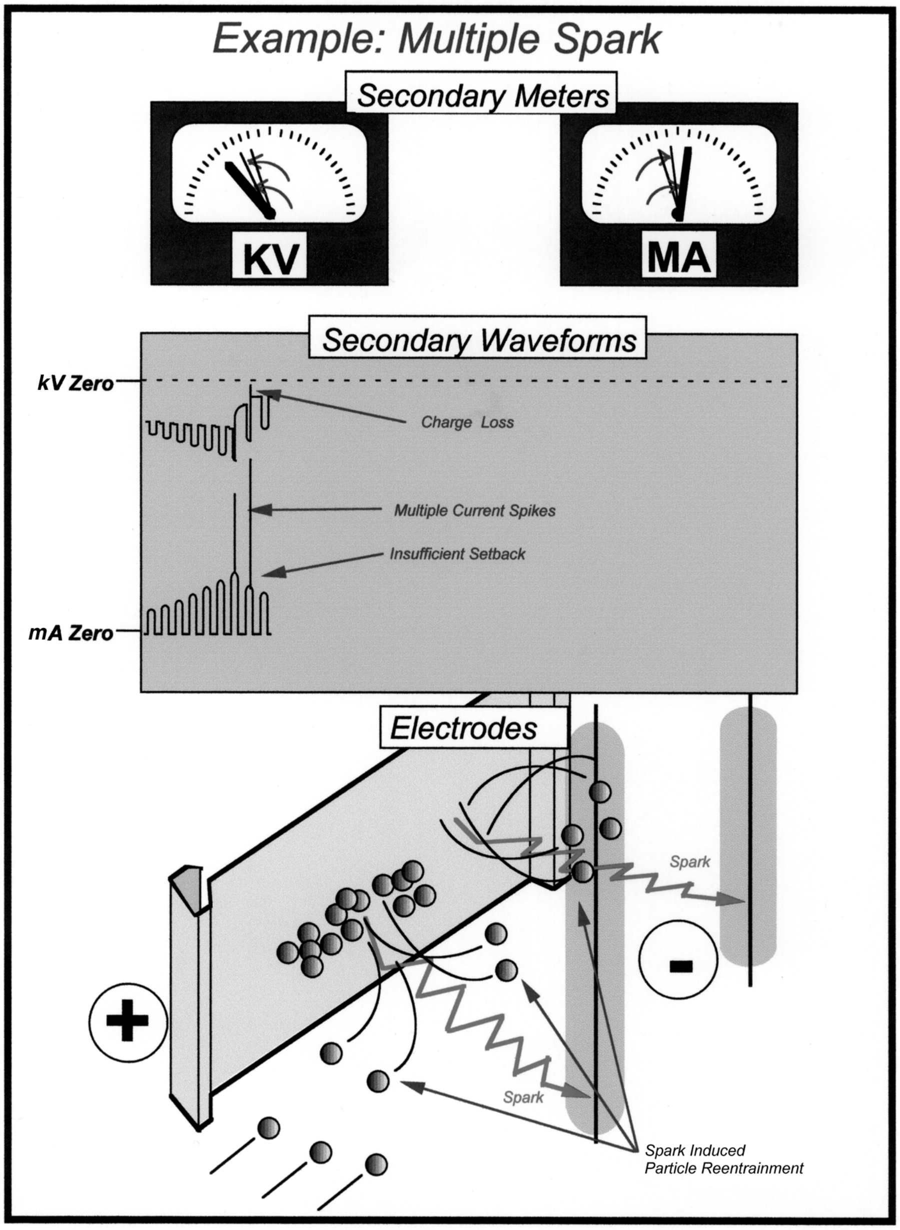


Figure 3-18
Shows the Occurrence of Several Sparks and the Response of the Control System. In This Case, the Spark Has Repeated. This Multiple Spark Condition Is Undesirable, as It Tends to Drive the Average Secondary Voltage Down, Reducing the Electrical Collecting Force and Encouraging Particle Reentrainment. The Reentrainment, in Particular, Comes from a Disruption of the Surface of the Collected Fly Ash Layer by the Sparks and by an Overall Reduction in the Electrical Holding Force Over Large Regions of the Layer Because of Decreased Current to Those Regions.

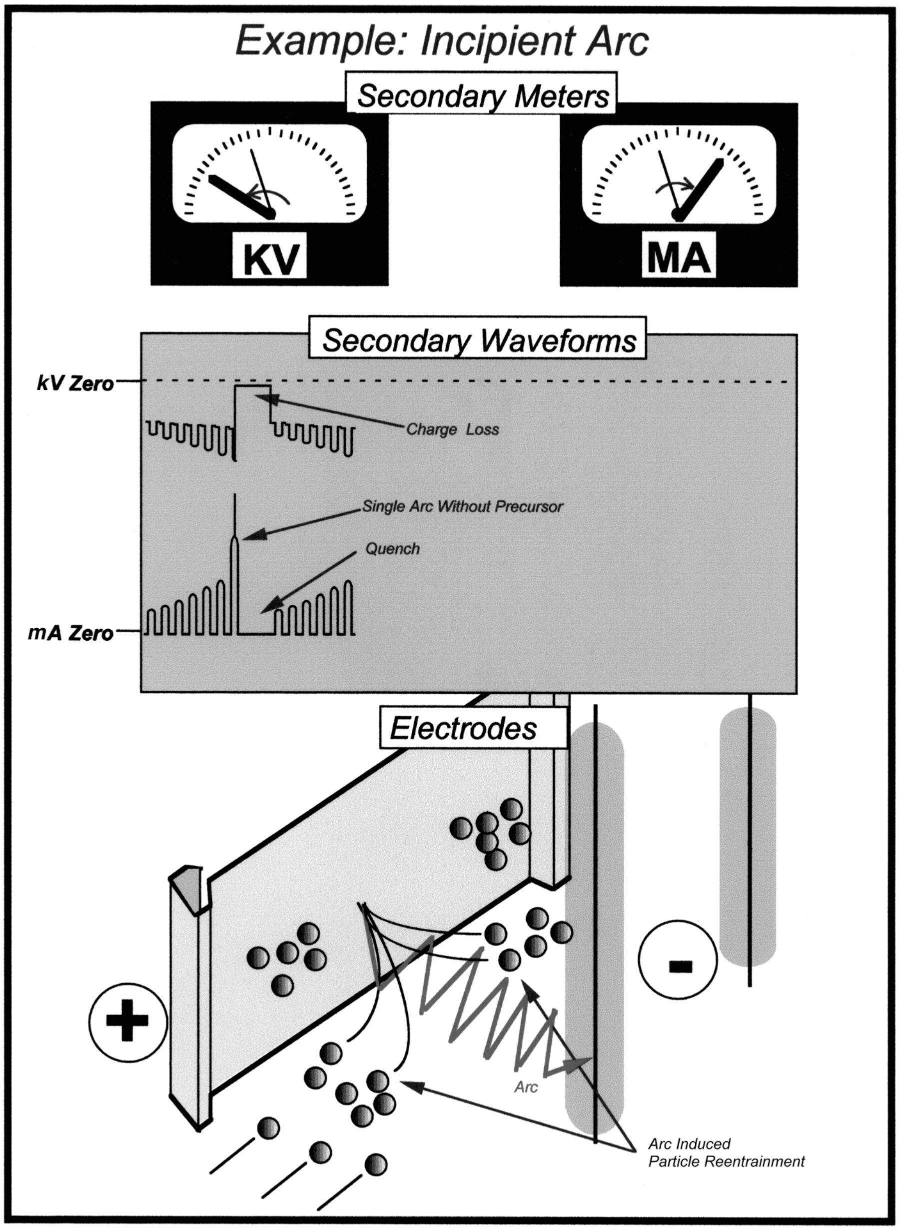


Figure 3-19
Suggests the Formation of an Arc. A Single Occurrence Such as This Usually Cannot Be Avoided. This Undesirable Condition May Be Either the Result of Unstable Electrodes or a Process Upset. The Control System Must Reduce the Voltage to the ESP to Near Zero to Quench the Arc.

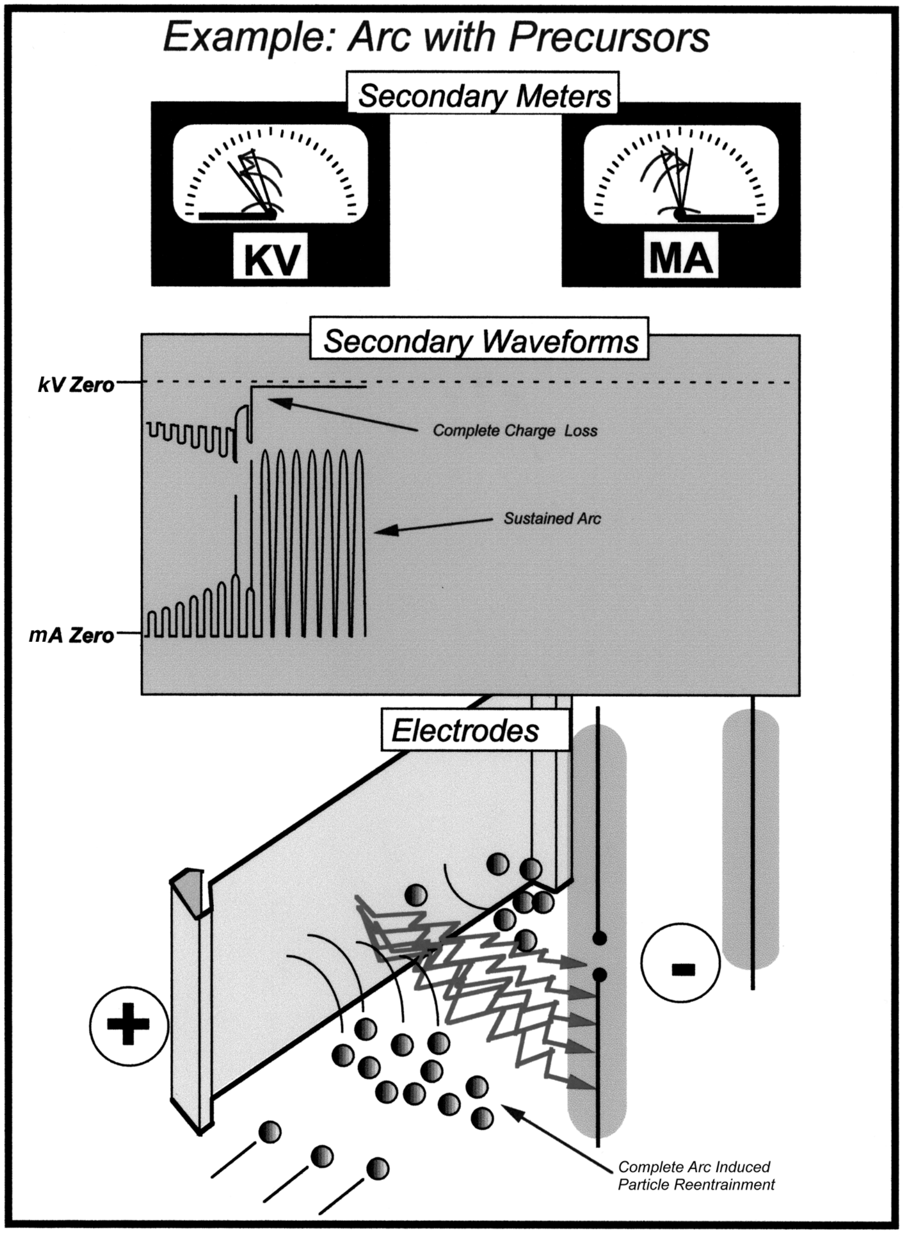


Figure 3-20
Illustrates a Recurring Full Conduction Arc Existing Over Many Half-cycles with a Significant Reduction in Secondary Voltage. This Depiction Suggests a Series of Unregulated Sparks That Are Increasing in Amplitude. This Is a Very Damaging Event That Can Lead to Wire Failure. The Broken Wire Can Then Cause a Short, Which Is Itself Manifest by Sustained Arcing.

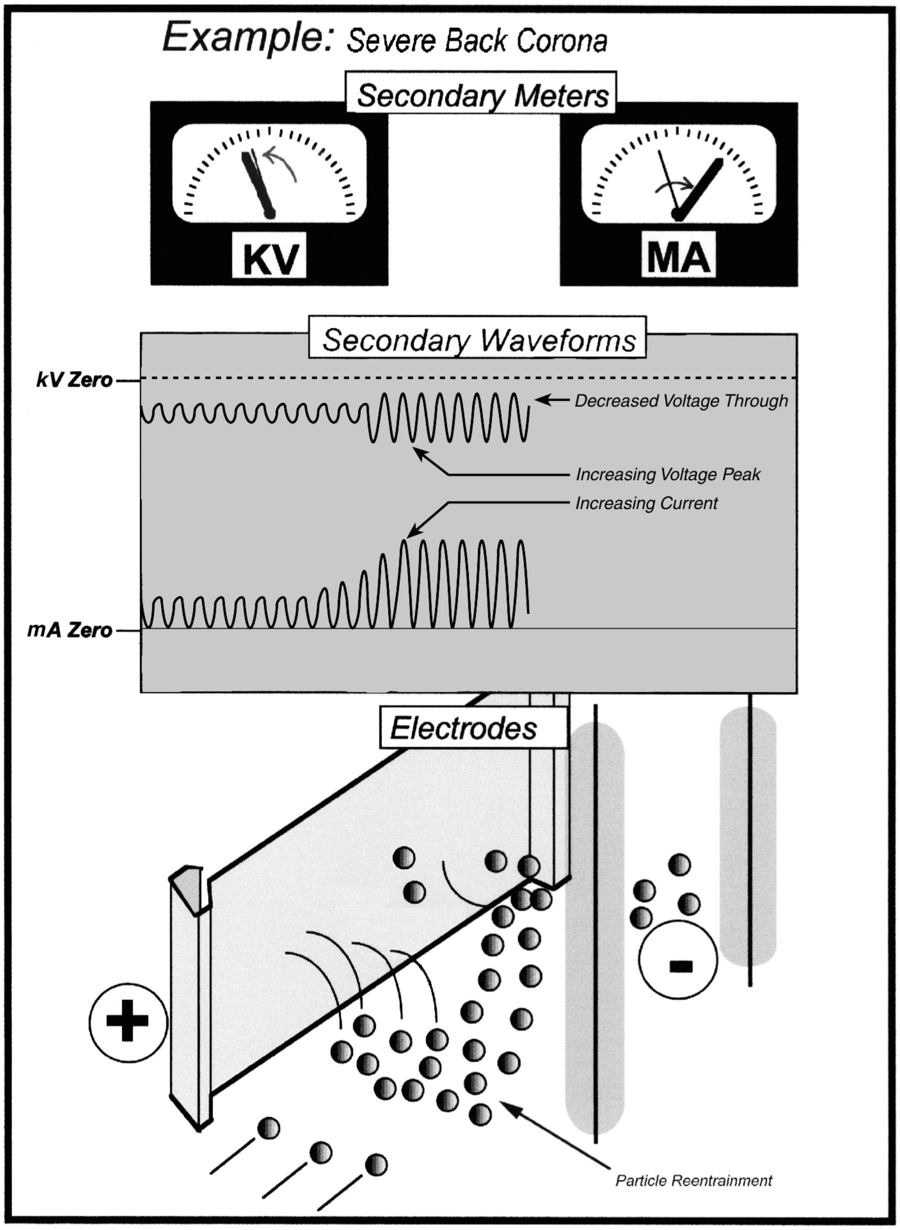


Figure 3-21
Illustrates the Effect of Severe Back Corona. The Voltage Is Low and the Current Is at Limit with No Sparking. This Condition Will Result in Loss of a Large Amount of Material from the Collecting Plate. The Resistivity of the Dust on the Collecting Plate Is So High (Over 1012 Ω-cm) That the Entire Dust Layer On the Collecting Plates Starts to Discharge Positive Ions. There Is No Outstanding Steamer to Create a Spark over and the Voltage Drops as the Ion Flow from the Discharge Electrode Is Basically Neutralized by the Positive Flow from the Collecting Surface. With No Current Flow Through the Dust Layer, the Static Forces That Normally Hold the Dust to the Collecting Plates Is Low and the Material Will Actually Fall Off of the Plates in Large Amounts, Dramatically Increasing Opacity.

3.2.6.2 Interpreting Secondary V-I Waveforms

Figures 3-14 through 3-21 depict secondary voltage and current waveforms under various normal and abnormal operating conditions. Figures 3-22 through 3-24 show how to recognize severe back corona using the secondary voltage waveform.

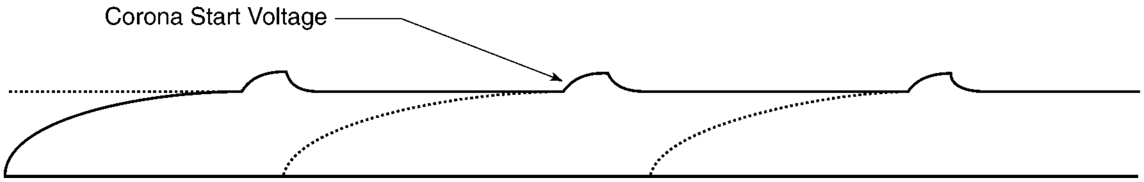


Figure 3-22
Secondary Voltage Waveform (Voltage vs. Time) at Corona Start

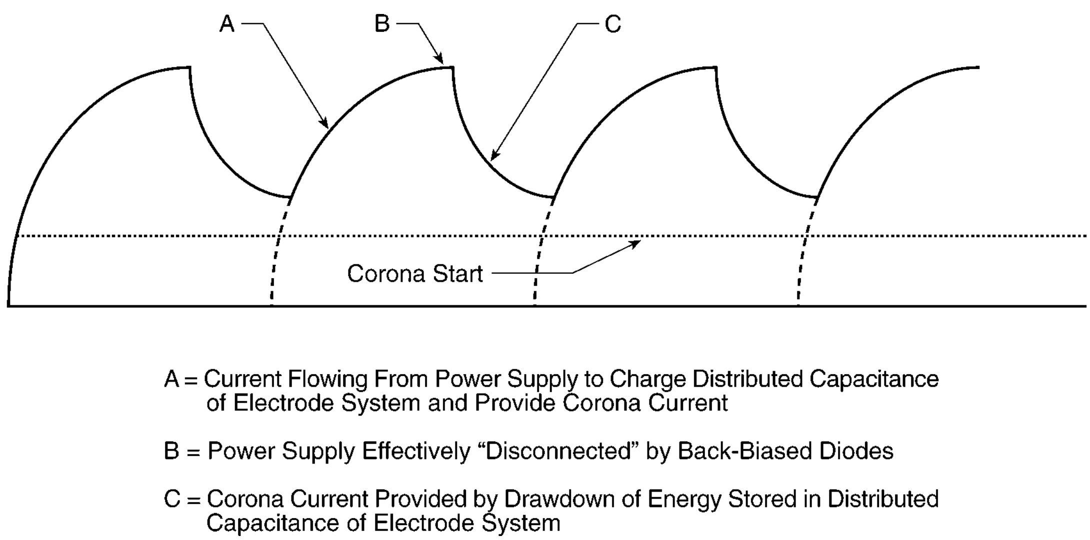


Figure 3-23
Secondary Voltage Waveform with No Back Corona

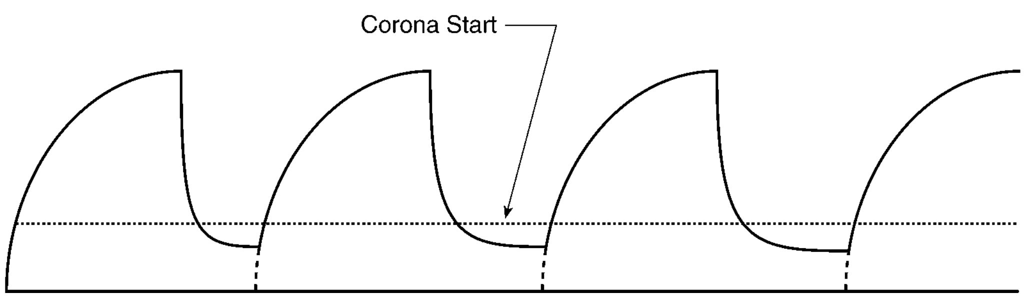


Figure 3-24
Secondary Voltage Waveform with Heavy Back Corona

Caused by high resistivity fly ash, the presence of back corona significantly degrades ESP collection efficiency. Back corona generates ions that serve as charge carriers in addition to the desirable charge carriers from the normal corona process. These additional positive ions neutralize much of the negative space charge from the discharge electrode, causing a significant increase in the total current flowing in the inter-electrode space. (The resulting increase in the current in each field can be detected via a characteristic change in the shape of the V-I curves, as discussed in Section 3.2.5.3.) Some of the positive ions formed in back corona flow to the fly ash particles and neutralize a portion of the negative charge on them, thereby decreasing their probability of being collected.

Key Technical Point

Caused by high resistivity fly ash, the presence of back corona significantly degrades ESP collection efficiency.

Figures 3-22, 3-23, and 3-24 give oscilloscope waveforms of secondary voltage as a function of time for corona start, normal, and back corona conditions. Corona start voltage is indicated on the operating waveforms for reference. Note that under conditions of heavy back corona, the rectified voltage waveform dips below the corona start voltage value.

3.2.6.3 Interpreting V-I Curves

A baseline set of V-I curves, taken under air-load conditions, will have been obtained during ESP commissioning (the vendor uses these data to help evaluate plate alignment during erection of the ESP). The ESP logbook should also contain more recent air-load and gas-load V-I curves. These historical records provide a useful baseline against which to compare the V-I data taken during the present gas-load test. When it comes to actual values of voltage and current, it is far more instructive to compare your data to earlier data from your unit rather than to the generic graphs. The sample graphs in this guide are included to illustrate characteristic normal and abnormal curve shapes.

As will be discussed in this section, the general shape of a V-I curve is influenced by several factors, including:

- Electrical space charge (responsible for curve variations between fields; see Figure 3-25)
- Ash resistivity (high resistivity causes back corona, which has a characteristic *back slant* curve shape; see Figures 3-26 and 3-27)
- Thickness of ash layer (see Figure 3-28)

Figure 3-25 illustrates a V-I plot for a healthy ESP with 10 in. (254.0 mm) plate spacing, operating at a temperature of 300^{o}F (149^{o}C), with no significant resistivity limitations.

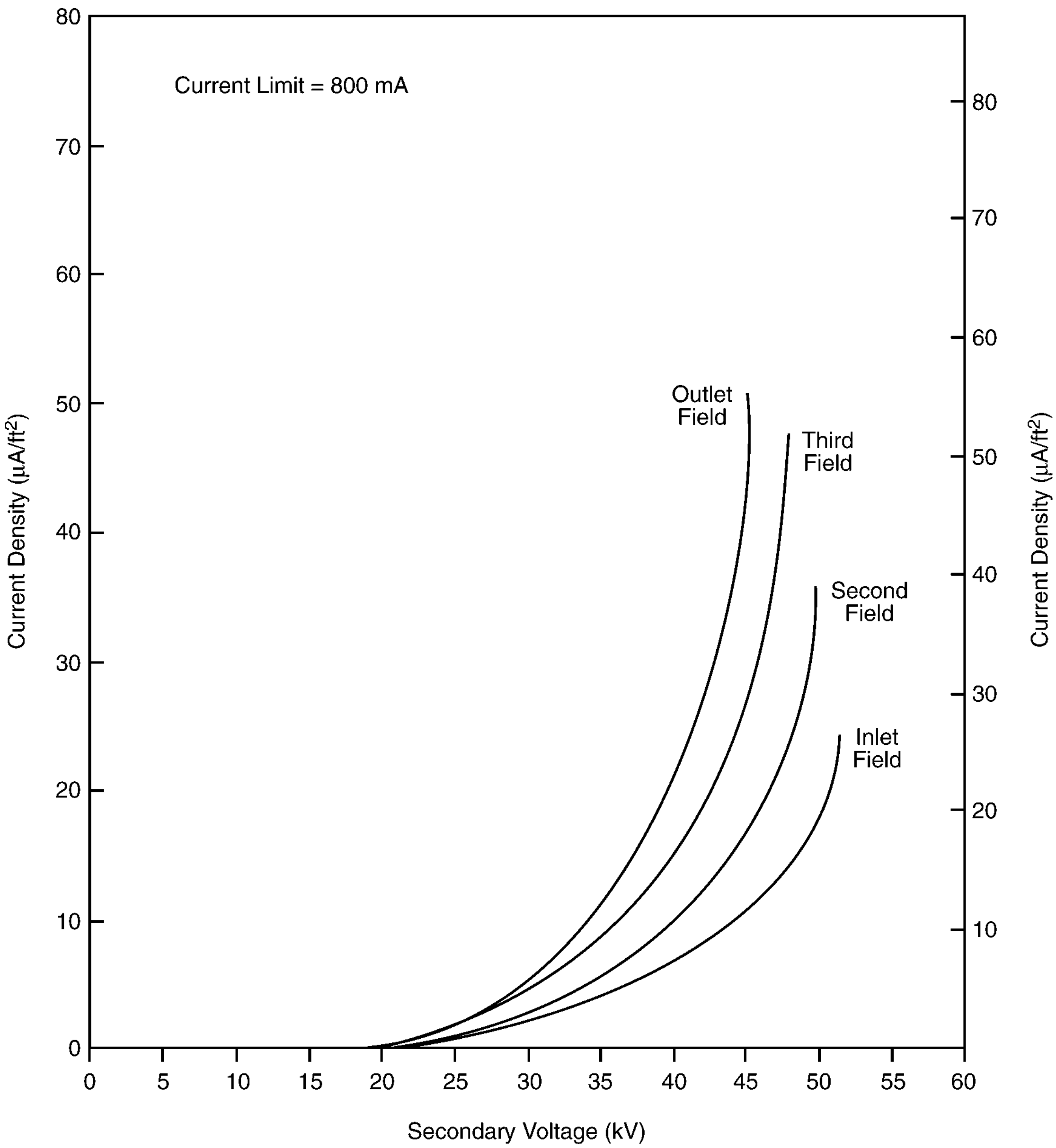


Figure 3-25
Typical Gas-Load V-I Curves for a Healthy, Four-Field ESP (with Low Loading)

In Figure 3-25, observe that the curve for the inlet field is to the right of the second field (that is it exhibits a lower current density for a given secondary voltage), and that this pattern continues from field-to-field in the ESP. This variation in the V-I curves is caused by the change in electrical space charge among the different fields. Approximately 70% of the total fly ash particles are collected in the first field of the ESP. Thus, the particle loading (and corresponding electrical space charge from the particles) in the second field is about 30% of that in the inlet section, and so on down the line, until there are relatively few charged particles remaining in the outlet field. It is this successive reduction in space charge that causes the shift in the V-I curves from field-to-field. Removing the space charge allows more current to flow for a given applied voltage, resulting in a systematic decrease in voltage coupled with a systematic increase in current density from the inlet to the outlet field.

The amount of space charge influences the amount of shift to higher currents at a given voltage as you progress from inlet to outlet. If the fly ash contains an unusually large amount of very fine material, which is harder to collect, the space charge will be higher and the resultant V-I curve will shift to a higher voltage (shift to the right) for a given current density. This sometimes occurs with combined ammonia and sulfuric acid conditioning or ammonia injection into a high sulfur gas stream.

To analyze the V-I data, compare the V-I curves within a field and between fields. Ideally, the curves for each section within a field should be almost identical (data points within a few percent) unless different sections are equipped with different corona-wire designs or are operated with different energization methods. In actuality, however, most ESPs have variations in gas-flow or temperature distribution that will cause variations between the V-I curves for sections within the same field.

Curves for different fields should share the same basic upward curve shape, but have different values of voltage and current due to the difference in electrical space charge in the different fields. When comparing curves, look for differences in:

- General shape of the V-I curves
- Corona start voltage (the beginning point of the curve)
- Sparking voltage

Also compare the curves to historical gas-load V-I curves, if available, to determine if there has been a change in their appearance. If the curves for some sections deviate from the majority of others, or differ significantly from previous V-I data, mechanical damage is likely. For example, sparking at lower voltages than on previous occasions would suggest the possibility of electrode misalignment or an insulator problem in that electrical section. Operating at higher current for a given voltage would suggest an electrical fault or mechanical misalignment. An internal ESP inspection is warranted to determine the cause(s).

Changes in the general shape of the V-I curves provide useful clues as to potential problems in the unit. For example, if the ESP is exhibiting early spark over and back corona, the appearance of the V-I curves should resemble those in Figure 3-26 rather than those in Figure 3-25. The *back slant* appearance to the curves as current rises indicates the presence of back corona. The arrow drawn at the top of the inlet curve indicates the spark over.

For a microprocessor power supply, the shape of a V-I curve indicating back corona will appear as depicted in Figure 3-27. In this plot, note that as the SCR firing angle is increased (thereby increasing the operating voltage above corona start) the peak, average, and trough (minimum) values of secondary voltage increase until back corona is formed. After back corona is initiated, further increases in the conduction angle for the SCR cause the peak value to continue to increase, the average value to increase initially then decrease, and the trough value to decrease. When back corona becomes severe, the trough value falls below the corona start voltage, indicating that the back corona is supplying positive ions as charge carriers even though the corona from the discharge electrode has been interrupted between energization cycles.

Figure 3-28 illustrates other deviations from a *normal* set of curves. In this figure, Curves 5 and 6 are normal, whereas curves for the other sections indicate problems, as noted below:

- **Ash buildup on discharge electrodes -** If the discharge electrodes have a large buildup of ash on their surfaces, they behave as electrodes would with a much larger diameter as suggested by Curve 1.
- **Overfilled hopper or ash buildup on high voltage insulators -** If there is a significant ash deposit on the surface of the high voltage insulators, a relationship such as Curve 2 results. In this case, current flows through the ash deposit on the insulator before the operating voltage is high enough to generate a corona at the discharge electrode. The slope of the linear portion of such a curve is related to the actual ash deposit thickness: the greater the deposit thickness, the greater the slope. Such a curve shape may also indicate an overfilled hopper, with current flowing from the discharge electrode through the hopper ash to the collecting plate.
- **Back corona (severe) -** Curves 3 and 4 indicate the presence of back corona as discussed above.

Curves 5 and 6 indicate no problems. Curve 5 represents a curve with either a near clean collecting electrode or one with an ash deposit with resistivity less than about 5×10^{10} ohm-cm. Curve 6 is expected to have a reasonable thickness of deposit with a resistivity on the order of 5×10^{11} ohm-cm. Curve 6's shift to the right relative to Curve 5 represents the voltage drop across the ash layer.

3.2.7 V-I Curves at Part Load

V-I curves taken at part load show the same characteristic shapes to indicate the same ESP problems as curves taken at full boiler load. However, gas-load curves at partial loads are not as informative as a curves run at full load. Mechanical problems such as gross misalignment or damaged electrodes can generally be detected just as well, but ash related problems cannot. The lower flue gas temperature at part load changes the ash resistivity, which can result in better than actual electrical readings for cold-side units (that is the back corona could be undetectable) and worse than actual readings for hot-side units (because temperature reduction in a hot-side unit increases ash resistivity, back corona is likely to develop in hot-side units at part load).

To detect back corona, evaluate secondary voltage waveforms obtained with an oscilloscope while the plant is operating at full load. If the secondary voltage increases and the current density decreases as you reduce load (and temperature), you likely had back corona in a cold-side unit at full load.

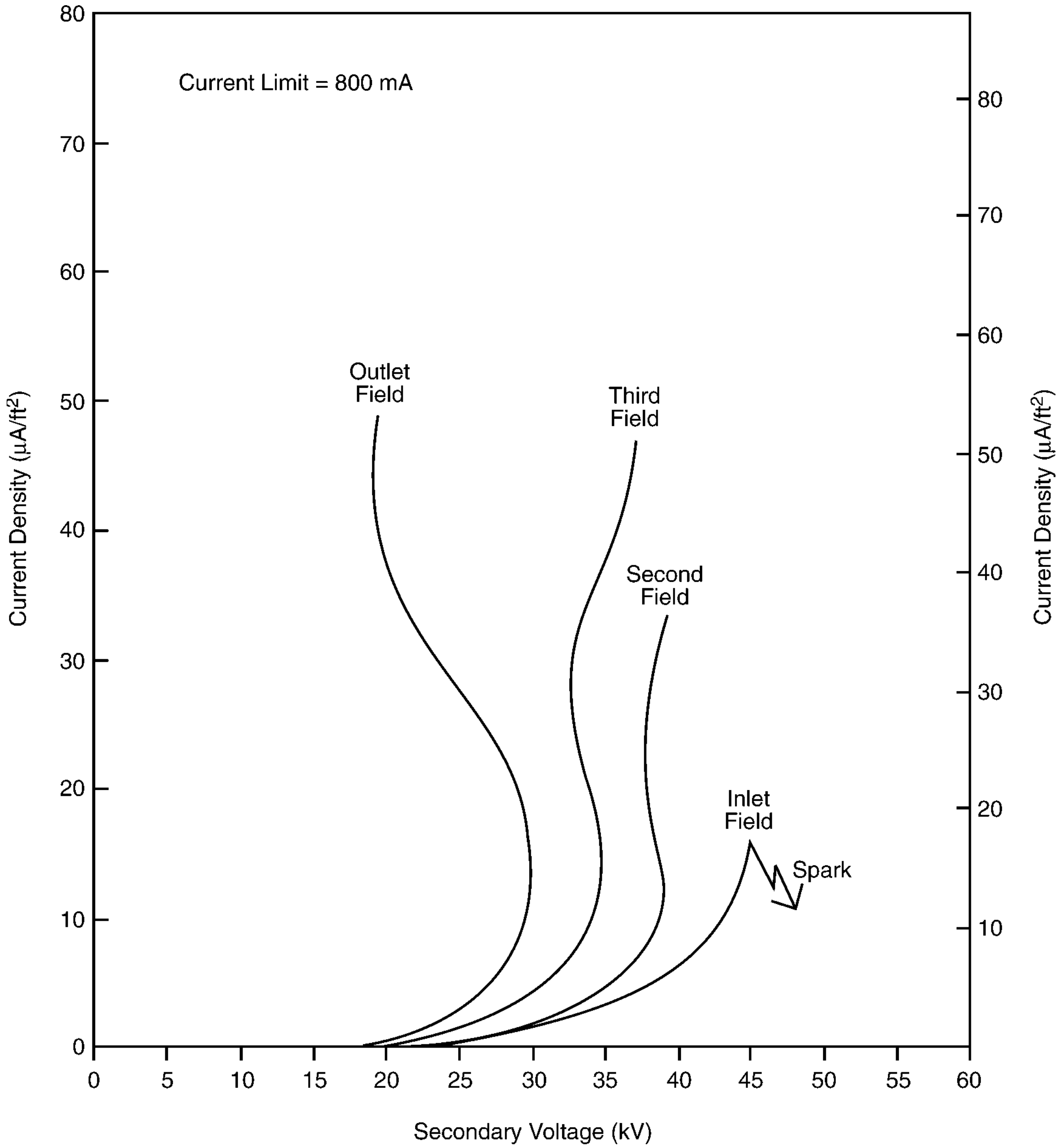


Figure 3-26
Severe Back Corona and Premature Sparking Due to High Resistivity Ash (10^{12} ohm-cm)

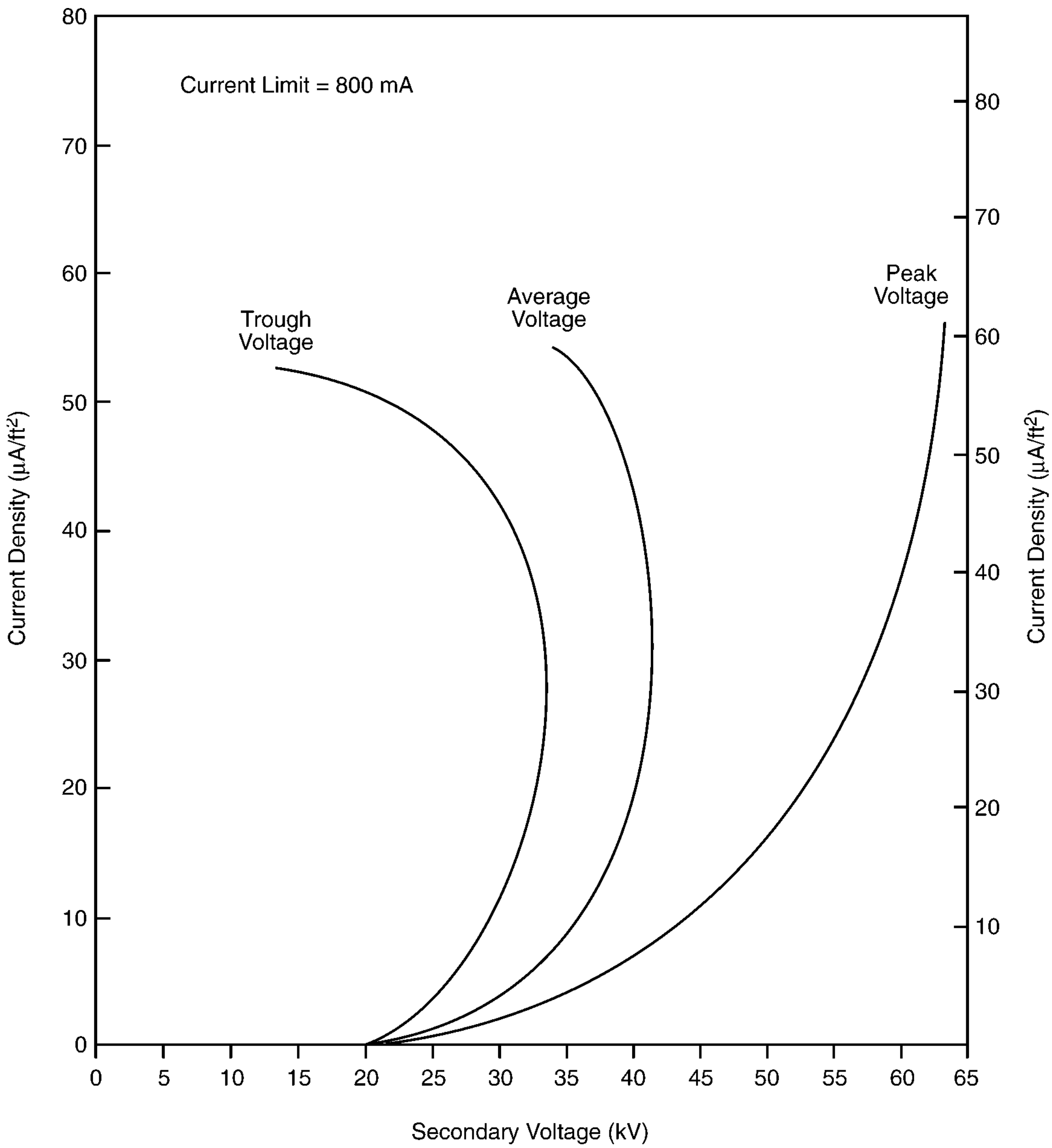


Figure 3-27
V-I Curve from a Microprocessor Control with High Resistivity and Heavy Back Corona

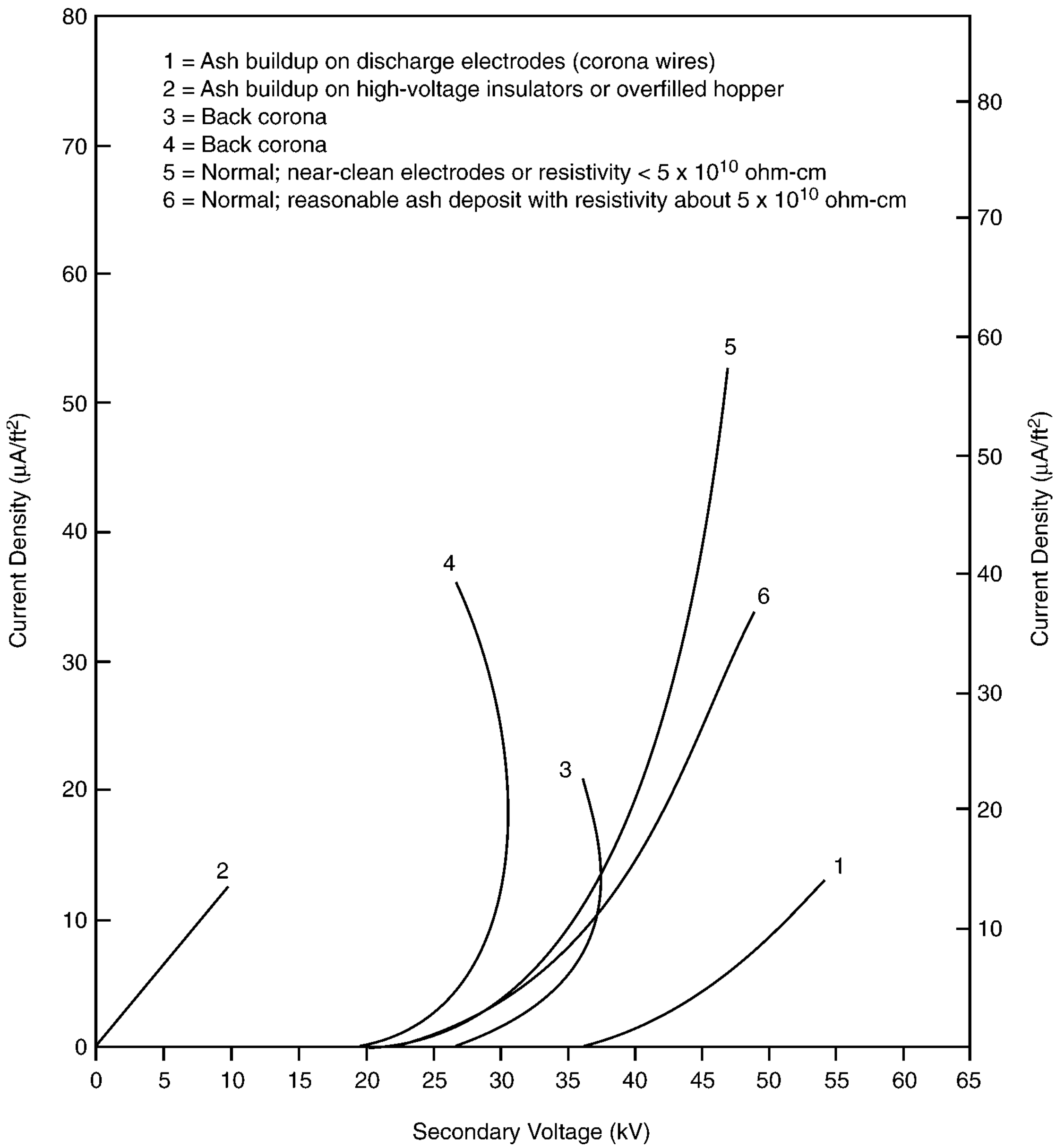


Figure 3-28
Example *Problem* V-I Curve

3.3 Off-Line Inspections

If findings from the on-line diagnostics covered in Section 3.2 indicate problems with the ESP internals, the next step is to take the unit off-line for a visual inspection. Typical off-line diagnostics consist of the following:

- **Air-load test under *dirty* conditions -** yielding V-I curves to indicate mechanical and electrical problems. When compared with V-I curves obtained through gas-load and clean air-load tests, these *dirty* V-I curves can isolate problems due to ash deposits.
- ***Dirty* visual inspection -** to diagnose problems with ash buildup, electrical tracking, poor gas flow or leakage, and inadequate rapping.
- **Air-load test under clean conditions -** for V-I curves to evaluate mechanical alignment.
- ***Clean* visual inspection -** to locate misalignment, corrosion, leaks, and other mechanical damage.
- **Gas velocity distribution evaluation -** to determine the condition of the gas-flow distribution and determine if changes could improve ESP collection efficiency.

This section covers the key areas and procedures to perform a *dirty* and *clean* inspection of the ESP. In Section 4.0, detailed discussions of the individual components are provided that will elaborate further on the use of these inspections and explain the best corrective action that should be taken when problems are found.

3.3.1 General Notes on Inspections, Shutdowns, and Startups

3.3.1.1 Safety First

Extreme caution is required when conducting an internal inspection of an ESP and the associated ductwork. The first precaution is to make sure that the electrical power supplies are off and tagged out. Short each individual discharge electrode structure to ground with an appropriate clamp-type shorting shunt. Install adequate lighting when entering the ESP. Inspection should normally begin at the top of the unit to check for potentially dangerous ash buildup that might become dislodged. If possible, visually verify that the hoppers are clear of material prior to opening. This can often be done from side access walkways located above the hoppers, or some other point of access located overhead. Exercise care when moving through the unit, especially on ladders and walkways. Be aware that ash falling from plates and structures presents an eye hazard. Wear respirators, hard hats, safety glasses, and gloves as appropriate. A detailed list of safety concerns and procedures is covered in Section 5.3, which should be reviewed before entering the ESP.

Key Human Performance Point

Extreme caution is required when conducting an internal inspection of an ESP and the associated ductwork. The first precaution is to make sure that the electrical power supplies are off and tagged out. Short each individual discharge electrode structure to ground with an appropriate clamp-type shorting shunt. Install adequate lighting when entering the ESP. Inspection should normally begin at the top of the unit to check for potentially dangerous ash buildup that might become dislodged. If possible, visually verify that the hoppers are clear of material prior to opening. This can often be done from side access walkways located above the hoppers, or some other point of access located overhead. Exercise care when moving through the unit, especially on ladders and walkways. Be aware that ash falling from plates and structures presents an eye hazard. Wear respirators, hard hats, safety glasses, and gloves as appropriate. A detailed list of safety concerns and procedures is covered in Section 5.3, which should be reviewed before entering the ESP.

3.3.1.2 Shutdown and Start-up Techniques

Most manufacturers recommend not operating the ESP if the flue gas temperature is below the dew point. This is particularly important during startup to avoid tracking on insulators and fouling of the ESP electrodes. However, there are plants that are required to keep the ESP on as long as the fan is on. In these situations, special care is needed to avoid damaging the ESP. It may even require upgrading parts of the ESP (such as the installation of a heated purge blower system or hopper heaters). Normally, there are two different shutdown procedures that most plants follow. One is used to perform a dirty inspection and the other is to clean up the unit.

Key Technical Point

Most manufacturers recommend not operating the ESP if the flue gas temperature is below the dew point. This is particularly important during startup to avoid tracking on insulators and fouling of the ESP electrodes.

Shutdown Procedures for Dirty Inspection

When shutting down the ESP to perform a dirty inspection, normally as soon as the fuel is stopped, if not several hours before, the rapper system should be turned off. The TR power should be left on until the unit has been cooled and the fans are turned off. This will help preserve the ash layer and buildup patterns on the collecting plates and discharge electrodes. This is essential for the dirty air-load test and inspection. Normally, after a dirty inspection is competed the unit is cleaned. If the unit is not scheduled for cleaning, then it would be best to only shut the rappers off on the inlet fields and perforated plates and let the rest of the ESP clean up using the cleaning techniques discussed in the following section.

Shutdown Procedures for Cleaning the ESP

The best technique to keep the ESP operating well is to clean the unit while it is being shutdown. Most ash flows very freely at operating temperatures and it is much easier to remove hot material than material that has absorbed moisture and hardened. Remember that heavy deposits left to harden can cause startup problems and reduce the rapper's effectiveness during the next operating period. It is important to remember that the TR power on the electrical field will hold the material on the plates even if the rappers are left on. The removal or reduction of these electrical forces as soon as possible after fuel has been stopped is recommended. Unfortunately, de-energizing TRs along with rapping at relatively high air velocities through the precipitator will result in poor stack appearances. Therefore, the plant needs to develop an operating procedure that allows the ESP to be cleaned up without causing a violation or problems elsewhere in the ESP.

The following points should be remembered when developing a procedure:

- Maintain the hopper evacuation system at full operating capacity until 2 to 3 hours after the fans are shut off.
- Minimize airflow in the ESP for two or more hours to minimize stack discharge. One method entails going to minimum flow and then reducing all the power in the precipitator to minimum settings. Keep rappers on at normal settings. Adjust the voltage as needed to keep the stack below 20% capacity or within compliance levels. After about 10 minutes or at least two rapper cycles, start deenergization of power supplies on a frequency to keep stack appearance satisfactory. Usually this is done from outlet to inlet. After the TRs are deenergized, change the rapper program to a fast cycle for about 10 to 20 cycles. This can be done one field at a time, or with as many fields as emissions will allow. After all the fields have been shutdown, re-energize at least the last half of the precipitator and return the fans to the normal cooling procedure. The rappers will have stayed in operation during this whole cycle. Sometimes, to keep opacity in check, it is a good idea to not deenergize the outlet fields.
- Another preferred method includes bottling up the whole system (fans off) for about an hour or two before the cooling begins, and then cleaning down the precipitator on an accelerated basis. On large systems, this will add very little time to the overall cooling cycle, yet is simpler and more effective. Increase rapper frequency and intensity. At the end of the hour, re-energize the latter half of the precipitator and begin normal cool down of the system. It is important to increase fans slowly after this procedure to minimize the entrainment of fallout material to minimize opacity levels.
- There can be variations in the above methods that should be discussed between operator and maintenance personnel for the best shutdown implementation at each plant. The object is to obtain the maximum precipitator cleaning before temperatures fall below 200 to 250°F (93 to 121°C) in the ESP.
- In some installations where the above shutdown procedures cannot be implemented, make some attempt for improved cleaning of the collector surfaces during the normal cool down cycle. Increase rapping intensity and frequency. High intensity rapping for short periods,

approximately 1/2 hour. This rapping should not physically damage any of the ESP's internal components. Reduction of power settings should be done in a manner to keep the opacity of the stack discharge within acceptable limits.

Startup Procedures

A good startup procedure is crucial for good ESP performance. If the ESP is not started correctly, components can be damaged, or the ESP internals can become fouled. This can limit ESP performance for several days or weeks. The key factor is still dew point and most manufacturers recommend not operating the ESP if the flue gas temperature is below the dew point, which is typically 180 to 250°F (82 to 121°C). However, most plants need to energize the ESP prior to that point.

The following points should be helpful when developing a plan at your site:

- Do a final check of the ESP prior to closing the doors to insure that all foreign material was removed. Check that all ground straps have been removed and that the key interlock system has been done correctly so all of the TRs are properly connected for energization.
- Energize the penthouse heaters, purge blower, and hopper heaters at least four hours prior to energizing the ESP. The longer the better if possible. It is important to verify that the heaters are operational in the fields; just flipping the breaker is not enough. In the winter, heat up may need to be longer. For units that do not have heaters, energizing the ESP before the unit has been heated (for air load or other reasons) always runs the risk of tracking on one of the insulators. Therefore, if the ESP does not have a heating system, it is a good idea to limit the TR voltage to 250 V or less until the ESP has been heated above dew point for several hours.
- Air-load test the ESP prior to lighting off the boiler. The primary purpose of energizing each TR under an air load is to make sure there are no grounds or other conditions present in the ESP that would require reentry to correct. V-I curves and other testing is only a secondary concern in most cases. If ambient conditions are damp and wet the TR limits may not be attainable. However, if all of the sets are sparking at the same level and there are no problem sections, then the air load is normally considered good.
- Energize the ESP either when the ESP has reached dew point (on large units, using an ESP outlet ductwork temperature is much better than the air heater exit temperatures). Only energize enough TR sets to keep the stack opacity within code requirements, until at least stable operation is achieved. This usually occurs within 1/4 to 1/2 of the process rating of the system, after which the remainder of the precipitator is energized. In most fly ash applications, partial energization occurs with the start up of the first mill.
- Collector surface rappers should not be operated until the unit is at 1/2 load to prevent any combustibles that are collected in the ESP during start up form entering the hoppers. This can cause bridging and fires in some cases. Start the ash system once the rappers have been turned on, but not before the first mill has been put in service.

- If the start up period drags out with an excessive production of carbon particulate caused by incomplete combustion, or the oil burners are not adjusted well, the greatest danger lies in the hopper area. Energization, collection, and rapping down of substantial amounts of carbonaceous material during the early period could cause conditions for spontaneous combustion in the hoppers. This is especially true if air in-leakage or even the presence of aeration stones exists. This is another reason for holding off the rapper system on some jobs until a certain amount of fly ash has been collected.
- If large amounts of soot are collected on the plates, high spark rates could occur for several days. This happens because the soot will tend to create many sharp points and edges on the collecting surface that will control the spark-over voltage. When combustion is a problem, it is best to energize the center or inlet fields only in order to minimize the collecting surface that is coated with the oil ash, and then deenergize these sections once the boiler is at 1/4 to 1/2 load to allow the plates to be cleaned more quickly.
- Regardless of what start up procedure is used, the TRs should be started one at a time on a low setting and watched for at least a 1/2 minute before moving to the next control panel. It is best to limit the controls at 250 V until about 1/2 the rated process operation is attained, then swing all controls on automatic or normal power settings.

Checklist and Map

Do not rely on memory. Bring a checklist, which can also be used to record observations. One such list is included in Table 3-12. Another aid to the inspection is a map or cell diagram of the internals, such as that illustrated in Figure 3-29. *Be sure the map is accurate and includes all areas to be inspected.* This map can be used to mark areas of poor electrical clearance, general alignment clearances, build-up thicknesses on the electrodes, corrosion damage, bowed or damaged components, missing wires, or any other items that will require repair or replacement. Such a pre-prepared map allows the inspector to quickly and accurately note problem areas, rather than spend inspection time developing a sketch. Moreover, having problem areas marked on a graphical layout of the ESP makes it easier to envision and plan the repair work. It also serves as a permanent record and can make it easier to detect any patterns to problems by examining the maps from successive internal inspections.

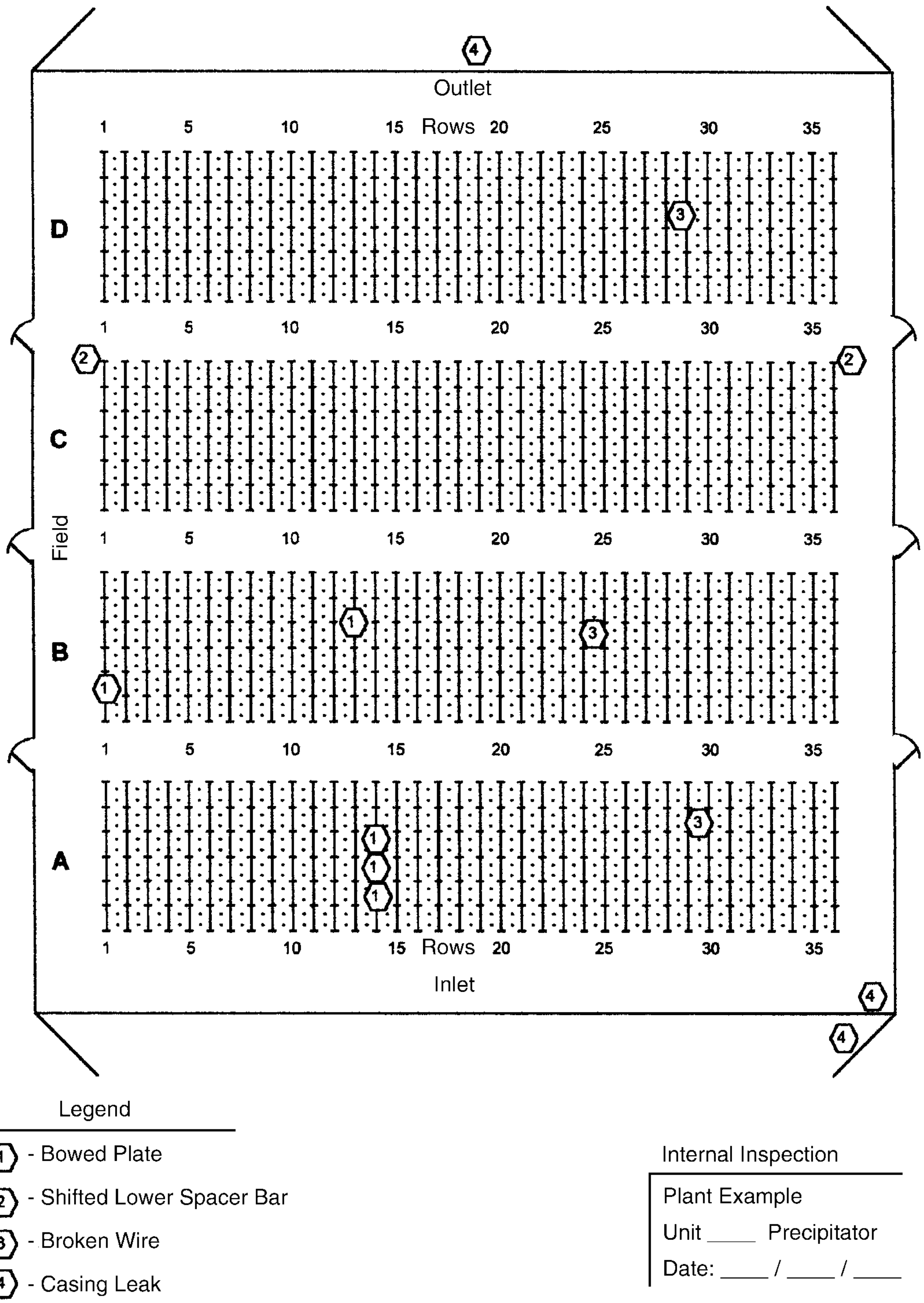


Figure 3-29
Diagram of ESP for Inspection Use

Table 3-12
General ESP Inspection Area Checklist

Area for Inspection	Inspected	Notes
Weather Enclosure (Rooftop)		
Insulator compartments		
Bus ducts		
Switcher/jumpers		
Support insulators		
Support insulator sweep vents		
Set-off insulators		
Heaters		
Penthouse		
Bus conductors (high voltage)		
Clearances		
Overall cleanliness (no fly ash)		
TRs		
Casing		
Fluid level/leaks		
Rappers and Vibrators		
Mounting		
Energy transmission shafts		
Ground connections		
Interlock System		
Keys accessible		
Locking mechanisms		

Table 3-12 (cont.)
General ESP Inspection Area Checklist

Area for Inspection	Inspected	Notes
Inspection Doors		
Corrosion		
Latch mechanisms		
Key interlock switch		
Gaskets		
ESP Internals		
Structural corrosion		
Structural cracking		
Rapper connections		
Wire support frames		
Plate support beams		
Missing bolts/broken welds		
Plate (top)		
Connections		
Tears		
Wires (top)		
Loose or damaged connections		
Broken/missing		
Rigid discharge electrodes		
Loose connection		
Bent		
Alignment		
Plate to wire clearance		
Wire frame to casing (ground) clearance		

Table 3-12 (cont.)
General ESP Inspection Area Checklist

Area for Inspection	Inspected	Notes
Casing		
Cracks		
Tears		
Warped (deformed but not torn yet)		
Lower Walkway Access		
Access doors		
Sealing		
Corrosion		
Door seal integrity		
Plates		
Warped		
Alignment frame		
Anti-sway connection		
Wires		
Weights for each wire		
Alignment frame		
Anti-sway insulator		
Clearance between wires and plates		
Clearance between wire frame and casing (ground)		
Rappers		
Excessive wear		
Missing hammers		
Ash buildup		

Table 3-12 (cont.)
General ESP Inspection Area Checklist

Area for Inspection	Inspected	Notes
External		
Holes		
Latching system on doors		
Pass-through boots/insulators		
Hopper vibrators		
Ash valves		
Leakage		
Proper function		
Ductwork		
Expansion joints		
Holes		
Ash buildup		
Corrosion		
Flow distribution vanes		

3.3.2 Conduct Dirty Air-Load Test

Before opening up the ESP for inspection, it is useful to run a *dirty* air-load test. Similar to the gas-load test described in Section 3.2.5.2, this test generates V-I curves that provide insight into the precipitator's electrical operation and mechanical integrity, and can indicate problem areas warranting special attention during inspection.

3.3.2.1 Procedure for Air-load Test

The procedures for this test are the same as for the gas-load test described in Section 3.2.5.2, except that the unit is off-line with ambient air rather than flue gas flowing through the ESP. The test is conducted with either the natural draft of the chimney or the induced draft fans operating at a low power level (keep it low to avoid disturbing ash deposits). Airflow is necessary to purge any ozone generated by the corona process out of the ESP system to minimize its effect on the electrical conduction characteristics of the air in the inter-electrode space. Airflow is also necessary to avoid ion formation in the air stream. Such ionization causes sparking during the power-up cycle at a lower level than normal. This early sparking could give a false indication of poor electrical clearances or regions of excessive ash buildup that do not actually exist. As in the gas-load test, it is important to begin obtaining data at the outlet electrical fields, working back toward the inlet. This precaution ensures that ozone generated in the upstream fields does not influence measurements in the subsequent fields.

Although the procedures for air-load and gas-load tests are the same, the expected *end-of-test* limitation is different. A gas-load test typically terminates in sparking or back corona. Air-load curves will seldom terminate in sparking unless misalignment is present. They usually reach the power supply current limit, typically almost 100 $\mu A/ft^2$ (108 nA/cm^2) of collecting surface.

A notable exception can occur with certain very-high-resistivity ashes, such as Powder River Basin ashes, in very dry climates; in this case, the resistivity is high at ambient temperatures, causing either sparking or back corona. For such ashes in such climates, a dirty air-load test is inappropriate. If you begin conducting the test and get immediate sparking or back corona, this is probably the reason. (Severe misalignment could also be the cause, but that would have shown up in the gas-load test as well.) Simply record the onset of back corona, discontinue the test, and rely on the air-load V-I curves to be collected at startup.

In general, however, an ESP inlet field with plate spacing at 9 or 10 in. (229 or 254 mm) should withstand an applied secondary voltage of 42 to 48 kV before sparking begins. (Voltages for wider plate spacings should increase about proportionally to the plate spacing increase; thus 12 in. (305 mm) spacing would reach about 60 kV.)

If sparking commences before the current limit is reached (that is at a lower voltage than 42 to 48 kV for 9 to 10 in. [229 to 254 mm] plate spacing), mechanical damage may be indicated. Plates may be misaligned, or there may be protrusions from the collecting electrode, such as a plate clip that has become displaced, corrosion spots that create rough protrusions from the collecting electrodes, necked-down regions on the corona wire, or perhaps some welding rod tips that were left behind after a repair job. When sparking occurs in one or a few electrical sections at voltages significantly less than those on the other sections, this suggests a problem in those sections warranting inspection and repair.

Although it would be unusual for all sections to spark before reaching the current limit, there have been instances of this occurring in hot-side ESPs where the support structure has deformed because of localized overheating or marginal design of the original structure. If the support structure is permanently deformed, there is a chance that some or even all of the electrical sections will have regions of misalignment where the air-load V-I curves would exhibit sparking before reaching the current limit. Early sparking on all sections could also indicate a malfunction of the power supply controls.

3.3.2.2 Interpretation of Air-Load V-I Curves

In an air-load test, there is no ESP activity to alter the space charge between fields. Thus, there should be no systematic shift between curves from one field to the next, as in Figure 3-25. Rather, V-j curves from all fields should match fairly closely, as in Figure 3-30. Otherwise, interpretation of air-load curves is the same as discussed for gas-load curves in Section 3.2.5.2.

The air-load test can help isolate the cause of a malfunction. For example, if the gas-load V-I curves indicate plate misalignment, but the air-load V-I curves are normal, which would indicate a *live* misalignment (that is a warpage or other problem that [so far] is manifest only at operating temperatures, such as would be caused by a plate constrained from expansion. Similarly, discrepancies between dirty air-load V-I curves and clean air-load V-I curves can indicate the contribution of ash buildup to the problem (that is a problem with electrical tracking on insulators). If you were not able to run a gas-load test due to regulator restrictions, the dirty air-load test will be your only source of V-I data regarding ash-induced problems.

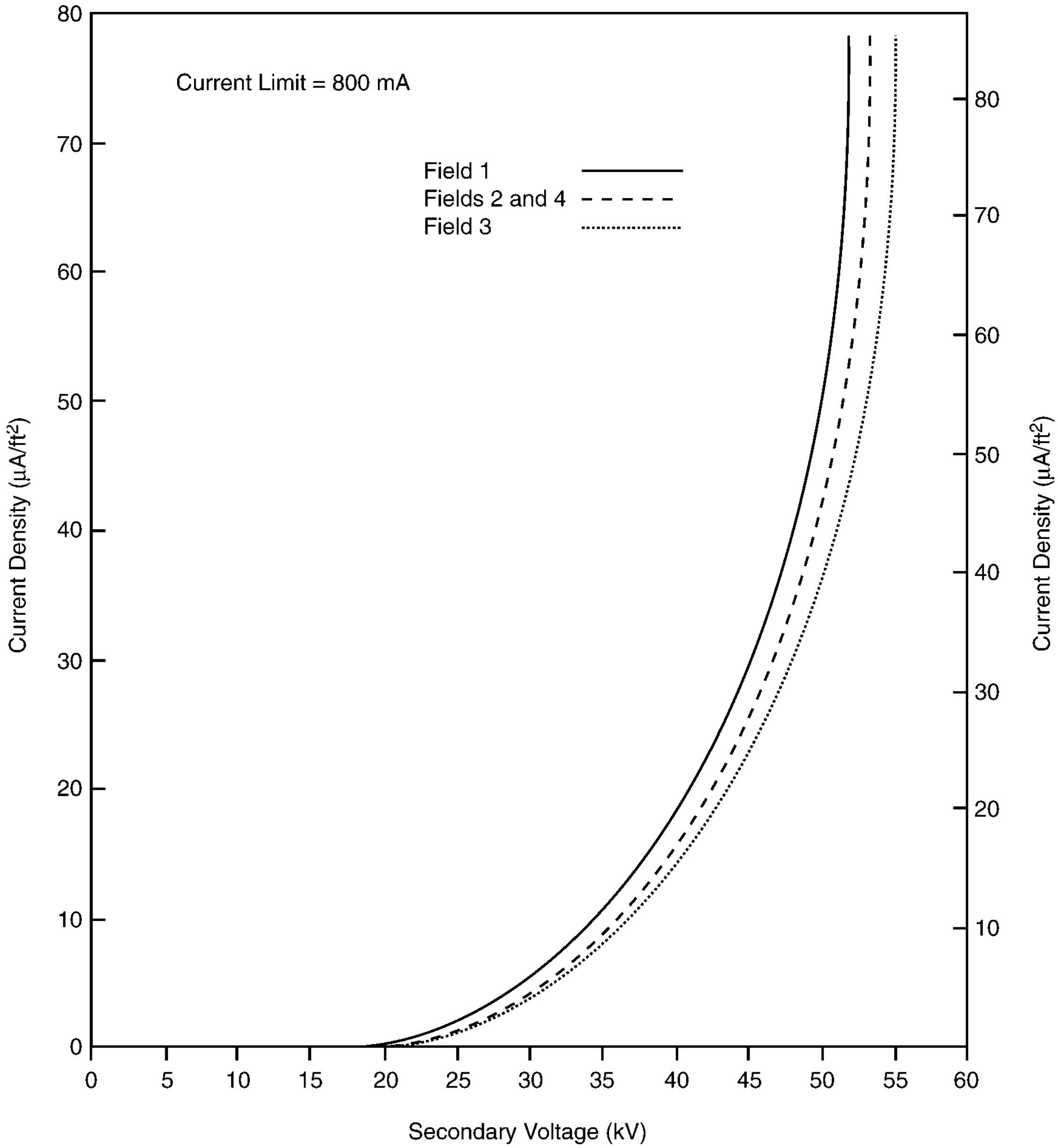


Figure 3-30
Normal Air-Load V-j Curves from a Healthy ESP

3.3.3 Conduct Dirty Inspection

The *dirty* inspection provides, as closely as possible, a view of the ESP internals in their operating condition. The inspection reveals patterns of ash buildup, which provide insight into gas-flow distribution and rapping adequacy. This initial visual inspection will also reveal much of the mechanical damage that may exist. Obvious mechanical damage (that is broken wires or severely warped plates) will also be evident at this stage and should be noted. However, if the unit is being cleaned, the clean inspection will allow a detailed mechanical inspection and the focus of the dirty inspection should just be to determine ash build-up levels.

3.3.3.1 Plates, Discharge Electrodes, and Other Main Structures

The first step is to inspect the plates, electrodes, struts, vanes, baffles, and gas distribution devices for ash buildup to ascertain if there are any problems with gas flow or rapping. Consequently, the inspector must exercise great caution while moving throughout the ESP to avoid inadvertently disturbing the ash deposits (as well as for safety reasons). The level of ash buildup on the collecting plates and discharge electrodes will give an idea of the success of the collecting system in capturing the ash evenly and from the proper place in the ESP internals. For example, if there is excessive ash on the plate area directly across from the discharge electrode and none in the plate areas between electrodes, there may be an electrical field problem due to poor electrode clearances or the particular design of the discharge or collecting electrode.

The ash layer should generally be about 0.125 to 0.500 in. (3.2 to 12.7 mm) thick; a layer more than about 0.500 in. (12.7 mm) deep is probably excessive, but some units have operated with 1.00 in. (25.4 mm) of buildup if resistivity levels are low. The absence of ash buildup and possible scouring of the steel indicate areas of high gas flow. The leading edges of turning vanes and internal struts for duct supports are the areas most prone to scouring. Ash buildup may be excessive in areas of low gas flow; most likely to occur in corners and behind turning vanes. Blockage of flow control devices may be caused by acid or moisture condensation as a result of a process upset, air in-leakage, or insulation failure.

When an area of high or low gas flow is encountered, judge whether the evidence signifies a problem that should be reviewed and resolved, or if the distribution is as expected and does not warrant change. Bare in mind that ash buildup can change the gas-flow path in a downstream area. This is especially true if upstream capture devices, such as mechanical collectors or air heater and economizer hoppers, have been taken out of service. When vanes and other distribution devices become partially or totally plugged by fly ash, the flow pattern changes from the design distribution, which if modeled was under clean conditions, and the new gas-flow distribution may be very undesirable. The dirty inspection should note these areas. (Bear in mind that a dirty inspection is not a definitive check on gas flow. The gas velocity distribution can be far outside a good range without being evident in an inspection.

3.3.3.2 Ash Hoppers

Hoppers should be emptied before the dirty inspection. Leaving the hoppers full of ash endangers the inspection personnel, who could be burned or otherwise injured. Corrosion may also occur as the ash cools. Moreover, little can be learned from a full hopper. (The one exception is that flow patterns in the deposited ash can indicate malfunctioning hopper baffles; however, this evidence of mal-distribution is often obscured by ash falling from the other internals as the ESP is shut down.)

If, after supposedly emptying, there is still ash in the hopper, clearly there is a problem with the ash removal system. Note the problem and then manually empty the hopper and continue the inspection. Guidance on repairing ash removal systems is provided by an earlier EPRI technical report:

In-Plant Ash-Handling Reference Manual, EPRI, Palo Alto, CA: CS-4880. Now Out of Print.

Unusual buildup in the hopper corners or other trouble spots will still be evident after hopper evacuation. Ash caking and *wind trails* on the ash can indicate cracking and air in-leakage. Pay special attention to hopper valleys and upper flanges, as these are areas of great structural stress concentration, especially in hot-side precipitators.

3.3.3.3 High-Voltage Support Insulators

The H-V electrical support insulators should be inspected for evidence of electrical tracking, ash buildup, or cracks. Tracking can cause support insulator failure by concentrating excessively high temperatures on the surface. Ash buildup on the insulators can allow the tracking to occur during operation if the dew point temperature is sufficiently high.

There will normally be a small amount of dry ash on the surface of the insulators unless they have been recently cleaned. However, the ash layer should be thin and regular in appearance. If the ash contains a significant amount of carbon (that is it appears blacker than the rest of the ash) or if the ash is wet from either moisture or acid condensation, the problem must be investigated and corrected. Check for air in-leakage and problems with the insulator heaters. Deposits of high-carbon ash or moist ash will lead to insulator failure and poor ESP performance.

3.3.3.4 Inlet and Outlet Ducts

Inspect these components to determine the gas-flow and ash build-up patterns. Excessive buildup in a particular area indicates a low flow, and distribution devices should be assessed for effectiveness. The biggest problem with fly ash buildup in corners is that it provides a medium for moisture collection and a place for corrosion, which cannot easily be seen in a visual inspection.

3.3.3.5 Discharge Rapping and Rapping Force

As discussed in Section 3.2, almost all aspects of the rapping system can be assessed while the unit is on-line. The exceptions are discharge rapping performance and transmission of rapping force, which should be checked during the dirty inspection.

Discharge Rapping

Rapping adequacy cannot be easily determined by visual inspection, as the electrodes will often appear fairly dirty. For rigid electrodes, only the discharge tips need to be clean. Of course, if the tips are not free of ash, then rapping frequency and/or intensity should be increased. However, do not rely solely on visual inspection. Determine acceptable cleanliness by evaluating the V-I curves and meter readings taken under both dirty and clean air-load conditions during the shutdown.

Transmission of Rapping Force

To determine whether the force is being properly transmitted through the rappers to the plates and discharge electrodes, simply stand inside the ESP and observe each rapper in operation. Save this test until the end of the dirty inspection so as not to disturb the ash deposits before they have been examined.

If rapping causes the whole collecting plate (or discharge electrode) to shake and drop ash, rapping force is probably being transmitted effectively. If, on the other hand, the rappers seem to affect only a small area near the rapper attachment, there is likely a problem with force transmission. Turn up the rapping force (if possible). If rapping is still not effective at the outer edges of the plate (or discharge electrode), a problem with force transmission is indicated.

Key Technical Point

If rapping causes the whole collecting plate (or discharge electrode) to shake and drop ash, rapping force is probably being transmitted effectively. If, on the other hand, the rappers seem to affect only a small area near the rapper attachment, there is likely a problem with force transmission. Turn up the rapping force (if possible). If rapping is still not effective at the outer edges of the plate (or discharge electrode), a problem with force transmission is indicated.

When assessing rapping force, be aware that the rappers are not supposed to shake loose all the ash. It is normal for a small amount of ash to remain on the plates and wires in an adequately rapped ESP. It is not unusual for the ash to break off in patches: one rapper operation removes material primarily from one location while the next rap removes material from another. This type of removal pattern is normal. The material builds up to an appropriate thickness to break off, while in another region the layer is not yet thick enough.

3.3.4 Clean the ESP

The need to clean the ESP has been debated in the industry with the main concern being corrosion and cost. There are units that run well that have never been cleaned, and other units that are cleaned or need to be cleaned every outage. The ESP may need to be cleaned if there is a high arsenic level in the ash, if extensive work (such as a wire change-out or extensive repairs are planned), if there is some problem with the ash chemistry that is effecting performance (such as sodium depletion), if there are high sulfur levels that will cause corrosion during extended outages and/or if the unit is extremely dirty. This cleaning can be accomplished by dry blasting with sand, mill slag, or grain; by water washing; or air lancing. After cleaning the internals, clean the inlet and outlet ducts as well, either by vacuuming or shoveling.

Be careful during cleaning because there is a possibility of creating an opacity violation. The natural draft of the stack will carry some of the ash liberated during the cleaning process up and out of the chimney. This problem is more likely when removing the ash with a dry process.

Key Human Performance Point

Be careful during cleaning because there is a possibility of creating an opacity violation. The natural draft of the stack will carry some of the ash liberated during the cleaning process up and out of the chimney. This problem is more likely when removing the ash with a dry process.

3.3.4.1 Dry Blasting

The blast operation should begin at the top of the ESP and proceed to the lower parts in a field-by-field manner. Blasting should also include the inside of the high-voltage support insulators. After cleaning, the ash removal system can be used to empty the ash and blast material out of the hoppers for disposal either in the landfill or into trucks for transport to a suitable disposal area.

Dry blasting has several advantages over a wet wash:

- Blasting is not hampered by freezing weather, as is water washing.
- It does not introduce water into the ESP that could cause the ash to cake and stick.
- Special handling of the waste is not required.

However, blasting has its disadvantages:

- The effectiveness of blasting is velocity dependent: that is cleaning is limited to the maximum throw distance of the medium. Complete cleaning is often not possible on large precipitators or on units with limited access.
- During the cleaning process, operator visibility is extremely limited. It is likely that the operator would inadvertently dwell in an area, which could cause localized electrode damage. Using grain can mitigate this problem. Grain is softer than sand and unlikely to damage the electrodes and structural supports. Note that blasting with grain may take longer due the softness of the blast material.

- Suspension of ash in the air exiting up the stack (and the concomitant potential for an opacity violation) is much more likely with dry blasting than with a wet wash.
- While effective for restoring performance hindered by ash deposition, blasting may not get the ESP clean enough for a thorough mechanical inspection. Residual electrical and van der Waals forces can attract dust from the air after cleaning, requiring the inspector to wipe off surfaces for proper inspection.

3.3.4.2 Water Wash

An alternative to a blast cleaning is to wash the ESP internals with water. This either entails the use of multiple high-volume, high-pressure water hoses or the installation of a permanent wash header. Use plenty of water to avoid ash caking. Once this effort has started, there should be no interruptions of the cleaning, especially in the presence of high-calcium ashes. The pozzolanic activity in high-calcium ashes can cause the formation of cement-like substances that are very difficult to remove. Use of high water volume should minimize this problem because large quantities of water will dilute the mixture sufficiently to avoid setting-up the material.

The advantages of water washing are as follows:

- A more thorough cleaning is possible, because reach is not limited to throw distance.
- It can be done quickly by few personnel. Because reach is not limited to throw distance, most units can be completely washed from the top elevation.
- There is less airborne ash, and thus less likelihood of a cleaning-induced opacity violation.

But water washing also has its disadvantages:

- The ambient temperature must be above freezing.
- A sluicing system is necessary for drainage and disposal.
- It can cause corrosion damage if the ESP is not washed completely and allowed to dry.

3.3.5 Conduct Clean Air-load Test

The clean air-load test can be performed either before or after the clean visual inspection, although conducting the test beforehand on large units (when outage time is limited) offers the advantage of alerting the inspection team to the locations of specific problems. Follow the same procedure as for the dirty air-load test.

V-I curves or power readings obtained from a clean air-load test are the most reliable indicators of permanent (*dead*) alignment problems. Compare your results to readings from previous air-load tests, starting with the original air-load curves from ESP commissioning. Also, compare test data to gas-load and dirty air-load data, to help isolate the cause of the problem(s).

3.3.6 Conduct Clean Inspection

Table 3-12, found earlier in this chapter, provides a checklist of areas to be inspected. Note that this list is meant as an illustrative starting point for inspection and repair records. If you know any other potential problem areas (for example, holes that were deliberately drilled for observation) add them to the list. Figure 3-31 shows a sample inspection report including photographs of ESP internals.

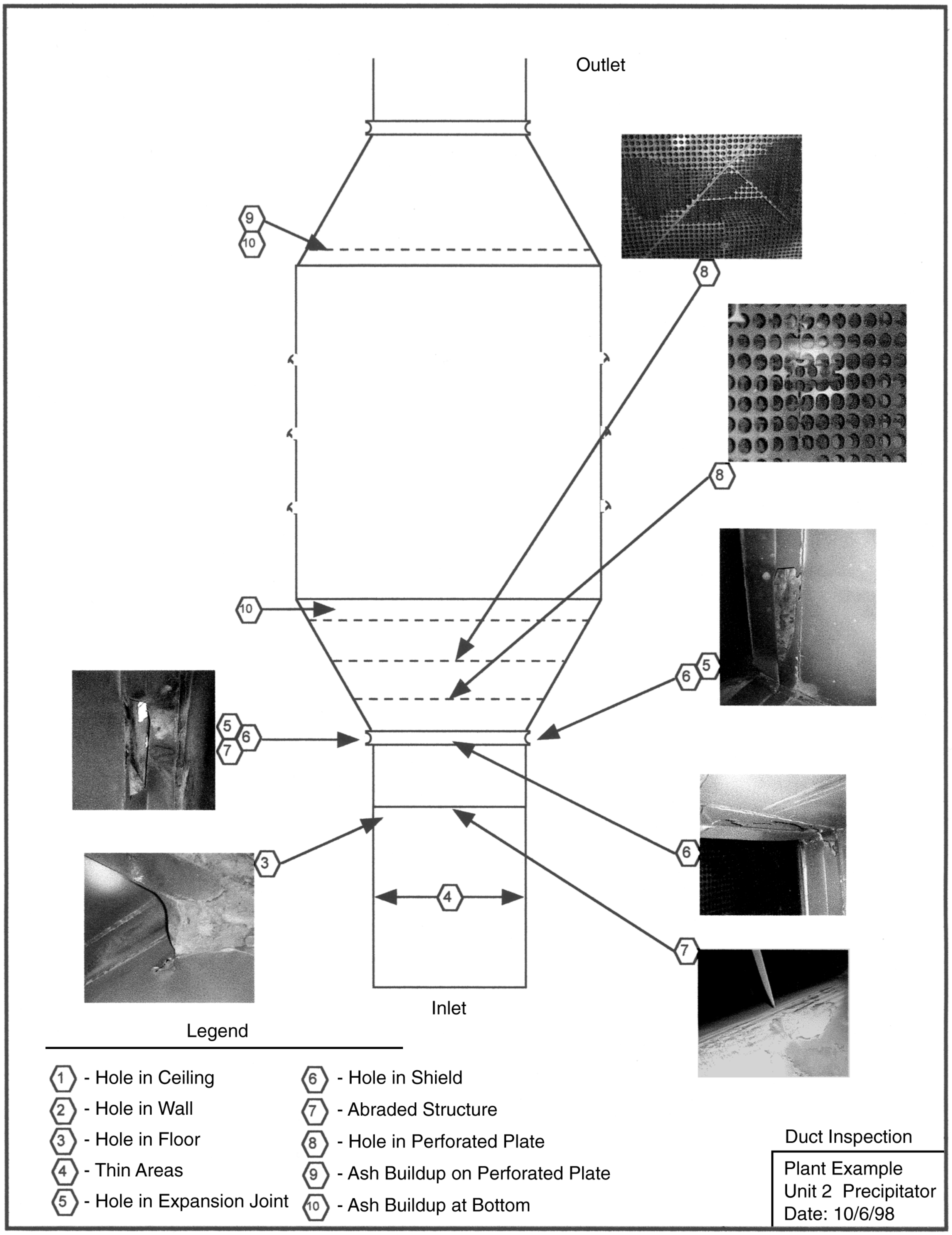


Figure 3-31
Example of an Inspection Report with Photographs

3.3.6.1 Collecting and Discharge Electrodes

Fundamental to ESP performance, the collecting plates and discharge electrodes are critical components to examine during the clean inspection. The air-load readings should alert inspectors to areas likely to present problems.

Check Alignment

Proper alignment and clearance of these components is crucial to ESP performance. Use a ruler or template to evaluate all clearances between plates and electrodes, plates and frames, electrodes and the casing, and high-voltage busses and the casing. Alignment within 0.25 in. (6.45 mm) is desirable; for a unit with 9 or 10 in. (229 to 254 mm) plate spacing, misalignment by more than 0.50 in. (12.7 mm) warrants correction. Pay special attention to areas exhibiting unusually high or low ash deposits in the dirty inspection; poor clearances could be the cause.

Most personnel performing precipitator inspections are accustomed to looking for misalignment *across* the direction of the gas flow. However, it is also important to look for misalignment occurring in the direction of the gas flow, often called longitudinal misalignment. Areas with improper clearances should be marked directly on the component and on a map of the internals.

Key Human Performance Point

Most personnel performing precipitator inspections are accustomed to looking for misalignment *across* the direction of the gas flow. However, it is also important to look for misalignment occurring in the direction of the gas flow, often called longitudinal misalignment.

Measure Plate Thickness

A precipitator's life expectancy is limited by its collecting plates, which degrade over time. Take this opportunity to measure plate thicknesses. By plotting plate thicknesses over periodic inspections, usually annually, you can predict the unit's expected service life. Be sure to take multiple measurements at the bottom elevation of the outlet, as plate wastage usually begins here. Also pay special attention to any areas that appeared *scoured* during the dirty inspection. Make sure there is enough material left intact for the component to work properly.

Inspect Discharge Electrodes

In weighted-wire ESPs, it is not uncommon to find wires broken or missing. Locations of failed and missing wires should be documented. The location of wire failure should also be recorded. Efforts should be made to try to determine the cause of failure and if possible, correct the condition causing the failure. Failed discharge electrode wires need to be removed. There is some debate over replacing failed wire electrodes. It is not a clear-cut issue. Some suggest that broken or missing weighted wire electrodes should be replaced unless a pattern of consistent failure at a single location is identified. The authors of this guide argue that, in general, a failed or missing wire electrode should not be replaced, unless the source of failure has been identified and eliminated and the entire bus section of wires is being replaced. A new wire, installed in place of the failed wire, will likely fail again if the cause of failure has not been removed. Additionally, a new wire, installed in place of the failed wire, may exhibit different electrical characteristics when energized than the other wires in the same bus section that have been in operation for an extended period of time. Wear will have reduced the diameter of the failed wire or dulled the corona emitters on a barbed type wire. Since all the wires in the same bus section are energized by the same power source, replacement with a new wire can adversely influence the overall power to that section especially if the cause of the failure has not been corrected. A small number of randomly missing electrodes, less than 5-10% of the total, will not adversely affect the performance of the ESP. The larger the specific collecting area (SCA) of an ESP, the more randomly located wires that can be removed with impunity.

Key Technical Point

In weighted-wire ESPs, it is not uncommon to find wires broken or missing. Locations of failed and missing wires should be documented. The location of wire failure should also be recorded. Efforts should be made to try to determine the cause of failure and if possible, correct the condition causing the failure. Failed discharge electrode wires need to be removed.

For electrodes with a frame, check the attachment integrity of the electrodes to the frames to determine if a problem is developing. Often this takes the form of spark erosion, whereby each spark vaporizes a small portion of the electrode, eventually causing failure. With rigid discharge electrodes, check the attachment shunt straps installed to avoid sparking at the point of support.

The suspension systems for the discharge electrodes often use support insulators to provide a stable position centering the electrodes between the collecting plates. Carefully check these insulators, as they can accumulate significant ash buildup that can cause electrical tracking and subsequent cracking. Damaged insulators can no longer maintain proper positioning of the discharge electrodes relative to plates and other parts, resulting in poor ESP performance.

The lower weight guide grid or electrode-restraining grid is often held in place by an anti-sway insulator that attaches to the hopper wall or to the collecting plates. The insulator maintains electrical isolation for the discharge electrodes and prevents the entire discharge electrode assembly from swaying due to either gas flow or electrical forces. This insulator should be inspected and cleaned each outage, and replaced if damaged or broken.

Rapper Attachments

Examine the rapper system for cracks, tears, rubbing, and leakage, paying special attention to penetrations of the casing by the rapper shafts, energy transmission shafts, and boots. Also pay special attention to the point where the rapper shafts connect to the discharge electrode frames or plate supports. Tears in the weld connection can occur when the rapper energy is greater than the connection was designed to accept. (Sometimes plant personnel misinterpret normal ash buildup as excessive, or decide there is insufficient energy in the rapper when the real problem is poor energy transmission. In either case, the subsequent decision to use a *bigger hammer* can lead to torn welds or broken attachments.)

Be sure to examine the connections of the energy transmission shafts and the couplings that transmit the rapper energy from the rapper to the collecting plate frames or discharge wire suspension system. These connections can become loose and, therefore, inefficient at energy transmission. When there are cracks in the coupling, the rapper energy is not fully transmitted. If the rapping energy is dissipated in the coupling, degradation (of the coupling and, eventually, of ESP performance) may result. The pieces may not fit properly, further exacerbating the poor energy transfer. Improper fit may be due to wear, the use of retrofit parts, or perhaps missing parts in the energy transmission system. Because of this, there may be an inappropriate determination to replace the original rappers with bigger rappers that can cause breakage of the welds and other connections.

Casing and Structural Elements

Check the casing and internals for leakage, which can take the form of in- or out-leakage, depending on the operating pressure of the ESP. In the case of out-leakage, the cause is usually a structural failure resulting in the discharge of flue gas and ash into the surrounding area. Such leakage can cause secondary deterioration of lagging, rappers, and controls. Moreover, out-leakage of high concentrations of SO_2 poses a safety hazard to plant personnel.

Key Human Performance Point

In the case of out-leakage, the cause is usually a structural failure resulting in the discharge of flue gas and ash into the surrounding area. Such leakage can cause secondary deterioration of lagging, rappers, and controls. Moreover, out-leakage of high concentrations of SO_2 poses a safety hazard to plant personnel.

In-leakage can occur with just air or a combination of air and water. Both are detrimental to precipitator operation and reliability. Air in-leakage, if in sufficient volume, can cause corrosion that takes years of service from the life of downstream internals in a period of weeks. In-leakage near the bottom of an ESP poses added potential for problems because air flow into the ESP casing near the collected ash can reentrain some of that ash, thereby increasing emissions as well as causing ash caking from moisture condensation. Water (primarily rainwater) in-leakage can plug hoppers, thus resulting in electrical shorts if the discharge electrodes contact overflowing ash, plus accelerated corrosion even more severe than that caused by air in-leakage.

Key Technical Point

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Conduct a detailed inspection of all areas prone to leakage. As needed, clean off any remaining ash residue to get a clear view of component surfaces.

Be sure to include the following:

- **Access doors -** When properly fitted and maintained, the gaskets sealing the access doors in the ductwork and casing will not allow air leakage. If the doors are not properly sealed, air in-leakage can cause cold spots, with consequent condensation and eventual corrosion. The problem self-perpetuates as damage increases with time, causing the holes to get larger and thereby allowing more leakage. Eventually, leakage increases to the point that the gas distribution in the ESP is affected. The capability of the I.D. fans to draw the flue gas through the ESP may also become a problem, resulting in unit de-rating. (Obviously a de-rate would occur only after a long time, but there have been door seal leaks which eventually formed holes about a square foot, or 0.1 m^2, in size!) Carefully examine the door seal as you close up the ESP after inspections or maintenance. Extra care as the doors are closed can minimize repair costs in the future.
- **Corners near the inlet mouthpiece and outlet nozzles -** These are prone to cracking and tears.
- **Vertical columns, horizontal beams, turning vanes (that is any structural element completely immersed in flue gas) -** These are particularly prone to cause punctures in the adjoining casing. This is because these members expand and contract with temperature changes at a faster rate than the exterior casing. This relative movement pushes against the casing wall like a piston until the wall finally yields.
- **Support stanchions, walkway anchors, conduit struts, and other casing attachments -** These are heat sinks that produce a relatively cold spot on the interior of the casing wall. If conditions favor acid condensation, these areas will become perforated in time, allowing flue gas to escape or air and rainwater to leak in.

- **Slide plates on the stub columns -** If the plates do not move as they should (that is because of grit in the sliding area or retainer [guide] bars not functioning properly), the seal welds at the hopper attachment areas can tear.
- **Intentional holes or pass throughs such as those for opacity meters or sampling ports -** Make sure that seals are in good condition and there is no corrosion of the surrounding casing.

One source of intentional air in-leakage is through the high-voltage support insulators. Ideally, each insulator should be equipped with a heated purge/ventilation system to minimize ash and highly conductive carbon buildup on these insulators, thereby preventing electrical tracking and subsequent cracking. Such a system features holes in the insulator cap that allow ambient air to enter, become warmed, and purge the ash deposits. (Note that the heater-only systems installed on some ESPs provide only minimum protection against condensation and are ineffective against high concentrations of unburned carbon.)

Carefully check the insulator holes for corrosion or blockage. Cold air entering through the purge system sometimes results in secondary corrosion of the insulator compartment floor (where applicable) and the support shafts. Personnel entering the crawl space area (if equipped) could be injured if the upper frame should collapse as a result of deteriorated support shafts. As a rule, natural-draft purge systems should be replaced with forced-draft combination heat and purge systems whenever possible.

Ash Handling System

In addition to checking for cracking, carefully inspect the valves and connections that attach each hopper to the ash removal system. In a pressurized systems, poor valve seals can allows the transport air to enter the hopper causing an increase in emissions by entrainment of hopper ash. Poor sealing of the hopper valves also degrades the performance of the ash removal system. Pay particular attention to these areas during inspection.

Ductwork

The entire ductwork system should be inspected as well. Examine the corners, seams, and access doors for tears and corrosion, especially if there was a significant ash buildup in the area. Loose or damaged turning vanes, expansion joints at inlet and outlet flanges, and connections should be noted so appropriate repairs can be made.

Also check for holes in the ductwork. In many instances, leaks in ducts and expansion joints can be determined from an external inspection of the duct while the unit is in service. However, some holes may be too small to be visible from the outside or may be blocked by insulation and lagging on the ducts. These holes can usually be detected from the interior of the duct by turning off all the lights inside and observing the entry of sunlight. It is also helpful to check the ducts for water leakage if it happens to rain during the outage.

4
ESP COMPONENTS

In this section the components of the precipitator are discussed in detail, describing their function, maintenance requirements, operating procedures, and safety considerations. Also discussed, as applicable, are inspections, operating evaluations, typical problems and modes of failure, troubleshooting and repair methodology, recommended spare parts, upgrade options, performance enhancements, and tips. The intent of this section is to provide maintenance personnel with quick and easy reference to information on the maintenance requirements of the individual components of the precipitator system.

4.1 Controls and Instrumentation

4.1.1 Transformer Rectifiers

The ESP's performance is directly related to the operating voltages in the system and the Transformer Rectifier (TR) is the key system component providing the high voltage dc power (voltage and current) directly to the discharge electrodes. TRs, used on ESPs, are uniquely designed to operate at both high voltage and under relatively high sparking conditions. Generally, these devices will provide at least 20 years of reliable service. The standard power supplies are designed to operate with an incoming voltage ranging from 220 to 600 volts, single phase, at either 50 or 60 Hz. The secondary outputs of these power supplies are typically designed to provide voltages ranging from 35,000 to 75,000 volts dc. The output can be positive or negative, but normally negative has proven to be the best polarity to collect fly ash. The amount of electrical current is determined by the collecting field size and the loading of the precipitator. The typical output currents for TRs can be as low as 100 mAdc to as high as 3500 mAdc.

Throughout the developmental history of ESPs, the ESP's design and performance has been limited by the rating and design of the power supplies and voltage controllers. As the TRs design improved and higher voltages were achievable, the ESP designs evolved to utilize the high voltages by increasing the collecting plate-to-discharge electrode spacing. The TR is the most expensive single piece of equipment used on the ESPs and also the most dangerous to personal safety. This section of the manual will cover the proper procedures for installation, operation, maintenance, and troubleshooting of a TR set.

Key O&M Cost Point

The TR is the most expensive single piece of equipment used on the ESPs and also the most dangerous to personal safety.

4.1.1.1 Equipment Protection

To prevent damage of the equipment, the following items should be noted. More concerns are discussed later in this section.

- At no time during normal operations should the TR be operated in an open condition. Without a connected load, voltages can exceed the TR's rating causing a failure and potentially, an explosion. This is especially true on systems with no kV feedback voltage or when manually operating. (The exception to operating the TR open circuited would be during specific testing and even then it should only be done for a short period of time, less than a minute.)
- The bus connection to the ESP field should be disconnected when there is welding work being done inside the ESP. The welding current can feed back through the TR switch and into the diodes, damaging the switch and the TR internals.
- The TR switch should never be moved while the TR is in service. The resulting arc can damage the TR components and contaminate the oil on internally switched units.

4.1.1.2 Safety Concerns

The most important issue governing the content of the procedures described in this manual is the safety of the equipment installers and operators. It is critically important that these procedures be carefully followed. TR sets contains dangerous and potentially lethal voltage levels. The general instructions listed below should be followed for a safe work environment. There may also be additional safety concerns that are specific to your site.

- Do not attempt to service the device while it is powered up or operating.
- Turn off the power to the unit. Carefully follow the grounding procedures described within this manual and the manual provided with your equipment before doing any physical or electrical work on the unit.
- Take precautions against shock or electrocution.
- Do not stand in water or on damp surfaces while working on the unit.
- To reduce the risk of electrical shock, carefully follow the instructions within this manual. Only authorized and trained personnel should open, operate, or maintain this equipment.

4.1.1.3 Equipment Evolution

Historically, the rating and design of the power supply and voltage controllers have limited the design and performance of the ESP. As the TR designs improved and higher voltages and current levels were achievable, the ESP design evolved to utilize the higher voltages and currents by increasing the collecting plate spacing, increasing the total collecting area connected to one TR, and with modifications to the discharge electrode geometry.

4.1.1.3.1 Mechanical Rectifiers

Mechanical rectification was the first option available for converting alternating current (ac) to direct current (dc). Mechanical rectifiers function through the use of multiple switches that are opened and closed to alter the electric path of the electric current. For 60 cycle power, the switch-over must be made twice for each cycle, resulting in a switching rate of 120 times per second. The implementation of mechanical rectifiers was accomplished through the use of multiple rotating arms that made and broke connections to a series of contacts around the perimeter of the arc of the arm. Since the rectification on ESPs must be done on the HV side, voltages as high as 40,000 volts were across the contacts. The rotating arms were driven by a motor/gear system that caused rotation that was synchronized to the line frequency. As the arms rotated across the contacts, a great amount of arcing and heat was generated, thus causing extreme wear and deterioration of the contacts. Mechanical rectifiers were referred to as *whirling dervishes* because of the extreme high maintenance required to keep them online and for the dramatic display of sparks that they provided.

4.1.1.3.2 Tube Rectifiers

Vacuum tube rectifiers were a breakthrough that permitted dc electrostatic precipitation to become more practical. The tubes are fairly large because of the high voltages needed and were typically glass enclosures. Tube rectifiers consist of a filament heater element, a cathode, and a plate, all encased in a vacuum vessel. The heated cathode, together with high voltage between the cathode and plate, permit electric current to flow in one direction while effectively blocking flow in the opposite direction. The tube rectifiers offered a quantum improvement in reliability and practicality over mechanical rectifiers. The tube disadvantage as compared to solid-state rectification is the relatively high cost, limited life cycle, and excessive heat created by the filament.

4.1.1.3.3 Solid State Rectifiers

Modern precipitator TRs use silicon diodes for rectification of the HV output of the step-up transformer. Silicon rectifiers are made of extremely high purity silicon that is *doped* to form a p-n junction. This junction permits current flow in one direction while blocking current in the reverse direction. Silicon junctions can typically be manufactured to withstand from 1,000 to 10,000 volts. Higher voltages, such as required for precipitators are accommodated through the use of a series string of diodes to withstand higher voltages: up to 150,000 to 200,000 volts.

Early technology diodes, and to a lesser degree modern diodes, have a wide tolerance on the amount of current that they allow under reverse or blocking condition (leakage current). This variation causes an uneven distribution of reverse voltage across individual diodes under blocking conditions and could result in a *domino effect* failure. To overcome this problem, early rectifier systems used mega-ohm resisters and capacitor wires across each diode to force the blocking voltage to be more evenly shared by the series string of diodes. Most modern systems use controlled avalanche diodes in the rectifier stack. These diodes are manufactured such that the *breakdown* voltage is consistent and predictable, and thus eliminates the need for the shunt resistors and capacitors.

4.1.1.4 Power Supply Components

The power supply consists of a single-phase, HV transformer, HV rectifier bridge, air core reactor, and a voltage divider. These components are all contained in a tank filled with dielectric coolant fluid. Optionally, the unit may include a current limiting reactor internal to the tank, and internal or external switches.

The tank is sealed and suitable for outdoor use. If the unit is to be installed outdoors, a bus duct must enclose the HV bushing. If installed indoors, the TR may use a HV cable connection or HV bus shielded by protective screening. The low voltage junction box on the side of the tank contains the input power terminals, feedback and metering terminals, and contacts from any gauges.

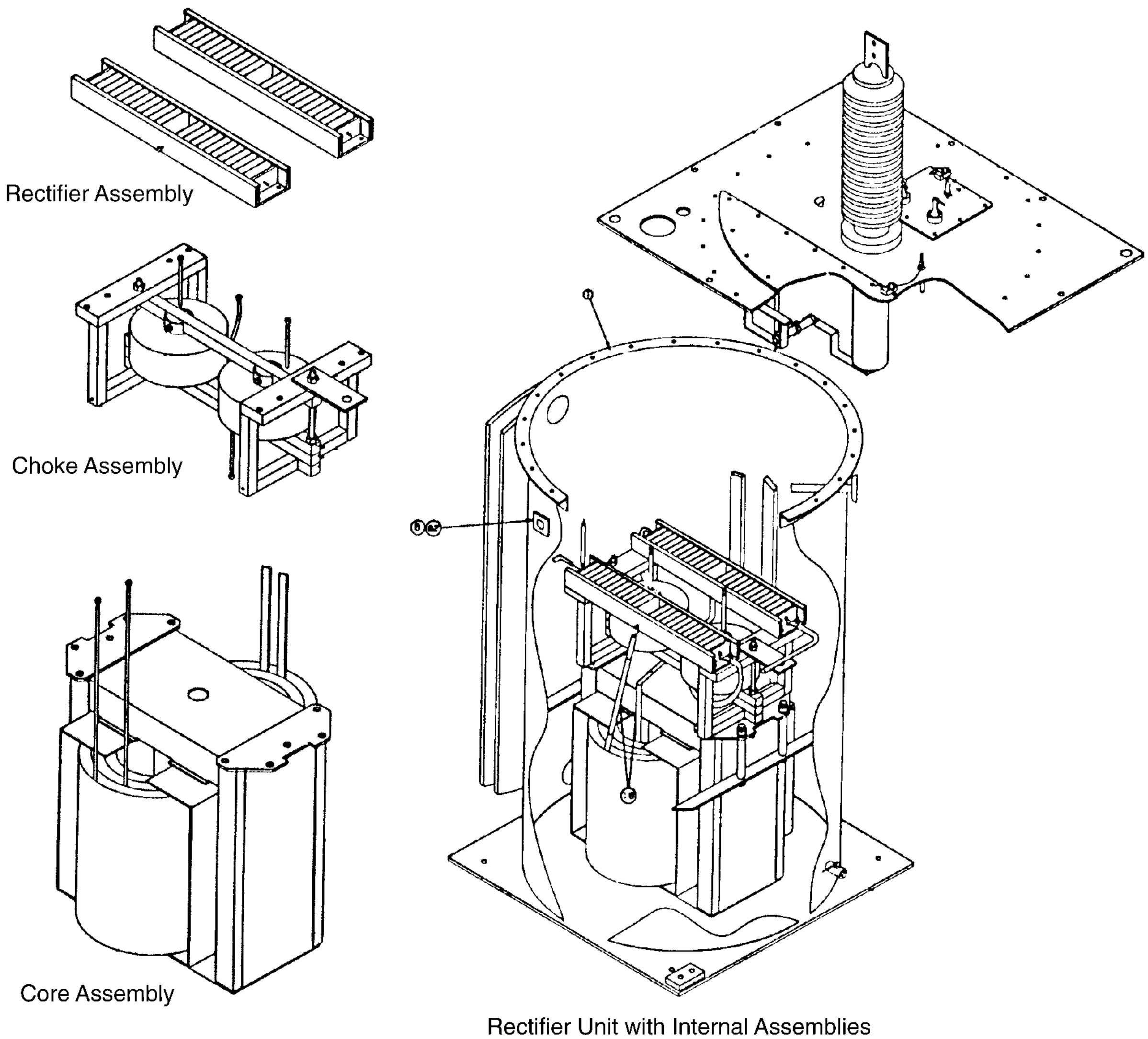

Figure 4-1
Typical Exploded View of a Single Bushing General Electric TR

4.1.1.4.1 Main Components

Main Transformer

The function of this magnetic component is to step up the incoming primary voltage to the higher levels required for ESP operation. The transformer coils are solidly braced to withstand the forces created during arcing of the load. The transformer is located in the bottom of the tank.

Rectifier Bridge

A full wave, single-phase, HV rectifier bridge is connected across the secondary of the transformer.

Air Core Reactor

An air core reactor (ACR) is in series electrically with the HV, dc output in order to limit high frequency current surges to the rectifier generated during sparking in the precipitator field. The ACR will not limit 50/60 Hz load current.

Voltage Divider Network

A high resistance series network is connected between the HV, dc output and the HV metering terminal in the low voltage junction box. A surge suppressor, connected in parallel with an appropriate resistor, will provide an output voltage signal for monitoring. Voltage metering resistors may or may not be provided. If a resistor is not supplied, a shorting link will be installed in its place. Remove the shorting link after the resistor has been installed.

Connections to the TR Internal Components

All connections to the TR internal components are connected using either bolted connections or Amphenols for easy removal should this become necessary. Access to these components is through the handhole cover, located on the lid of the TR set.

Load Current Monitoring Network

The low potential end of the rectifier bridge is connected to a metering feedback terminal in the low voltage junction box. A surge suppressor needs to be connected in parallel with the properly sized resistor to provide a load current signal to monitor. Current metering resistors may or may not be provided. If a resistor is not supplied, a shorting link will be installed in its place. Remove the shorting link after the properly sized resistor has been installed.

4.1.1.4.2 Standard Accessories

The following items may be provided with each TR power supply. Refer to the specific electrical schematics for the exact details.

Surge Suppressors

Surge suppressors are mounted in the junction box and are connected between ground, the low potential terminal of the rectifier bridge, and the kV metering terminal of the voltage divider network. These prevent voltage on the metering terminals from exceeding a safe value if the metering circuits were to open. In some cases, a shunt resistor is mounted across the surge arrestor to provide addition personnel safety. These also are referred to as *lightning arrestors* and they will protect the TR in the event of a lightning strike. The TR should not be operated if the surge arrestors are not in service.

Temperature Gauge

A dial-type temperature gauge indicates top liquid temperature. It includes an independent well for easy field replacement.

Liquid Level Gauge

A magnetic, dial-type liquid level gauge indicates coolant level.

Pressure Vacuum Gauge

A dial-type pressure gauge monitors internal pressure.

Alarm Contacts

Alarm contacts may be supplied with any of the above gauges. If contacts are supplied, terminal connections will be located in the low voltage junction box.

Pressure Relief Valve

A pressure relief valve located on the handhole cover will release excess pressure in the tank.

Fluid Drain

A valve with a plug is provided for draining and sampling coolant.

Ground Boss

A steel threaded boss with thread or grounding pad is provided on the side of the tank for grounding purposes.

Current Limiting Reactor

A current limiting reactor (CLR) must be connected in series with the primary of the transformer to limit the short circuit current during sparking. It can be located in the TR tank (submerged in the oil), the TR low-voltage junction box, the AVC control cabinet, or in a separate housing normally mount on the roof of the ESP.

TR Nameplates

All TRs should be supplied with a nameplate that specifies the equipment's ratings and shows the internal circuit.

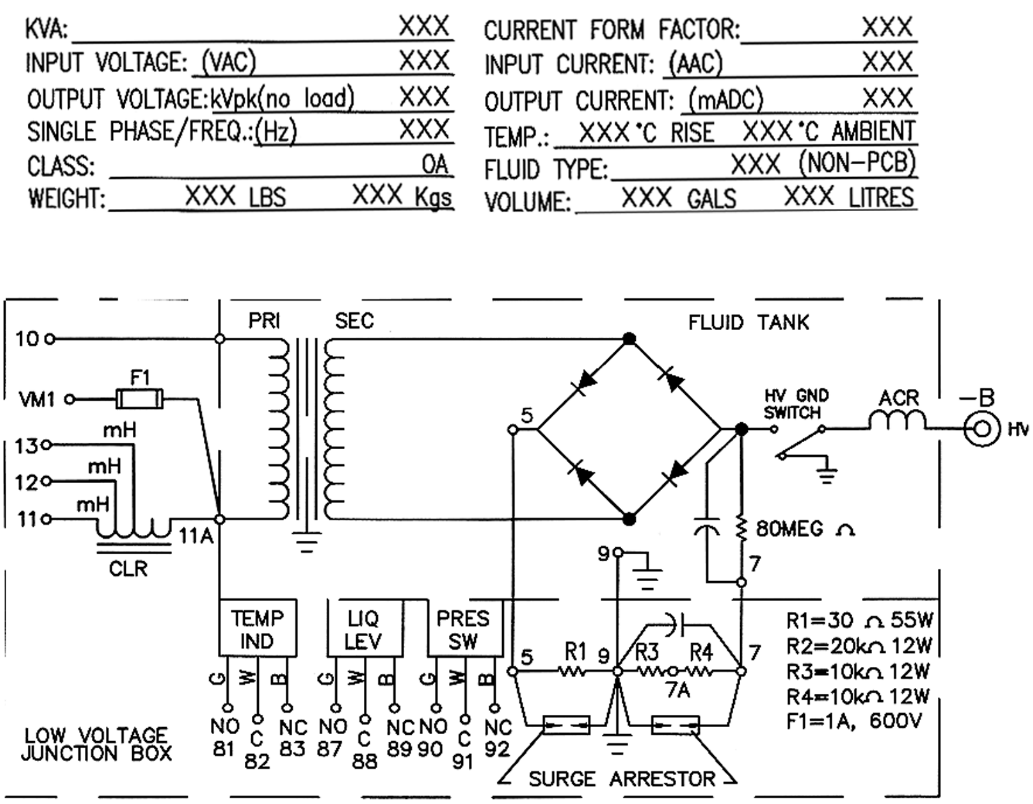

Figure 4-2
Typical TR Nameplate Data and Single Bushing TR Schematic

Schematic Description

- Terminals 10 and 11A are the input connections on the low voltage side of the TR. The TR primary can also be tapped to provide different voltage input and output ranges (see Figure 4-3).
- Terminals 11 through 13 are taps on the CLR mounted in the junction box. In some designs, the CLR is also mounted in the tank. The optional taps on the CLR are provided to match the impedance to the operating precipitator load.

- VM1 is a protective fuse used to protect personnel and metering circuits in the controllers primary voltage input.
- PRI and SEC represent the primary and secondary of the step up transformer.
- Terminal 5 is the feedback circuit for secondary mAdc metering.
- Terminal 7 is the feedback circuit for secondary kVdc metering.
- The HV GND switch, as shown, is an internal, two-position disconnect switch. Various switch configurations are available and described in the following section.
- ACR is the air core reactor, which was discussed previously.
- Terminals 81 through 83, 87 through 89, and 90 through 92 are contacts for the temperature gauge, liquid level gauge, and pressure vacuum gauge. Depending on the control circuit design, in operation the contacts will be in either the open or closed position. When conditions exceed operating limits, the contacts will actuate and send a signal to the control to respond as programmed.
- Terminal 9 is the system ground circuit.

4.1.1.4.3 HV Switch Options

Some TRs have internal switches and others use manual or external disconnects and ground switches. The following is a list of the typical switch options available.

- **Internal, two-position disconnect ground switch:** In the ground position, the switch will isolate the transformer while grounding the precipitator field.
- **Internal, two-position ground switch:** In the ground position, the switch will ground both the transformer and the precipitator field.
- **Internal, five-position switch:** The switch design will allow the use of a two bushing TR to power two independent bus sections. (Can be configured using four positions only.)

Table 4-1
Internal, Five-Position Switch Operating Modes

Operating Modes	Bus A	Bus B
1	Fullwave	Fullwave
2	Fullwave	Ground
3	Halfwave	Halfwave
4	Ground	Fullwave
5	Ground	Ground

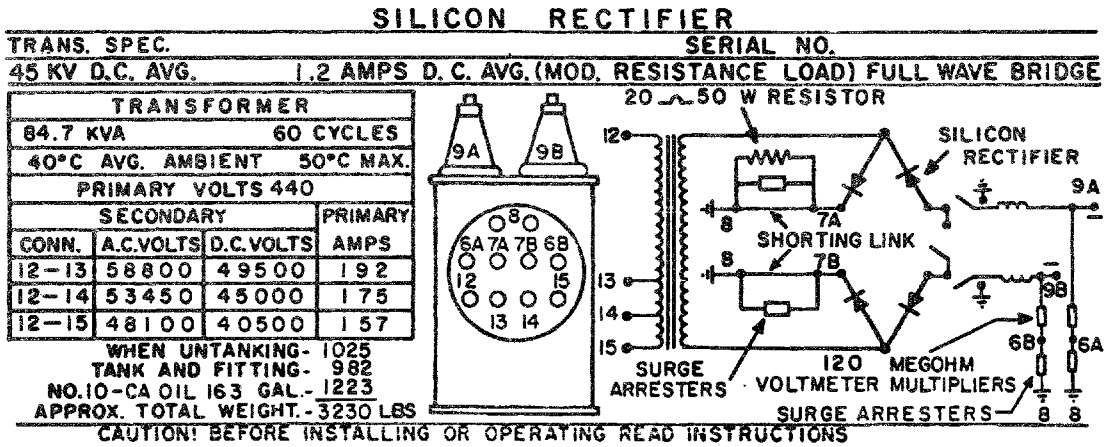

Figure 4-3
Typical Five-Position General Electric TR

- **External, two-position ground switch:** In the ground position, the switch grounds both the transformer and the precipitator field.
- **External disconnect ground switch:** In the ground position, the switch will isolate the transformer while grounding the precipitator field.
- **External Four-position switch:** The switch design will allow the use of a single bushing TR to power two independent bus sections.

Table 4-2
Four-Position Switch Operating Modes

Operating Modes	Bus A	Bus B
1	Fullwave	Fullwave
2	Fullwave	Ground
3	Ground	Fullwave
4	Ground	Ground

All of the switches referenced above are designed for off-load switching. The TR switch should never be switched while the TR is in service. The resulting arc can damage the TR components and contaminate the oil. These switching mechanisms should not be used in place of safety grounding for personnel safety. All switches should be provided with provisions for interlock mounting. Interlocks must be used to insure proper switch function and safety. The TR set should never be energized unless the proper locks are installed.

4.1.1.5 TR Installation

The TR set is shipped completely assembled and full of dielectric fluid. It is ready for mounting and electrical connection. Most manufacturers recommend that the TR be shipped using an air ride trailer bed to minimize shock of the shipping on the internal parts. It is important to megger test all TRs after receiving them to insure that no damage occurred during transport to the site. Also make sure that there are no leaks and that the fluid level registers between the limits indicated on the liquid level gauge. (Do not drain the fluid if the level is high.)

Key Human Performance Point

It is important to megger test all TRs after receiving them to insure that no damage occurred during transport to the site. Also make sure that there are no leaks and that the fluid level registers between the limits indicated on the liquid level gauge. (Do not drain the fluid if the level is high.)

If any of the feedback resistors are to be customer supplied, install them in the low-voltage junction box. As the resistors are installed, remove the shorting links that were shipped with the unit. *Do **not** operate the unit without either shorting links or appropriate resistors installed.*

Key Human Performance Point

Do *not* operate the unit without either shorting links or appropriate resistors installed.

4.1.1.5.1 Verify the Rating

- The maximum fault capability of the power system at the point of installation should be verified and must not exceed the short-circuit rating of the unit.
- All system accessories such as surge suppressor, lightning arrestors, and the like should be checked to also verify their ratings capacity.
- Do not exceed the ratings specified on the unit nameplate or system accessories.

4.1.1.5.2 Check Area Conditions

- The equipment should not be exposed to corrosive or explosive fumes, dusts, vapors, dripping or standing water, abnormal vibration, shock, tilting, or other abnormal operating conditions.
- The temperature of the ambient air surrounding the power supply should be between the limits of -40°F (-40°C) and 104°F (40°C).

Note: Temperature or altitude conditions outside of the usual limits may require derating the unit or additional special equipment, such as heating, cooling, or ventilation.

4.1.1.5.3 Unit Installation

- This is heavy equipment and must be securely anchored to prevent tipping. The recommended size for anchor bolts is 0.5 in. × 13 UNC.
- The unit should be leveled and firmly secured to its supporting foundation.

4.1.1.5.4 Grounding

(See Section 4.1.7 – Ground Systems for More Detail.)

- Connect the grounding cable to TR to the grounding lug on the side of the tank. This lug is internally bonded to the transformer ground.
- The unit must be grounded in accordance with the National Electrical Code (NEC), the Canadian Electrical Code (CEC), or the International Electrotechnical Commission (IEC); whichever is applicable, before making any incoming power connections. If a main ground bus is furnished, make the ground connection to this bus.
- If there is no ground bus, all equipment should be connected in such a way as to ensure a continuous grounding path. There must not be a break in the ground wire connecting all equipment to earth ground, unless a ground bus is used as an extension of the wire. This would allow equipment to be removed without breaking the ground. Special attention should be paid to:
  - Protection for the operating personnel
  - Protection of the equipment itself (such as ground fault relays, if used)
  - Protection of sensitive transducers or electronic control devices

4.1.1.5.5 Making Connections

Before making any connections, perform a megger test to confirm the integrity of the unit's internal connections. Then proceed with the following steps.

1. Route the cable and wire bundles that enter the enclosure to avoid interference with moving parts. Observe minimum-bending radius for the type of cable used.
2. Power cables should be braced and/or laced to withstand short-circuit forces wherever such cables are unsupported.
3. Power cables should be adequately sized to carry the full load current in accordance with NEC or other applicable requirements, and have an adequate voltage rating.
4. Cables should be dressed and terminated as appropriate to the voltage class and cable manufacturer's recommendations. Conduit grease should be used on all connections.

5. If possible, it is best to bring the feedback and power cables from the side or top of the junction box to minimize oil contamination of the cables and conduit if an oil leak develops at the low voltage bushings. Connecting the conduit at the bottom of the junction box can reduce the oil containment pan effectiveness.

6. Connect the primary input terminals in series with a current limiting reactor, and then to an appropriate control system. For proper primary voltage metering, be sure the polarity is correct.

7. Connect the load to the HV bushing. If the switch is a splitter or external disconnect, make the connection to the HV output connection, not the HV bushing. Special precaution must be taken when terminating, handling, and routing HV leads to ensure sufficient voltage clearances. The electrical connection to a high voltage bushing should be designed to cause minimal stress and allow for thermal expansion of both the bus bar and bus ductwork. Otherwise, small cracks may develop in the porcelain bushing and support insulators. Flexible connections are best. If the electrical conductor is rigid, its design should be such that it provides for ease of adjustment and accounts for expansion.

8. If the unit is to be operated outdoors, the HV bushing must be enclosed within a bus duct. Sufficient clearance must be allowed for the rated dc kV output level. *Grounding straps must be used across all bolted flange connections to provide adequate ground continuity.*

Key Human Performance Point

Grounding straps must be used across all bolted flange connections to provide adequate ground continuity.

9. Connect the low-impedance ground to the Power Supply, as per Section 4.1.7 – Ground Systems.

10. Check to see that no components in the junction box have sustained any transportation damage (resistors, surge arrestors, and the like).

11. Connect all feedback wiring, adjust feedback resistors, and remove shipping links in the junction box.

4.1.1.6 System Checkout and Startup

The system checkout and startup process consists of four steps:

1. Megger test: Verify connections integrity.

2. Switch continuity test: Verify high voltage switch operation.

3. Control system setup: Setup current limit and overload trip features on control system.

4. Start Up the TR Set: Energize unit and verify proper operation.

4.1.1.6.1 Megger Test

1. Use a mega-ohm meter (megger) of 500 to 5000 Vdc.
2. If the high voltage bushing is connected to the precipitator, it is best to disconnect it.
3. The feedback terminals in the low-voltage junction box must be open or have a path to ground for this test. Temporarily disconnect the kV feedback and jumper all mA feedback terminals to ground.
4. Place the HV switch in the HV position. If unit has a two-, four-, or five-position disconnect switch, place all arms of the switch in the ground position.
5. Connect the megger between the high voltage bushing and tank ground. With the bushing positive and ground negative, the megger should read less than 3 megaohms. Reverse the leads and take another measurement. With reverse polarity, the megger should read the value of the voltage divider. The divider is connected between the bushing and the kV metering terminal. Refer to the electrical schematic for the value. Typical values are 50, 80 or 120 megaohm but others can be used.
6. Basically a high megaohm reading in both directions indicates an open connection. A low reading in both directions indicates a defective rectifier bridge. In either case, an internal inspection is required.

See Appendix B for typical megger forms for an air-switch TR and a five-position internal switch TR.

4.1.1.6.2 Switch Continuity Test (Ohmmeter Required)

1. Interlocks should be installed for this test.
2. Place the switch in its HV position. The ohmmeter should read infinity.
3. Refer to Section 4.1.1.4.3 - HV Switch Options to verify the switch type of this unit. Place the switch in the GND position. If the switch is an internal ground, an internal disconnect, or an external ground type switch, measure the resistance between the HV bushing and tank ground. If the switch is an external disconnect or a splitter type switch, measure the resistance between the HV output connection and tank ground.

4.1.1.6.3 Control System Setup

Each control manufacturer has different procedures and it is best to refer to the manufacturer's manual for a specific control setup procedure. The following is a typical procedure that should be followed at a minimum. Use the following procedure to set the current-limit and overload-trip features in your control system to protect the TR.

1. Check that the wiring between all components (incoming power, controller, TR set, and precipitator) is correct and secure.
2. Place a temporary ground on the HV bushing. (Do not use the TR switch ground.)

3. Interlock the switch in the HV position.

4. Disable or change the AVC under-voltage trip setting to zero to allow the TR to operate in a grounded state for this procedure.

5. Set up the controller adjustments for zero volts output when energized. Energize the controller in manual mode of operation.

6. Start with the current limit set at minimum, then increase until the unit has reached 110% of rated current. Set the overload to trip at this point and record how long it takes to trip the unit off-line.

7. Lower the current limit to 100% of rated current.

8. Set the under-voltage trip level at the desired point (usually 10 kV or 80 V) and record the time it takes the controller to trip off-line (typically 15 to 45 sec).

9. Deenergize the controller and use the proper safety interlock procedure to remove the temporary ground from the HV bushing.

4.1.1.6.4 New TR Startup

Each control manufacturer has different procedures and it is best to refer to the manufacturer's manual for a specific procedure. The following is a typical procedure that should be followed at a minimum. Use the following procedure to start up the TR:

1. Interlock the switch in the HV position.

2. With the controller set for zero volts output, energize the unit. Bring the TR primary voltage up slowly. When the output reaches approximately 25 kVdc, (150 Vac if kV metering is not available), ensure that both primary and secondary currents are registering on their respective meters. If either current does not register, or if they are excessive, deenergize the system then check for an open or shorted condition within the precipitator. *Be sure to use proper interlock procedures to ensure personnel safety!*

Key Human Performance Point

Be sure to use proper interlock procedures to ensure personnel safety!

3. Set the under-voltage trip level at the desired point (usually 10 kV or 80 V) and record the time it takes the controller to trip off line (typically 15 to 45 sec).

4. Let the unit run at 25 kVdc for 30 minutes.

5. After the TR has run at the reduced voltage level for 2 to 8 hrs, increase the input until the unit reaches rated voltage or current, whichever comes first. *Do not exceed either the rated voltages or rated currents of the TR set!*

Key Technical Point

Do not exceed either the rated voltages or rated currents of the TR set!

4.1.1.7 Equipment Troubleshooting

Operational problems can, in most cases, be diagnosed by analysis of the meter reading displayed on the control cabinet. Listed below are typical meter readings along with other testing suggestions.

4.1.1.7.1 Case 1

Volts ac	Amps ac	kVdc	mAdc
High	Low	High	Low

In this condition, it appears there is an open circuit in the secondary of the system.

Tests

1. Run the TR set with the HV bushing externally grounded.

    a. If current flows, this indicates there is an open circuit in the precipitator.

    b. If no current flows, the TR set has an open circuit.

2. If the precipitator is open, check all HV connections to the electrodes.

3. If the TR is open, megger the unit and check the HV connections between the transformer, switch (if an internal switch is supplied), rectifiers, ACR, and bushing.

Internal Switch Testing

Should it be necessary to check the function of an internal switch, an ohmmeter or megger can be used to check for switch continuity. With the switch in the ground position, measure the resistance between the HV bushing and tank ground. In this configuration, the only resistance measured is that of the ACR. This resistance should be less than 100 ohms. With the switch in the HV position, the ohmmeter should read infinity. To be more thorough, you can perform a complete megger test of the TR. Typical data sheets and the procedures are included in Appendix B.

4.1.1.7.2 Case 2

Volts ac	**Amps ac**	**kVdc**	**mAdc**
Low	High	Low	High

In this condition, it appears there is a short circuit on the HV dc side of the TR set.

1. Run the TR set with the HV bushing disconnected from the precipitator (an open circuit test). This test should only be done for less than 10 sec to protect the TR from damage.
   a. If no current flows, the short is in the precipitator.
   b. If current still flows the short is in the TR set.
2. If the precipitator is shorted, check the electrode clearances, insulators, and other components for shorts.
3. If the TR appears to be shorted, check the HV bushing and switch for shorts.

4.1.1.7.3 Case 3

Volts ac	**Amps ac**	**kVdc**	**mAdc**
Low	High	Low	Low

Under this condition there appears to be a short in the TR set.

1. Megger the diodes for shorts.
2. Run the TR set without the diodes connected. If Amps ac are still high, this indicates the transformer has failed.

4.1.1.7.4 Case 4

Volts ac	**Amps ac**	**kVdc**	**mAdc**
Low	Low	Low	Low

1. The first check for this mode of operation is to verify that the control electronics are functioning properly. Using an oscilloscope, verify that the control electronics are correctly responding to sparks and arcs.
2. Check that both the circuit breaker and contactor are operating correctly.

3. Verify that the SCRs are operating properly.
4. Check all wiring connections between the incoming power connections through to the TR set primary.

4.1.1.7.5 Lamp Test

A simple means for testing TRs is to perform a *lamp test*. The TR lamp test can be performed on TRs that are already installed, as well as on TRs that are disconnected. This test should be done in conjunction with the megger test that was discussed earlier in this section and is included in Appendix B.

When testing an installed TR, the TR lamp test can be performed either at the TR location or at the controller location. While the lamp test should by no means be considered a complete TR test, it does provide a means of ruling out many common failure modes. In addition, the test provides a high confidence level that the TR system is *safe* to energize with a fully powered control system (typical 480 Vac).

Key Human Performance Point

When testing an installed TR, the TR lamp test can be performed either at the TR location or at the controller location. While the lamp test should by no means be considered a complete TR test, it does provide a means of ruling out many common failure modes. In addition, the test provides a high confidence level that the TR system is *safe* to energize with a fully powered control system (typical 480 Vac).

But, before you proceed with this test, some warnings are in order:

- The tests describes results in HV output on the TR HV bushing, as well as the possibility of high voltage on feedback connection points.
- This test should ONLY be performed by persons familiar with HV systems.

Lamp Test Procedure

The lamp test uses an ordinary incandescent light bulb to permit low-level energization of a TR. This technique can provide excellent information about the unit's functionality. The test setup consists of a light bulb that is wired in series with the TR primary windings, connecting to a 120 Vac power source, available as a standard wall plug

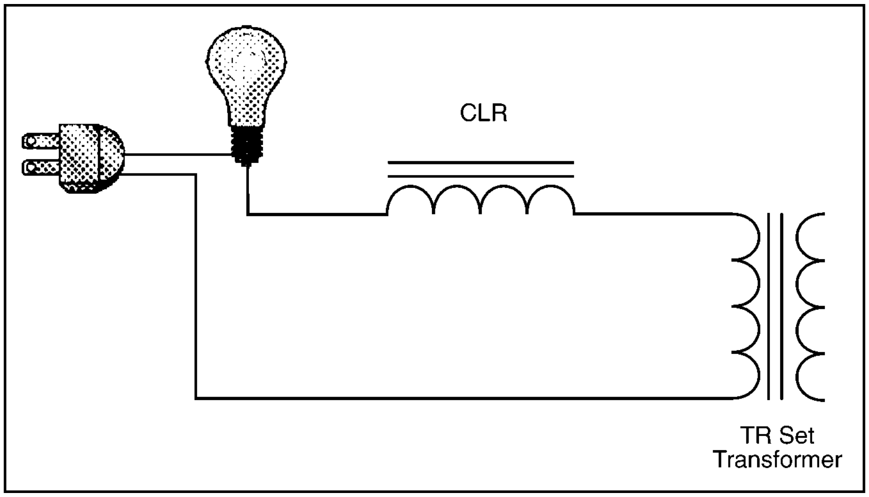

Figure 4-4
Lamp Test

A recommended lamp size of 60 to 100 watts will limit the maximum current draw to about 1 ampere under a short circuit condition. The test operator can draw various conclusions by simply observing the brightness of the light bulb. In addition, if the test operator has the skill to use other instruments, such as a volt/ammeter and/or an oscilloscope, significant additional information can be assessed as well.

The basic indicator of the lamp test is the observation of a dull glow of the light bulb. In general, this will indicate that the TR is in operable condition (a bright illumination or no illumination indicates an abnormal condition). If an abnormal condition is suspected, then this hookup can provide a configuration for further testing.

Test Rig Assembly

1. Connect a wire of desired length between the *hot side* of the wall plug and one terminal (or wire) of the lamp socket (the hot side is normally the smaller prong).

2. Connect a wire to the return side of the wall plug. The wire should be long enough to reach the test connection point. The loose end of this wire should be suitably dressed (lug or clip) to hook up to the TR connection point. This is the *return wire*.

3. Connect the return wire to the second terminal or wire of the lamp. This is the *hot* wire.

4. Install the light bulb.

5. Verify proper connections by connecting the hot wire to a ground point, plugging in the wall plug, and observing the lamp illuminating brightly.

Configuration for an Installed TR

1. The hookup to the system may be either at the TR junction box or at the controller output terminals. In all cases, the circuit breaker feed to the TR must be opened.

2. The HV connection (bushing) to the ESP field may be open or connected at the operator's option. Upon conducting the test, HV in excess of 20,000 V will be present on the TR output. All interlocks and safety precautions for the ESP and HV duct work *must be observed*! If the ESP field is connected, then a shorted field will give the same results as will a shorted secondary in the TR.

3. If the hookup is at the controller output, then the CLR will also be in the primary circuit. The impedance of the CLR will have negligible impact on the test indications since the current draw is so low.

4. If the system is equipped with a kV feedback capability, the operator must be mindful of the HV that will be present on the HV bushing as well as on the kV feedback system. Verify that the kV feedback signal has an appropriate resistance path to ground. This path may be through the kV indicator meter or through an external resistor. *If the kV feedback wire is open circuit to ground, then HV will be present on this wire! If there is any doubt of this, then connect the kV feedback terminal to ground!*

Key Human Performance Point

If the kV feedback wire is open circuit to ground, then HV will be present on this wire! If there is any doubt of this, then connect the kV feedback terminal to ground!

5. Connect the test fixture hot wire (the wire from the lamp) to the hot side (the terminal that connects the SCRs to the CLR and then to the TR). If the connection is to be made at the TR junction box, then the hot side of the system is the connection point between the TR and the CLR.

6. Connect the test fixture return wire (the wire from the plug) to the return side of the system under test.

7. Plug the fixture into a wall socket and observe the lamp. A dull glow indicates a basically *healthy system*. A bright illumination or no illumination indicates trouble. The choice of lamp size, 60 to 100 watts, should be a function of the TR size. For units under 700 mA, the lower wattage lamp is more effective.

Interpreting the Results

Very Dull Glow

- Normal indications from a very dull glow: the TR does not have any shorted turns in either the primary or secondary windings.
- There are no direct shorts in the hot-side feed to the TR or shorts to ground in the transformer winding.
- There are no shorts to ground in the CLR (if connected during test).
- The TR rectifier bridge does not have a shorted leg.
- The output, HV feed system and ESP field (if connected) are not shorted to ground.

Brighter Than Dull Glow

A brighter than dull glow indicates potential for:

- Shorted turns in transformer
- Shorted HV bushing or ESP field or HV duct
- Shorted rectifier bridge
- Short in primary voltage feed system

No Glow

No glow from the bulb indicates an open circuit on the 480 Vac system. The open circuit may be in the interconnection wiring, in the CLR (if present), or in the TR primary winding or connections.

Safety Precaution for This Test

- Never switch the TR set on or off with full rated input voltage unless a load is connected.
- Never run the TR set open circuited except for test purposes.
- This equipment must be grounded externally using a grounding stick and cables to provide adequate personnel protection during servicing and inspection. Switches with grounding provisions are not fail safe devices and are inadequate for personnel safety.
- A current limiting reactor must be utilized in the primary circuit to limit overload surges.
- Do not drain the dielectric fluid. Even after refilling the unit, catastrophic failure may occur.
- The TR set must be protected with an overload device located in the controller.

4.1.1.8 Maintenance

Warning: When any maintenance work is performed on the TR set, the HV bushing should be grounded with a ground stick. Even if the TR has not been energized, a large voltage potential could build-up on the precipitator plates.

Key Human Performance Point

Warning: When any maintenance work is performed on the TR set, the HV bushing should be grounded with a ground stick. Even if the TR has not been energized, a large voltage potential could build-up on the precipitator plates.

Generally, the TRs are designed to provide reliable service for more than 20 years. However, failures do occur and are usually in the HV section consisting of the HV rectifiers, internal switch, and the ACR. A failure in any of these components usually results in internal arcing under the oil and results in a contamination of the insulating fluid. When such a failure occurs, in most cases, carbon is typically formed which will contaminate the dielectric fluid (transformer oil). In addition to correcting the actual internal failure, the oil contamination must be corrected to prevent further damage. Depending on the nature of the failure and degree of oil contamination, the unit may need to be returned to the manufacturer or a qualified repair facility for draining, coil cleaning, and reprocessing.

Key Technical Point

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In addition to catastrophic failures, TR dielectric fluid could become contaminated if the tank loses its airtight seal. Moisture and other gaseous and particulate contaminates can make their way into the oil. Water contamination is especially a problem for silicon filled TRs since this fluid rapidly absorbs moisture. The periodic sampling of the dielectric fluid of TRs, with analysis by a qualified laboratory, is strongly recommended to ensure long life and low probability of sudden failure. Often times, trace amounts of contaminants can be detected and corrective action taken before a hard failure occurs.

Key Technical Point

The periodic sampling of the dielectric fluid of TRs, with analysis by a qualified laboratory, is strongly recommended to ensure long life and low probability of sudden failure. Often times, trace amounts of contaminants can be detected and corrective action taken before a hard failure occurs.

All TRs, regardless of the manufacturer, are vacuum filled to provide maximum insulation in the innermost portions of the HV windings, insulating both turn-to-turn and layer-to-layer to eliminate the possibilities of shorting. In some cases, depending on the manufacturer, their tanks were design to withstand a full vacuum pulled on the tank. With these types of tanks, it is possible to allow a TR to be refilled in the field after cleaning of the coils. It should, however, be noted that original manufacturers have special processing techniques for the insulating fluid prior to impregnation. This processing includes heating and degassing to increase the dielectric strength of the fluid prior to filling.

Certain suppliers, such as General Electric and Westinghouse, provided round tanks and most of these units may be able to have a vacuum pulled in the field. Newer designs, from suppliers such as NWL and others, process the TRs in vacuum chambers. This eliminates the need for providing a vacuum rated tank. Therefore, a vacuum cannot be pulled in the field.

In some cases, most typically in the event of a rectifier failure or loose connection failure, some modest carbon contamination can occur. The carbon is caused by internal arcing associated with such failures. If these types of failures are detected and corrected quickly, then there is good possibility that the oil can be cleaned on site. The most common technique for removing carbon deposits is to use a suction pump and filter press that will remove visible carbon. Generally however, once carbon is present in the oil, there is a high probability the carbon deposits are present within transformer windings and if salvageable at all, then considerable purging of all internal components is necessary. Whenever any service is done to the internals of a TR, caution must be taken not to expose the HV ACR or the transformer coils, since this will lead to equipment failure in many cases.

Various fluids react differently when exposed to ambient site conditions. In servicing mineral oil filled units, these should not be exposed to rain, dust, or other conditions that could contaminate the fluid. Silicone, however, needs to be serviced under special conditions. Silicone has an affinity to rapidly absorb moisture, thus reducing its dielectric strength. When servicing such units, the atmosphere needs to be dry and clear of dust or other contaminates.

4.1.1.8.1 Preventive Maintenance

1. **Weekly:** Check the TR for leaks. The pressure on the tank should always be positive or negative, indicating that the tank is sealed.

2. **Annually:** Perform a megger test on the TR internals.

3. **Clean the HV Bushing:** Remove any accumulation of dust or other foreign matter from the HV bushing as often as necessary. Such matter may cause the bushing to track or arc to ground. Do not use any abrasive material or tools when cleaning that can damage the ceramic or the glazing on the ceramic.

4. **Check Dielectric Fluid:** The insulating fluid should be tested, per ASTM D877 after the first six months of operation. This test measures the dielectric strength of the fluid. Should the dielectric strength of the fluid fall below 28 kV, the fluid will need to be filtered and dried. If the results show no signs of fluid deterioration, the oil should be tested every other year. Items to check include:

    a. Check the dielectric fluid level. The indicated fluid level on the liquid level gauge is for a 77°F (25°C) ambient temperature.

    b. Take a sample from the drain valve and test it for dielectric strength. Purify the fluid when testing shows a need for it. Every two to three years the dielectric fluid should be tested for dissolved gas using a syringe to take the sample. This test indicates the gases dissolved in the insulating fluid. Analysis of the results will allow the user to determine the aging of the equipment and also pinpoint various components that need to be replaced to prevent equipment failure.

    c. Check the fluid sample for carbon deposits. If visual inspection of the sample indicates the presence of carbon, it may need to be reconditioned or replaced.

    d. If the dielectric is silicone fluid, check its water content per ANSI/ASTM D1533. Levels higher than 75 ppm at 77°F (25°C) require filtration.

    e. If it is necessary to top off the unit with insulating liquid, use only the type of liquid that is specified on the nameplate. Fill through the filling hole on the cover. Care should be taken to not introduce air bubbles in the oil. Do not allow the unit to stand without liquid. Pressurize the tank with nitrogen after opening.

5. **Containment Pans:** Normally, oil containment pans mounted under the TR tank are required if flammable liquid is used. The pans should be checked regularly for leaks and should be drained of water regularly to maintain enough capacity if a catastrophic failure of the tank would occur. A drain valve should be installed and piped to a holding tank to drain the water.

4.1.1.8.2 Repair Maintenance

Some manufacturers use TR construction that permits the removal and replacement of subassemblies from the top of the TR, without the need to drain dielectric fluid. Primarily, this type of repair is limited to the change out of rectifiers, the ACR, or internal switch components. When this type of repair is done, the potential for damage of the main transformer is greatly reduced since the transformer should not have been exposed to air. Most TR manufacturer's manuals have a description of the repair and replacement procedures for the internal components. If a TR is repaired in the field, it is a good idea to follow the procedure recommended by the manufacturer. At a minimum, follow the procedure described below to minimize damage when reenergizing the TR.

As part of any repair maintenance, the dielectric fluid should be inspected and preferably sampled for testing by an outside lab. Visual inspection should include the following:

- The fluid should be clear of any suspended particles, such as carbon particles. Silicon fluid is *water clear* in color while mineral oil has a slight amber color. If discoloration to a brownish color is observed, it does not automatically indicate that the oil must be replaced, but is cause for sampling and analysis. Sometimes, pigments can leach from TR internal components, such as varnish, and will not necessarily be detrimental to the fluid characteristics.
- Observe the bottom of the tank using a strong light and look for signs of water and/or rust on the tank bottom. Observe any horizontal surfaces, such as the transformer windings and core for any particles such as rust that may be deposited. If any such contaminants are present, then it is possible to use a combination pump/filter to remove such particles. If a continuous loop is used (return fluid directly to tank) then the oil level need not be dropped below the level of internal components.

There are various *press pumps* available for rental that can effectively remove contaminants from transformer oil. In addition, there are outside companies that perform such services. Generally however, the filtering process is quite slow and is typically done for over 24 hours on a TR-size transformer.

Whenever the oil is dropped below the level of a TR- transformer winding, then special care must be taken to minimize the possibility of trapped air being present inside the windings. Small air bubbles create a source for partial discharge (corona) inside the tank, which then will result in breakdown of the oil as well as insulation materials in the transformer. The best way to remove such trapped air is through a combination of elevated temperature and vacuum. In most cases, the TR tank cannot support a vacuum, so if a field repair is done then heat and time are the only methods of driving off as much air as possible. One method that is commonly employed for doing this is to short out the HV bushing and run the TR at or near current limit for a prolonged period of time (8 to 24 hours or more if possible). The idea is that this will heat-up the oil, circulate the oil, and drive out air bulbs and moisture absorbed in the insulation. This method has proved effective in instances where the transformer has had limited time in air exposure, but in no way is this a guaranteed system for removing the possibility of trapped air.

Key Technical Point

Whenever the oil is dropped below the level of a TR- transformer winding, then special care must be taken to minimize the possibility of trapped air being present inside the windings. Small air bubbles create a source for partial discharge (corona) inside the tank, which then will result in breakdown of the oil as well as insulation materials in the transformer. The best way to remove such trapped air is through a combination of elevated temperature and vacuum. In most cases, the TR tank cannot support a vacuum, so if a field repair is done then heat and time are the only methods of driving off as much air as possible.

If the TR tank is suitable for vacuum processing (usually either round tanks or square tanks with *belly bands*) then the tank should be processed in this way. Heat along with vacuum is the preferred way of processing a TR tank. Heat can be created through the shorting of the bushing as delineated above. Vacuum can be achieved via a portable vacuum pump. The time for vacuum processing should be a minimum of 8 hours.

It is important to note that in rare instances the TR windings can be damaged as a result of trapped air or moisture, even if the above field procedure is followed, and that shop repair is the best method if the windings have been exposed.

4.1.1.9 Sizing and Upgrading TRs

The design and sizing of the TRs is generally dependent on location, cost, ESP design, and performance needs. Typically, the TR would be sized for the change in load from: the inlet to the outlet of the ESP. That would mean that the inlet TR would be sized for higher voltage and lower current ratings and the outlets would be sized for lower voltages and higher current ratings. However, many systems are not designed that way. Since the TR is the most expensive single item on the ESP, there is a great effort to use as few TRs as possible without sacrificing performance. One method is to connect more collecting area to the TR set. However, in large fields, the weakest area in that field will tend to control the spark-over voltage and the problem may be worsened where there is a large temperature gradient across the field that will create several different resistivity zones in that field. Another method that has been used is to purchase the same size TR for all of the sections to reduce cost. This usually creates a mismatch of the TR set's current ratings with the inlet being too big and the outlet being too small. Methods used to improve ESP performance are to upgrade the TRs to better match the size to the load or to improve sectionalization of the fields.

4.1.1.9.1 Matching Power Supplies with Loads

Mismatching may be a result of improper original design, or from changes in operation since initial startup such as changes to the fuel, changes in the operating temperatures, the addition of an SCR for NO_x control, or other changes that would affect the electrical properties of the ESP. TR mismatch occurs when operating and rated current levels or voltage levels are significantly different. Typically, this falls into two categories either the TRs are too large or too small for the operating condition. The TR is considered properly matched if the TR is operating at 70 to 80 % of its current rating on a sparking TR set. TRs that are operating at the current limit or voltage limit could be limiting further increases in voltage, which would be limiting a potential increase in performance. Low kV ratings in the inlet fields and low current ratings in the outlet fields can create this condition. The only solutions when TRs are limited are to add more TRs, sectionalizing the fields more, or changing the TR to a larger rated TR.

When operating at low voltage levels caused by sparking, the AVC keeps the firing angle of the silicon-controlled rectifiers (SCRs) at a low level, allowing more time for the kV signal to degrade. This reduces the average electric field (kV) applied to the particle. On the other hand, low current levels cause the current conduction time to be reduced, decreasing the time ions are being discharged into the gas stream and through the dust layer. This may also reduce particle charging and reduce the bonding force of the dust layer, dramatically affecting ESP performance. The maximum current conduction time should be 85% of the normal ac cycle. It is typically determined by the TR design and the CLR sizing. A mismatch can sometimes be corrected by adding more impedance, by changing the CLRs, or by changing to different discharge electrode geometries. It is also possible to change the TR's primary tap settings to open up the SCR more and to increase the voltage conduction time.

Key Technical Point

The maximum current conduction time should be 85% of the normal ac cycle. It is typically determined by the TR design and the CLR sizing. A mismatch can sometimes be corrected by adding more impedance, by changing the CLRs, or by changing to different discharge electrode geometries. It is also possible to change the TR's primary tap settings to open up the SCR more and to increase the voltage conduction time.

Sometimes, power supplies should be replaced because of age, because they contain polychlorinated biphenols (PCBs) that are known carcinogens, or because they fail. This is a good time to investigate matching the power supplies with the loads. When adding larger TRs or more TRs to the system, it is important to make sure that the substation or load center has enough capacity to handle the increased loading.

4.1.1.9.2 Electrical Sectionalization

Many different studies and evaluations have shown that increased sectionalization of the electrical fields with the addition of TR sets enhances ESP performance. The increased sectionalization of an ESP improves reliability and reduces the overall effect on performance of any anomaly that exists in a particular electrical section of a precipitator, allowing voltage to be maximized. Intuitively, the smaller the independent electrical section, the less effect any disturbance, such as sparking, heavy dust load, misalignment and localized reduced electrical clearances, or a thermal gradient, has on the remainder of the ESP. Basically, the voltage in any field is limited by the weakest area in that field and by sectionalizing, we are reducing the size of the field and allowing each independent bus section to operate at its maximum spark-over voltage or its new weakest point.

Key Technical Point

The increased sectionalization of an ESP improves reliability and reduces the overall effect on performance of any anomaly that exists in a particular electrical section of a precipitator, allowing voltage to be maximized. Intuitively, the smaller the independent electrical section, the less effect any disturbance, such as sparking, heavy dust load, misalignment and localized reduced electrical clearances, or a thermal gradient, has on the remainder of the ESP. Basically, the voltage in any field is limited by the weakest area in that field and by sectionalizing, we are reducing the size of the field and allowing each independent bus section to operate at its maximum spark-over voltage or its new weakest point.

Ideally, ESPs would be designed with a TR set for each individual discharge electrode. Since the cost would be ridiculously high, ESP suppliers strike a compromise, providing the sectionalization needed for performance but maintaining cost at a reasonable level. A rule of thumb is that a single electrical section should include about 20,000 to 30,000 ft^2 (1858.1 to 2787.1 m^2) of collecting plates, which should all be in the same electrical field. Of course, there are successful ESPs that have more collecting area per TR set than this rule of thumb suggests, and there are those with less. Sectionalization design varies among suppliers based on their actual experience.

Key Technical Point

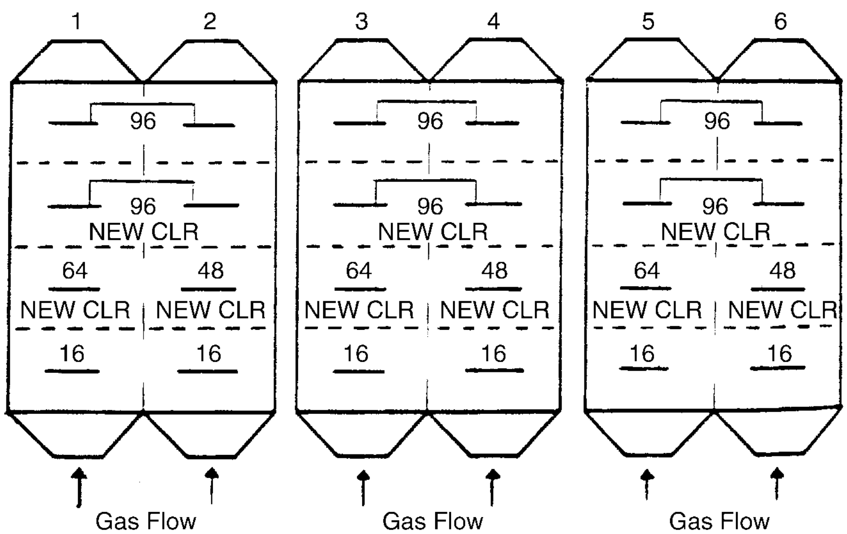
A rule of thumb is that a single electrical section should include about 20,000 to 30,000 ft^2 (1858.1 to 2787.1 m^2) of collecting plates, which should all be in the same electrical field.

The performance improvement expected after resectionalizing the ESP can be estimated with an ESP computer model. Resectionalizing can be fairly expensive unless the original design included space and opportunities for resectionalizing. In some of the older units, sections across the ESP are fed by a single transformer, even though individual regions may have independent insulators. These can be easily resectionalized by adding TR sets. There are also instances of independently supported bus sections/HV frames in series that are jumpered together and energized by a common TR set. These too, can be easily separated and independently energized with the addition of TR sets. However, for many installations, added sectionalization would require extensive modification for the addition of new support and feed-through insulators as well as new TR sets. Rigid frame ESP designs, for instance, typically have large electrical sections that cannot be easily sectionalized. In these cases, further sectionalization in the direction of gas flow is usually not possible without a major rebuild. Sectionalizing across the gas flow will improve the ESP operation in cases where there is a large change in dust resistivity across the face of the field (typically caused by the air heater gradient). It can also be beneficial if there is any mechanical damage that is limiting the parallel bus section.

It is important to match the TR and CLR to the load when sectionalizing the ESP. This would require changing the CLRs for the existing reused TRs since they would be connected to less collecting area after sectionalizing them. The new TRs that are purchased (especially in the inlet fields) would normally be smaller in kVA rating, but it would be advisable to increase the kV slightly in the inlet fields and reduce mA ratings to match them to the new loading. If there is a rebuild possibility in the future, it is best to install a widely tapped TR that is rated for 60 to 70 kV so the TR can be used in any future, wide plate-spacing rebuild of the unit. The TR primary taps should be used to maximize the SCR's firing angle to the actual operating limits.

Sectionalizing the ESP can reduce damage to the ESP and extend the useful life of the existing TRs by derating them. This is most important in weighted-wire installations since wire damage caused by sparking is reduced. During a spark, the capacitive energy release is what actually damages the wire. With less collecting area connected to one TR, the stored energy is less and the CLR (if matched to the load) is larger, which relates to less energy released during a spark-over condition and a quicker choking of the current surge caused by the increased impedance in the circuit. This will protect the equipment better, reduce damage to the equipment, and extend the useful life of the equipment. It can also reduce electrical noise in the system caused by sparking.

As mentioned previously, when adding larger TRs or more TRs to the system, it is important to make sure that the substation or load center has enough capacity to handle the increased loading. Typically, it would be best to purchase new TRs in the inlet fields and reuse the existing TRs either in the second field or the outlet fields to improve sectionalization. Moving the TR to the outlet field or the second field would depend on the dust resistivity levels. In a low resistivity condition, the outlet fields normally would operate at low voltages and at current limits. Moving the inlet TR to sectionalize the outlet would allow the outlet field voltage to increase by allowing the TR field current density to increase. The increase in current density would also help to reduce reentrainment losses by increasing the bonding force on the dust layer. In cases where the fly ash resistivity is high, or where there is poor gas or temperature distribution, sectionalizing the second field would be best. Below is an example of sectionalization of a large ESP operating at high resistivity with poor temperature and gas distribution.



Improved Layout to Compensate for Poor Gas
Distribution and/or High Resistivity Dust Conditions

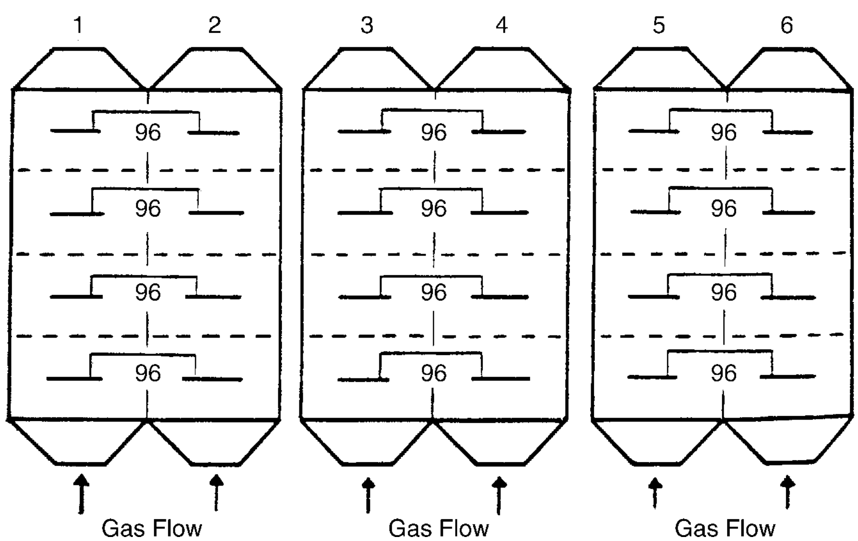


Figure 4-5
Examples of TR Sectionalization Before (Below) and After (Above)

4.1.1.10 Emerging and Alternative Technologies

4.1.1.10.1 Pulse Transformer Rectifiers

Pulse energization currently requires the installation of a separate power supply on each electrical section. The conventional power supply is retained and operated with a background voltage at or near corona start to maintain a collecting electric field on the ESP between pulses. The new power supply provides pulses of voltage to the ESP with rise times on the order of a few nanoseconds, with pulse duration ranging up to several tens of microseconds.

The pulse power supply requires a significantly higher, peak-current capability than the conventional power supply. The higher current capability is required to charge the distributed capacitance of the ESP field to a peak voltage on the order of 70 to 100 kV in a few microseconds, in order to provide the very short rise times on the pulses. The average value of current needed is approximately the same as for a conventional power supply.

Advantages

Testing of pulse energization in ESP installations showed that the primary improvement in collection efficiency was the ability to operate with a nearly uniform current density distribution on the collecting electrodes. There was also some increase in the level to which the larger particles could be charged with pulse energization, but the primary improvement was associated with the more uniform current density distribution. (Even though the larger particles are charging toward the peak value of the pulse-established electric field, the pulse duration is so short that the actual incremental difference in field charging is small.) The more nearly the current density approaches uniformity, the greater the applied voltage can be, without forming back corona. Thus, pulse energization allows the ESP to operate at higher peak and, to some degree, higher average voltages than conventional energization.

Disadvantages

The technology is expensive and good reliability was not proven in any full-scale applications.

For more information on pulse energization, see the EPRI Report: *An Investigation of Pulse Energization*, CS-4717.

4.1.1.10.2 High Frequency Switchmode Power Supplies

With new higher current semiconductors available in the marketplace, integrated gate bipolar transistors (IGBT) have now been developed for the precipitator industry. Unlike conventional TRs that operate at 60 Hz, the high frequency switchmode power supplies operate at frequency levels up to 30 kHz.

Advantages

The following is a list of anticipated advantages that should improve the precipitator's performance, but at the time of printing, some of these advantages have not been confirmed with field experience.

- Imparting a higher voltage electrical charge on the particles to be collected enhances operational performance. Conventional TRs operating at 60 Hz have a dc ripple of 35 to 45%. This is also known as *kV min. – max*. The switchmode power supply provides dc output voltage ripple of only less than 3 to 5%, thus resulting in a higher potential charge on the particles.
- Due to the speed at which the electronics operate, when a spark or arc occurs within the precipitator, the IGBT can react at over 250 times the speed of conventional power supplies, clearing the upset and returning back to the optimum voltage level, thus optimizing particulate charging.
- These new power supplies differ from traditional TRs since they use 3-phase input rather than 1-phase input. This results in a much-improved power factor (0.94 vs. 0.63). Over time, this provides the user a significant energy cost savings.
- Since this equipment operates at such high frequencies, the size of the HV magnetics is reduced to approximately 10%, when compared with 60 Hz units. In applications where new precipitators are being installed or on some rebuilds, this may eliminate the need for heavyweight lifting and monorail systems. Also, due to the reduced size, weather enclosures should be able to be lower in height.
- On new precipitators, significant dollar savings can be realized since the HV power supply and control are supplied as a unitized package. Due to this configuration, it may reduce or eliminate the need for a separate control room.

Disadvantages

Most of the controls are proprietary and, in some cases, do not easily interface into the existing Data Management Systems. The ability of the controls to handle back corona and other conditions has not been established.

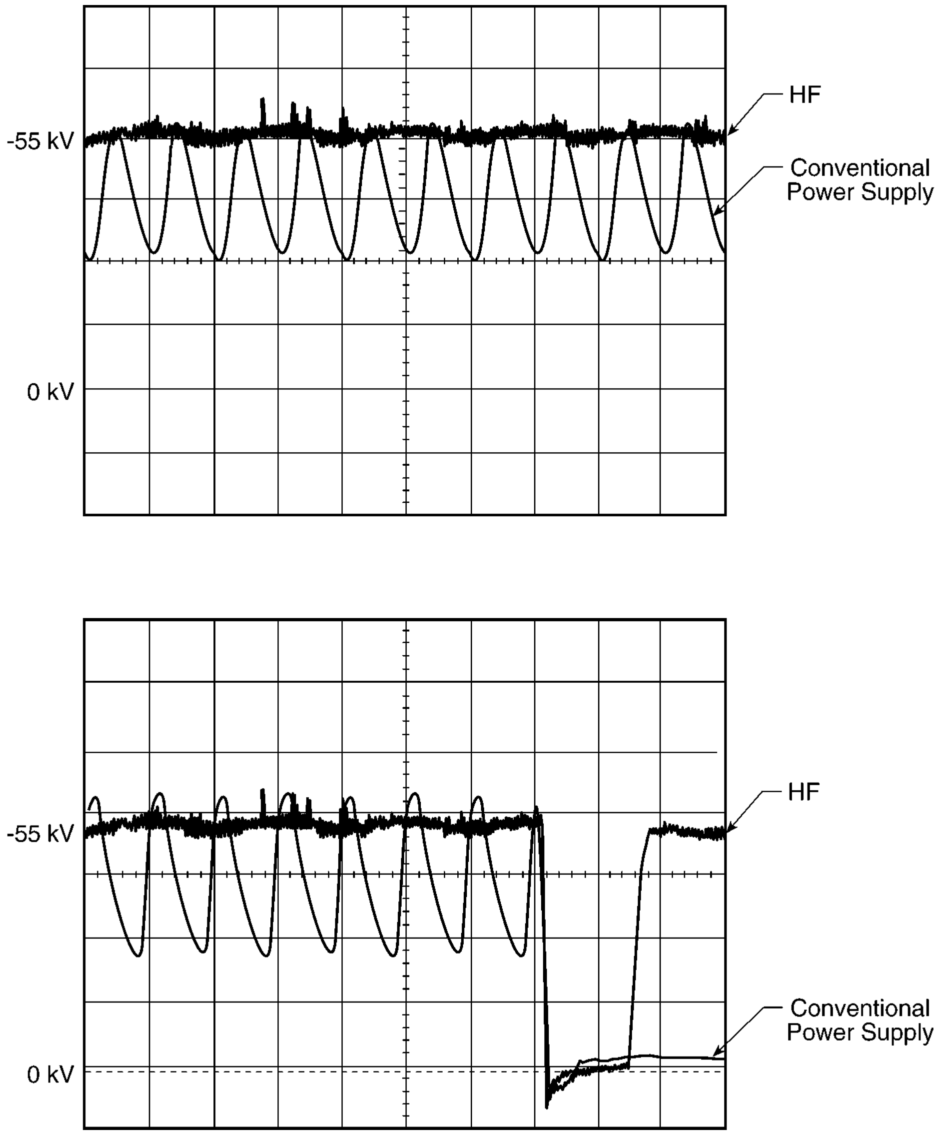


Figure 4-6
Comparison of a HF Power Supply and a Conventional TR. (Lower Trace Shows How Much Faster the Spark Response Can Be.)

4.1.2 Automatic Voltage Controls (AVC)

The primary purpose of an AVC is to protect the equipment. The secondary purpose is to optimize performance of the ESP. To optimize performance, most controls attempt to operate at the spark-over voltage or at one of the power supply design limits. The equipment used to supply power to the ESP internal components is relatively simple. Most systems today use SCRs to regulate the voltage to the power supply (TR). There are still some systems in service that use saturable core reactors to regulate voltage, but this is no longer very common.

Key Technical Point

The primary purpose of an AVC is to protect the equipment. The secondary purpose is to optimize performance of the ESP. To optimize performance, most controls attempt to operate at the spark-over voltage or at one of the power supply design limits.

Early automatic control systems started to be used in the early 1950s. Prior to that period, most power supplies used mechanical rectifiers that operated in manual mode with no real control. As the power supply technology has improved, so has the control technology. Controller technology has evolved from automated variacs (autotransformers), to tube circuits, to transistor circuits, to small-scale integrated circuits, to the present day microprocessor circuits, and, in some cases, to microcomputers. Early control systems used a technology generally referred to as *analog control*, while more modern day systems are generally referred to as *digital controls*. Analog controls were effectively used for many years from approximately 1950 until the mid-1980s. Since then, digital controls have dominated. As the technology evolved, more flexibility and higher levels of performance and reliability have been realized.

The modern-day controls use a pair of SCRs to regulate power to a TR. The SCRs are mounted in a reverse-parallel configuration. The TR generates a HV dc output. The output voltage will vary depending on the electrode spacing and geometry (40 to 105 kV average). Usually, the negative output of the rectifier bridge is used but, in rare cases, positive discharge is used. The SCRs are fired by an output from the AVC or a component of the AVC circuit (referred to as a *firing circuit card*). The AVC can utilize four TR feedback signals:

1. Primary volts
2. Primary amps
3. Secondary volts (kV)
4. Secondary amps (mA)

The use and interpretation of these feedback signals will vary between manufacturers. However, usually all four feedback signals are used when available to limit the output or input to the TR to its design nameplate limits. Fundamentally, all AVCs use one to four inputs to control one output to the SCRs. This means the AVC only has control over the voltage in the circuit, since the AVC only controls when the SCR is turned on. That means the current level in the circuit is dependent on the condition in the ESP, and the SCR cannot be used to directly limit the current flow. This can be very dangerous in a shorted condition. To help protect the circuit components, a CLR is installed in series with the SCRs to limit the current flow in a shorted condition. Breakers and fuses are used to also protect the equipment in a shorted condition.

This section is divided into several parts. In the next part, the basic AVC circuit is shown, including a glossary of terms explaining the typical components and their function in the circuit. Later, the control interface, control features, AVC startup, and troubleshooting are discussed. Also included near the end of this section are examples showing different types of spark responses used by different AVC manufacturers. It is important to read the manufacturer's AVC manual since most controls differ slightly and often use different terminology.

Although spark response and other AVC features are discussed in this section, it would be best to review Section 3.2 - On-Line Diagnostics for a discussion on how to interpret and utilize the AVC meter readings and how to utilize V-I curves and oscilloscope traces to evaluate and tune the AVC's operation.

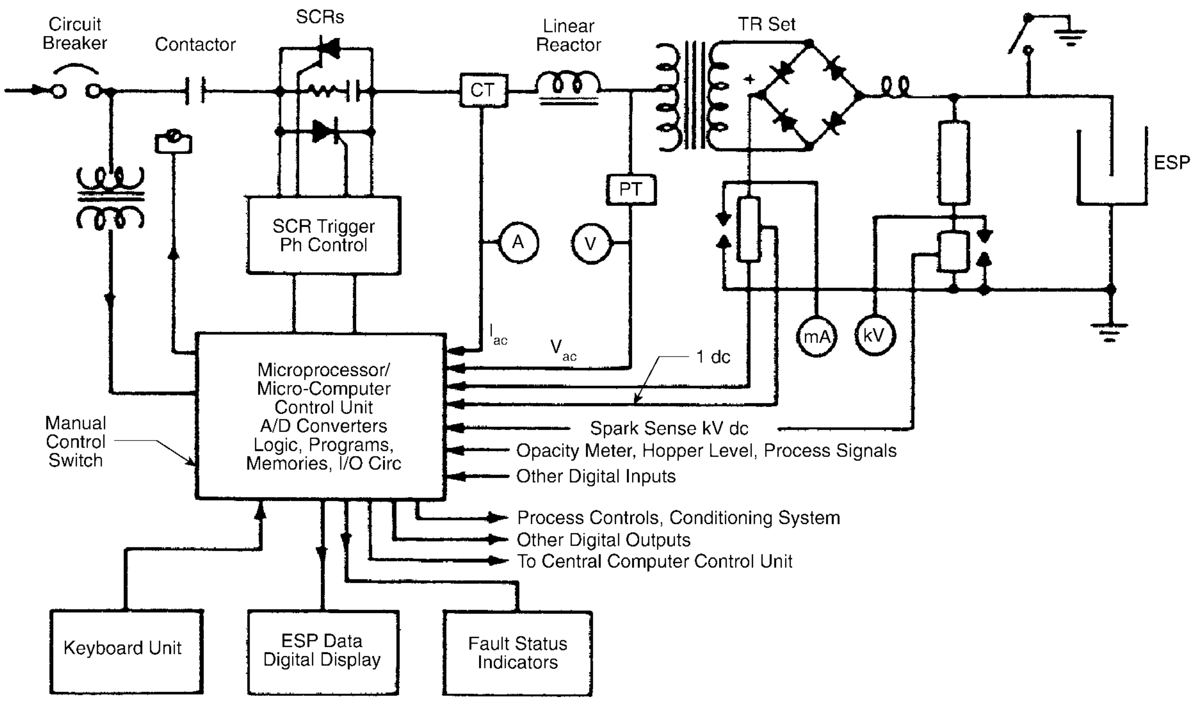


Figure 4-7
Typical AVC Control Circuit

4.1.2.1 Basic Components

Control cabinet: This cabinet contains the control and monitor apparatus of the power supply. Features mainly involve low voltage breaker, overload controls, metering, and the AVC components.

Automatic voltage control (AVC): A control used to protect the TR and related equipment and to optimize voltage input in the ESP.

Current limiting reactor (CLR): This is primarily a ballast of reactive impedance placed in the low voltage circuit to provide current limiting ability under spark-over, arc-over, and short-circuit conditions in the ESP. (For more information, see CLR Sizing later in this section)

Silicon-controlled rectifier (SCR): SCRs are the most extensively used method of voltage control consisting of two silicon rectifiers mounted in an inverse parallel fashion in the primary ac circuit of the TR set. Thyristors are also used instead of silicon diodes, but the principle is basically identical.

Primary ammeter: This meter measures the current flow through the low-voltage, primary winding of the TR set in ac amperes. The meter normally receives its signal from a current transformer in the primary circuit.

Primary voltmeter: This meter measures the voltage drop across the primary winding of the HV transformer in the TR set. The voltage can be measured in various manners, but the object is not to include any other equipment or apparatus within the measurement point located at the main power cables going directly to the TR set. With recent SCR controls, the true value of this voltage varies with the waveform at different levels of load current.

Secondary ammeter: This meter measures the average dc secondary current, which is actually the precipitator corona current passing through the ground path on its return to the rectifier connection of the TR set so as to complete the electrical circuit. This meter has a low-resistance movement and the scale reads in milliamperes (mA) or amps (A) depending on the size of the TR set. The secondary current waveform can usually be observed by connecting an oscilloscope across the meter. There is usually a shorting device or surge arrester across the meter for protection. Under no circumstance should the leads be removed from this type of meter with the TR set energized. Another method generally used is a voltage-based meter that measures voltage across a resistor.

Secondary voltmeter: This measurement is made between the rectifier output and the outlet bushing of the TR set by use of a voltage divider installed inside the tank or in the bus duct or air switch.

Sparkmeter: This meter, common on older controls, attempts to represent the number of sparks per minute by integrating transient surges by some type of capacitance circuit. New AVC controls actually count the number of sparks the control responded to in a 10- to 15-second window and translate the value to spark rate as a count of the sparks per minute.

Transformer rectifier (TR): The standard TR set used today transforms 320 to 575 ac volts to a high-secondary ac voltage that is then rectified through a silicon diode bridge circuit. The output voltage ratings are normally dependent on the ESP collecting-plate spacing, process loading, and electrode geometry. Normal ratings would be 45,000 to 50,000 V level for 9 to 10 in. (228 to 254 mm) plate spacing; the 55,000 to 65,000 V level for 11 to 12 in. (280 to 300 mm) plate spacing; the 70,000 to 90,000 V level for 15 to 16 in. (380 to 400 mm) plate spacing. Secondary current ratings normally vary from 100 to 3500 mA.

4.1.2.2 AVC Electrical Interfaces

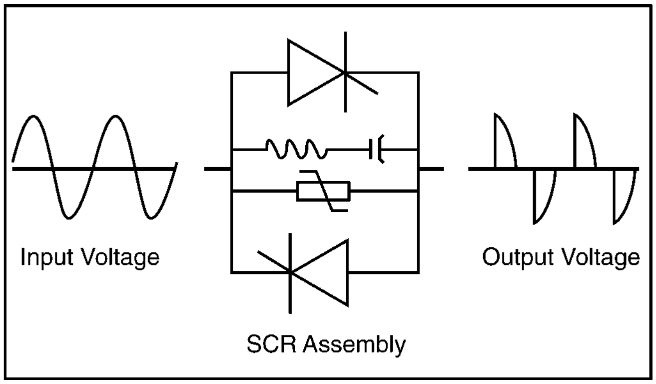


Figure 4-8
SCR Assembly

4.1.2.2.1 SCR Interface

The function of the controller is accomplished through the control of the gate signals to the system SCRs that regulate the level of power that is delivered to the TR. The SCR actually consists of two SCR devices connected in reverse parallel that are in series with the 320 to 575 Vac power feed to the TR. The SCR is also commonly referred to as an *ac switch* since it functions by turning power on and off (as would a switch) in sync with the 60/50 Hz line feed. Two devices are needed for bi-directional ac power since each device can only conduct in one direction. A snubber network is used to protect the SCRs from damage caused by high dv/dt transients. The snubber network consists of a capacitor and resistor in series, paralleled by a metal oxide varistor (MOV). SCRs are also protected from over-current conditions with a fuse. The SCRs are turned on by their gate signal at a precise time in the 60 Hz cycle, such as to permit a controlled portion of the power to pass. Through variation of the ratio of power passed vs. power blocked, the average power to the TR is controlled. SCRs are turned on by the gate signal but cannot be turned off externally. The SCRs turn off when the current through the SCR decreases below a minimum level referred to as the *holding current*. Therefore, the power signal to the TR is actually a series of pulses of varied duration, occurring at alternating polarity, and at the line frequency 60 Hz (for the United States).

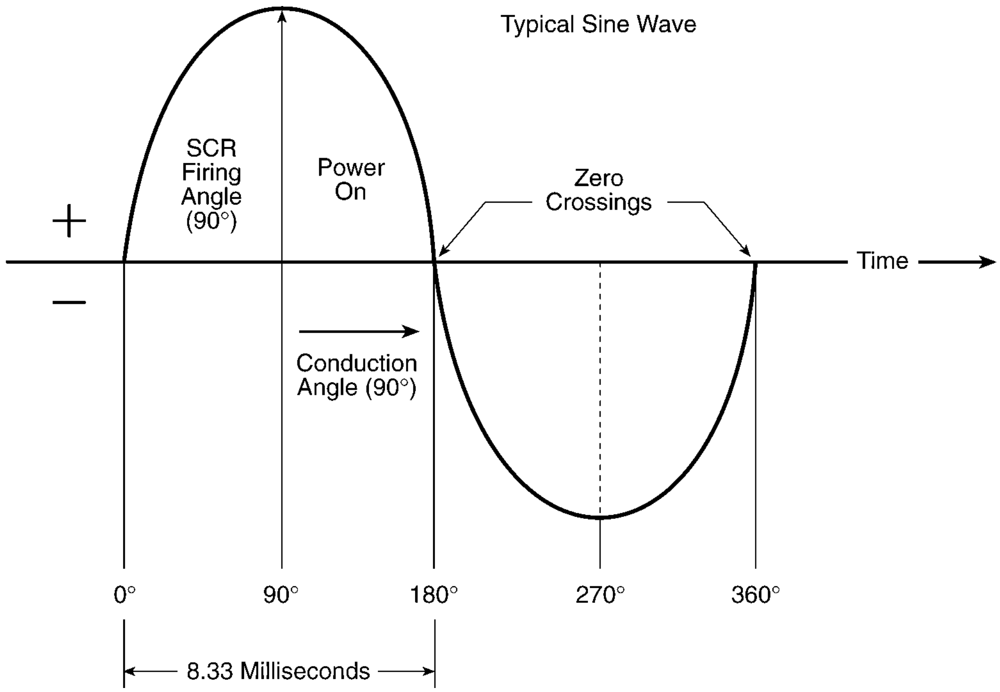


Figure 4-9
AC Sine Waveform (60 Hz)

Most controls have a SCR firing angle limit or conduction angle limit. It is important to check the AVC manual since these terms have often been interchanged. The firing angle is the angle on the ac waveform where the gate pulse is initiated. This would start at 0 degrees firing angle for 100% *ON* (480 V) to 180 degrees firing angle for 0% *ON* (0 V). The SCR conduction angle is the exact opposite with 0 degrees conduction angle for 0% *ON* (0 V) to 180 degrees conduction angle 100% *ON* (480 V). In this application, the SCRs should not be operated at 100% *ON* or *OPEN* to allow the SCRs to be controlled during a spark-over condition. The phase shift between the current and voltage causes the current to conduct after the voltage has reached the zero crossing point. This means that the SCR is still conducting and has not turned off even though the applied voltage is off. Most controls limit the firing angle limit to 10 to 45 degrees to allow the AVC to control properly. As the phase shift increases (typically from more capacitance in the ESP, as would occur from a change in fuel or an increase in ash load), the firing angle limit should be increased to control the SCRs properly. If the firing angle limit is not increased, it can result in uncontrollable arcing in the ESP and damage to the electrical components and internal components. Using a firing angle of 10 to 45 degrees would create a slight voltage drop across the SCR of about 10 to 40 V. This drop, in combination with the voltage drop across the CLR, means that the TR will never see the full line voltage and is the reason why some TRs are supplied with only 400 V taps. It is also important to note that SCR conduction angle or time does not represent, nor can it be correlated directly to, the current conduction time. These terms are often misused or misapplied in many AVC manuals. The current conduction time is the actual time the current is conducting in the circuit.

Several different methods of interfacing the AVC to SCRs are employed. Since the SCRs are directly connected to the ac line feed, a method must be used to isolate this high voltage from the low-voltage control electronics. The isolation device (commonly referred to as a firing circuit board) is mounted between the control electronics and the SCRs. Mounting the firing circuit on the SCR assembly makes for a safer installation as compared to locating the firing circuit directly on the AVC interface board. This requires the high voltage (480 V) to be connected directly to the AVC interface boards. In these designs, extra care must be taken when working on the AVC control cards (such as during calibrations or testing).

There are three methods commonly used for providing isolated gate current to SCRs. All methods, when properly designed, will perform the desired function. SCRs generally have a wide range of gate power level permitted for proper operation. However, each SCR type does have minimum and maximum gate signals. Gate signals that fall outside of the device specification may function for some time, but will cause premature device failure and/or occasional *misfiring* of the device. When retrofitting controls, the compatibility of the SCR and gate signal should be considered. The three methods are:

1. Isolation transformers are 60 Hz devices that output a single, continuous pulse to the SCRs each half-line cycle. Typically, the power delivered to the SCR is derived from the 60 Hz line feed.

2. Opto-isolators are semiconductor devices that use optical coupling between the input and output. Opto-isolators are limited in the level of power that they can deliver and are not always suited for high power, TR systems.

3. Pulse transformers are higher-frequency devices, typically used in the 30,000 Hz range. These devices derive power from the control circuit and have a wide range of power levels that can be delivered to the SCR.

It is possible to operate the gate pluses out of phase with the line voltage phase. This will typically result in the SCR hard starting (turning *ON* 100% at startup). Most controls have a sensing circuit to prevent this firing while some have only an alarm. To correct the problem, the polarity of the voltage input to the AVC or the firing circuit can usually be reversed or the gates and cathode leads to the SCR can be swapped between SCRs.

4.1.2.2.2 High Voltage (kV) Feedback

Most control systems make use of a feedback signal that provides an indication of the kV voltage of the ESP. This signal is an output from a voltage divider that is typically part of the TR. External dividers are sometimes used, and may be located in the HV ductwork or air switch compartments of the TRs. The dividers usually have a resistance of 80,000,000 (80 meg.) to 120,000,000 (120 meg.), but other values have been used. The signal produced will be 1 mA current from an 80 meg-ohm resistor operating at 80 kV. Usually, this mA signal is converted to a voltage through the use of a 5000 to10,000 ohm resistor that is mounted in the low voltage junction box of the TR or in the AVC console. This results in a feedback signal to the AVC of 5 to 10 V corresponding to 80 kV. A high energy MOV or Zenor diode should be placed across this resistor to prevent a high kV from developing on the feedback circuit. Also, a surge arrestor is commonly connected to ground in the TR junction box to protect the control from lightning strikes and other power surges. The control should not be operated without a surge or lighting arrestor in place.

The kV feedback signal is used with some controls to detect sparks, but the signal strength is low at 1 mA or less and problems with electrical noise have made its use less reliable than the mA feedback signal (which is at 250 to 3000 mA). To minimize electrical noise, a continuous run of shielded cable should be used from the TR to the AVC cabinet. In some installations, a filter has also been used to reduce noise.

4.1.2.2.3 Milliampere (mA) Feedback

The mA feedback is a signal that is provided by the placement on a fixed resistor between the low-voltage, return side of the HV rectifier bridge and earth ground. The size of this resistor is determined by the rating, in mAs, of the controlled TR. A resistor value is normally used to provide a 0 to 5 or 0 to 10 Vdc voltage that corresponds to 0 to the full rating of the TR. For a TR rated at 500 mA, a resistor of 10 ohms would be used (0.500 A × 10 ohms = 5 V). The mA resistor is typically mounted in the TR low-voltage junction box or the AVC cabinet, and the actual value is determined by the requirements of the particular controller in use.

In the majority of the AVCs made in the United States, the mA feedback signal is usually the primary sensing method for spark and arc detection. The resistor value used must be low enough to permit the sensing of the high-peak current caused by a spark/arc, that can be greater than two to three times the magnitude of the TR-rated current. This peak voltage across the feedback resistor must be compatible with the peak-voltage capability of the AVC control circuit. As with the kV feedback, a high-energy MOV or Zenor diode should be placed across the feedback resistor to prevent a high kV from developing on the feedback circuit. Also, a surge arrestor is commonly connected to the ground in the TR junction box to protect the control from lightning strikes and other power surges. The control should not be operated without a surge or lightning arrestor in place. It is important to use a continuous run of shielded cable from the TR to the AVC cabinet to minimize electrical noise. In some installations, a filter has also been used to reduce noise, but shielding and good system grounding is preferred.

4.1.2.2.4 Primary Voltage and Current Feedback

Both the primary voltage and current are commonly used with most modern controllers. These signals provide a very reliable indication of field power levels and can be used, under some conditions, as control parameters. The primary voltage is typically derived from an instrument-type, step-down potential transformer (PT) that connects across the primary winding of the TR. The most widely used type is a 600 to 150 Vac ratio (4:1). The volt signal is normally connected directly to the AVC without a resistor network. Monitoring of this signal must employ a true RMS metering device for accurate reading since this signal is almost never a sinusoid waveform.

The primary current signal is typically derived through the use of a current transformer (CT) suitably sized for the TR rating. The most commonly used devices use a 5 A secondary that provides a 300:5 CT ratio, referring to a 300 A to 5 A device. The 0 to 5 A output is typically connected to a meter using a 5 amp meter movement, as well as to a low resistance. A 1 ohm resistor would be used for control input voltage to the AVC of 5 V for a 5 A signal. As with the primary volt signal, a true RMS converter is commonly used for accurate feedback.

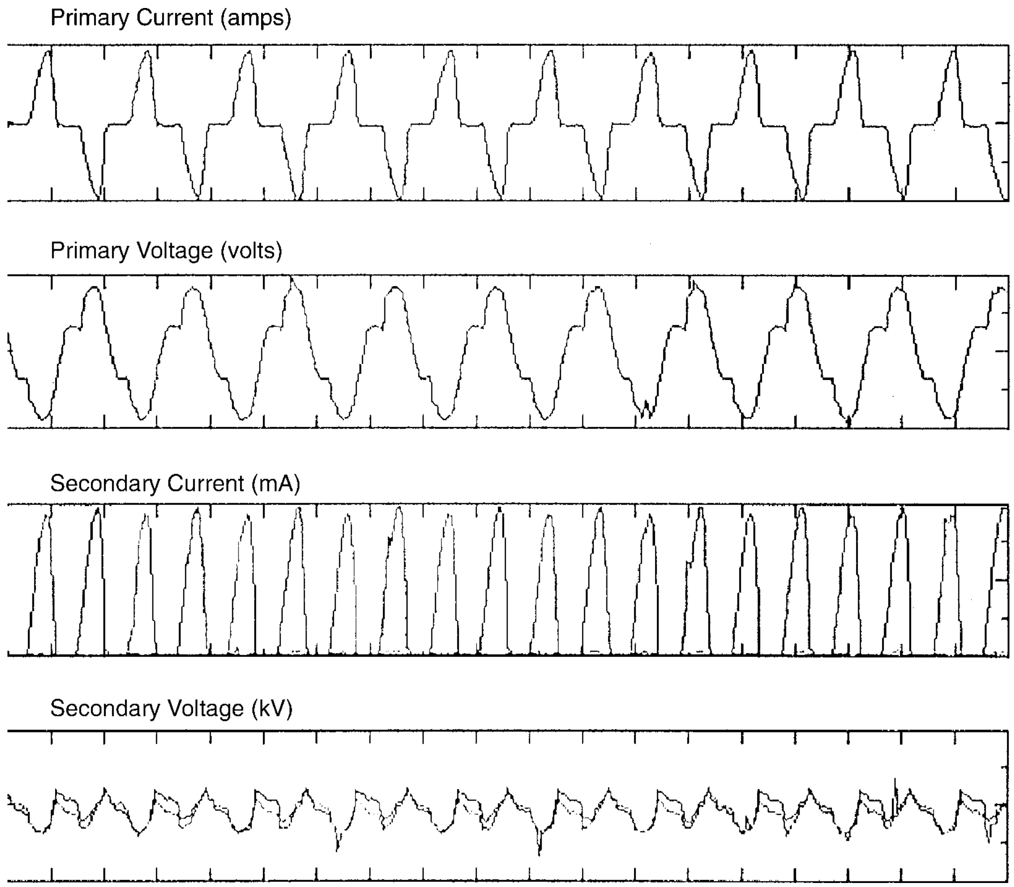


Figure 4-10
Typical AVC Feedback Waveforms

4.1.2.2.5 Alarm Feedback

Most systems have several internal and external alarm signals to cause the controller to shut down. External alarm signals are often 120 Vac signals, but could be lower dc voltages, dependent on the controller used. Alarms such as the following are often supported:

- Console cabinet over temperature
- SCR over temperature
- TR over temperature
- TR oil level low
- TR high pressure
- External over-current trip
- Cabinet fan failure
- High hopper alarm
- Rapper failure
- Miscellaneous emergency conditions (for example, fan interlock, or high CO)

4.1.2.2.6 Contactor Control

In addition to control of power via the SCRs, many systems also provide a means for power shutdown through use of a series of external, mechanical contactors. Typically, the contactor coil is controlled by a 120 Vac signal that may use an additional interposing relay. The contactor permits an additional level of safety for removing power during troubleshooting and especially in the event of an SCR failure. If an SCR were to fail in the shorted condition, which is most common, the system needs to rely on a circuit breaker trip to remove power. Often, the control sensing circuits can detect SCR failure before current levels rise to the level needed to trip the breaker and release the contactor to prevent potential TR and other component damage. Shunt trip breakers have also been used to shutdown the power. The problem with using shunt trip breakers is that control power to the AVC is also removed. This can result in a loss of the stored information in the AVC (such as the cause of the trip and the power levels the control was at just before the trip occurred). This can make troubleshooting more difficult.

4.1.2.2.7 Metering and Indicators

Most modern controllers provide digital indication of various operating parameters. In addition to the basic feedback parameters of primary voltage, primary current, secondary kV, and secondary mA, parameters such as spark rate, arc rate, conduction angle, form factor, and others are provided. In addition, some modern controllers provide the capability of displaying a *trend line* of operation levels over a period of time. Others go so far as to provide a *scope depiction* of the field voltage and current waveforms. Most of these more sophisticated readouts are useful for troubleshooting and are not used on a day-to-day basis.

The basic readout of the feedback parameters is the most important of the indications since it provides critical information about the operating performance level of a particular field. Many modern retrofits of controllers result in the removal of analog panel meters when digital controls are installed. Although most modern controllers do provide an accurate readout of the feedback levels, a considerable amount of real information is lost when the analog panel meters are not available. In addition to instantaneous levels, the panel meters provide the observer with a wealth of information regarding sparking and arcing intensity. Recovery rates from such disruptions can be used for a quick overview of the field performance at a glance. Analog meter movement can also give an indication of when a wire or HV frame is oscillating, which can not be picked up on any digital meter.

4.1.2.2.8 Operator Input

Modern controllers use a wide variation of methods for operator input. Many use membrane type keypads or buttons that have excellent reliability. The degree of difficulty (that is *user friendliness*) is subjective. Fortunately, most controllers, after being initially set up, require minimum operator action on a day-to-day basis.

4.1.2.2.9 Data Management Systems or Remote Control/Monitoring

The ability to connect all of the AVC controls to a data management systems (DMS) or to the plant's digital control system (DCS) is a common feature of most modern controllers. Systems normally allow the AVC to be set up and allow for changes in operating parameters to be done remotely at the DMS. Most use a proprietary data communication protocol, although some use modicon, ethernet, and other open communication protocols. Remote interface permits the readout of multiple controllers as well as associated systems such as opacity levels, boiler load, and rapper status at a central location. In addition, remote control of the DMS provides a means of support for energy management, power-off rapping, system trending, and general parameter fine-tuning of the ESP system as a whole.

4.1.2.3 Basic Functions of the AVC

4.1.2.3.1 Protecting the Equipment

All controls have a way to limit the operating current and voltage, and to trip or stop the feed power to the TR if a maximum limit is exceeded. The basic operating limits are primary and secondary volts and amps. These limits are normally adjustable. Trip limits should be set to protect the weakest system component. Normally, these limits are based on the TR ratings, but it could be the CLR or the cabinet wiring if the TR size has been increased or the CLR has been downsized to better match it to the load. It is important to document in the ESP logbook and to indicate on or in the cabinet any limits that are not the same as the TR ratings to prevent damage in the future as personnel change. The under-voltage and over-current trips should be set at the initial AVC startup and tested at that time to make sure the AVC trips properly. The readings should be documented in the ESP logbook. In some cases, the calibration, test results, and initial readings are required to be submitted to the TR manufacturer for warranty purposes.

Over-current trip: The over-current trip is set to trip the AVC when it exceeds 110% of the rating; either primary or secondary rating. Normally, the trip is instantaneous but it can be time delayed for as much as 15 seconds.

Under-voltage trip: The under-voltage trip is normally set at 10 kV on the secondary and 100 V on the primary to trip after the control has operated below this level for 15 to 45 seconds. This would indicate that the field was grounded. Some controls require that there is at least 50% or more of the TR rated current concurrent with the low voltage to indicate an actual ground and to prevent false trips.

Key Technical Point

Over-current trip: The over-current trip is set to trip the AVC when it exceeds 110% of the rating; either primary or secondary rating. Normally, the trip is instantaneous but it can be time delayed for as much as 15 seconds.

Under-voltage trip: The under-voltage trip is normally set at 10 kV on the secondary and 100 V on the primary to trip after the control has operated below this level for 15 to 45 seconds. This would indicate that the field was grounded. Some controls require that there is at least 50% or more of the TR rated current concurrent with the low voltage to indicate an actual ground and to prevent false trips.

All of these operating and trip limits are usually adjustable. It is important to read the manufacturers manual to determine what limits and trips are included and if these limits also affect the spark response. For example, there are a few controls that use an over-voltage trip on the secondary (kV) to prevent operation of the TR above 110% of the TR rating. The SCR firing angle (or conduction angle) is another limit some controls use to limit the maximum firing angle to prevent the SCRs from operating fully open. To prevent damage to the TR and CLR, or to indicate a shorted or open SCR, the SCR's balance is monitored and the AVC will alarm and/or trip if the SCRs are determined to be out of balance.

4.1.2.3.2 Spark/Arc Response

In an effort to maximize the operating voltages in a field, the AVC increases the voltage until a TR limit is reached or a spark occurs. Sparking will occur when there is damage in the ESP, close clearances, ash bridging, or when the ash resistivity reaches a high enough level to create conditions that will cause a momentary short circuit between the discharge electrode (cathode) and the collecting plates (anode). Sparking in an ESP should be considered a normal part of good ESP operations when it occurs at elevated voltage and in moderation. All AVCs have some filter network and algorithms to detect and respond to a spark when it occurs. In many occurrences, the spark will actually extinguish itself due to the system impedance of the TR and the CLR, as well as the effect of gas flow velocity and turbulence. In other cases, the spark will maintain itself indefinitely unless some control action is taken. Sparks that tend to persist over several half-line cycles are referred to as *arcs*.

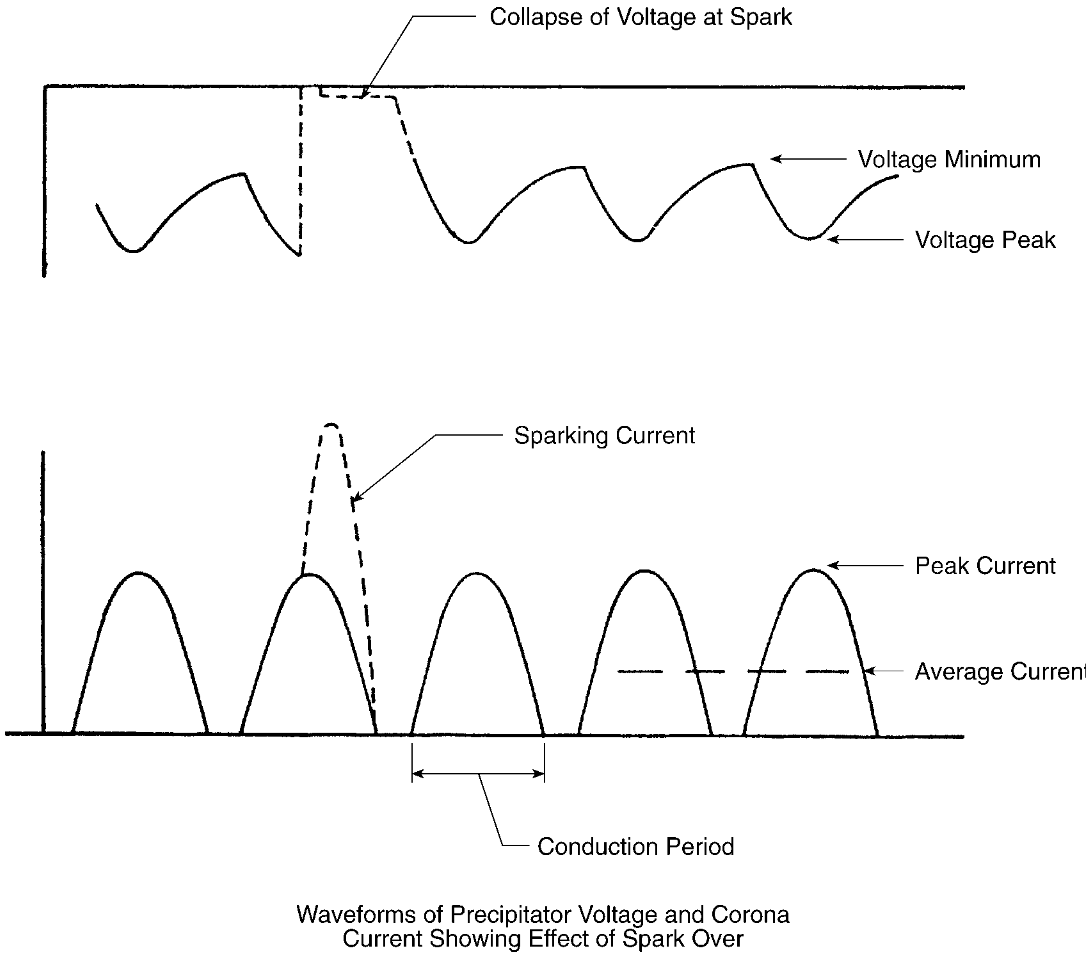


Figure 4-11
Effect of a Spark on Voltage and Current (the Voltage Drops and the Current Rises During a Spark)

Sparks are sensed by the control system as a rapid rise in mA level and/or a rapid drop in kV level. When a spark is detected, the control system reduces the SCR's conduction angle for the next line cycle for the purpose of extinguishing the spark. The amount of reduction that is imposed depends on the energy level of the spark, as well as the setup of the controller. There are two accepted methods for responding to sparks; generally referred to as *setback* (or phase back) and *quench*. Setback is a reduction in power (typically 10% to 20%) and quench is a total interruption of power for a brief period (typically 10s of milliseconds or some number of line cycles). The amount of setback, as well as the period for quench, are set points for the controller and are user selected.

When a quench cycle is initiated and all power is inhibited for a brief time, the system then recovers at a rate that is generally referred to as *fast ramp* (or pedestal rate/recovery rate). The fast ramp time is also user selected and is typically 1 to 20 line cycles (8 to 180 ms). The recovery from a quench at the fast ramp rate continues until the conduction angle reaches a level slightly below the level at which the spark occurred. The reduced level is usually expressed as a percentage of the spark-over level and is termed *setback*. The setback increment is typically set from 5 to 30% and is a user-selected parameter. The setback should be the lowest possible amount that will permit the spark to extinguish, since large amounts of setback will result in lower average power to the ESP. For low-level sparks, the quench cycle is not typically used and the setback is the only reduction employed. During an arc condition, the controls should always quench and, typically, the quench is for two to four times as many cycles as the spark response. This allows more time for the material inside the ESP to move away form the flashover area to prevent a restrike in the same spot.

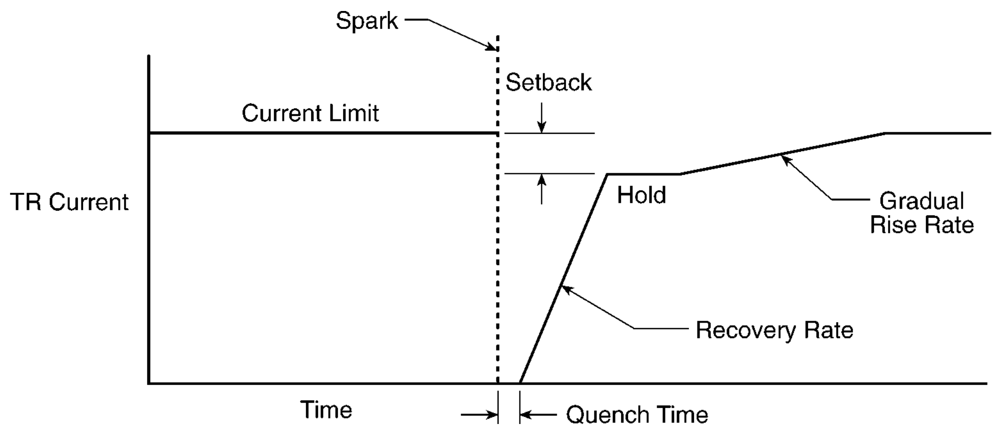


Figure 4-12
AVC Spark Response

After the setback level is reached, the system then can hold for a short period of time and/or start a slow rate of power increase that is referred to as *slow ramp* (or rise rate/ramp rate). The slow-ramp time, which is the time that the system will take to fully recover to the previous spark-over level, is typically several seconds. The slow-ramp time indirectly determines the system spark rate for systems that have relatively constant operating parameters (that is, gas flow). A slow-ramp time of 10 seconds would therefore result in a spark rate of 6 times per minute, while a slow-ramp time of 5 seconds will result in a spark rate of 12 times per minute. Some modern controllers permit the user to enter the desired spark rate and the AVC will normally adjust the slow-ramp rate to achieve the programmed spark rate. The methods and algorithms used to detect and respond to sparks can be quite different between manufacturers. The sign of a good control is one that can detect all of the sparks and respond to them per the description in the manufacturer's manual. The response may be to ignore sparking, or it may be to shutdown the power for a long period, but regardless, the controller should be operator adjustable for the desired response. If the parameters are not adjustable, or the AVC misses sparks after tuning, the control should be replaced to properly protect the equipment.

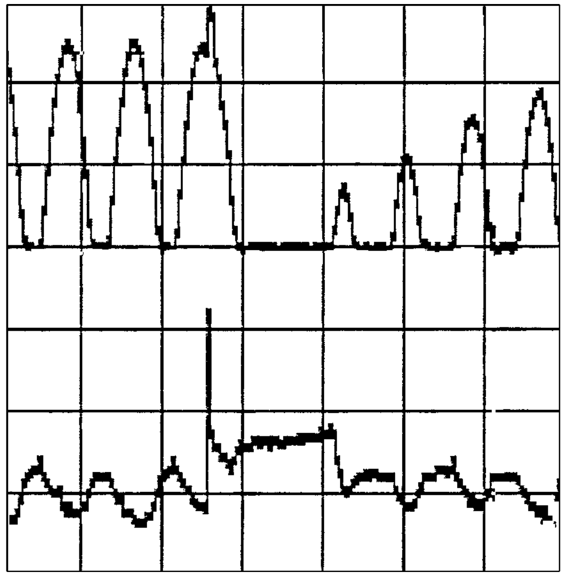


Figure 4-13
Scope Trace of a Typical AVC Spark Response

4.1.2.3.3 Spark Rates

The proper spark rate and response method will also be dependent on the ESP's internal conditions. Since the spark is actually a short circuit of a capacitor (the ESP field), progressive damage to the internal components can develop from the stored energy being release at one location. If the sparking is caused by the dust buildup and/or is related to dust resistivity, then the sparking should be random throughout the ESP field with each spark blasting the mound of dust that attracted the discharge. This kind of normal sparking will result in minimal-to-no damage. However, if the sparking is localized due to reduced electrical clearances, then repetitive spark over can lead to erosion damage that can eventually lead to failure of a discharge electrode. Spark rates should be kept low where damage is known to exist and can be higher where the sparking is random. In sections where the field is small (less capacitance) or the CLR is large (more impedance), spark rates can be higher. Overall, it is a good idea to taper spark rates down from inlet to outlet and to keep rates low in the outlet fields to minimize the dust reentrainment caused during the spark. Table 4-3 should be used as a guideline.

Key Technical Point

Overall, it is a good idea to taper spark rates down from inlet to outlet and to keep rates low in the outlet fields to minimize the dust reentrainment caused during the spark.

Table 4-3
Suggested Spark Rates

Condition	Range of Sparks per Minute
Location of field	Taper number of sparks from inlet to outlet more to less
Large size of the TR set	Low - No more than 30 if on the inlet field
Large area of collector surface per TR set	Low - No More than 30 if on the inlet field
Small TR set on a small sized field	High spark rates (under 60)
Outlet field	Minimum number of sparks/min

4.1.2.3.4 Spit Sparking

Spit sparking is a spark that occurs between two components that are in contact, but are at slightly different voltage potentials. The difference in voltage happens because there is a slight resistance between the components, or there is a poor connection between them. The spit spark can occur when the ESP is discharging after the SCR is off and, in some cases, the controls pick up the discharge as an actual spark and respond to it.

The main difference between a spit spark and an actual spark would be that there would be no large drop in voltage when a spit spark occurs. There is no large voltage drop because there is not a short circuit created to ground when a spit spark occurs. This is why kV spark detection is felt to be more accurate since it will not pick up spit sparking by accident. Most controls that use the mA signals to detect sparks try to differentiate between a spit spark and a spark by either using amplitude of the spark or the time the spark occurs. Typically, low amplitude sparks, or sparks that occur when the SCR is not conducting, are recognized as spit sparks.

Spit sparking can also occur when a real spark (a short circuit) in the ESP occurs. The stored capacitive energy in the discharge electrodes is quickly discharged to the short point (spark point). This energy can jump across a poor connections, making a slight spark that erodes the metal at the poor contact points. As the high frequency spark energy makes its way to ground, it will spit spark across the poor connections on the high voltage components, collecting plates, and other parts of the ground grid. Think of it as similar to the spark that you see across a welder's cable connections when a welder first strikes an arc; a spark can occur across the output of the welding machine or the ground connection. This type of repetitive sparking can eventually damage the equipment to the point of failure. This is typically seen on shrouds, wire support pins, high voltage frames, wire retainer rings, and any other mechanical, HV connection. This type of sparking can also be seen on the ground systems at the rapper-rod penetration (from the rod to the casing), at the rapper grounds, and across the bus duct connections. If this type of damage is seen during the internal inspection, it would be best to minimize sparking until the internal connections can be improved to stop the spit sparking. Spit sparking on the ground grid components can generate a large amount of noise that can interfere with the operation of the AVC and rapper controls. In the worst cases it can damage the controls.

Key Technical Point

This type of repetitive sparking can eventually damage the equipment to the point of failure. This is typically seen on shrouds, wire support pins, high voltage frames, wire retainer rings, and any other mechanical, HV connection. This type of sparking can also be seen on the ground systems at the rapper-rod penetration (from the rod to the casing), at the rapper grounds, and across the bus duct connections. If this type of damage is seen during the internal inspection, it would be best to minimize sparking until the internal connections can be improved to stop the spit sparking.

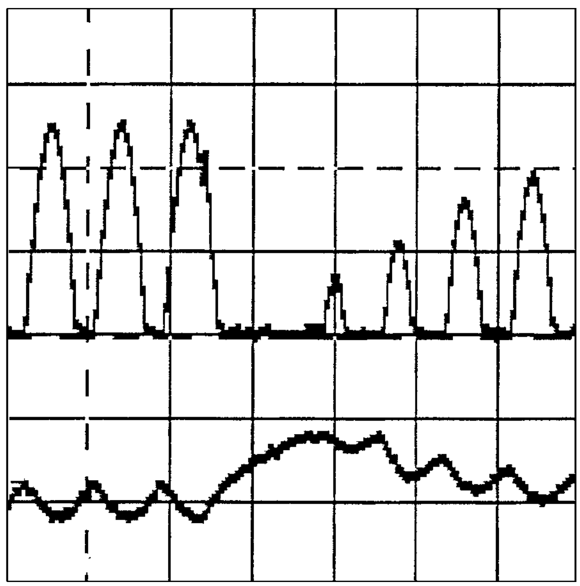


Figure 4-14
Example of the Control Responding to a Spit Spark. (Notice There Is No Sudden Drop in the kV Signal.)

4.1.2.4 Advanced Control Functions

4.1.2.4.1 Back Corona Detection

Back corona is a phenomenon that results in a large discharge of positive ions from the collecting surface with no spark-over location standing out to cause a localized short circuit. Back corona is not a very common problem but does occur when very high resistivity ash is on the collecting plates. A detailed discussion of how to identify back corona is covered in Section 3.2.

Most controls have some type of automatic back corona detection algorithm that uses a V-I curve. It is generally accepted that the *fold back* of the V-I curve characterizes the back corona condition. That means that a point will be present in the V-I curve where voltage actually decreases with increased current level. Some systems use this characteristic and periodically perform a V-I curve to detect its presence. Other systems sample the kV waveform for the presence of back corona by looking at the kV minimum, kV average, and kV peak. The point the kV minimum stops increasing is the point where the back corona starts. This detection method can determine the starting point more accurately than controls that use the average kV. In the event that back corona is detected, system performance can sometimes be improved by either operating at the *knee* of the V-I curve or using intermittent energization (IE). Most controls will automatically start IE or limit the control to the knee of the curve and periodically run a V-I curve to determine if the back corona condition still exists.

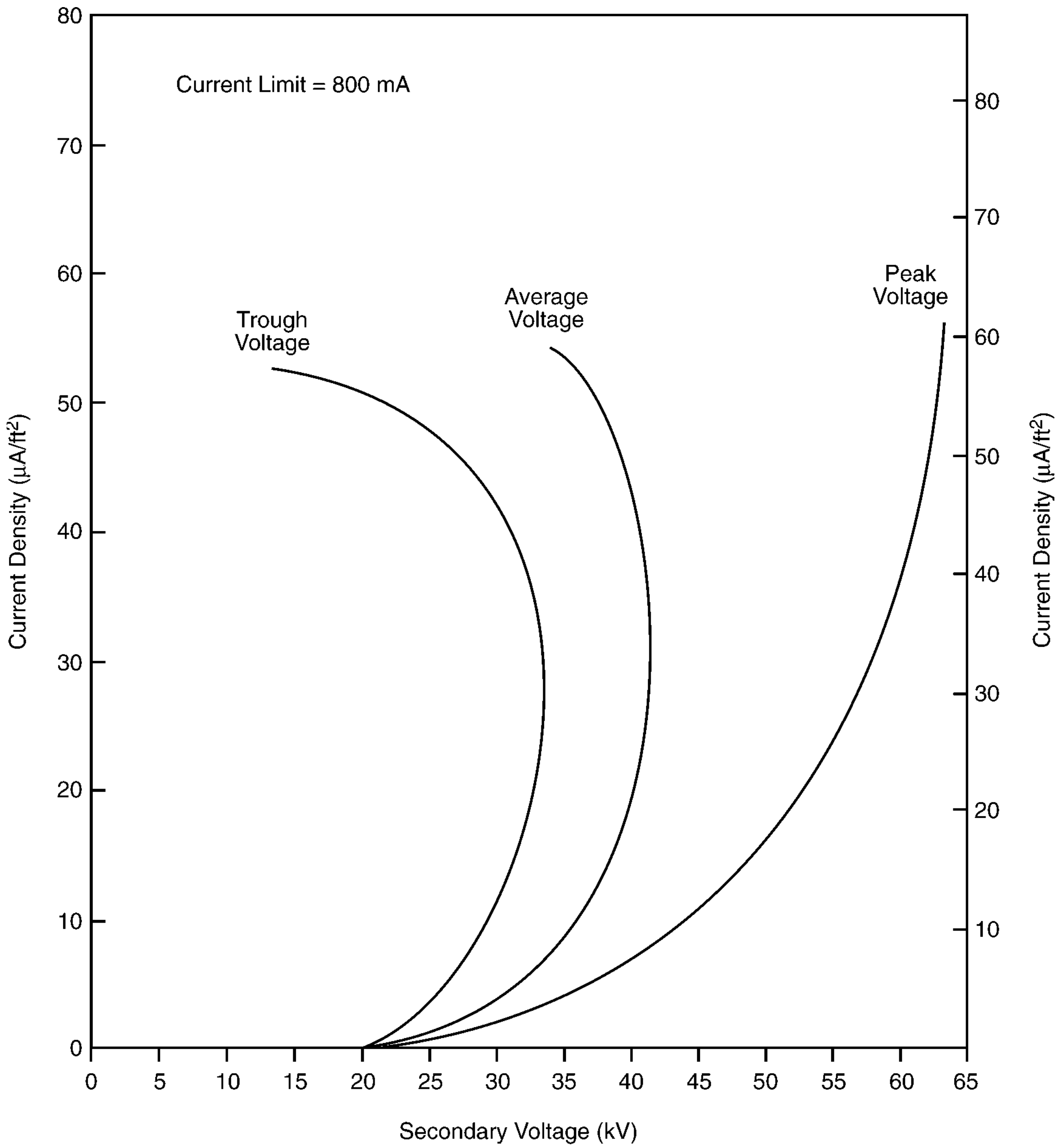


Figure 4-15
V-I Curve of a Back Corona Condition

4.1.2.4.2 Intermittent Energization - Semi-Pulsing/Pulse Blocking

Intermittent Energization (IE), also referred to as *semi-pulsing* or *pulse blocking*, refers to a method of powering the TR with pulsating power. This method applies power for one or more half-line cycles, then blocks power for a varied period of time. Pulsing of this type has proved to be effective in improving performance under unique conditions such as extreme back corona. It has also been used to save power by allowing cycles to be blocked. It is important to always operate the *OFF* cycles in full cycles (multiples of two half cycles) so as to always operate the

CLRs and TRs in a balanced condition and preventing damage of these components. *ON* cycles can be any count. Most controls only allow full *OFF* cycles to protect the equipment.

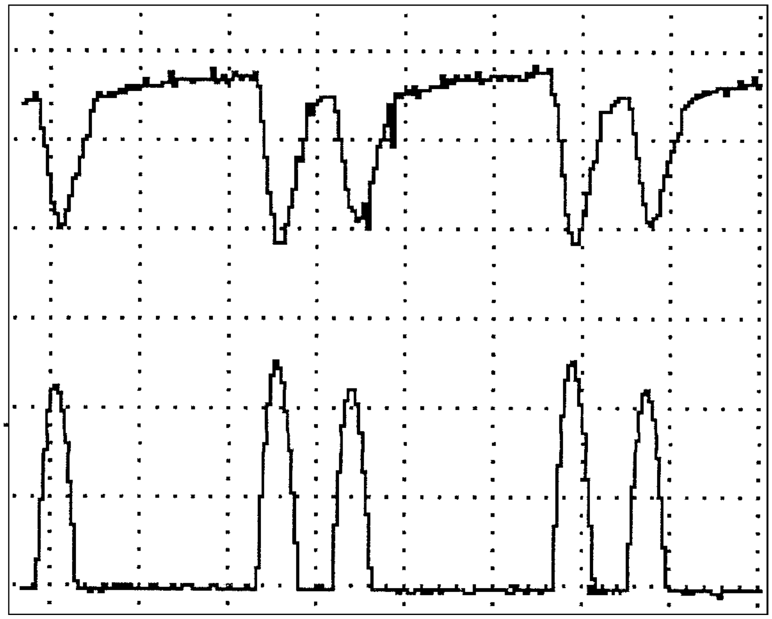


Figure 4-16
Example of IE Mode (Two Half Cycles *ON*/Two Half Cycles *OFF*)

4.1.2.4.3 Lay-Down or Process-Sense Response

Lay down of an ESP field refers to a condition that can occur as a result of heavy sparking caused by a sudden severe change in the process conditions. This would include soot blowing, mill startups, heavy rapping, tripping of a field, or anything else that would cause a dramatic increase in sparking. The heavy sparking normally drives the kV levels down in that field, which, under normal slow-ramp rates, might take minutes for the control to return to full power. Many modern systems have provisions to sense and recover from such events by changing the slow ramp to a faster ramp in a programmable time frame.

4.1.2.4.4 Power-Off Rapping (POR)

Applications with high resistivity and/or sticky ash may benefit from occasional rapping of the collecting field with the TR power either removed or reduced. Typically, to do this, both the rapper controller and the TR controller must be from a common supplier and connected in conjunction with a central control and monitoring system. Other suppliers offer external inputs that can be used to turn off the controller for a period while a power off rapping (POR) sequence is initiated externally. See Section 4.1.4 for a detailed description of this feature.

4.1.2.4.5 Digital Signal Processing Waveform Capability

Digital signal processing (DSP) is a technology that uses rapid sampling of a signal and then thorough computer processing. DSP has been used on ESP controls to ascertain the actual conduction angle, to determine the capacitance of the field by measuring voltage decay on the kV signal, and to detect presence of back corona. The most popular use of DSP, however, is to permit an operator to observe the actual waveform of the ESP voltage and current signals at the DMS without the need for an oscilloscope.

4.1.2.4.6 Fault Memory Readout

Many modern controllers include non-volatile memory systems to allow the recording of conditions of the field just before a fault or trip occurs. This feature is very useful for troubleshooting after an unusual occurrence that results it a system trip.

4.1.2.5 Startup Procedure

The following is a general procedure for starting up an AVC. The manufacturer's manual should be reviewed for specific instructions.

1. Check the cabinet for loose connections and proper wiring.

2. Verify that the feedback-resistor values are consistent with the ratings of the TR and the ratings of the control circuitry. Be aware that the peak voltage levels on the mA signal can be multiple levels higher than the peak level per the TR rating when sparking occurs.

3. Verify that the proper ratings of the TR are entered into the AVC, or have been adjusted in an analog control.

4. Check external alarm inputs.

5. Operate the TR in a short-circuit condition and verify the over-current and under-voltage trip functions.

6. Use a true RMS meter on the feedback signals and verify that the analog meters are correct, that the AVC feedback signals are calibrated, and the digital readout is accurate. Normally, the controller should be set to below spark-over level to get stable readings.

7. During initial startup, hook up a storage scope to the mA feedback and slowly bring up power in a manual mode. Set the scope to trigger on a spark and observe that the controller reacts correctly.

8. Run up to maximum operating levels and use a scope to observe the conduction angle (percent conduction) on the secondary current. The system should run with some minimum *OFF* time for proper control capability (normally no less than 15% of the total cycle time).

9. Run a V-I curve and record the meter readings for each console and put the readings in the ESP logbook.

4.1.2.6 AVC Console Maintenance

The AVC controls require minimal routine maintenance. Table 4-4 is a basic list that should be followed. Consult the manufacturer's manual for any special items.

Table 4-4
Minimal Requirements for AVC Control Routine Maintenance

Frequency	Procedure
Daily	Record the meter readings and verify that there are no alarms.
Monthly	Verify that the analog meter matches the digital meters and the remote DMS or DCS values.
Quarterly	Check the cabinet filters and change as needed.
Annually	Perform an air-load test. Check with the manufacturer for software upgrades. Verify and record all AVC parameters. Check and calibrate all of the feedback signals. Inspect the cabinet wiring for loose connections. Thermally scan the cabinets checking for poor connections. Inspect and clean the CLR and check for loose connections. Inspect and clean the TR and check for loose connections. Megger test the feed cable to the TR ground. Check the dashpot fluid (where used for over-current protection).

4.1.2.7 AVC Troubleshooting

4.1.2.7.1 Detection of Problems by Panel Meters

The symptoms and potential causes listed in Table 4-5 address the most commonly found problems in precipitators. The control panel meters will reflect the subtle and sharp changes that might occur internally within the precipitator. The problems considered here are confined mostly to equipment rather than those caused by general gas or dust conditions. The AVC manual should be checked for a list of control specific problems.

Table 4-5
AVC Troubleshooting: Symptoms and Possible Causes

Symptom		Possible Causes
1.	No AVC power	No console power or blown fuse Bad control cards Loose cable connections Key interlock open
2.	No voltage No current	No power or blown line fuse Tripped overload circuit Safety-interlock circuit (open relay contact) Improper control setting Key interlock open SCR phasing is reversed
3.	Full power at start-up	SCR phasing is reversed Shorted SCR Control malfunction
4.	Low volts and kV (about half rating) Noisy CLR High primary current Low secondary current	One SCR is not operating Control is malfunctioning One out of two SCR fuses are blown
5.	Primary voltage and no primary current No secondary voltage No secondary current	Open circuit in line to TR primary Open circuit in the TR
6.	High voltage and no current	Open circuit in TR Open circuit between TR and internal bus section Improper control settings or feedback
7.	Low voltage and high current	Wet insulators Dirty insulators Partial bridging Heavy buildups on plates Improper control settings High resistivity dust
8.	Low voltage, high current, and heavy sparking	Swing discharge electrode Swinging lower rack Cold air in-leakage near a high voltage area Poor clearances Heavy dust buildups

Table 4-5 (cont.)
AVC Troubleshooting: Symptoms and Possible Causes

Symptom		Possible Causes
9.	No voltage (or very low voltage) and high current	Broken wire Dust buildup in hopper Broken or wet and dirty support insulators Short circuit in the TR Dust bridging across electrodes
10.	Low power input	Poor clearances High resistivity dust Faulty or improperly set controls
11.	High voltage, but low current	High resistivity ash Heavy buildup on electrodes Improper control settings Poor clearances High particle concentration Poor TR load match
12.	Poor electrical control: - Sluggish ramping - Heavy continuous sparking - Frequent overload trip outs	Faulty automatic control Improperly set controls Ash buildups or bridging Poor clearances
13.	Repeated (rhythmic) heavy sparking	Broken electrode Loose collecting plate

4.1.2.8 Upgrading the Controls

There are several reasons to upgrade the AVCs. Usually, it is because additional performance is needed out of the ESP. Poor service ability, lack of spare parts, need to connect the controls to a DMS, or the need to add power off rapping are other typical reasons to upgrade the controls. It is a good practice to evaluate several manufacturers' controls at the plant site prior to making a decision. The controls should be evaluated under different operating conditions. Things to consider when evaluating and retrofitting controls:

- Are the controls compatible with the existing equipment? Are the controls used on another ESP at the same plant? Compatibility will reduce costs and spare parts.
- Are the controls user-friendly? Can the plant personnel easily adjust the AVCs and understand the AVC manual.
- Cost can be a major factor if a large amount of controls are needed. However, performance and reliability should take precedence over cost. Additionally, if the controls are not user-friendly, then they will not be used, effectively reducing any performance benefits.
- Is the control well supported by the manufacturer?
- Can the control be easily interfaced to the rapper panel and plant DCS?

- Are the AVC manufacturer's rapper panel and DMS user-friendly?
- Does the ground grid need to be upgraded to reduce electrical noise? Digital controls can have trouble from noise on the ground and through the ac feed.
- Are the TR feedback cables shielded? Shielded cables are normally needed with new controls. In some cases, it is necessary to run temporary shielded feedbacks and communication wiring to properly evaluate a control.
- The analog panel meters should be left in service. The panel meters, by virtue of their reading and meter movement, give a wealth of information about the controller performance that trending and digital meters can not.
- Verify that the SCR drive signal of the controller is compatible with the SCRs in use. Insufficient gate energy will result in misfiring and early failure of the SCRs. Excessive gate energy will result in early SCR failure due to excessive gate heating.
- If a contactor is not present, give careful consideration for the need to add an external contactor. Be mindful that in the event of an SCR failure, the contactor can be used to remove power before tripping a circuit breaker.

4.1.2.9 Tuning the Circuit and Controls

There are many components in the ESP system that can affect the ESP's performance and that can be used to improve performance. The proper sizing of the CLR and TR and the tuning of the AVC controls are key to improving the input voltage to the ESP.

4.1.2.9.1 CLR Sizing

Matching the power supplies to the operating load can enhance ESP performance. Mismatching may be a result of improper original design or from changes in operation since initial startup. Power supply mismatch occurs when operating and rated current levels are significantly different. When operating at low voltage levels, the AVC keeps the firing angle of the SCR at a low level, allowing more time for the kV signal to degrade. This reduces the average electric field (kV) applied to the particle. Low current levels cause the current conduction time to be reduced, decreasing the time ions are being discharged into the gas stream and through the dust layer. This may also reduce particle charging, corona distribution, and/or reduced bonding force of the dust layer, dramatically affecting ESP performance.

The maximum current conduction time should be 85% of the normal ac cycle. Typically, it is determined by the TR design and the CLR sizing. A mismatch can sometimes be corrected by adding more impedance by changing the CLRs. Some CLRs are equipped with taps that can be used to change the impedance. Other options are to connect another CLR in series or to purchase a new properly sized, tapped CLR to optimize the impedance in the circuit. Some suppliers also offer variable CLRs (VI-CLR) that optimize the impedance continuously for the operating conditions. If the impedance (CLR) in the circuit is changed, it is important to derate the current limits so the circuit cannot exceed an 85% current conduction time. As discussed earlier in this section, if the capacitance in the circuit is high, it is possible to lose control of the SCR gating if the current conduction time exceeds 85%. This can cause the ESP to power arc uncontrollably, damaging the equipment. Changing the TR size or switching the primary taps on multi-tap TRs are other methods used to optimize the voltage and current waveforms. When primary volts are low, the TR primary tap settings should be changed to open up the SCR more to increase the voltage conduction time. Adding impedance can serve the same purpose since additional impedance will create more voltage drop across the CLR, causing the SCR to open more.

The reactor should be sized for 50% impedance to provide about 85% current conduction times at the operating current.

Table 4-6
Typical CLR Sizes for 50% Impedance, 480 V, 60 Hz System

Rated Secondary dc Current (mA)	Size of Reactor (Millihenries)
250	13.0 ± 10%
500	7.5 ± 10%
750	4.5 ± 10%
1000	3.3 ± 10%
1500	2.2 ± 10%

Actual sizing of the reactors will depend on the operating voltages and current levels. It is important when selecting a CLR to avoid sizing the CLR at the present operating levels since adding the CLR (more impedance) should improve performance and increase current levels. It is a good idea to experiment with one CLR to evaluate the effect, or try to series a spare CLR before purchasing new CLRs for all of the TRs. Normally, if there is an improvement in the inlet fields, no CLR change is needed in the outlet fields. It is always recommended to install tapped reactors that offer a wide range of impedance to allow the impedance to be decreased if ESP performance improves as a result of the additional impedance, or as a result of other system improvements. It is also advisable to use an oscilloscope to set the current limits on the AVC so the operating levels do not exceed 85% current conduction time.

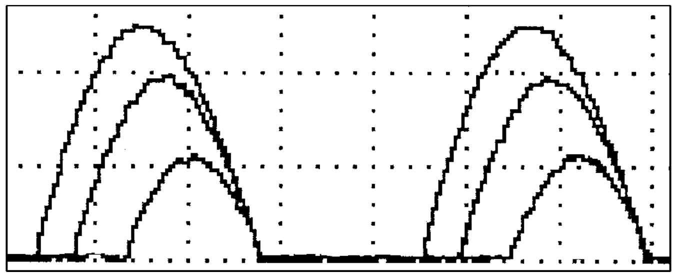


Figure 4-17
Example of the mA Waveform at Different Current Conduction Times

4.1.2.9.2 AVC Adjustments/Tuning

Each manufacturer has different features and they use different terminologies, and methodologies of control. Sparks are sensed by all controls by either rapid rise in mA level and/or a rapid drop in kV level. Based on one or both of these inputs, the AVC control determines the best way to gate the SCR to control and optimize voltage levels and to protect the equipment from damage. It is important to realize that optimizing performance does not always go hand in hand with protecting the equipment. Many AVC controls can be set up to improve ESP efficiency at the expense of damage to the ESP internals or electrical equipment. It is interesting how such a variety of control philosophies can be developed for basically two feedbacks (and most times only one is used) and one output.

Optimizing the controls and control adjustment were mentioned earlier in this section and in Section 3.2. The following discussion is made in an effort to summarize the basic approach that maintenance personnel should take when tuning the AVC. The section that follows includes several examples of different manufacturers control methods. Tuning the controls can be an art in itself but fortunately there are only a few basic parameters that should be adjusted and beyond that most of the modern controls can automatically control spark rates. Spark rate control generally works well. Normally, the best starting point to optimizing the controls is to set up a spark rate that decreases from inlet to outlet.

The first step to system tuning is to determine if the AVC has good spark detection. If the control does not detect the sparks correctly, then optimization cannot be done very well. The control should be checked with an oscilloscope to insure that it actually is detecting a spark. If not, the manufacturer's manual should be checked on how to adjust the spark sensitivity. In some cases, it may be necessary to make modifications to the kV or mA input filter network to change the sensitivity (this would normally require help from the manufacturer).

Once the spark is detected, the second step is to determine the best response. Options include:

- Do nothing. This can work well if the sparks are self-extinguishing or if the majority are spit sparks. In most cases, this can cause damage to wires or in the fields that have known alignment problems. But in some cases, it is the only way to keep the voltage up in the ESP and the opacity down.
- Setback or phase back the controls at some percentage to prevent spark over at the same location (a restrike spark).
- Quench the voltage by shutting one off the SCRs for one to several line cycles. This is normally done to prevent a restrike if an arc is detected. The rate the voltage is increased after the quench to the setback is normally adjusted to prevent a restrike and to minimize the in-rush current needed to recharge the circuit.
- Once a setback is reached, the control normally slowly increases the voltage until a TR limit is reached or until another spark over occurs.

The purpose of all of these adjustments is to increase the applied voltage to the field, maintain the applied voltage without causing a spark restrike to occur, and/or to prevent localized damage. This would mean evaluating the controller's response and tuning or adjusting the response parameters correctly. This should only be done by a qualified person using an oscilloscope. Once the initial calibration and set up is completed with an oscilloscope, minor adjustments can be made without using an oscilloscope. Typically, the control would be adjusted with less % setback and faster slow-ramp rates in the inlet and more % setback and slower slow-ramp rates in the outlet, proportionally changing these values from the inlet to the outlet. This would result in higher spark rates in the inlet with the spark rate decreasing from the inlet to the outlet.

If there is suspected or known damage in a field, spark rates should be kept to a minimum in that field. If the controls are allowing spark restrikes or if arcing is occurring, the spark rates should be kept to a minimum to protect the equipment. In larger ESPs or in systems that operate at low opacity levels, spark rates should be minimal to reduce damage. Some controls offer several different preprogrammed spark adjustments that allow the controls to be changed easily to compensate for startup, soot blowing, low load, or high opacity conditions. Most of these changes can be made from the AVC interface, remotely from the DMS, or initiated automatically from the DCS. Ultimately, it is important to adjust the controls for a stable operation that can handle a variety of process changes. This can be done by monitoring and evaluating the AVC's performance under different operating conditions. This is most easily done by collecting power readings regularly, or by trending the controls against different operating parameters to see what affects the AVC operations.

4.1.2.9.3 Discussion of Typical AVC Spark Responses

As stated earlier, each AVC manufacturer has its own unique methodology for responding to sparks. The waveforms on the following pages show several different approaches. The waveforms represent the precipitator's peak-current waveform versus time for various programmable parameter settings. These waveforms can be duplicated on an oscilloscope with single sweep and storage capability by connecting the positive scope lead to the mA input terminal on the AVC or the panel meter, and the scope ground to a cabinet ground. These waveforms show the envelope of the secondary current signal.

The following list of terminology is needed to understand the following examples:

- **Pedestal rate:** is the rate at which the power is reapplied to the precipitator after each quench. The pedestal rate is a programmable parameter. The rate is the number of cycles to recover from zero to the equivalent phase back level.
- **Phase back:** is the amount of power reduction that takes place after each spark occurrence. The amount of phase back is programmable.
- **Process-sense circuit:** monitors the time between sparks and arcs. It automatically overrides the ramp function if a spark or arc does not occur within a programmable period of time from the last spark or arc occurrence. This control feature assures stable and rapid recovery after a process upset has subsided.
- **Quench mode:** refers to a type of spark response where the control will only quench for specific conditions: *Arcs Only* or for *Sparks and Arcs*.
- **Ramp rate:** is the rate at which the precipitator power increases after a phase back. Power recovery starts from the phase back level and continues at the ramp rate until either the current or voltage limit is reached or a spark or arc occurs. The time programmed for the ramp rate is the time it takes the power to increase from the phase back level to pre-spark current level.
- **Spark rate control:** allows a specific spark rate to be programmed into the control. The control will then automatically readjust itself to maintain a maximum spark rate equal to the programmed rate.

Waveform #1, Quench Mode, Arc Only, Pedestal Programmed to 1 Cycle

Starting in the upper left-hand corner, the precipitator current is at its maximum rating. The current is stable at this level until a spark occurs. The AVC senses the spark and within one-half cycle (8 ms) reduces the conduction angle of the SCRs, causing an almost instantaneous reduction in precipitator current. This current reduction after a spark is called the phase back. Phase back is a discrete key programmable parameter.

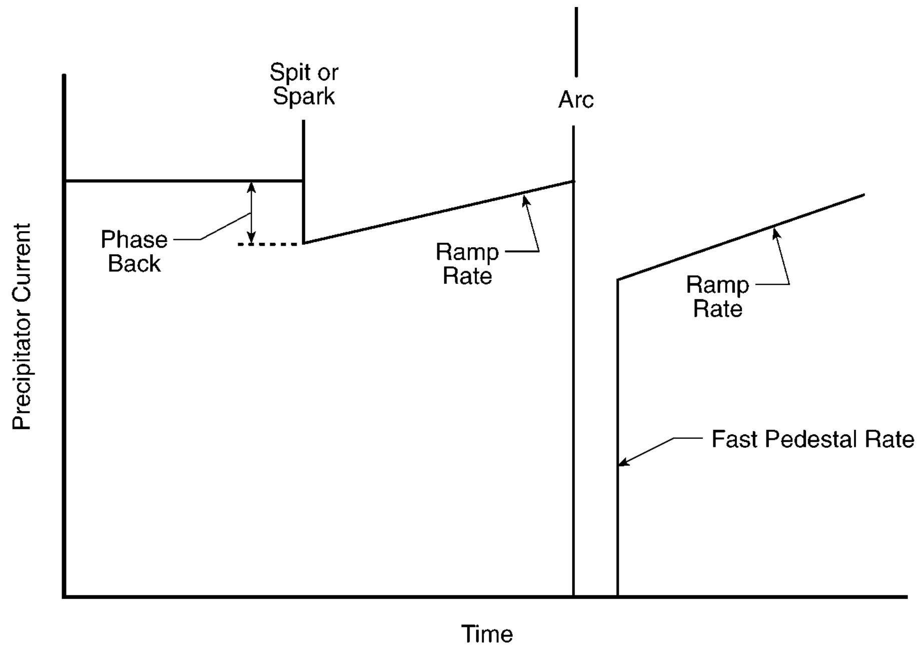


Figure 4-18
Waveform #1 - Quench Mode Arc Only

Within one-half cycle after reaching the phase-back current level, the AVC starts to increase current towards its rating by increasing the conduction angle of the SCRs. The period of time it takes for the current to increase from the phase-back level to the current level where the spark occurred is called the ramp rate. The ramp rate is a discrete key programmable parameter.

If an arc occurs in the precipitator, the AVC detects the arc and quenches the arc within one-half cycle by interrupting the firing pulse to the SCRs. This turns off the power to the precipitator for the programmed quench time, forcing the arc to extinguish. After the quench time, the SCRs are again turned on and the power increases to the phase-back level in the programmed 1 cycle pedestal rate. At the phase-back level, the rate of current increase is transferred to the ramp rate, which continues to increase the current, but at a slower rate. This control action repeats every time an arc and/or spark occurs in the precipitator.

Waveform #2, Quench Mode, Arc Only, Pedestal Programmed to 5 Cycles

This waveform is generated by the same parameter responses as described for waveform #1. The only difference is the pedestal rate is now longer than 1 cycle; it is 10 cycles.

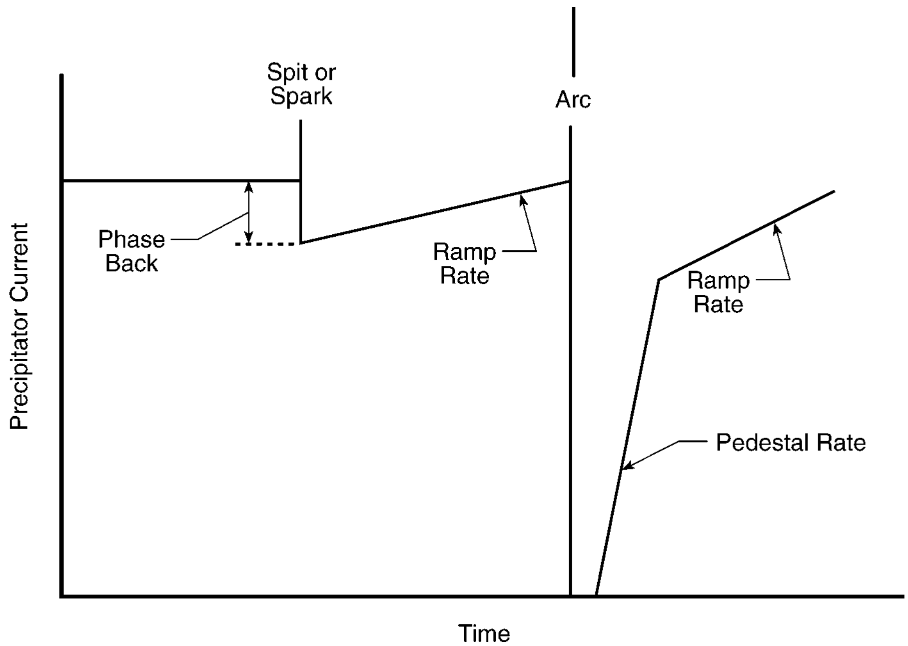


Figure 4-19
Waveform #2 - Quench Mode Arc Only

After a quench, the current is increased at a slower rate than in Waveform #1. The pedestal rate still transfers operation to the ramp rate at the Phase Back level.

Larger pedestal rates are used when heavy or repetitive arcing is present in the precipitator. Whipping discharge electrodes, arcing across insulator surfaces, or clinker formation on the discharge electrodes usually cause heavy or repetitive arcing. Programming the pedestal rate for greater than 1 cycle increases the time between arcs and allows the precipitator to operate at a longer time at reduced current rather than short bursts of higher current rapidly interrupted by arcing, sparking, and current quenches.

Waveforms #3 and #4, Quench Mode, Arcs and Sparks, Pedestal Programmed to 1 and 10 Cycles

These two waveforms show typical current waveforms when the AVC is programmed for a quench mode of both arcs and sparks. In this mode, each arc and spark initiates the quench time and turns the power off for the programmed time period.

If conditions within the precipitator are extremely severe and a great deal of sparking and arcing is occurring, operating in the *Arc and Spark Quench Mode* can reduce the wear on the electrodes.

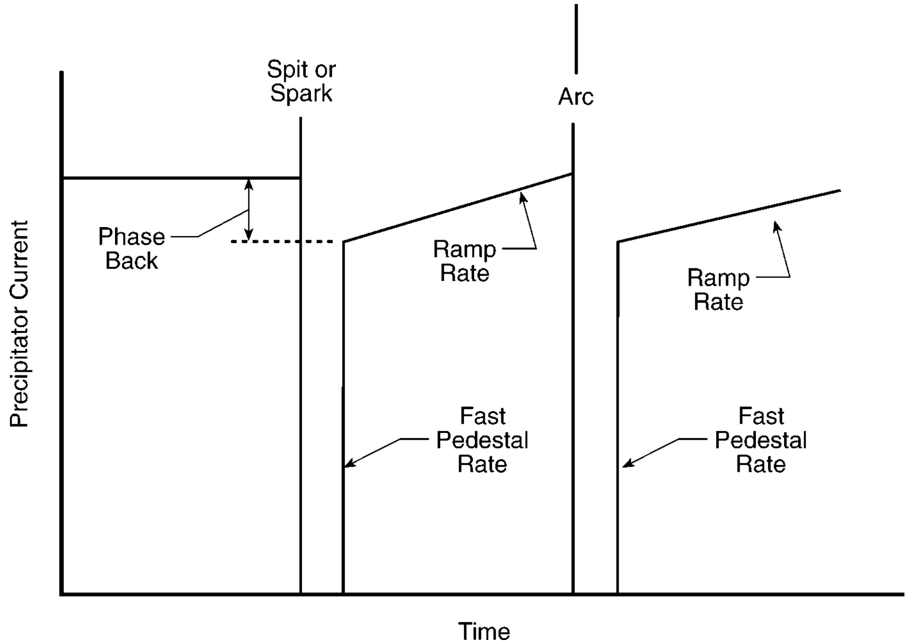


Figure 4-20
Waveform #3 - Quench Mode Arc and Spark

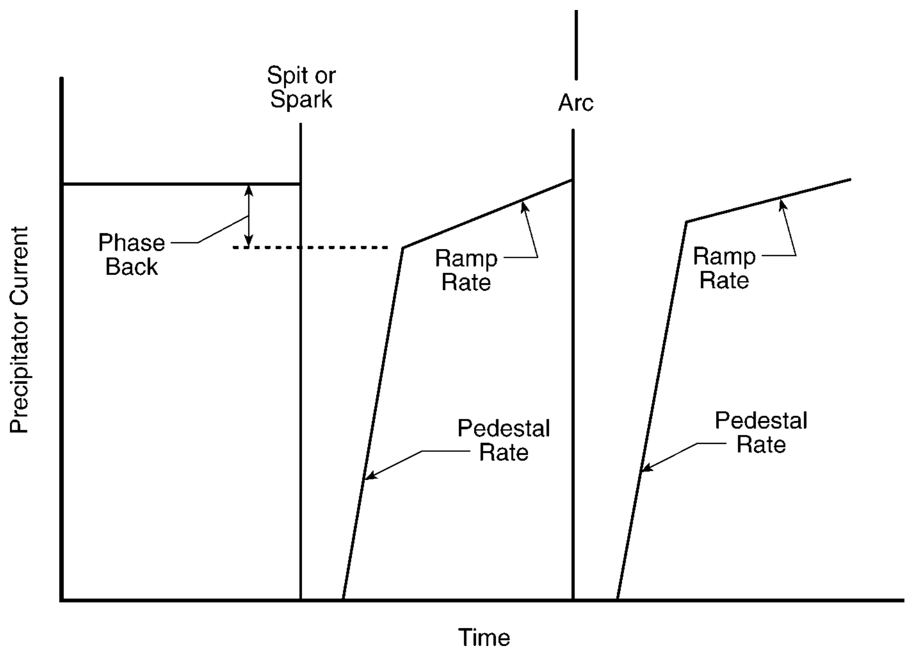


Figure 4-21
Waveform #4 - Quench Mode Arc and Spark

Waveforms #5 and #6, Automatic Spark Rate Adjustment with Sparking and Arcing

Using spark rate control allows the AVC to adjust the percentage phase back and the ramp rate differently for each electrical field within the precipitator. The least phase back and greatest ramp rate are in the inlet fields; and the greatest phase back and the least ramp rate are in the outlet field.

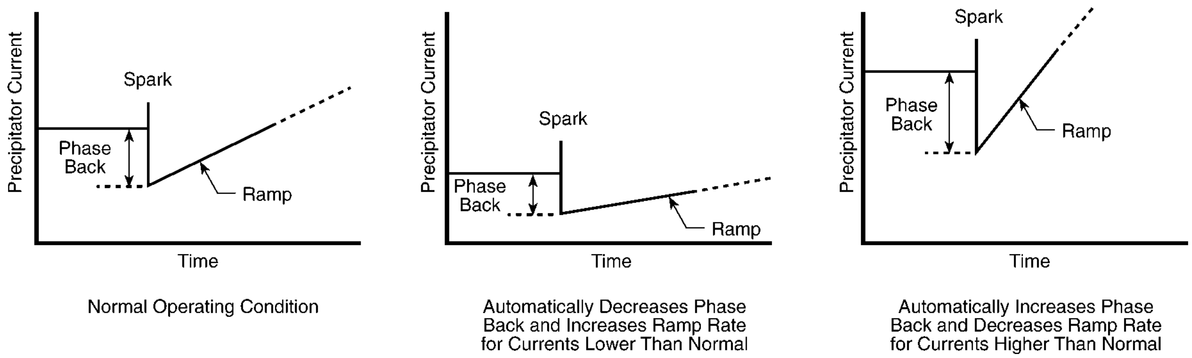


Figure 4-22
Waveform #5 - Typical Control Without Arcing

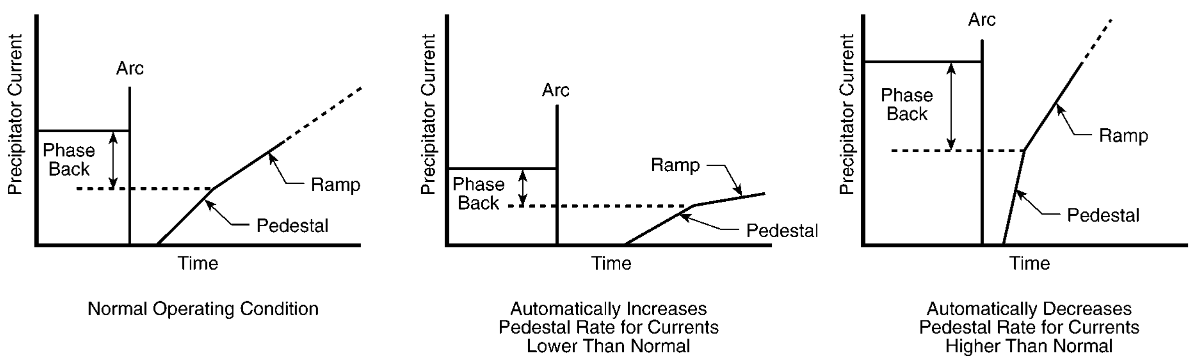


Figure 4-23
Waveform #6 - Typical Automatic Control with Arcing

The phase back, ramp rate, and pedestal rate are all referenced to current levels. As current increases, the phase back is automatically increased, the ramp rate is automatically decreased, and the pedestal rate is automatically decreased, based on a preprogrammed formula to control a specific spark rate. Conversely, as power decreases, the parameters change in the opposite direction.

Waveform #7, Typical Control Waveform

This control waveform shows the action and relation of phase-back ramp, quench, pedestal, and process sense. The leading part of this waveform shows the gradual reduction of precipitator current due to an upset operating condition. When an arc is encountered, the AVC quenches the current for a programmed quench time, then the pedestal is initiated and the AVC again tries to reach normal operating power levels. A spark occurs as the AVC attempts to increase current and the phase back and ramp go into operation. Sparking becomes more frequent and occurs at lower and lower power levels. The AVC phases back after each spark to establish a new operating level just below the threshold of sparking. Note that as the current gets lower, the amount of phase back decreases automatically.

After each phase back, the ramp rate tries to increase the current level back to maximum. However, due to existing conditions, another spark is encountered and the current phases back again. Notice that the slope of the ramp rate automatically decreases as the current level drops. If the process-sense time elapses and a spark has not occurred, a faster recovery rate takes over and rapidly increases the current level until either the current rating is reached or a spark occurs.

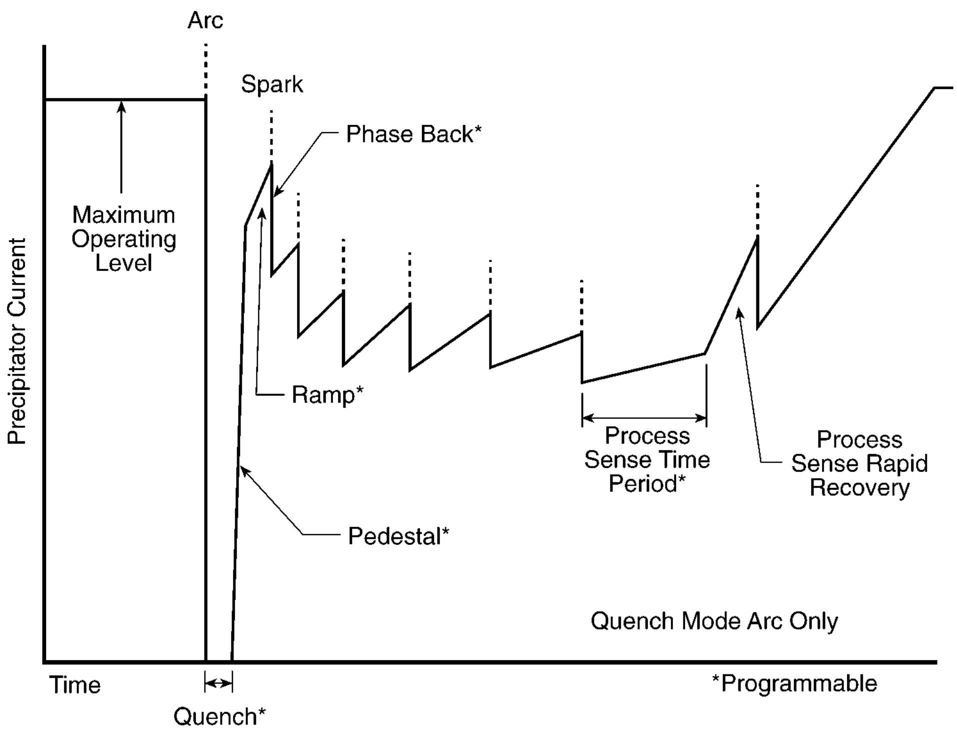


Figure 4-24
Waveform #7 - Typical Spark Cycle (Using Arc Only Quench Mode)

4.1.2.9.4 Alternate Spark Detection Methods

Some manufacturers quench on all sparks using different programmable modes to determine the spark response. Fast ramp, slow ramp, and spark rate are also programmable for each mode selected.

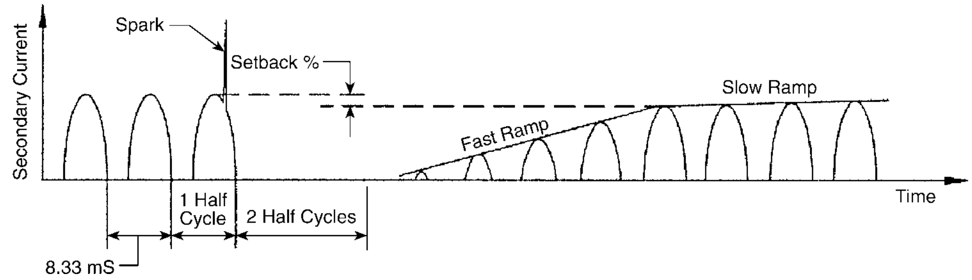


Figure 4-25
Mode 1: Quenches On Every Spark, Fast Ramps to the Setback Level, Slow Ramps to the Spark Threshold, and Counts One Spark.

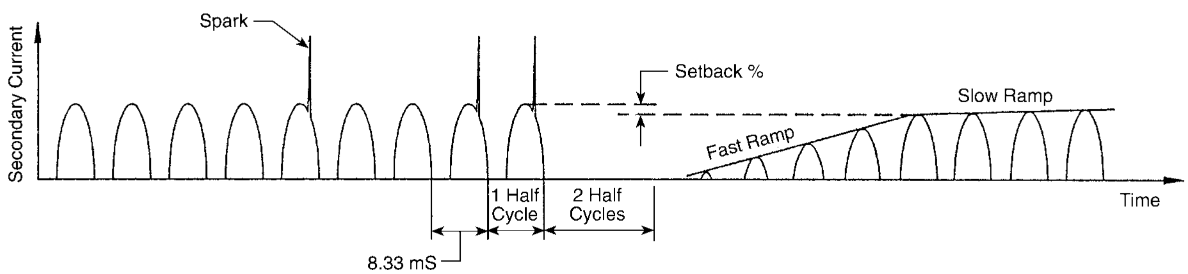


Figure 4-26
Mode 2: AVC Ignores the First Spark. If the Next Spark Occurs Within the Next One-Half Cycle, It Quenches, Fast Ramps to the Setback Level, Slow Ramps to the Spark Threshold, and Counts One Spark.

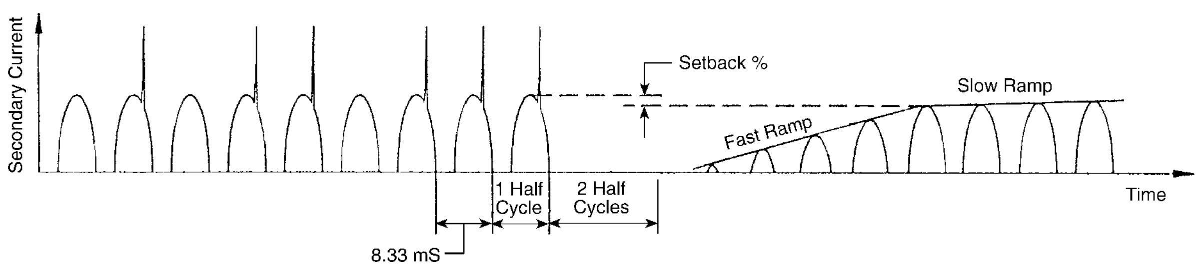


Figure 4-27
Mode 3: AVC Ignores the First Two Consecutive Half-Cycle Sparks. If the Next Spark Occurs Within the Next One-Half Cycle, It Quenches, Fast Ramps to the Setback Level, Slow Ramps to the Spark Threshold, and Counts One Spark.

Caution is recommended: Do not use Mode 2 or Mode 3 with a dual bushing TR Set operating in double-half-wave mode.

Mode 1 is normally used on ESPs that produce high intensity sparks. Mode 2 would be used if spit sparking was occurring with some high intensity sparks. Mode3 is used in cases of very low intensity sparking.

4.1.3 Rappers

The purpose of the rappers is to remove fly ash that has collected on the collecting plates and discharge electrodes as a result of the precipitation process. The collected material must be periodically dislodged for proper precipitator operation and performance. Failure to remove buildup on the collecting plates can lead to levels of ash buildup that reduce power input to the associated field(s). As the dust layer on the collecting plates increases, the voltage drop across the dust layer increases, which requires an increase in secondary voltage to maintain a constant secondary current. Material reentrainment back into the gas stream can also result from ineffective rapping of the collecting plates. Buildup on the discharge electrodes is generally less problematic. It is not thought to contribute much to reentrainment emissions; however, heavy buildup can inhibit corona generation and/or lower the spark-over voltage as clearances are reduced.

Rappers are also frequently used to minimize ash accumulation on the gas distribution media. Buildup of material on the gas distribution media can adversely affect performance by changing the gas distribution and velocity profile entering the precipitator.

A well-designed rapping system causes the fly ash that is collected on the collecting and discharge electrodes to be transferred to the hoppers without massive reentrainment of the ash back into the gas stream. Criteria that are important in a rapper to help meet this goal include:

- The rapper should provide the flexibility to adjust the intensity and frequency of rapping.
- The collecting surface area and discharge electrode area associated with a single rapper should not be so great that rapping is ineffective, or that rapping causes substantial material reentrainment.
- The rapper should have the ability to effectively transfer rapping energy. This will be influenced by the collecting surface and high voltage support assembly designs, location of impact point, and type of connection.
- The rapper should not cause damage to internal components.
- The rapper should be reliable, function with uniformity, require minimal maintenance, and operate for extended periods without undue operator attention.

Differences exist among precipitator manufacturers regarding methods and philosophy of rapping. American ESP manufacturers tend to favor the use of roof mounted rappers such as the electromagnetic impulse or vibrator type, whereas European manufacturers tend to favor mechanical tumbling hammer rapping systems that may or may not be located in the gas stream. There are advantages and disadvantages to each type of rapping system.

The more common types of rappers used in the utility application, their advantages and disadvantages, and some common problems that may be encountered with their use are discussed in the following sections. The discussion assumes that the designs of the ESPs do not assign too much collecting plate area to a single rapper and that the high voltage and collection surface assemblies are not so rigid that they inhibit rapper transmission. As a general rule, a single rapper should not rap more than 1500 ft^2 (139.4 m^2) of collecting surface area. However, there are many

ESPs that operate successfully that are exceptions to this rule. Rapping requirements for each unit will vary and may change with process conditions and the age of the unit.

> **Key Technical Point**
>
> **As a general rule, a single rapper should not rap more than 1500 ft^2 (139.4 m^2) of collecting surface area.**

4.1.3.1 Electromagnetic-Impulse Gravity-Impact Rapper

The electromagnetic-impulse rapper is the most widely used rapper on precipitators of American design. These top mounted rappers are sometimes referred to as magnetic-impulse gravity-impact (MIGI®) rappers, which is a registered trademark of the Hamon Research-Cottrell Corporation that has become the generic name for rappers of this type. Electromagnetic-impulse rappers are available in a variety of configurations from different manufacturers, but function similarly.

An electromagnetic-impulse rapper is a solenoid rapper that consists of a dc electrical coil in a sealed housing assembly and a steel piston. When the coil is energized, the piston is lifted. Rapping impact occurs when the coil is deenergized and the piston falls under the influence of gravity to strike a rapper shaft that transmits the force to the collecting plates/discharge electrodes/distribution plates. The weight of the piston and the distance it falls after being released from the influence of the energized coil (lift height) determine the rapping intensity.

> **Key Technical Point**
>
> **An electromagnetic-impulse rapper is a solenoid rapper that consists of a dc electrical coil in a sealed housing assembly and a steel piston. When the coil is energized, the piston is lifted. Rapping impact occurs when the coil is deenergized and the piston falls under the influence of gravity to strike a rapper shaft that transmits the force to the collecting plates/discharge electrodes/distribution plates. The weight of the piston and the distance it falls after being released from the influence of the energized coil (lift height) determine the rapping intensity.**

Several factors determine the lift height. They are primarily the ON time (number of line cycles) programmed by the rapper controller and the piston penetration in the coil. In order to achieve consistent, repeatable rapping, it is important to follow the manufacturer's recommendations regarding initial rapper mounting and adjustment. Many specify the visible piston exposure between the rapper rod and the bottom of the rapper (usually 4 in. [101.6 mm]) in order to assure the desired piston penetration in the coil housing. Tolerances are generally tight (± 0.125 in. [3.2 mm]) in order to produce consistent, repeatable lift.

The rapper must also be mounted correctly and be vertically plumb. Out of plumb mounting will accelerate wear of the coil and inner sleeve that guides the piston. The rapper is usually supported with all-thread rod from a mounting flange. A few manufacturers offer impact rappers that mount directly to the rapper rod. The rapper rod penetration of the precipitator needs to be air, water, and gas tight. A flexible boot seal is used for this purpose. Rappers on the HV frames are electrically isolated using rapper rods/shafts with an insulated section.

Wiring to rappers should use sufficient wire gauge to preclude excessive voltage drop on the feed wire. Number 14 American wire gauge (AWG) or number 12 AWG are typically used. The selection of wire size should take into consideration the length of the wire run and the peak current required for the rapper. Since in most installations only one rapper is fired at any given time, the return lines (neutral) can be bussed or daisy chained to reduce wiring costs. However, be aware that this limits future ability for simultaneous rapping, and problems can develop if there is a loose neutral.

Advantages:

The design is simple and reliability is high. Rapper intensity and impact frequency are easily adjustable from the controller, and lifts are verifiable. Pistons available in weights ranging from 8 to 20 lb (3.0 to 7.5 kg) provide additional intensity flexibility. External mounting allows on-line inspection, maintenance, and replacement. The rapper is available in 120 and 240 Vdc.

Disadvantages:

These types of rappers can only be mounted vertically. Rapper impact (piston lift) can be influenced by variations in coil temperature that occur as a result of changes in air temperature and the ability of the coil to dissipate heat. For programmed lifts of over 4 in. (101.6 mm) this is not likely to have a noticeable effect, however, for low lifts of 2 in. (50.8 mm) or less, this thermal effect can be an issue of concern. Magnetization between the piston and the steel rapper rod it impacts can develop that inhibits piston lift. Pistons should be fitted with a stainless steel tip, or a stainless steel impact anvil fitted over the rapper rod, to reduce any magnetizing force.

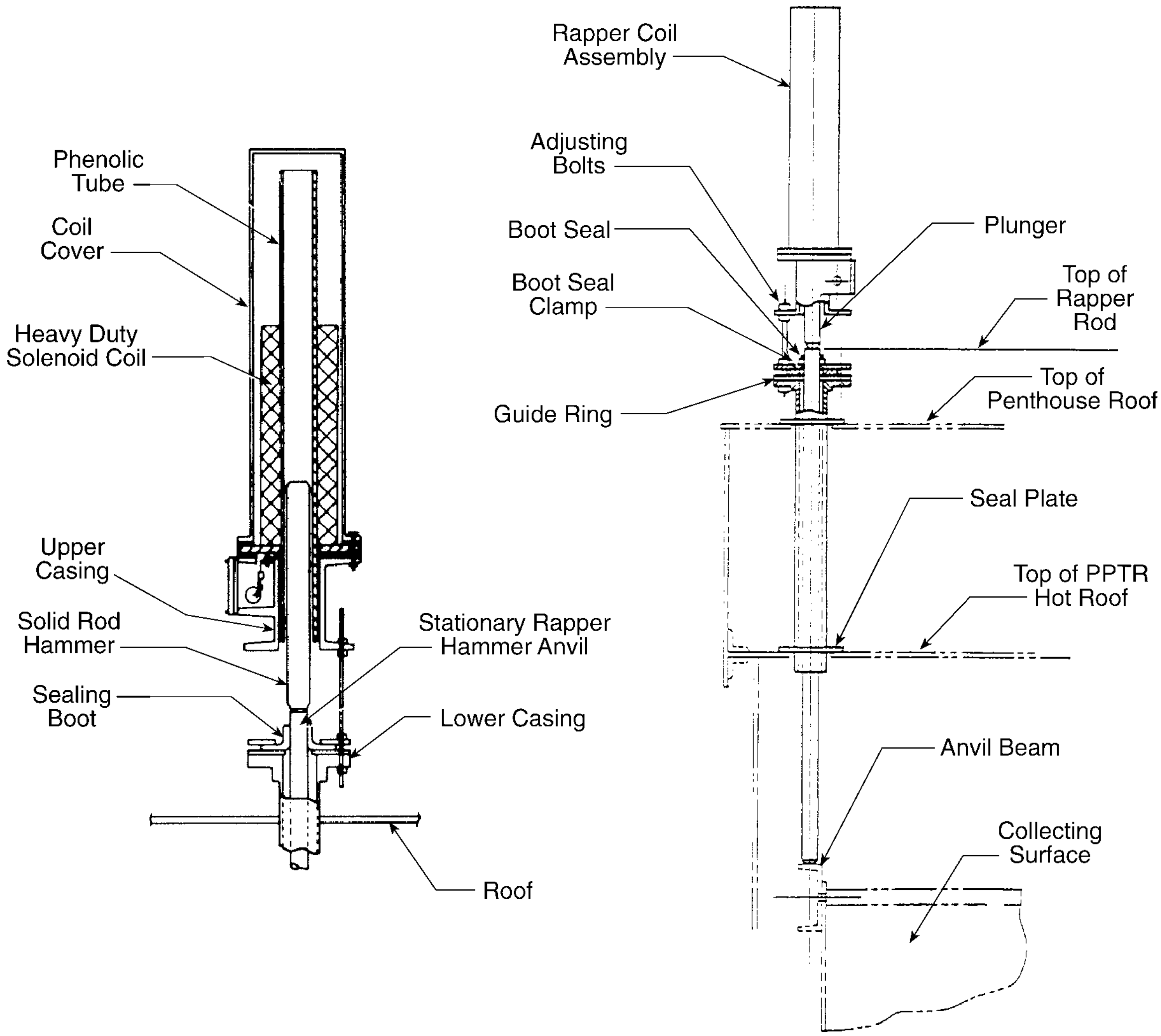


Figure 4-28
Electromagnetic-Impulse Gravity-Impact Rapper

4.1.3.2 Electromagnetic-Impulse Spring-Assisted Rappers

Electromagnetic-impulse spring-assisted rappers are very similar to magnetic-impulse gravity-impact rappers, except that they use a spring mechanism at the top of the piston/plunger travel. Spring-assisted rappers are typically shaft-mounted devices. The device operates by energizing an electric coil in the rapper housing that lifts the piston/plunger up to compress the top mounted spring. When power to the coil is removed, the energy delivered to the rapper rod is the sum of the gravitational fall of the piston plus the kinetic energy imparted from the spring.

Advantages:

The design is simple, it mounts directly to the rapper rod, and it can be mounted off vertical. Rapper intensity and impact frequency are easily adjustable from the controller. External mounting allows on-line inspection, maintenance, and replacement.

Disadvantages:

Fatigue or failure of springs make these rappers less reliable and uniformity of rapping less consistent than that offered by the gravity-impact rapper (although improvements in spring technology have minimized these problems). The springs also increase maintenance requirements as compared to the gravity-impact rapper. Not all manufacturers offer a means to verify lift. Since the coil and piston are encased within the rapper housing, visual verification of lift height is not possible. Like gravity-impact rappers, these rappers are subject to the influence of temperature.

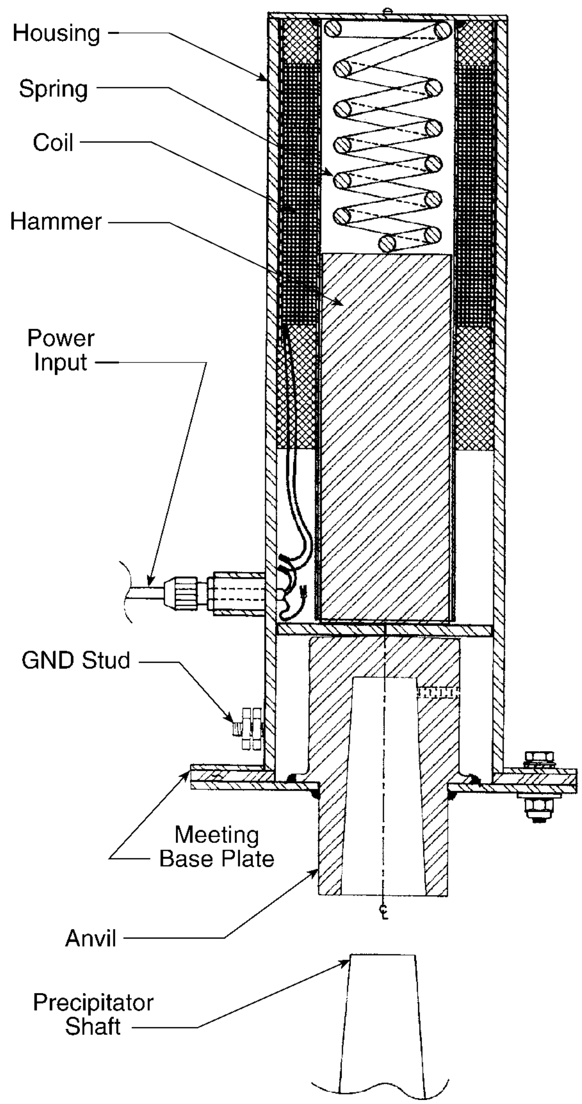


Figure 4-29
Electromagnetic-Impulse Spring-Assisted Rapper

4.1.3.3 Electromagnetic Vibrators

An electromagnetic vibrator consists of a balanced, spring-loaded armature suspended between to synchronized electromagnetic coils. When energized, the armature vibrates at line frequency. This vibrating energy is transmitted through a rapper rod to the electrodes. When employed for discharge electrode cleaning, an insulator is used as a section of the rapper rod in order to electrically isolate the high voltage from ground and protect personnel. This device is used mainly in the vertical position for discharge electrode wire cleaning. Control consists of varying the electrical energy input, which changes the amplitude of vibrations, the operation time, and the frequency of vibration.

Two types of vibrators have had wide usage. One is an ac vibrator, the other a dc vibrator. Usually, dc vibrators are used when rappers are fired in pairs to rap a common grouping of collecting surfaces or HV frame support points so that rapping of both locations is synchronized. This minimizes node oscillation of the internals that can cause damage. The ac type vibrators should only be used when energizing one vibrator at a time.

Electromagnetic vibrators were commonly used on weighted-wire design ESPs. In general, vibrators are high maintenance devices that have limited effectiveness. Their effectiveness decreases dramatically with the mass, height, and length of rapped components. They have largely been replaced by use of impact type rappers. Vibrators are still widely used on hoppers.

Key Technical Point

Electromagnetic vibrators were commonly used on weighted-wire design ESPs. In general, vibrators are high maintenance devices that have limited effectiveness. Their effectiveness decreases dramatically with the mass, height, and length of rapped components. They have largely been replaced by use of impact type rappers. Vibrators are still widely used on hoppers.

Advantages:

In most cases, vibrator intensity and duration and frequency of rapping are adjustable from the controller. Electromagnetic vibrators may prolong wire discharge electrode life by reducing the fatigue risk of impact rapping if proper rapping durations are maintained (usually no more than five seconds). External mounting allows on-line inspection, maintenance, and replacement.

Disadvantages:

Electromagnetic vibrators are high maintenance devices. The strike pads and springs wear with prolonged use, weakening the vibration and reducing their effectiveness. Consistency of vibration from one vibrator to another is difficult to achieve. Reliability is much lower than impact type rappers. Too long a rapping duration can promote material reentrainment and discharge electrode wire oscillation that can promote sparking and mechanically fatigue the wires.

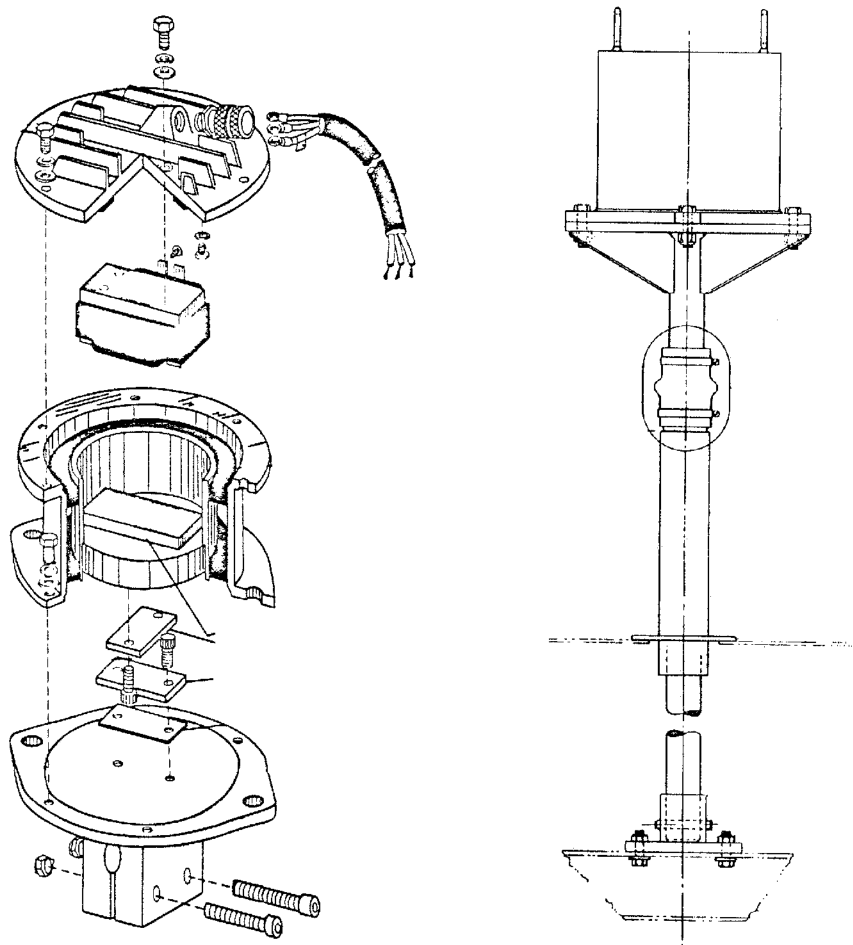


Figure 4-30
Electromagnetic Vibrator

4.1.3.4 Pneumatic Rappers

Pneumatic rappers are not widely used in the utility application, however there are some exceptions. In most of these cases, they have been replaced because of poor reliability and high maintenance. Pneumatic rappers tend to be of two types: 1. the pneumatic, single-impact rapper; and 2. the pneumatic reciprocating rapper (vibrator). The pneumatic vibrators have a piston that is pneumatically reciprocated within a cylinder over a relatively long stroke. The piston impacts at the lower end of the stroke, and is air cushioned at the top. Changing the air supply pressure can vary both frequency and amplitude. The pneumatic, single-impact rapper works similarly, but provides only a single rap with each in-rush of air.

Advantages:

Pneumatic rappers mount directly to the rapper rods, and the rappers can be mounted off vertical. Rapper intensity and impact frequency are easily adjustable from the controller. External mounting allows on-line inspection, maintenance, and replacement.

Disadvantages:

The reliability of pneumatic rappers can be low. These rappers often fail or operate poorly because of water and/or oil contamination of the airlines, or because the solenoid fails to open the air-supply line. Some of the reciprocating type pneumatic rappers can be operated at intensities and frequencies that do damage to internal components of the ESP.

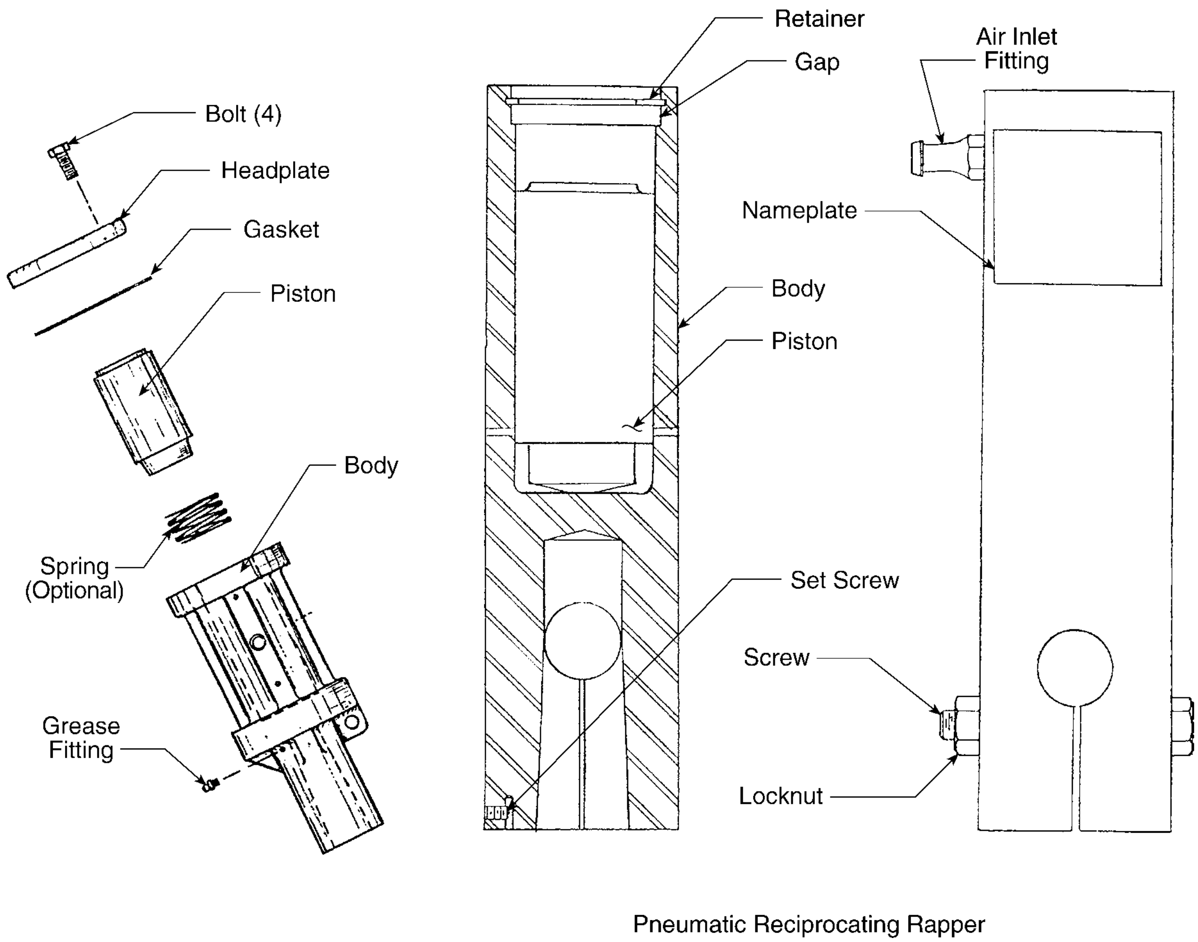


Figure 4-31
Typical Pneumatic Rappers

4.1.3.5 Mechanical Tumbling-Hammer Rappers

Mechanical, tumbling-hammer rapping systems are used primarily in European-design precipitators. These systems utilize a long, motor driven shaft with clamped hammer assemblies located at intervals along the length of the shaft. As the shaft turns, the rapper hammers rotate until they reach their apex, then fall in an arc under the force of gravity and strike anvils that are connected to the collecting plates and discharge electrodes. Rapping intensity is governed by the weight of the hammers and length of the mounting arm. Rapping control is achieved by adjusting operating time and shaft speed.

The rapper hammers and shafts are most often mounted in the gas stream inside the precipitator, but they can also be located external of the gas stream with the hammers striking anvils that extend through the precipitator shell. Figures 4-32 and 4-33 show examples of internally and externally located mechanical rapping systems. Seals must be provided with an external arrangement to preclude leakage around anvil rods where they pass through the precipitator shell. The internally located mechanical rapping system is usually driven from the side of the ESP with a low-speed gear motor that is linked to the hammer shaft by a drive insulator.

Advantages:

Usually, there is one rapper hammer per plate, so the collecting area associated with a single rapper is minimized. The point of impact is often more direct than top mounted rapper systems. Rapper impact is usually at the bottom of the plate, which minimizes material reentrainment losses because most of the material dislodged near the point of impact falls quickly into the hoppers. An internal or penthouse located mechanical rapping system minimizes the interferences at roof level associated with externally located top mounted rappers.

Disadvantages:

Tumbling-hammer rapper intensity cannot be adjusted, except by the costly and time-consuming task of changing the hammers to a heavier weight (caution must be exercised converting to heavier hammers to avoid damaging electrodes). The number of parts, both moving and stationary, that comprise a mechanical rapping system (hammers, bearings, shafts, insulators, motors, gear reducers, and the like) require regular inspection and maintenance. Operation of many of these components within the gas stream of the precipitator leads to wear and other problems that add to the maintenance requirements. Problems with internally located components, such as hammer failures; hammer misalignment with anvils, or a broken drive shaft cannot be diagnosed or repaired until the ESP is shut down. All of the hammers should be periodically replaced on a scheduled duty cycle, typically four to seven years, to maintain system reliability.

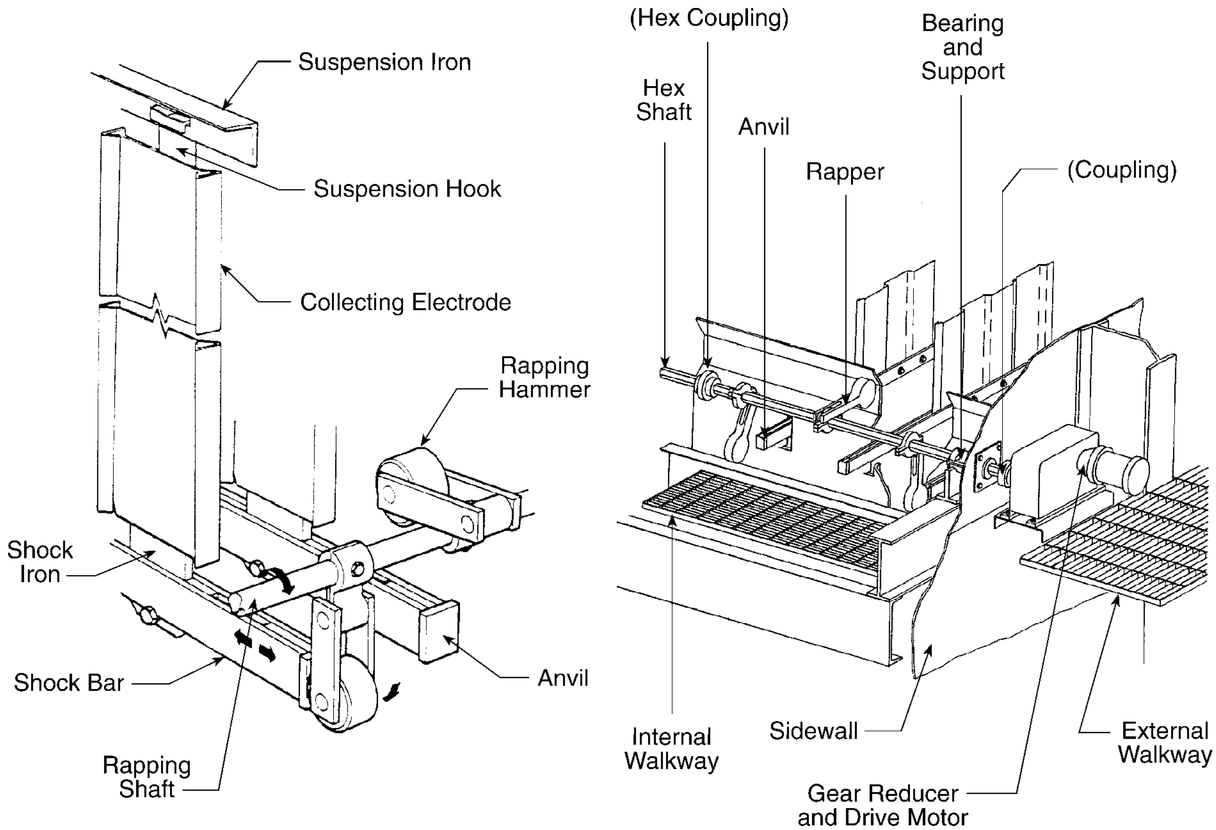


Figure 4-32
Mechanical Tumbling Hammer (Internal, of Collecting Surfaces)

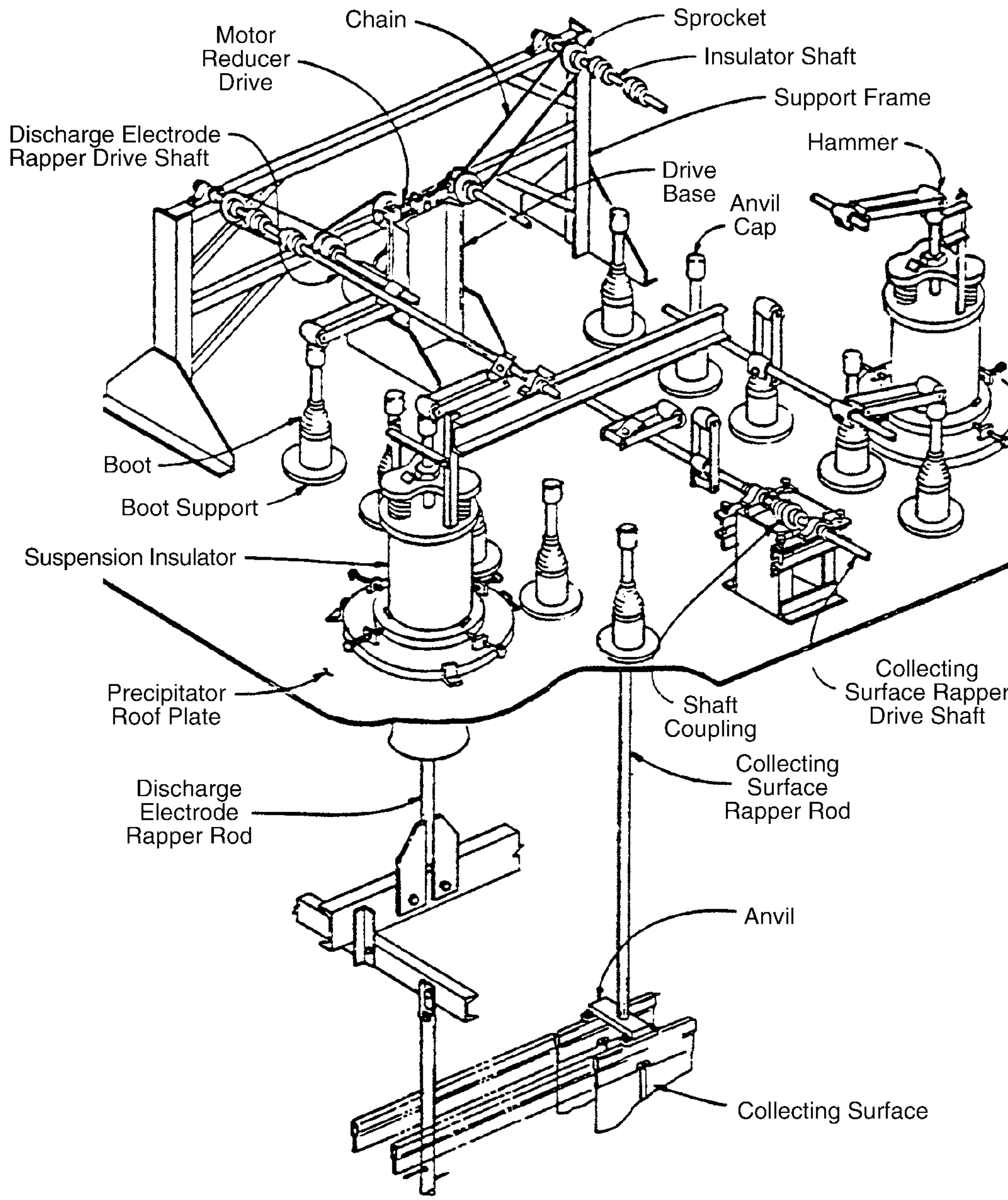


Figure 4-33
Mechanical Tumbling-Hammer (External, Located in the Penthouse)

4.1.3.6 Drop-Rod Single-Impact Rappers

Another design used by European manufacturers, though less commonly than the tumbling-hammer type, is the drop-rod single-impact rapper. A drop-rod single-impact rapping system consists of motor driven shafts running horizontally across the precipitator, external to gas flow, as illustrated in Figure 4-34. Cams, located along the length of the shaft, raise heavy rods from the rods' top ends. When a rotating cam reaches the end of its lobe, the rod, which extends through the precipitator casing, drops downward. It strikes an anvil that is attached to the discharge or collecting electrode assemblies. Control is accomplished by changing the speed of the rotating shaft or by changing the weight of the drop rod.

Advantages:

The intensity of rapping may be more easily increased than in some designs of mechanical tumbling-hammer systems. Space requirements are typically less than the tumbling-hammer type. Initial cost is likely lower than externally mounted systems, while rapping at the same locations with comparable collecting surface areas. An internal or penthouse located mechanical rapping system minimizes the interferences at roof level associated with externally located top-mounted rappers.

Disadvantages:

Like the tumbling-hammer system, the intensity of rapping cannot be easily adjusted. Increasing the intensity would require changing the cam size to increase lift height, or using a heavier drop rod. The system is maintenance intensive. The number of parts, both moving and stationary, that comprise the system are subject to wear and require regular inspection and maintenance.

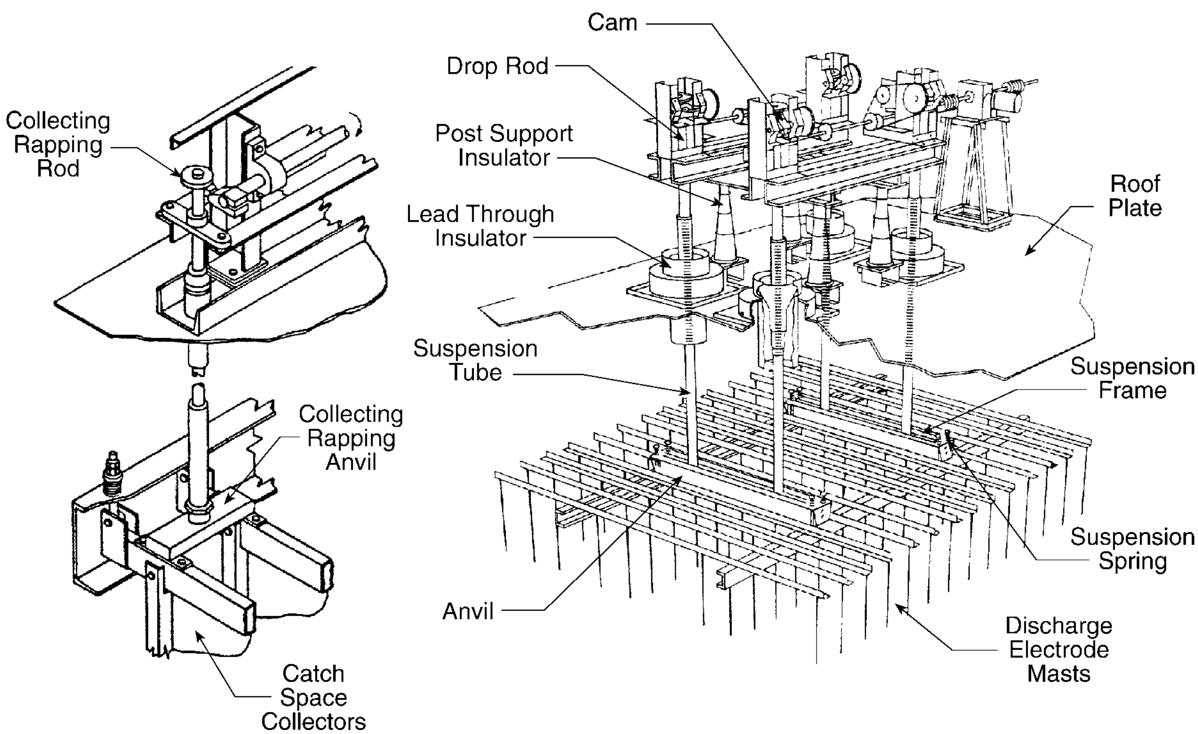


Figure 4-34
Drop-Rod Rapping System

4.1.3.7 Acoustic Horns

Although not a rapper, acoustic or sonic horns are mentioned because they are sometimes used to augment the effectiveness of an existing rapping system. Their use in ESPs has been limited and their effectiveness depends largely on the location and orientation of the horns, as well as the dust and gas characteristics.

4.1.3.8 Inspection and Maintenance

On-line inspection of the rappers should be made on a routine basis to verify operation. Rappers that are located external to the precipitator shell, such as the roof mounted, electromagnetic-impulse rappers and vibrators, are easier to evaluate and maintain than internal rappers. Other than checking that externally located motors are functioning and shafts are turning, a thorough inspection and repair of internally located rapping systems generally requires an outage.

A cursory check of the rappers and controls should be made on a daily basis to verify that they are operating. A more thorough check should periodically be made to verify the operation of each roof-mounted rapper. Most modern-day controls provide the ability to sequence the rappers in an order that aids verification. Data management systems (DMSs) with the appropriate inputs can further enhance the rapper-verification process by alarming malfunctions and identifying failed or non-operating rappers. However, they should not replace a physical check of the rappers.

Key Human Performance Point

A cursory check of the rappers and controls should be made on a daily basis to verify that they are operating.

An outage will provide the opportunity to make a more complete inspection of the rappers and to evaluate their effectiveness. A dirty inspection of the precipitator can provide insight into rapping adequacy. In general, the ash layer on the collecting plates should be about 0.125 to 0.500 in. (3.2 to 12.7 mm) thick. A layer of more than about 0.50 in. (12.7 mm) thick is probably excessive, but some units have operated with buildup layers of 1 in. (25.4 mm) or more if resistivity levels are low. Discharge electrode rapping adequacy cannot be easily determined by visual inspection, as the electrodes will often appear dirty. For rigid electrodes, only the discharge tips need to be clean. Of course, if the tips are not free of ash, increasing the rapping frequency and/or intensity may be warranted. The level of ash that is collected on the collecting plate and discharge electrode surfaces will vary from site-to-site as a function of dust loading, dust characteristics, gas characteristics, and ESP design. Requirements for the intensity and frequency of rapping may be unique for each unit and may change with process conditions and the age of the ESP. It is therefore important that each rapper function at design rapping intensity.

Evaluating the rapping during a dirty inspection was discussed in Section 3.3-Off-Line Inspection. The discussion that follows focuses more on the inspection and maintenance requirements of the rapper installation and some typical problem areas that may be encountered.

4.1.3.8.1 External Rappers

As stated, rappers that are located external to the precipitator shell, such as the roof mounted, electromagnetic-impulse rappers and vibrators, are easier to evaluate and maintain than internal rappers. Much of the necessary inspection, maintenance, and repair can be done while the ESP is on-line. An outage provides the opportunity to inspect the rapper components that penetrate the ESP to transfer rapping energy to the collecting plates, discharge electrodes, and gas distribution media.

When inspecting an external rapping systems, attention should be paid to the following areas:

- Electromagnetic, gravity-impact rappers should be vertically plumb and mounted to assure uniform piston/slug lift at a given electrical input. In most cases, this involves setting piston exposure of all the rappers at a uniform level (most manufacturers specify 4 ± 0.125 in. [101.60 ± 3.18 mm]). This should have been done during initial installation. The piston should also be reasonably well aligned with the rapper rod or strike anvil to prevent peening or deformation of the piston and/or strike surface. Top mounted vibrators that are mounted directly to the rapper rod should be near vertical.
- All rapper ground straps should be intact. Each rapper should have an external ground tying the rapper rod and rapper housing to ground. This ground serves as a safety device on the high voltage rapper rods, providing a path to ground in the event of electrical tracking across the insulated section of the rapper rod. The ground strap also serves to direct high frequency energy created during sparking to the ESP casing ground and away from the rapper panel. If these grounds are loose or missing, the rapper panel components can be damaged and/or the microprocessor operation affected.
- In the case of vibrators or pneumatic rappers, the inspector should note the sound and feel of the rapper during its operation. Weak activity indicates need for repair or replacement.
- Check for air or water leakage and corrosion where the rapper rods penetrate the ESP shell. This is particularly important at the high voltage rappers, where water penetration can cause tracking of the insulated portion of the rapper shaft and result in a ground condition. Boot seals should be flexible and free of cracks. Clamps on the boot seals should be tight.
- Inspect the insulated portion of the rapper shaft used on HV frame rappers. The insulators should be inspected for cleanliness and any cracks, deformation, or evidence of electrical tracking. The insulators should be vertically aligned in the couplings used to connect them to the steel portions of the shaft. Misalignment can lead to wear that detracts from rapper transmission. Where porcelain or ceramic insulators are used, misalignment can introduce shear forces on rapper impact that break the insulator. Over-tightening of bolted coupling connections can also lead to failure of ceramic insulators.
- Check all connections between the rapper device and the collecting plates, high voltage frames, and gas distribution media. Failed or loose connections (broken welds, loose coupling connections, failed anvil shoes) can detract from the transmission of rapper energy. Loose coupling connections can lead to degradation of the coupling. Broken welds may indicate over-rapping at too great an intensity, or poor quality welds. Careful welding with the appropriate rod material is important.
- Check for binding of the rapper shafts that extend through the precipitator shell to transmit rapper energy. This can occur as a result of poor initial installation and/or a shift in position of the collecting plates, discharge electrode frames, or the ESP structure. It is often the result of thermal expansion, particularly on hot-side ESPs. Binding of shafts can detract from energy transmission and result in damage or breakage of insulators, rapper rods, anvils, and connections.

- Check for corrosion of the rapper rods at the penetrations of the hot and cold roofs of the ESP. These areas are subject to temperature differentials where dew points can be reached and corrosion is accelerated. The rapper rod deteriorates in these areas and necks down in diameter until it eventually fails. The rapper rod usually passes through the penthouse encased in a pipe sleeve. This can make it difficult to determine if corrosion is occurring at these locations. Deterioration of the pipe sleeves at the hot or cold roof would be a possible indicator. Actual checking would require cutting away a section of the pipe sleeve to expose the rod within. If the rod has lost more than half its original diameter, plans should be made for replacement. Assume that if it is happening at one location, it is happening at others. Insulating these areas of the pipe sleeve can help reduce the rate of corrosion.
- With the electromagnetic-impulse gravity-impact rapper, magnetization of the piston can develop that inhibits piston lift. If this occurs, pistons should be fitted with a stainless steel tip, or a stainless steel impact anvil fitted over the rapper rod, to reduce any magnetizing force. Most new designs incorporate this feature.
- Check the collecting plates in the vicinity of the rapper connection. Broken welds or tears in the upper corners of the plates can develop on plates that are rapped at the collecting plate support channels. This is often an indication of over-rapping at too high an intensity. It may also be due to fatigue or age-related deterioration that has weakened the plate.
- The quality of air being delivered to pneumatic rappers should be checked. These rappers often fail or operate poorly because of water and/or oil contamination of the airlines, or because the solenoid fails to open the air supply line.

An adequate supply of spare parts should be available for the external rappers. The electromagnetic-impulse rappers are highly reliable and suppliers usually inventory replacements. Even so, it is a good idea to have a few available in the plant spare parts inventory. Vibrators and pneumatic rappers are less reliable and should be inventoried in greater quantity. Quantities will depend on the size of the ESP. Age and operating history should also influence inventory quantities. Rapper boots, seals, and insulators should be readily available.

Key Human Performance Point

An adequate supply of spare parts should be available for the external rappers. The electromagnetic-impulse rappers are highly reliable and suppliers usually inventory replacements. Even so, it is a good idea to have a few available in the plant spare parts inventory. Vibrators and pneumatic rappers are less reliable and should be inventoried in greater quantity. Quantities will depend on the size of the ESP. Age and operating history should also influence inventory quantities. Rapper boots, seals, and insulators should be readily available.

4.1.3.8.2 Internal Rappers

Most internal rapping systems, such as the mechanical, tumbling-hammer, or drop-rod single-impact rapping systems, have few components that can be inspected while the precipitator is in service. Other than checking that externally located motors are functioning and shafts are turning, a thorough inspection and repair of internally located rapping systems generally requires an outage. An adequate supply of spare parts (rapper hammers, strike anvils, boot seals, packing glands, bearings, stop collars, cams, and insulators) should be readily available for outage maintenance on internal rappers. It would also be prudent to have a spare motor(s) and gearbox(es). The quantity of parts that should be inventoried will depend on the size of the ESP and the operating history. Age of the rapping system should also influence inventory.

Key Human Performance Point

An adequate supply of spare parts (rapper hammers, strike anvils, boot seals, packing glands, bearings, stop collars, cams, and insulators) should be readily available for outage maintenance on internal rappers. It would also be prudent to have a spare motor(s) and gearbox(es). The quantity of parts that should be inventoried will depend on the size of the ESP and the operating history. Age of the rapping system should also influence inventory.

When inspecting an internal rapping system, attention should be paid to the following areas:

- Oil levels in externally located gearboxes should be checked monthly and the oil changed every six months. All external drive chains and shaft bearings should be lubricated each month.
- During a maintenance outage, mechanical rapping systems should be inspected as follows:

  Tumbling Hammer Systems-

  – Verify proper rapper shaft rotation.
  – Verify that hammers are spaced properly and that they strike near center of the anvil (wear marks should be near center). Tumbling hammers that operate in high temperatures should impact offset of center in the cold position to compensate for thermal growth of the collecting plates and discharge electrodes when the ESP is in operation. Also check for loose or misaligned rappers.
  – Inspect for defective hammers, shafts, and couplings. Repair or replace as necessary.
  – Inspect bearings for wear and replace as necessary.
  – Verify that all rapping-shaft stop collars have proper clearance between themselves and their shaft bearing.
  – Listen for any abnormal motor and gearbox noises.
  – Verify alignment and lubricate the gearbox to shaft coupling.
  – Verify that all shock bars are properly located in the alignment guides and that the collecting plates are free to move as designed on impact.
  – Check all seals and packing glands where the rapper shafts pass through the precipitator walls. Check and lubricate the pillow blocks outside the precipitator.
  – Inspect and clean all shaft insulators.
  – Change the gearbox oil.

Drop Rod Rappers-

- Verify proper shaft rotation.
- Verify that the cam lobes are properly affixed to the shaft and are properly spaced.
- Inspect for defective or worn cam lobes.
- Remove, clean, and lubricate all drive chains. Inspect for wear on the chains and sprockets. Properly tension the chains after reinstallation.
- Verify that the drop rods are not binding inside their guides.
- Inspect all bearings for wear. Replace them as necessary.
- Clean and inspect all shaft insulators.

- On mechanical rapping systems that are located external of the gas stream, check for leakage and corrosion where the rapper rods penetrate the ESP shell. Boot seals should be flexible and free of cracks. Clamps on the boot seals should be tight. Also check for binding of the rapper rod.
- Off-center impact of rappers (misaligned rapper), slippage of the hammers on the shaft, and separation of the anvil shaft from the collecting plate can lead to ineffective rapping and wear or failure of the rappers and anvils. It can also do damage to the collecting plates and discharge electrode frames. Realign, tighten, and replace rapper hammers and anvils as necessary.
- Check the discharge electrode frames and collecting plates for damage in the vicinity of the point of rapper impact. Look for cracks, broken welds, or broken bolts. Make repairs as needed.
- Locations where the rapper shafts penetrate the ESP are subject to air in-leakage and corrosion. Material buildup in the packing glands and boot seals tends to harden and can detract from rapping. Periodic repacking and boot replacement will help to minimize this problem.
- The rapper system may be locked-out for an outage. However, at some point the rappers should be energized or the shafts manually rotated, to verify that all hammers make proper impact. It takes only one malfunctioning hammer to result in buildup that can adversely affect power levels of the entire electrical field.
- At no time should the rapper drive be operated in reverse. Many systems can be severely damaged when operated in reverse. If any work has been done in the motor control center (MCC) or any maintenance done to the motors, the motors should be bumped first to check shaft rotation prior to placing the rapper system back in operation.

4.1.3.9 Upgrading the Rapper System

As previously stated, a well-designed rapping system causes the fly ash that is collected on the collecting and discharge electrodes to be transferred to the hoppers without massive reentrainment of the ash back into the gas stream. If rapping equipment is in good condition and the intensity and frequency settings have been fully optimized, and yet rapping performance is still substandard, design modifications, equipment upgrades, or replacement will likely be necessary. The need to do this may be the result of an inadequate original installation that assigned too much collecting surface area to individual rappers, or ineffective and/or unreliable rappers. It may also be that process changes (for example, fuel, temperature, low NO_x burners) or the addition of gas conditioning have over-taxed the original rapping system.

Changing the type of rapper may improve both rapper effectiveness and reliability. Electromagnetic vibrators were commonly used to remove ash from collecting plates, discharge electrodes, and gas distribution devices, particularly on earlier, weighted-wire American-design ESPs. In general, these are high maintenance devices that have limited effectiveness. The same would apply to pneumatic rappers. Their effectiveness decreases dramatically with the mass, height, and length of the rapped components. They are also subject to wear that weakens their impact. The most common type of replacement for vertically mounted vibrators is electromagnetic-impulse rapper. The electromagnetic-impulse gravity-impact or spring-assisted rappers are more effective and more reliable than vibrators. The electromagnetic-impulse rappers are also more flexible than vibrators. They provide the flexibility for changing the intensity, number of impacts, and cycle time. However, with this change in the rappers, there must also be a change in the rapper control panel. Impulse rapper designs that allow direct mounting to the rapper shaft will reduce mounting requirements and installation costs.

The mechanical rapping systems (tumbling-hammer and drop-rod) can be very reliable over an operating cycle if well maintained. However, these systems generally have many moving parts inside the ESP that are subject to wear and corrosion, which can detract from reliability and performance. They require periodic replacement of bearings, bushings, gears, drives, and other moving parts. Frequency of part replacement is site specific and is influenced by factors such as scheduled maintenance, age of the equipment, and the abrasive characteristics of the ash. Rebuilding a precipitator provides an opportunity to consider a different type of rapping system if the mechanical rapping system is inadequate or maintenance requirements are deemed to be too high.

Increasing the rapper intensity is another means of improving rapper effectiveness. Intensity of the electromagnetic, gravity-impulse rappers can be easily adjusted from the rapper controls up to the limits of the piston lift height. Replacing the piston with a heavier one can sometimes further enhance intensity. Other times, this may require upgrading the rapper to a physically similar model having a heavier piston and/or higher piston lift capability. Generally, the impact of tumbling-hammer rapping that impacts the bottom of the collecting plates, and directly impacts the HV frames, is sufficient to keep these surfaces clean. Unfortunately, if not, the only way to change the intensity is to change the weight of the hammer. Increasing the intensity on a drop hammer system is equally inconvenient, requiring a change in the cam size to increase lift height, or installing a heavier drop rod.

Be advised that increasing rapper intensity by the addition of weight, or by increasing the lift height, may introduce fatigue or failure problems with internal components of precipitators that were designed for less intense rapping. Sometimes, untrained personnel determine that there is not sufficient energy in the rapper as evidenced by ash buildup on the collecting plates or discharge electrodes. This buildup is often quite normal: on rigid-discharge electrodes, for example, only the tips must be clean. Even if the buildup is excessive, it could be because of poor energy transmission rather than a lack of rapping energy. If this is suspected, the anvil to plate connections and the collecting plate support system should be investigated. Unfortunately, the *bigger hammer* approach is all too often used in response to perceived rapper deficiency. The high rapping energy from increasing intensity, or use of larger retrofit rappers, often causes tearing of welds or breaking of the attachment of the rapper shaft to the plate or wire suspension system. Failure of the ceramic insulator portion of the HV rapper rods is commonplace with excessive rapping. In general, rapping intensity of HV rappers with ceramic insulators should never exceed 6 ft/lb (1.8 m/kg).

A common deficiency in older, American-design ESPs with top rapping was to assign too much collecting surface area to a single rapper. The collecting plates were supported in large groupings from channels along the leading and trailing edges. There were often up to 10 collecting plates supported from one set of channels. The plate groupings were rapped by a rapper/vibrator at the leading- and/or the trailing-edge support channels. This lead to an excessive collecting surface area being rapped. The recommended limits of collecting plate area vary with the ash properties, but a general rule is that a single rapper should not rap more than 1500 ft^2 (139.4 m^2) of collecting surface area. If there is only a single rapper on either the leading or trailing collecting plate support channels, a simple improvement can be made by adding a rapper to the opposite support channel and firing the rappers in pairs. Re-sectionalizing the plates to smaller groupings and adding rappers would gain greater improvement. In some cases, this can be done relatively easily by cutting and resupporting the existing support channels so that each channel supports a smaller grouping of plates. In other cases, resectionalizing an existing ESP can be less straightforward and require a rebuild to accomplish. In either case, the addition of rappers will require modifications to, or replacement of, the rapper control. The advantage to resectionalization is that it reduces the amount of area being rapped at one time, which improves rapper effectiveness and reduces reentrainment losses. Additional resectionalization can help improve rapping effectiveness and reduce opacity, but the point of diminishing economic return is often reached at about 1200 ft^2 (111.5 m^2) of collecting area per rapper.

The installation of acoustic or sonic horns is another means used to augment the effectiveness of an existing rapping system. Their use in ESPs has been limited and their effectiveness depends largely on the location and orientation of the horns, as well as the dust and gas characteristics.

If rapper effectiveness has deteriorated due to worn or corroded parts, in-kind replacement is in most cases the easiest and most cost-effective solution available to restore performance. However, if the existing rapper system is in good condition, but remains ineffective after exhausting available improvement efforts, then replacement with a more effective rapping system is more appropriate. This is most easily done during a rebuild of the precipitator. The rebuild should be used as an opportunity to enhance rapping effectiveness. Even if there may be no immediate need for improved rapping, the rebuild may provide the opportunity to incorporate design changes that will provide greater rapping flexibility to respond to changing process and operating conditions. Rebuilding an ESP often provides an opportunity to improve rapper transmission by changing the collecting plate support assembly, increasing sectionalization to reduce the area associated with an individual rapper, and/or installing a more reliable and effective rapping system with an improved design of the same type, or of a completely different system.

The discussion thus far has focused on the rappers themselves. In reality, the rapper controller has a significant impact on rapping effectiveness. The most common cause of excessive dust accumulation on the internal components of the ESP is not the rappers themselves, but maladjustment or malfunctioning of the rapper controller. This should be one of the first areas checked if ESP power readings gradually decline for no other apparent reason. Assuming the rapper control panel and rapping system provide a sufficient degree of flexibility to adjust rapping-cycle times and optimize both the frequency and intensity (where applicable) of rapping, this problem is usually relatively easy to rectify. Rapper controls (types, features, limitations, and setting guidelines) are discussed in detail in Section 4.1.4.

Key Technical Point

The most common cause of excessive dust accumulation on the internal components of the ESP is not the rappers themselves, but maladjustment or malfunctioning of the rapper controller. This should be one of the first areas checked if ESP power readings gradually decline for no other apparent reason.

In terms of upgrading a rapper system, additional performance improvement may be gained by converting to microprocessor or PC-based controls, if the ESP is not so equipped. Most modern controls provide the ability to prevent simultaneous rapper actuations, referred to as *anti-coincidence*. Coincident operation of rappers, especially within the same energized field or gas flow path, can result in objectionable opacity spiking. Other features include the ability to perform automated, power-off or reduced-power rapping, multiple program capability to respond to changes in operating conditions, fault detection, rapper grouping flexibility, and the ability to multi-rap individual rappers. The ability to utilize these features will be governed by the type of rapper system being used. The electromagnetic-impulse type rappers are the rappers most able to exploit these features. Regardless, the flexibility of these controls can optimize the rapping within the limitations of the type of rapper.

4.1.4 Rapper Controls

The removal of collected particulate from the internal surfaces requires that mechanical energy be applied to disrupt the adhesive and electrostatic bond that causes the particle layer to adhere to the surfaces. Over the years, different methods have been employed, including various methods of striking hammer blows to the surfaces, vibration systems, lifting and dropping the collecting plates a short distance, as well as the use of powerful acoustic horns that employ sound energy. The different types of devices were described in Section 4.1.3 in detail. Generally, these cleaning devices are all referred to as *rappers*. All systems require some type of automatic rapper control to keep the ESP operating well.

4.1.4.1 Early Rapper Controls

Early rapper control systems were made up of a combination of electromechanical and electronic components. For vibrator controls, the most common control technique was to use a multi-pole cam timer. The ON time of the vibrator, which was typically several seconds, was set by the mechanical adjustment of the rotating cams that then depressed mechanical switches. The frequency of the cycle was adjusted by the speed of the motor drive and gear ratios. The vibrator intensity was controlled through the use of either a variable resistor or variac (autotransformer). All vibrators on a given cam timer would have the same intensity and cycle time.

Early impact rapper controls also used either a cam timer or stepper switch for rapper control. Using a charged capacitor, which was discharged through the switch to a given rapper, controlled electric-impulse type rapper lift. Rapper lift variation was controlled through the selection of the capacitor value and the voltage to which it is charged.

Although having fixed parameters and being high in maintenance requirement, such early systems typically provided many years of service to the ESP application. Most of the early systems have been converted to modern computer controlled systems for increased reliability, lower maintenance, and extensive flexibility in operational parameter change.

4.1.4.2 Modern Rapper Controls

There are several different manufacturers of rapper control systems in the United States and Europe. All modern controls are microprocessor or PC-based. Rapper controllers are typically contained within a National Electrical Manufacturers Association (NEMA) type enclosure suitable for indoor or outdoor mounting as required. Although each brand offers different features and terminology, the following features are common to most controls.

Power Feed

Most controllers require a dedicated power line feed for the control power and for rapper power. Typical feed line requirement is 240 or 480 Vac. It is important for most controllers that this feed be fairly well regulated since most controllers do not have the capability to compensate for excessive line voltage drop. The controller, typically, includes a dedicated circuit breaker and power transformer (2 to 3 kVA) inside the cabinet to provide power to the rappers. The rating of the feed line must be consistent with the peak power requirements of the rappers in use. Note: 120 Vdc electromagnetic-impulse rappers can draw up to 40 A peak.

Display/Control Unit

Most controllers use a multi-line, alphanumeric display unit for operator status and to facilitate program parameter input. The display unit is typically in a remote location and is only used for troubleshooting and for setup. The display shows current activity as well as fault indications as they may occur. The control input typically uses membrane type switches for reliability and for use in harsh environments. In general, all of the systems are somewhat difficult to use, especially if one does not regularly do so. Fortunately, rapper controls need not be reconfigured frequently. In addition, most modern controllers offer remote control through use of a PC for reprogramming and for system status.

Control Card Cage

Most controllers use a commercial or proprietary card cage for mounting the various circuit boards of the system. Most systems employ *output* cards that can accommodate up to 16 rapper devices and *power* cards that control rapper lift or intensity. In addition, various manufacturers include other control, computer, and feedback cards that are unique to the system. Some systems permit wiring to the rapper to be made directly to the control circuit board, but most use connectors to the circuit boards and use terminal blocks for field wiring.

In addition to providing status information on the display unit, some rapper controllers include light emitting diode (LED) indicators at the circuit board level. Such indicators are useful during setup and troubleshooting.

Central Processing Unit Card

The central processing unit (CPU) card normally is the brain of the control cabinet using a microprocessor chip on the new systems. Some systems may only require an interface communication board or modem board instead of a CPU card if the control is actually done remotely on a PC-based system. The CPU card serves as the interface between all of the cards and the alphanumeric display pad, remote computer, AVC, and/or DMS. Some systems require one CPU per card cage, while others only require one CPU per cabinet. Usually this card will have LEDs indicating it functionality or alarm features. The CPU card can also allow for local or remote control switching or program selection on the card and may have a LED indication of the operating mode. Most CPU cards have some kind of backup feature that lets the user store a back up or default program to be used if the remote control link is lost, for easy reprogramming, or if the primary programming is corrupted. Specific programming instructions should be in the manufacturer's manual and a copy of the default program and the instruction should be left in the control cabinet at all times.

Output Card (Stepper Card)

Output cards typically control up to 16 devices, either vibrators or electromagnetic-impulse rappers (electric impulse). Most manufacturers use bi-directional, solid-state switches called *triacs* for control of either dc (electric impulse) or ac (vibrators) devices. The output cards typically serve as stepping controls with the actual power level control done by the power card. Some systems include individual LEDs on each output channel of the card, indicating that a particular output is active.

Power Card or Module

Power cards are used by some systems to control the amount of energy or the power level delivered to a particular rapper device. In some cases, a separate module mounted out of the card cage is used in high wattage applications. For electric-impulse devices, the energy delivered is controlled by controlling the number of line half-cycles (8.3 ms pulses) that are delivered to the rapper. Some controllers control power in increments of full pulses, while some actually permit control to tenths of pulses. In addition, some controller power cards include current sensing as each device is activated.

Rapper Current Sensing

The sensing of the level of current (amperes) that is drawn by each rapper is a feature that is included in most systems. This feature permits the system to determine the presence of a rapper that has either failed or that has changed resistance. In the case of a rapper that fails short-circuited, the controller can typically remove power to the rapper before tripping either a circuit breaker or fuse. Since in almost all cases the individual rappers are not fused, a shorted rapper could bring down the entire controller should this feature not operate properly. In the event that a malfunctioning rapper is sensed, most control systems will remove the rapper from that firing sequence and indicate a fault condition via its local display or remote unit. The *trip point* for flagging a rapper is typically field set either via a control adjustment pot or through the operator-input panel. Additionally, all systems sense an open circuit condition where the current sensing card is adjusted for a minimum current trip point. In a system where two rappers are used, or where the rappers are mixed, multiple cards may be needed to provide the proper protection and feedback indication.

In addition to sensing a rapper failure, current sensing is used by some systems to compensate for variations in rapper current caused by temperature variations of the rapper coils.

4.1.4.2.1 Other Systems

Many existing systems use solid-state timers, timer cards, PLCs, or highbreds of the old cabinet and new microprocessor based controls. The primary concern in any of the cabinets and controls is reliability, flexibility of controls, and the user-friendliness of the systems. Some of the function of the cards mentioned above can be incorporated into one card or a PLC-based system may be used with different types of interfaces to perform the functions of the card cage. European ESP designs typically use PLC-based controls or direct control from the AVC controllers to energize the motor starters of the mechanical drive motors. The PLC system works fine on simple systems, but can be difficult to program on larger systems. It can be difficult to utilize power of rapping (POR) or alarm feedback features.

Key Technical Point

The primary concern in any of the cabinets and controls is reliability, flexibility of controls, and the user-friendliness of the systems.

4.1.4.3 Software and Control Features

4.1.4.3.1 Rapper Cycle, Frequency, and Grouping

Rappers and vibrators are assigned to a specific operational group through the control system. In some cases, the grouping is factory installed while in others the grouping is field assignable. Rappers within a given group must share any one of several parameters. Usually rappers within a group must be a common type (that is, rapper vs. vibrator) and have common timing. A typical group would be plate rappers of an inlet field or electrode rappers of a given field.

The program instruction for a rapper group includes information regarding how often each rapper is fired, the time between consecutive rappers, and possibly the *dead time* between the last rapper in the group and the first rapper. Different rapper systems use different terminology to define these parameters. The most basic controllers use an ON and OFF time settings to step through all of the rappers in the group in a manor that even spaces out each rapper by the fixed OFF times between energization of consecutive rappers. The total cycle time of the group is equal to the number of rappers times the combined ON and OFF times. Most controls allow the rappers to spread out equally over the maximum cycle time programmed, or allow a minimum setting which raps the rappers in a group quickly and then rests (dead time) until the next cycle.

4.1.4.3.2 Rapper Intensity and Lift

The amount of energy delivered to each electric-impulse rapper will determine the lift and, as such, the foot-pounds of energy that is delivered with each cycle. Most controllers allow the lift to be set by setting the number of full and/or partial line pulses that are delivered. The actual magnitude of lift that corresponds to this number varies with the brand of electric-impulse rapper used as well as other variables such as line voltage and temperature. Several suppliers of controllers actually permit the setting of the actual desired lift in inches. To accomplish this, the type of rapper and its characteristics must be known to the system, and it generally requires that the controller supplier supply the rappers. The correlation between actual rapper lift and delivered energy is extremely difficult to achieve for low lifts (under 2 to 3 in. [50.8 to 76.2 mm]) given the amount of variables that exist on a typical ESP roof.

Vibrator rapper intensities can be changed by modifying the control output voltage level to the vibrator and the ON time the vibrator is operated.

For most controllers, the intensity within a given group of rappers is the same. This is usually acceptable since grouping is done for rappers under common conditions. It is useful, however, to have the capability of defining the individual energy level for individual rappers within a group to compensate for non-uniform conditions in the ESP. In this situation, some rappers may be needed to rap with greater or lesser intensity than the rest of the group. If a particular controller does not permit this feature, then it may be accomplished by defining an additional group for such rappers or by physically changing the rapper piston exposure on electric-impulse rappers.

4.1.4.3.3 Multi-Rap Capability

Normal application of electric-impulse control provides a single rap or impact per cycle of operation. In cases where the plates are exceptionally large, high energy rapping may be necessary to properly clear the plate of particulate. An alternative to heavy rapping is the technique of using multiple raps in rapid succession. This allows less energy per pulse to be applied, thus reducing potential fatigue of support components. Some control suppliers permit multi-rapping with increasing or decreasing energy per rap to allow greater flexibility of aggressive rapping with potentially less reentrainment.

4.1.4.3.4 Anti-Coincidence Grouping

Anti-coincidence grouping is a feature that is offered by several suppliers. The anti-coincidence grouping is a feature that prevents the system from rapping several devices along the gas flow path within a given time. This concept is based on the premise that whenever a rapper is fired, a percentage of the particulate is reentrained to the gas flow. If not an outlet field, then the reentrained particulate should be reduced by subsequent fields. As different groups of rappers fire, essentially asynchronous with each other, a case may occur when multiple rappers along a given gas flow path fire such that the reentrained particles become additive and result in an excessive opacity spike. This feature permits the establishment of groups of rappers that share a common gas flow path. If, during the firing sequence, more then one such rapper is scheduled for firing within a given time (usually 10 seconds), then the rapper is held off from firing. If using this feature, care must be given to overall timing since in the case of large systems with frequent activity the anti-coincidence feature could significantly alter the rapping sequence of the ESP and in the extreme cases could prevent some rappers from firing at all.

4.1.4.3.5 Power-Off Rapping or Reduced-Power Rapping

The ability for rapping a given field with the TR power removed is advantageous under some conditions. Some control suppliers offer this feature. When used, this feature is usually activated periodically (for example, once per day) and is associated with high resistivity, sticky ash, and/or an inadequate or weak rapper system (that is a large amount of collecting area per rapper). To accomplish POR, the rapper controller and the TR controller must be communicating and have coordinated control capabilities. Traditionally, when the POR sequence is initiated, the TR associated with a particular assigned rapper group is turned down or turned off while a rapid rapper fire sequence is initiated. Since the possibility for opacity spiking is extremely great, POR is normally used at low-load conditions.

Some controllers use a continuous POR or reduced power rapping. Lowering and raising the power to the TR at a programmable fixed time of 0.5 to 2.0 sec before and after the rapper is energized. Normal cycle times can be used. This method minimizes the opacity spike associated with long off periods that occur with the traditional POR method that allows the program to be used on a continuous basis.

To minimize reentrainment losses, in most systems, it is not a good idea to use POR on the outlet fields of the ESP. In some cases, reduced power rapping can be used in the outlet fields once the ESP has reached a stable condition or at low boiler loads.

4.1.4.3.6 Repeat Mode Rapping

Most controllers include the capability for repeat firing of a particular rapper for maintenance and troubleshooting purposes. For some controllers, the normal sequence must be stopped, while others permit normal operation while repeating a given rapper. The repeat mode is a very valuable tool for maintenance and testing.

4.1.4.3.7 Maintenance Sequence

This feature permits the operator to cause either all rappers or a particular group of rappers to fire in rapid sequence for maintenance purposes. This operating mode is very useful for periodic testing of rappers since it allows one to walk along the roof and observe each rapper firing in turn.

4.1.4.3.8 Multiple Rapper Programs

Older controls typically allowed only one program installed and stored at a time. This is especially true with controls that use cams, switched, or timers. Newer controls normally have the ability to store three to six programs, and with some PC-based controls the number of programs is unlimited. The programmable features will vary between manufacturers but most will allow a program to be selected locally and remotely. The ability to install and change these programs easily will aid in routine maintenance and can improve the ESP performance by allowing programs to be changed to match different operating conditions (for example, load changes, low vs. high boiler loads, changes in fuels, soot blowing, and during high opacity periods).

4.1.4.4 Maintenance and Troubleshooting Guide

Preventive Maintenance

- **Daily:** If practical, walk the ESP roof daily to listen and/or observe each rapper or device operate. Record any device that either fails to fire or appears to be malfunctioning with either too much or too little lift/intensity.
- **Daily:** Check the alarm listing on the control display and/or DMS if such a feature is provided. Document and correct all failed rappers.
- **Weekly:** Verify operation of all control cabinet cooling fans. Change and/or clean the filters on the fans.
- **Weekly:** Set up the controls for maintenance firing if the control supports this feature, or set up the rapper/vibrator firing sequence to facilitate visual and audible checks via a walk through.
- **Annually:** Inspect the control cabinet for excessive buildup of dust. With the power removed, vacuum dust buildup, especially from electronic components where dust will inhibit air flow and proper cooling.
- **For electric-impulse rappers:** Observe the plumbness of the rapper, the tightness/stability of the mounting, and general condition of the device. Observe the amount of the piston that is exposed beneath the rapper housing as compared to manufacturer specifications (usually 4 in. [101.6 mm]). Observe if the guide tube over the rapper plunger has broken free. This common failure mode usually causes pieces of the tube to fall down to the striking rod.

4.1.4.4.1 Troubleshooting

A common sense approach should be used for most troubleshooting on any system. This is especially true with the rapper system. Since there are multiple components performing the same function, it is easy to test the components by swapping the good and bad components to pinpoint the problem area or component. This is easier when you have the control manual, circuit drawings, and some minimal training. It is always advisable to keep a copy of the rapper system drawings and manual in the control cabinet and to mark the rappers in the field to match the control designations. This will help to make it easier to identify and troubleshoot the rappers. The following are some basic steps to use when troubleshooting the rapper system.

Single Device (Rapper or Vibrator) Not Functioning at All

- Check the controller fault log (if this feature is supported) to determine if the device failure was sensed and the device was removed from service.
- With power removed, use an ohmmeter across the device connection points in the control cabinet and verify nominal resistance. If the nominal resistance is not known, then measure an operating device and compare readings. The resistance between devices should be within 10 %.
- If resistance is OK, clear the alarm and attempt to fire the device. If device then fires, the problem may have been caused by either a loose connection at the cabinet or at the device itself, or by an alarm level that is too close to the normal running levels. If the alarm level is too close to normal, then other false alarms will likely occur and the setting should be changed. If only one device alarms periodically, then check and reconnect the wiring between the device and the controller.
- If the resistance is low (10 % lower then nominal), then most likely the device has shorted turns on its winding. The coil should then be replaced.
- If the resistance is high or open, check the connections between the cabinet and the device. If the connections are OK, then read the resistance on the device itself. If reading is high at that point, then the coil has failed and should be replaced.
- If the resistance is OK and the device will still not fire, then swap connections at the cabinet between the devices that does not fire with a device that is working. If the known good device fails to operate, then the failure is probably in the output card that fires the device. Swap cards or replace suspect output card. Also, test fire the suspected bad device with a good output to verify that the field wiring and rappers are in good condition.

Multiple Devices Not Functioning

- Check the controller fault log (if this feature is supported) to determine if the device failures were sensed and the devices were removed from service.
- If the devices were flagged as failed, check if all devices had same problem (over-current or under-current). If the devices are not related to a single output card or ground connection, the trip point may be set incorrectly.
- Check the common components to the failed devices. If failures are all fed from a single output card, then swap the card and verify operation.
- Check the ground connections to the devices. In most installations, the ground return leads from multiple devices are bussed together. Verify good connections.
- Check to determine if failed devices are powered from a common fuse or power controller. If so, swap the component or replace the fuse if failed.
- If common failure point cannot be identified, then troubleshoot each device separately as in the previous section - Single Device (Rapper or Vibrator) Not Functioning at All.

Electric-Impulse Rapper with Low Lift

- Verify that the controller is capable of changing the lift by experimenting with different lift settings. If the lift adjustment does not occur, check the controls or the physical condition of the rapper.
- Check to see if the rapper slug has magnetized on electric-impulse style rappers.
- Check the physical condition of the rapper. Notice if the rapper plunger has proper bottom exposure (usually 4 in. [101.6 mm]) and that the rapper is reasonably plumb. Make corrections if needed.
- Measure the resistance of the rapper. If the reading is 10 % or greater on the low side, then the rapper coil probably has shorted turns on the coil windings and should be replaced.
- If the physicals look OK and resistance is OK, remove the rapper and check for any obstructions in the rapper tube. Verify that the plunger is free to move up the tube.
- If all the above points are OK, swap the rapper with a known operational rapper. If the problem remains at the location, then the wiring between the rapper and the controller is suspect and may need to be inspected or replaced.

Vibrator Rapper with Weak Intensity

- Most vibrators need periodic maintenance to set internal gaps. This is the most likely cause for this problem.
- Try to vary the intensity of the vibrator and compare its response at different intensities to the other vibrators.
- Swap the vibrator with another vibrator to prove the vibrator is OK.
- If the vibrator is proven to be OK, then clip on a voltmeter to the vibrator input connection and energize the vibrator. Verify that the voltage is consistent with nameplate rating.
- If voltage is low, then check the wiring to the vibrator for poor connections or poor control components.
- If the connection is OK, swap out the output card and/or power controller for the device.

Cross Talk Between Rappers

Cross talk refers to full or partial firing of a rapper out of its normal sequence and usually at the same time another rapper is operating. It appears as if the rappers are talking or communicating with each other. This is can be caused by problems in the rapper programming or the control cards, but typically it is caused by problems in the field wire or system noise. Small wire size or long runs can create problems.

Wiring to rappers should use sufficient wire gauge to preclude excessive voltage drop on the feed wire. Number 14 AWG or number12 AWG are typically used. The selection of wire size should take into consideration the length of the wire run and the peak current required for the rapper. Since, in most installations, only one rapper is fired at any given time, the return lines (neutral) have been bussed or daisy chained to reduce wiring costs. A loose or resistive neutral splice will cause the return current to pass through a rapper coil on the same run, partially energizing it. This can also reduce the intensity of the rapper that was intended for energization. Poor grounding can also cause noise to misfire a control card or provide a path to energize the rapper coil when another rapper is fired.

4.1.4.4.2 Rapper Optimization

As discussed in Section 3.2 - On-Line Diagnostics, the most frequent rapping problems can be investigated and fixed without any need for shutdown. The chief exception is a problem with transmission of the rapping force through the plate and/or discharge electrode system. This must be investigated during an internal inspection.

Rapping System Optimization

In rapping optimization, the chief focus is to increase total ESP performance thereby reducing emissions. Increasing operating voltages and/or reducing the reentrainment losses normally achieve this goal. Reentrainment from the outlet collection plates is usually the main contributor to the outlet emissions from the ESP.

Fly ash removed from the collecting plates (and to some degree from the discharge electrodes) will tend to break up when the rappers are activated. Most of the ash will fall into the hoppers, while the remainder will be reentrained into the flue gas with the uncollected fly ash. The reentrained ash will usually not contain any sub-micron particles, as it is comprised of mostly agglomerates of the previously collected material. The reentrained material from all but the last field will usually be recollected in the remaining downstream fields. Because there is no downstream section to recollect this reentrained material, proper adjustment of the rapping parameters for the outlet field is especially important to obtain optimum ESP performance.

Optimal rapping frequency and intensity are achieved by trial and error, that is, by making an adjustment and then checking the opacity trace and power levels to see if the adjustment had the desired effect. The process usually requires more than a week to establish the correct parameters. The basic goal is to minimize rapping puffs, which can be observed visually by use of a light and observation port near the plates of the last field, or by obscuration or opacity meters (or similar instruments) placed in the outlet duct near the precipitator. Several days may be required for the rapping reentrainment conditions to stabilize after the rapping system has been adjusted because the primary location for rapping reentrainment that effects outlet emissions significantly is from the outlet field and the ash buildup rate on the outlet field is very low. An ESP operating with a collecting efficiency of about 99.5% will have an average ash layer buildup rate for the outlet field on the order of 0.03 in. (0.762 mm) per day. Thus, changes in the equilibrium thickness for the ash layer on the outlet field may require several days to become established. Trying to achieve quick results can cause under rapping that, after several weeks, can cause a new set of performance problems.

Key Human Performance Point

Optimal rapping frequency and intensity are achieved by trial and error, that is, by making an adjustment and then checking the opacity trace and power levels to see if the adjustment had the desired effect. The process usually requires more than a week to establish the correct parameters.

For both discharge and collection rapping systems, it is easier to first optimize rapping intensity before adjusting the frequency interval. For electric-impulse rappers, intensity refers to slug weight, stroke length, and in some models, spring strength. For vibrators or for acoustic horns if installed, intensity refers to the applied voltage or air pressure. In the case of mechanical rappers (tumbling hammers or dropped weights), intensity refers to hammer weight and swing arc or drop weight and distance. Note that in many rapper models, the intensity variables, such as spring strength, hammer weights, and swing arc, are not easily changed. If you have such rappers, first optimize the frequency, which is totally controllable. If that is insufficient to achieve good performance, you may have to consider altering the weights, other intensity variables, or implementing reduced power rapping.

If, after these measures, rapping is still substandard, the rapping system will require significant modification or upgrade. Recommendations are discussed in Section 6.9.

Collection Plate Rapping

Determine the appropriate intensity for the collecting system by trial and error (that is, make an adjustment, then check the results with an opacity trace). The objective should be to find the minimum shear force necessary to dislodge the dust cake at the extremities of the system, while avoiding over-rapping some portion of the collecting electrode. For some top-rapped systems with very tall collecting plates, the required rapping energy can be quite high. In these cases, a compromise must often be reached between over-cleaning the upper portions of the system (which would create unnecessary reentrainment) while providing adequate cleaning at the bottom. This would also be true for very tall bottom rapped plates, but the opposite effect would occur with the bottom being over rapped and to keep the top part of the plates clean. However, reentrainment losses would be minimized since the rapper point is closer to the hoppers.

Intensity requirements usually decrease in the direction of gas flow. Along with shear forces (linear to the plate), some normal forces (perpendicular to the plate) are developed. Normal forces tend to disperse the dust cake, a condition that should be minimized in the outlet sections to limit reentrainment. Sometimes it is necessary to vary intensity across the gas flow, especially when gas velocities are unbalanced or the resistivity of the ash changes across the face because of temperature differences and/or high SO_3 concentrations. When this condition is present, the opacity profile may appear like the one shown in Figure 3-8 where significant reentrainment is occurring in a relatively small portion of the ESP. The instantaneous trace indicates this localized reentrainment.

When the appropriate intensity has been determined, further improvement is gained through optimizing the frequency. If 70% efficiencies were assumed for each field, then to achieve an equal layer of buildup in each field, the rapping would decrease from inlet to outlet by a factor of

3 for subsequent fields. Using a rapping interval of about 3 to 5 min for the inlet field, the following rapping time would be 10 to 15 min for the second, 30 to 45 for the third, and 1 to 2 hours for the outlet for a four-field ESP. The intensity settings for the inlet sections are usually not as critical as those for the outlet.

The first step is to establish reasonable settings for the two inlet fields that do not decrease spark over voltage levels, and then focus on fine-tuning the outlets. About a week of operation should allow the new conditions to become established and provide a representative opacity trace. The most important factor in optimizing any system is that all of the rappers are functional. The internal buildup caused by one rapper not firing can affect the power level in that field, which will reduce the effectiveness of any evaluation program.

Discharge Electrode Rapping

In contrast to collection rapping, discharge electrode rapping performance must be assessed off-line and evaluated by visual observation and air load V-I curves rather then opacity traces.

Discharge rapping is appropriately set for near-maximum cleaning levels because, unlike collection rapping, there is little or no significant reentrainment penalty associated with the discharge system. Plus, it is unlikely that the discharge electrode could be considered too clean. However, excessive rapping of the discharge system wastes energy and may lead to premature mechanical failure of the discharge electrodes, as well as the rappers themselves. The appropriate rapping level produces sufficient cleaning while limiting wear and tear on the discharge system.

Sufficient cleaning can be tricky to determine and requires testing during shutdown. Do not let a visual inspection fool you. The electrodes do not have to appear clean in a *dirty* visual inspection. Indeed, complete cleanliness is sometimes above the capability of the rapping system. On rigid electrodes, for example, only the tips or barbs must be clean. Instead of relying on visual inspection, determine acceptable cleanliness by evaluating current-voltage curves taken under both dirty and clean air load conditions during the shutdown. Ash buildups that increase the effective surface diameter of the wire, or cover the discharge point, will increase the corona start voltages and shift the V-I curve toward a secondary voltage noticeably higher than historical norms.

Typically, it is a good practice to use the same or similar cycle times for all of the discharge frames based on the cycle times used for the inlet collecting plates (in the example above, that would be 3 to 5 min). On large ESPs, the back half of the ESP can be increased by 1.5 to 2 times the front half.

Effects of Resistivity on Rapping

The resistivity of the ash should be a consideration when adjusting the rapper system to optimize the overall performance of the ESP. The resistivity of the ash layer in conjunction with the corona current in the field causes a voltage differential across the ash layer. This voltage results in an electrostatic force that will help hold the layer together, as well as to hold the layer onto the collecting surface. This tends to reduce reentrainment looses. As discussed in Section 2.4, the thickness and resistivity of the layer directly affect the spark-over voltage. Therefore, thicker layers of high resistivity ash tend to reduce ESP performance by lowering the voltages. Normally, with high resistivity ash, higher rapping frequency or intensity is needed to limit the layer thickness and increase spark-over voltage. Conversely with low resistivity ash, less frequent rapping is needed and/or lower intensities are required to minimize reentrainment losses. In some cases, the increase layer can have little effect on spark-over voltage.

Key Technical Point

Therefore, thicker layers of high resistivity ash tend to reduce ESP performance by lowering the voltages. Normally, with high resistivity ash, higher rapping frequency or intensity is needed to limit the layer thickness and increase spark-over voltage. Conversely with low resistivity ash, less frequent rapping is needed and/or lower intensities are required to minimize reentrainment losses. In some cases, the increase layer can have little effect on spark-over voltage.

Most rapper controls can be programmed either to spread the rapper firing out over the entire cycle time of any rapper group (maximum rest time between rapper firing) or to fire all of the rappers quickly in a minimum time and wait with no activity to complete the cycle time (minimum rest time between rapper firing). This is normally referred to as *MAX* or *MIN* operations. The location in the field, condition of the ash system, and the ash resistivity can dictate which mode of operation is better.

Key Technical Point

Most rapper controls can be programmed either to spread the rapper firing out over the entire cycle time of any rapper group (maximum rest time between rapper firing) or to fire all of the rappers quickly in a minimum time and wait with no activity to complete the cycle time (minimum rest time between rapper firing). This is normally referred to as *MAX* or *MIN* operations. The location in the field, condition of the ash system, and the ash resistivity can dictate which mode of operation is better.

Maximum rest time (MAX) is always good to use in the outlet fields to minimize the summing of any rapper reentrainment spikes on the 6-minute average. If the ESP is large, it is also important to tie all of the outlet rapper groups to the same anti-coincidence group so that only one rapper can be operated in the outlet of the ESP at any one time. MAX should also be used when the ash hoppers are very large and span a large amount of collecting area to prevent surges in the hoppers that can cause bridging. When low resistivity conditions exist, the MAX settings are also typically used since the thickness of the layer does not normally affect the spark over-voltage. This would be true on all fields that were not sparking.

Minimum rest time (MIN) is normally used in fields that are sparking from high resistivity ash conditions. The spark-over voltages are controlled by the weakest spot in the ESP. That means that the dirtiest collecting plates will control the voltage. When using the maximum rest period, this would create a condition where the next rapper to operate would constantly have the most amount of material on the plates, limiting the spark-over voltages. In this case, the MIN cycle should be used to clean all of the plates quickly and let the ash build on the plates slowly over the wait or dead time. In some cases, you can actually see the voltage move slightly as the materials builds on the plates during the wait period.

On American type ESP systems using impulse or vibrating rappers, it is usually easy to understand how to adjust the control for MIN and MAX operation. On European type systems, it can be more difficult to implement since most of the controls use PLC ladder logic or use basic ON/OFF timers. When using a tumbling hammer design, it is important to measure the time it takes for one complete revolution. Normally this is 60 to 120 seconds, but it can be as long as 5 to 7 min. This time is the minimum rest cycle time and the minimum cycle time (the fastest the rappers can be operated). Using MAX settings on a European-design system would require turning on the drive for a short period, which would let several hammers fall at a time. It is good practice to make the ON times no shorter than 10 seconds to prevent damage to the motor.

Since the resistivity constantly changes, the goal in any rapper optimization program is to reach a happy median of settings so that one program can handle the resistivity changes that occur on a daily basis, such as the normal temperature increase seen from morning to evening. The main goal of any rapper maintenance program should be to have 100% of the rappers operational.

4.1.5 Instrumentation - Meters, Temperature Sensors, and Opacity Monitors

Available instrumentation can be a great asset to monitoring ESP performance and diagnosing problems. These include the ESP primary and secondary voltage and current meters, spark rate meters, transmissometers, hopper level detectors, and temperature sensors. Other instrumentation might include gauges on airlines, LED indicators, gas and conditioning analyzers, and alarm annunciation panels. Use of this instrumentation for monitoring and evaluating ESP performance, and how it can be collected, is discussed throughout this manual. There are however, a few points that need emphasis, or reemphasis, particularly in regard to the three primary means to assessing ESP operation:

- ESP primary and secondary voltage and current meters and spark rate meters
- Temperature sensors
- Opacity transmissometers

4.1.5.1 ESP Voltage and Current Meters and Spark Rate Meters

The readings from the voltage and current meters and the spark rate meters, indicate how the ESP is performing. Precipitator primary and secondary voltage and current readings and spark rates may be displayed on analog meters and/or digital displays.

- Analog metering should be required on all new installations. When voltage controls are retrofit into an existing control panel, the original analog metering should be maintained. Many of the newer voltage controls only offer digital metering, but these do not provide the diagnostic advantages of analog metering. The ability to watch and evaluate meter fluctuations can aid in performance assessment and troubleshooting efforts.
- Voltage and current signals can be corrupted by extraneous electrical noise. Microprocessor automatic voltage controls are much more sensitive to electrical noise than their predecessors. Good grounding of the ESP structure, TRs, and auxiliary equipment is important.
- The voltage and current readings need to be periodically verified for accuracy and recalibrated if necessary. If there is additional remote metering or display of these values, they need to be consistent with one another.

4.1.5.2 Temperature Sensors

Temperature probes may be used in a variety of locations to monitor and evaluate ESP operation and performance. They can be used to help identify changes in resistivity, temperature gradients, or heat losses. On large, multi-chambered ESPs, they might also be indicative of volume differences between chambers. In some cases, a grid of thermocouples at the ESP outlet has been used to evaluate gas distribution.

The usefulness of temperature probes will depend on their number and placement. A temperature probe(s) at the precipitator inlet can be used to monitor the effects that changes in temperature (resistivity) have on ESP performance. Temperature probes located at intervals across the duct at the air heater (rotating regenerative) exit can help to identify a temperature gradient across the width of the precipitator. Temperature probes at both the inlet and outlet of the ESP that identify substantial drops in temperature, may indicate substantial air in-leakage or the need for an enhanced insulation barrier. Where and when possible, compensatory actions can be taken to address conditions that probe readings have identified.

4.1.5.3 Opacity Transmissometer

The opacity transmissometer is an extremely useful tool for monitoring, troubleshooting, and optimizing ESP performance. Opacity readings can be used to identify an overall change in ESP performance and/or rapping related material reentrainment. The device can then be used to optimize ESP rapping and AVC control functions, and/or change process conditions, in response.

An opacity transmissometer is typically used at the precipitator exit (ductwork, stack) as a measure of particulate emissions for purposes of regulatory compliance. The opacity transmissometer does this by directing a light beam across the gas stream and comparing the amount of light generated and transmitted by the device against the quantity of light received by the receiver. The difference (%), which is caused by absorption, reflection, refraction, and light scattering by the particles in the gas stream, is the opacity. Opacity is a function of particle size, concentration, and path length.

Key Technical Point

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Considerations and concerns regarding use of the opacity transmissometer include:

- Provision for real time (instantaneous) measurement of opacity is recommended. Regulatory compliance may only require 1 to 6 minute opacity averages, and some of the devices used for opacity monitoring only provide averaged readings. However, averaged readings limit the usefulness of the device for monitoring, troubleshooting, and optimizing ESP performance. For instance, this can make identification and correction of rapper reentrainment nearly impossible because related opacity spiking tends to get smoothed out in integrated averages such as the 6-minute average that is commonly used.
- Usefulness of the opacity monitor is diminished when, for example, there is only one opacity monitor in a common stack serving more than one ESP or parallel chambers with separate outlets. Although only one monitor at the common stack may be required for regulatory purposes, separate monitors at each outlet are useful in evaluating performance of each ESP or chamber and in troubleshooting. Separate monitors also allow more accurate use of the energy management feature offered by most of the current generation of TR controls and DMSs. This feature uses the opacity signal as a means to save energy by regulating power levels to the levels necessary to maintain a desired opacity.
- Given the importance of the opacity monitor for compliance reporting and its value as a diagnostic tool, maintenance and periodic calibration checks should be done according to the manufacturer's recommendations. Be aware that most monitors only calibrate the internal electronics. If there is buildup on the protective glass or lenses, buildup in the mounting tubes, or an eyebrow has developed over the mounting tube, this added material could cause a false increase in opacity. It is important to physically inspect the monitor for these types of buildups on a regular basis. Additionally, if the monitor's mounting points move from twisting of the ductwork, the light beam can skew, which can also give a false increase in opacity.

- All transmissometers require purge air systems to protect the optical windows or reflectors. Still, regular cleaning is required with the accumulation rate varying widely from one location to another. Most commercial instruments have automatic zero and span checking capabilities to verify proper functioning and calibration between cleanings.
- Opacity is a function of particle size, concentration, and path length. Be aware that because of the interrelation between particle-size distribution in a stack or duct and the opacity, it is possible to meet mass emission standards and still have an opacity problem. In fact, some changes in fuels, gas temperatures, and other parameters in flue gas streams have caused a reduction in flue gas emissions but have produced an increase in opacity (or vise-versa).

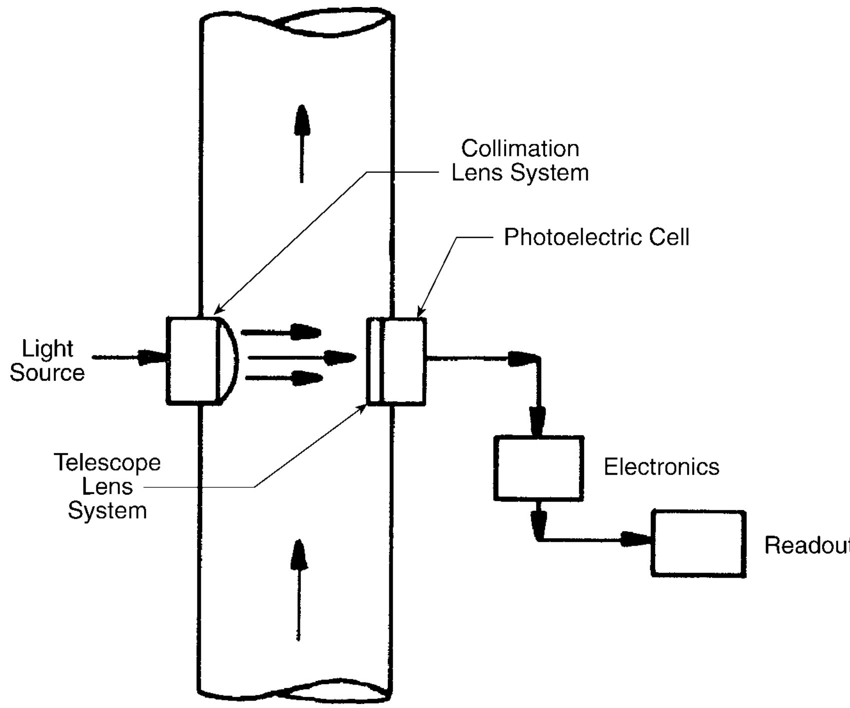


Figure 4-35
Opacity Transmissometer

4.1.6 Data Management Systems

DMSs have been used for over 20 years in the utility industry. The early designs linked the TR AVCs and rapper panels to a central monitor or computer to allow remote monitoring and control of the ESP. As technology has progressed, the monitoring and control features of the DMSs have expanded. With a tie-in to the plants DCS and interface with analog signals, most systems have become an invaluable tool for data analysis and system monitoring. Some data management systems function like a mini-DCS. A modern-day DMS system typically offers the following features and capabilities:

- Data acquisition of all the AVCs
- Rapper panel control and monitoring
- Remote control/setup of the AVC and rapper controls

- Digital and analog inputs and outputs
- DCS interface
- Trending of all inputs
- Alarm indication and logging
- Automatic and manual report generation
- Energy management
- ESP manuals and help features
- Control alarm and/or feedback of the auxiliary systems (purge fans, ash system, hopper heaters, level detectors, gas conditioning system, and the like)
- Remote access to the system via a modem or LAN network

Typically, there are three approaches used to acquire the data and control the equipment.

1. **Proprietary system:** In most systems, the interface is done through a proprietary computer using customized software.

2. **Direct DCS interface:** Some systems can also be configured to communicate directly to the plant's DCS via a communication interface. The programming and graphics are normally done by the plant programmers in the DCS or data acquisition software.

3. **Combination of the two above:** The information is passed through the proprietary system and finally trended and manipulated in the plant's DCS.

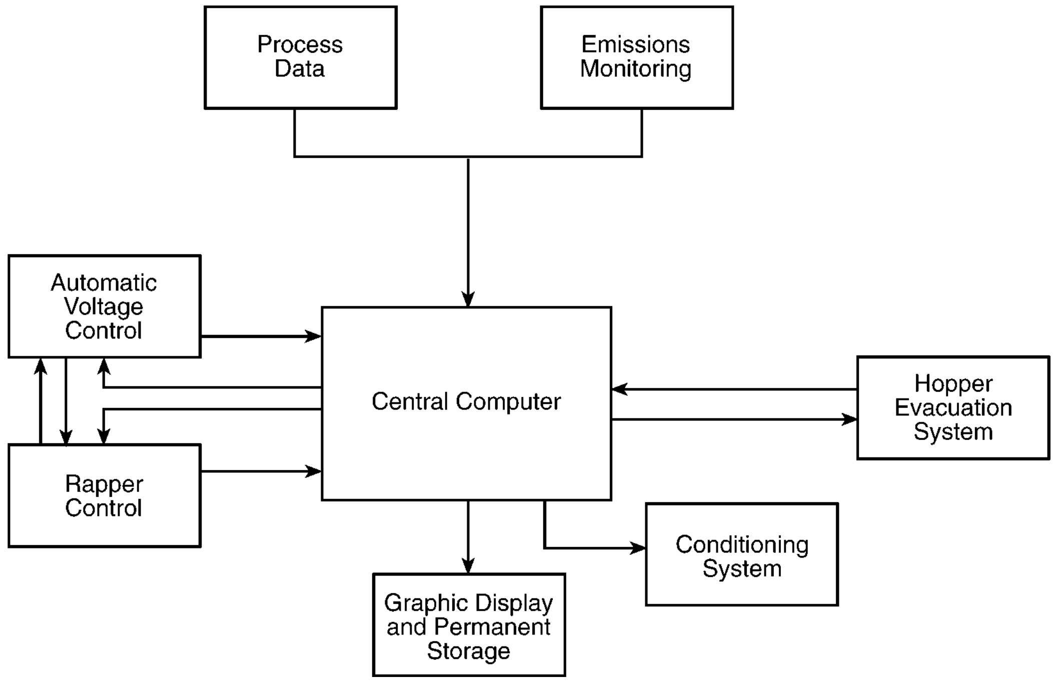


Figure 4-36
Example of a Typical DMS

There are some basic systems that provide only a communication network between the AVCs, the rapper control panel, and/or the opacity monitor to allow reduced power rapping and/or energy management based on opacity. Most of the older systems only performed these basic functions.

The main concern with any data management system is the usefulness of the system. There are some basic criteria that should be evaluated when choosing or designing a system.

- The system needs to be easy to use and user-friendly.
- The layout of the screens should reflect the actual layout of the ESP. The ESP power levels should be displayed in a manor that consolidates the readings on one page, listing them from inlet to outlet, separated by chamber and/or by ESP if there is more than one. Displaying power readings according to the physical layout of the ESP, not the cabinet numbering or DMS numbering scheme, will allow the voltage and current patterns described in the other sections of this manual to be easily used for analysis and troubleshooting.
- It is important to verify that the data on the DMS matches the values in the field. The data is only as good as the feedback signal, calibration of the feedback signal, and the method used to collect the data.
- It is important that the readings update in a timely manor and that there is the ability to choose whether to monitor the average, peak, or minimum values. The problem with systems that take a snapshot view of the power levels is that they can take a low reading that occurs during a spark response that does not represent the actual operating level.

- Trending feature should allow at least six parameters or more to be simultaneously displayed on one screen to allow correlation between variables.
- There is a need for instantaneous opacity levels at the DMS to correctly use the trending.
- All screens should be able to be printed easily.

Additional features offered by most modern-day DMSs are:

- Perform V-I curves.
- Capture and view oscilloscope traces of the voltage and current waveforms of individual AVCs.
- Analyze the relationship between different parameters using trending or scatter-grams.
- Correlate rapper operations to opacity trending to help identify the cause of rapper related opacity spikes.
- Allow energy management to be initiated or controlled by a variety of limits such as opacity, boiler load, kVA of the entire ESP or part of the ESP, by specified time, and/or manually.
- Allow power-off rapping or reduced-power rapping to be initiated or controlled by a variety of limits such as opacity, boiler load, kVA of the entire ESP or part of the ESP, by specified time, and/or manually.
- Allow automatic changes to be made to the rapper program or selection of different programs initiated by load changes, opacity increases, power decreases, and other selected parameters.
- Algorithms to control the SO_3 or other gas conditioning systems to optimize the ESP performance automatically.

4.1.6.1 DMS Maintenance

Most DMSs require minimal maintenance to keep them operational once the system has been setup and all of the initial bugs have been worked out. Problems have sometimes occurred because of noise in the system that has caused communication errors, or from software-related problems. Some systems have experienced problems with data collection when a large amount of controls are connected to one data highway, or there are controls on the same system with the same identification numbers. In general though, these systems are fairly reliable.

Maintenance requirements for the DMS will vary by manufacturer and the complexity of the system. At a minimum, the following items should be done to assure system accuracy and aid record keeping and trending of information:

- Regularly set up and update useful trending files to allow easy trending of individual control parameters, control of parameter patterns by chambers, and the combination of other system parameters to aid in troubleshooting and performance optimization.
- Annually contact the manufacturer to determine if there are any upgrades or patches to the software. Install the upgrades as needed. Be aware that software changes to the DMS can also require software changes (chips) to the AVCs and rapper control panel.

- Monthly, verify that the feedback signals from the AVCs and other system components match the field values. If needed, verify and calibrate the feedback signals to the system.
- During annual outages and routine monthly checks, inspect all communication cables for tightness. Verify that the grounding and shielding is intact.
- Annually print out all parameter settings for inclusion in the ESP logbook.
- Monthly or quarterly save log and data files for archiving the data to the ESP data library.
- Back-up the DMS software to allow easy reinstallation in case of system failure.

4.1.6.2 DMS Upgrading

Most DMSs are proprietary and require that the AVCs and rapper panels are all supplied by the same manufacturer for software communication compatibility. Installing a DMS system on an existing precipitator may require replacement of the voltage controllers and/or the rapper control panel(s) in order to exploit the benefits of a DMS. Other limitations to fully exploiting the features of the DMS could exist if ESP auxiliary equipment does not have usable inputs/outputs.

Manufacturers frequently upgrade DMS software as new features or capabilities become available, or to rectify operating problems that may have surfaced in the field. Plant personnel should periodically contact the manufacturer to determine if there have been any upgrades or patches to the software. Install the upgrades as needed. Be aware that software changes to the DMS can often require software changes (chips) to the AVCs and rapper control panel. If problems are being experienced with a DMS that appear to be inherent to the system, the manufacturer should be contacted. This may be the only way that the manufacturer becomes aware of a problem. They may have already developed a patch that can easily be implemented, or this may alert them to the need for developing a patch or software upgrade to address a problem.

4.1.7 Ground Systems

There are two important aspects of precipitator grounding that need to be understood. The first is in regards to personal safety when entering the ESP. The second involves proper grounding of the ESP structure and auxiliary equipment for optimum performance.

An ESP is, in effect, a large capacitor. It may retain a potentially dangerous electrostatic charge for some time after it is deenergized. Grounding devices *must always* be maintained for internal access and *must always* be used before entering any part of the precipitator. Ground all HV parts before touching them.

Key Human Performance Point

An ESP is, in effect, a large capacitor. It may retain a potentially dangerous electrostatic charge for some time after it is deenergized. Grounding devices *must always* be maintained for internal access and *must always* be used before entering any part of the precipitator. Ground all HV parts before touching them.

The integrity of the ESP structure and auxiliary electrical equipment grounding needs to be checked annually to be sure that it is intact, connections are tight, and for corrosion.

Good grounding of the ESP structure and auxiliary equipment/components is essential to optimum ESP performance. This is often overlooked during control retrofits and precipitator rebuilds. Modern day microprocessor-based AVCs are much more sensitive to electrical noise than their predecessors. Any extraneous noise may corrupt the signal to the controller and cause it to react erroneously to the conditions that actually exist in the collection zone of the precipitator. The result is reduced performance. If there is evidence of noise on the mA or kV feedback signals when sparking occurs in the ESP, grounding may be a problem. Upgrading the precipitator structure, TRs, and auxiliary equipment grounding may be in order.

Proper grounding helps to dissipate sparking and eliminate noise interference in the voltage control signal. Individual ground cables should run from each TR set to the ground grid at grade. Two grounds should be used in the AVC control cabinets: one for the AVC controls and another for the low-voltage components and physical cabinet. The AVC controls can be daisy chained together and taken to the ground grid with one of the grounds. The low-voltage components and cabinets can be daisy chained together and taken to the ground grid with the other ground. The rapper controls, rappers, and other auxiliary equipment can be tied to a common ground at grade. There should be an intact ground connecting the support structure to the ground grid at grade. There should also be ground jumpers across the slide pads, between the support steel and precipitator columns, at the four corners (minimum).

Good grounding is essential to optimum ESP performance and should be a part of any upgrade. It is important to use 4/0 size cable or larger for all runs to grade to help dissipate the high frequency energy released during a spark in the ESP.

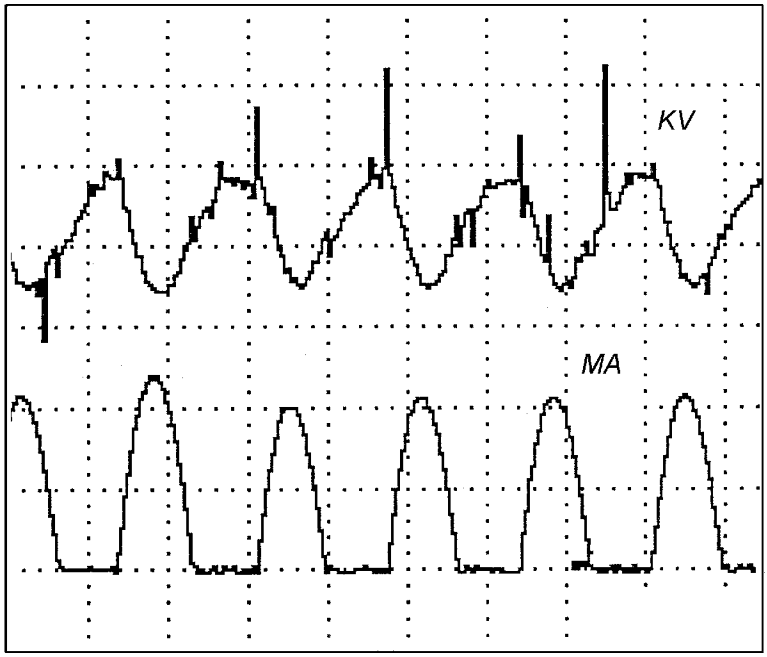


Figure 4-37
Oscilloscope Trace Showing the Effect of Noise on the kV Signal. In Some Controls, the Positive Spikes on the kV Signal Can Be Interpreted Incorrectly as a Spark.

4.2 Penthouse/Weather Enclosure Area

4.2.1 Weather Enclosures

Some precipitator installations have weather enclosures. Weather enclosures provide a more maintenance friendly working environment under inclement conditions. They also help to limit contamination from surrounding areas of the plant.

A weather enclosure usually refers to a non-gas-tight, weatherproof enclosure over the precipitator roof to shelter roof mounted equipment (TRs, rappers, rapper controls, purge air systems, and the like) and maintenance personnel. The sides and roof are typically fabricated of aluminum siding clad over a structural steel frame. They are usually equipped with exhaust fans and large man-doors for equipment removal or installation. It is not uncommon to have a monorail hoist system housed within for overhead removal of TR sets and other equipment. Some installations also have a lower weather enclosure at the base of the precipitator to protect the hopper area from wind and/or detrimental weather conditions. These lower enclosures can be of great benefit in preventing hopper pluggage in areas prone to high winds and cold temperatures.

Normally, little maintenance of the weather enclosure is required. Loose or missing sections of siding need to be repaired. Fans, dampers, and hoists need to be maintained, and doors need to open and close properly to provide a weather-tight seal.

4.2.2 Penthouse/Insulator Compartments

A penthouse or insulator compartments are used to house the insulators supporting the HV system. Insulator compartments (commonly referred to as doghouses, cans, or coffins) may contain one or more insulators, but do not cover the entire precipitator roof. A penthouse on the other hand, covers the entire precipitator hot roof and houses all of the insulators supporting the HV system under one enclosure. In multiple chamber ESPs, there may be partition walls that divide the penthouse. The HV bus bar and top-mounted, mechanical rapping systems may also be housed in the penthouse. Access to the insulator compartments is usually limited in comparison to a penthouse design.

Insulator compartments and penthouses are designed to provide a contaminant-free environment for the support insulators in order to maintain their mechanical and electrical integrity. Purge-air systems are utilized for this purpose. Ideally, the purge-air system includes a blower/heater combination to move air across the insulators to keep their inside surfaces clean and to provide heat to avoid condensation formation and thermal shock of the insulators. On positive-pressure systems, the blower must be able to pressurize the gas-tight enclosure area(s) at a pressure above that of the operating pressure of the ESP. Some insulator compartments and penthouses on negative-draft systems have openings or vents that draw ambient air under the negative draft of the fan to purge the insulators. Although ring or band heaters may be used around the base of the individual support insulators, this type of system can introduce cold air, moisture, and debris that leads to corrosion and contamination of the penthouse/insulator compartments and components housed within. These can also lead to failures. As a rule, natural-draft purge systems should be replaced with a forced-draft, combination purge blower and blast-heater system whenever possible. It is unlikely that negative-draft systems are negative under all conditions. Startup, shutdown, low load, and/or boiler-upset conditions may cause the precipitator to go positive, in which case the natural draft insulator compartment/penthouse would be contaminated. The combination blower/blast heater system prevents this from happening. The combination blower/heater system is preferable to a blower (no blast heaters) and band or ring heaters around the individual insulators. That type of system still has some of the potential problems related to the continuous introduction of cold ambient air.

The purge and heater systems should be started at least four to six hours prior to startup and be kept in operation at all times while the F.D./I.D. fans are in operation.

During inspection of the insulator compartments/penthouse, the condition and structural integrity of the enclosure needs to be assessed, and the support insulators and other HV components housed within need to be checked. The tightness and integrity of all electrical connections should be also be checked.

Any tearing or cracking of insulator compartment or penthouse walls may indicate inadequate provisions for thermal expansion, or improper construction welding that restricts expansion. This must be investigated on a case-by-case basis and repairs made as needed.

The presence of heavy corrosion might be due to condensation formation, air in-leakage or water penetration, inadequate insulation, the introduction of unheated ambient air, or gas penetration of the enclosure due to purge blower failure or inadequate pressurization. Be aware that the introduction of cold air can cause corrosion of the hot roof directly underneath. A deflector should be installed under the blower discharge to guard against this and to distribute purge air throughout the penthouse.

> **Key Technical Point**
>
> **The presence of heavy corrosion might be due to condensation formation, air in-leakage or water penetration, inadequate insulation, the introduction of unheated ambient air, or gas penetration of the enclosure due to purge blower failure or inadequate pressurization. Be aware that the introduction of cold air can cause corrosion of the hot roof directly underneath. A deflector should be installed under the blower discharge to guard against this and to distribute purge air throughout the penthouse.**

Any dust accumulation found in the insulator compartments/penthouse and on the surfaces (inner and outer) of the support insulators should be completely removed. Excessive dust buildup (greater than 0.25 in. [6.35 mm]) may indicate problems with the purge-air pressurization system. Hardened material buildup on the inside surface of support insulators may indicate a lack of adequate heat.

All penetrations of the insulator compartments/penthouse, such as for rappers and probes, should be inspected to verify the integrity of the seal and for any corrosion of the surrounding area. The penetration openings (pipe nipples) for rapper shafts should be inspected for material accumulation and binding of the rapper shafts. Any deposits should be cleared and the condition of the rapper boot seal should be checked. Cracked, deteriorated, or torn rapper boots should be replaced. Binding of rapper shafts in the penetration openings should be noted. This might indicate a shift in the alignment of the collecting plates or discharge electrode frames. It can lead to rapper shaft damage, anvil failure, and/or diminished rapping energy transmission. Discharge electrode frame rapper shaft insulators (ceramic or resin) should be checked for signs of damage or electrical tracking. These insulators should be tight in their coupling connections for good rapper-energy transmission.

> **Key Technical Point**
>
> **All penetrations of the insulator compartments/penthouse, such as for rappers and probes, should be inspected to verify the integrity of the seal and for any corrosion of the surrounding area.**

Other penetrations that should be checked are the purge air ducting and access doors. All air ducts should be checked for leaks, corrosion, or obstructions. Gaskets and seals should be inspected and replaced as necessary. Insulation and lagging of the enclosures and air ducts should also be inspected. Insulation of the penthouse will vary from site to site. At some sites, the penthouse roof (ESP cold roof) and sides will be insulated, while others will have the floor (ESP hot roof) insulated. The type and location of insulation will vary by design. Upgrading from a natural-draft purge system, or a roof-mounted purge blower with ring/band heaters on the insulators, to a forced-draft combination purge blower and blast heater system would normally require insulation of the penthouse/insulator compartment walls and roof.

Related Topics:

- HV bus system
- HV support assembly and support insulators
- Purge-air systems and heaters

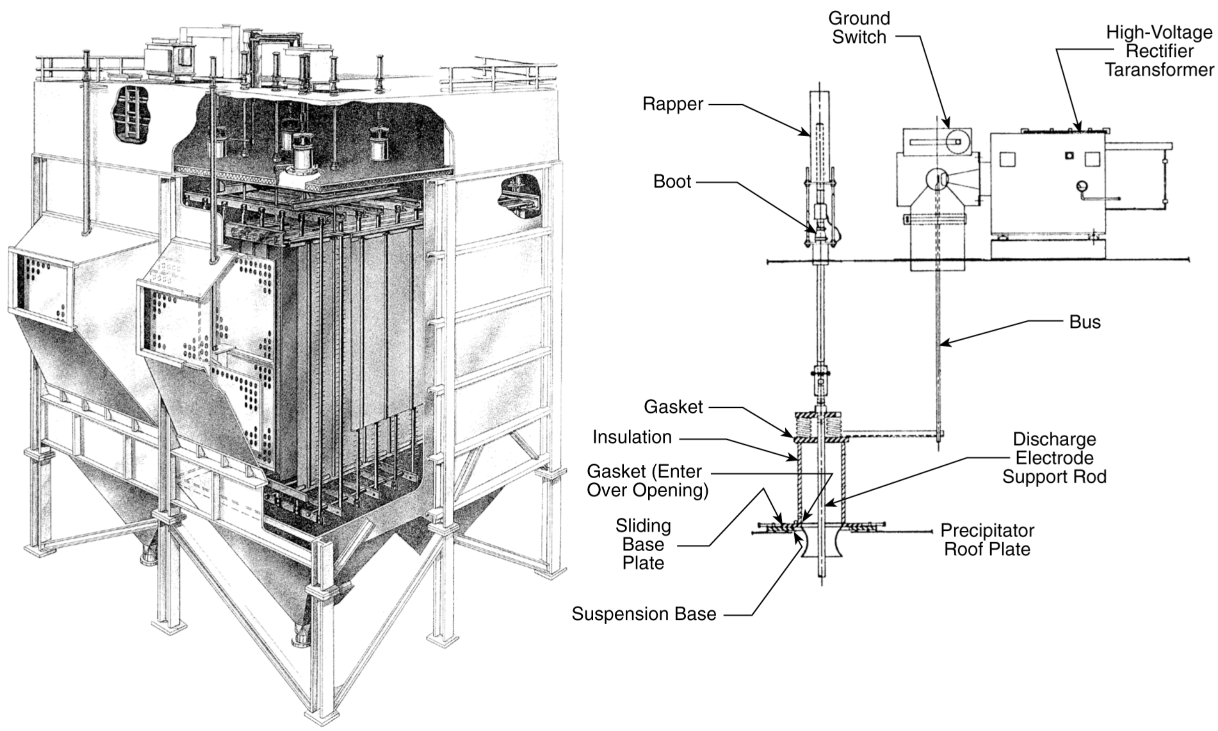


Figure 4-38
Penthouse Design ESP

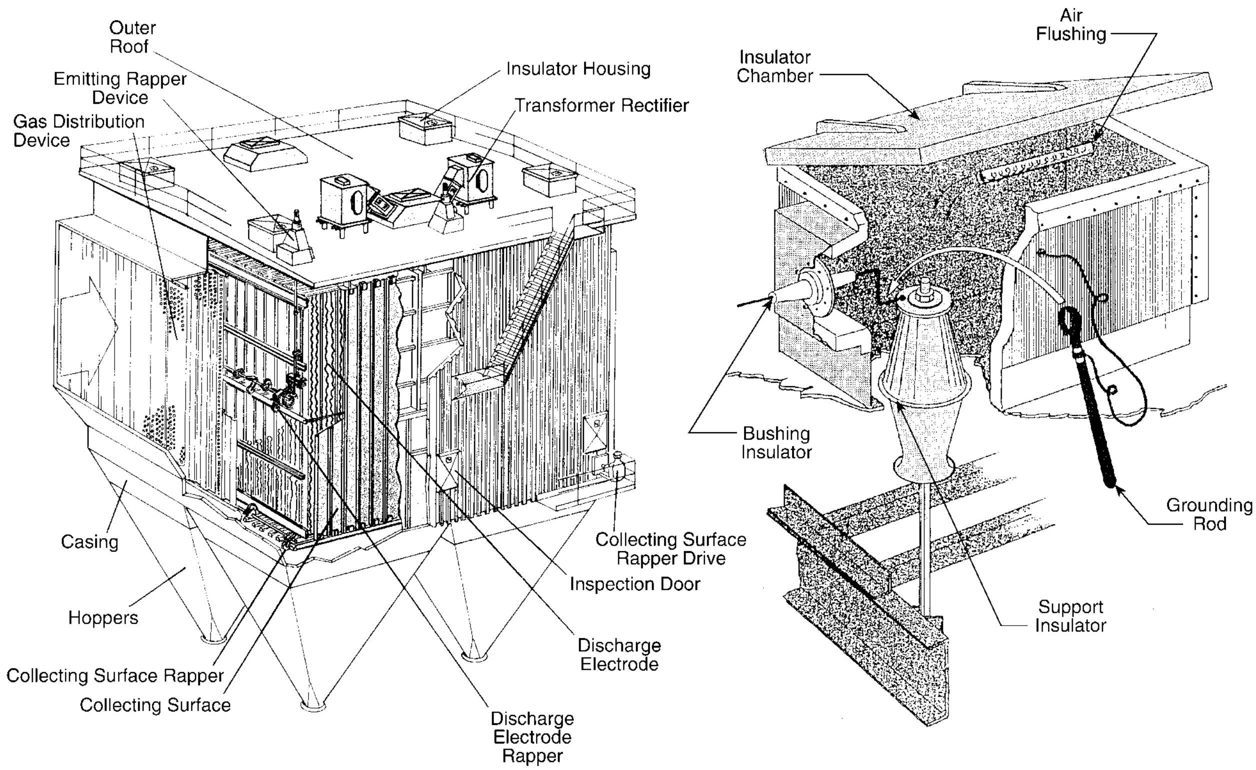


Figure 4-39
Insulator Compartment Design ESP

4.2.3 High Voltage Bus System (Bus, Bus Duct, Switches, and Insulators)

The HV bus system is used to transfer power from the power supplies (TRs) to the HV discharge electrode frames. The bus is the conductor and is usually made of pipe/bar, cable, or a combination of the two. Bus runs between the interlocked insulator compartments or penthouse are enclosed in watertight bus duct. The bus is supported with insulators, usually of the standoff/post insulator type. Thru-bushing insulators may or may not be used at the insulator compartment/penthouse and switch housing penetrations. Ground and/or disconnect switches may be part of the HV bus arrangement.

All components of the HV bus system should be inspected and cleaned during maintenance outages.

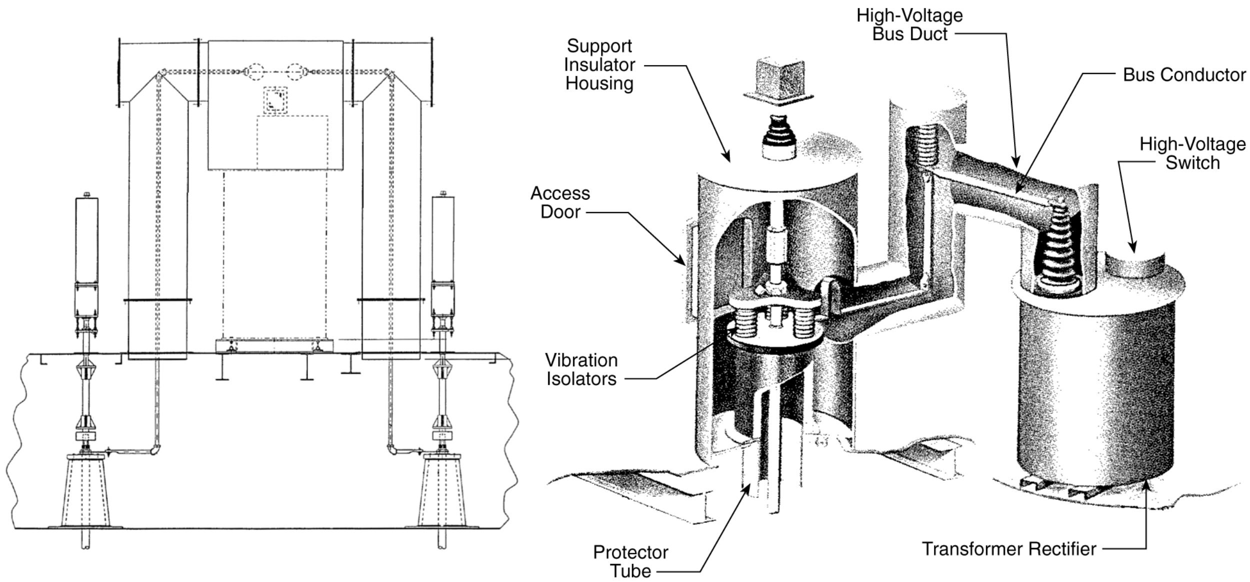


Figure 4-40
Typical Bus Arrangement in the Penthouse and Insulator Compartments

4.2.3.1 Bus

The bus or conductor is usually made of pipe/bar, cable, or a combination of the two. The bar or cable should be of sufficient diameter to avoid corona formation and sparking.

All HV bus should be inspected to verify the integrity of the bus and to assure all HV connections, such as to standoff insulators, thru-bushings, wall bushings, and the HV support assembly, are tight and secure. Where pipe bus is used, elbows used to redirect the conductor at turns in the duct must also be tight and secure. Poor connections can create differences in electrical potential that lead to spit sparking. This can lead to electrical erosion of the conductor. The sparking can also lead to ozone formation within the bus duct enclosure, which lowers the dielectric and promotes additional sparking within the duct.

The bus must also have some provision for thermal expansion. Inadequate provisions for thermal expansion can lead to broken insulators or TR bushings.

4.2.3.2 Bus Duct

Bus duct may be round or square and should be sized (cross section/diameter) according to the operating voltage to provide adequate clearances between the bus and the duct walls to prevent corona discharge and sparking. The dimensions of the duct should also make provision for any sharp edges created by duct connections, cover plate bolts that penetrate the duct, and the like that can promote sparking. The dimensional aspects of bus duct and other electrical clearances are often overlooked in rebuild situations where plate spacing is increased and larger power supplies are required.

The bus duct should be weather tight and sealed to prevent unwanted leakage. It should also have adequate provisions for thermal expansion. This is particularly true on ESPs that operate at high temperature and/or where there are long bus-duct runs. Inadequate provision for thermal expansion can lead to damaged insulators or TR bushings. Bellying or flexing of the ESP roof can shift the bus duct and also lead to damaged insulators or TR bushings.

Bonding jumpers should be used across duct connections to insure good grounding and prevent spit sparking across flanged connections.

The bus duct may be open to the penthouse/insulator compartment, or thru-bushings may be utilized to close off the penetration. Good bus-duct design should discourage condensation and ozone formation within the duct. This is usually accomplished by creating airflow through the duct. Where the duct opening to a penthouse is open, this is accomplished by the introduction of heated purge air. Where thru-bushings are utilized, there are usually purge vents in the section(s) of closed-off duct to promote airflow. There should be at least two of these purge vents in each separate, closed-off leg of ductwork: one at the high point and the other at the low point to create a natural draft for air circulation. One vent alone can allow condensation to form in the duct as a result of the natural breathing process created by the ambient heating and cooling of the duct that occurs over the course of a day.

All vent openings in the duct should have a pipe elbow on them oriented to prevent water penetration and the insertion of any rod or object that could contact the bus bars. Short, tightly-coupled sections of duct between the power supply and insulator compartment/penthouse may not require purge venting.

The bus duct should be opened during maintenance outages for inspection of the duct, insulators, thru-bushings, bus, and connections. Rust or scaling inside HV bus ducts should be removed. Rust that forms on the internal walls of the bus ducts can peel off and fall against the conductor, causing a ground on the secondary of the transformer. Seals on inspection covers should be inspected and replaced if necessary. Purge vents should be checked to verify they are open and not plugged or restricted in any way.

Key Technical Point

The bus duct should be opened during maintenance outages for inspection of the duct, insulators, thru-bushings, bus, and connections. Rust or scaling inside HV bus ducts should be removed. Rust that forms on the internal walls of the bus ducts can peel off and fall against the conductor, causing a ground on the secondary of the transformer. Seals on inspection covers should be inspected and replaced if necessary. Purge vents should be checked to verify they are open and not plugged or restricted in any way.

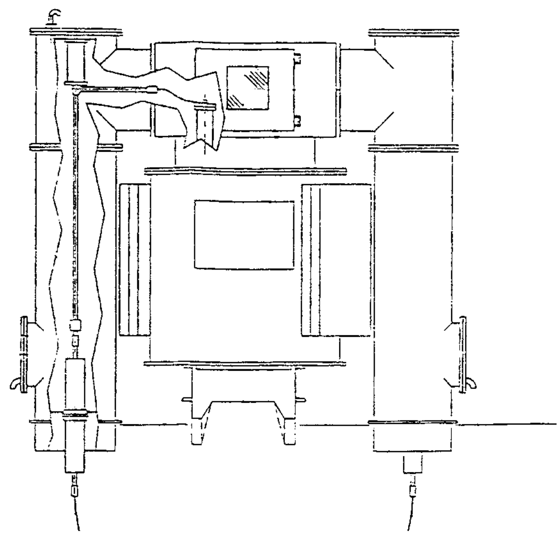


Figure 4-41
Where Thru-Bushings Are Utilized, There Are Usually Purge Vents in the Section(s) of Closed-Off Duct to Promote Airflow. There Should Be at Least Two of These Purge Vents in Each Separate, Closed-Off Leg of Ductwork: One at the High Point and the Other at the Low Point (as Shown Above) to Create a Natural Draft for Air Circulation. The TR Shown Above Uses an External Air Switch.

4.2.3.3 Insulators

Convoluted standoff/post insulators are used in the ductwork to support the HV bus and isolate it from the grounded bus duct. Thru-bushing insulators may or may not be used at the insulator compartment/penthouse and switch housing penetrations. As with all insulators, they should be relatively clean and free of contamination. Provisions for thermal expansion of the bus and duct must be sufficient to prevent cracking or failure of the insulators.

During maintenance outages, all insulators should be checked for cleanliness, cracks, chips, and signs of electrical tracking. Maintenance personnel should replace damaged insulators and remove dust accumulations with a nonabrasive cleaner.

4.2.3.4 Switches

The HV bus system may utilize external disconnect and/or ground switches. In the simplest arrangement, an external ground switch (wipe) might be supplied in order to ground the output bushing of the TR set and bus. A more complex arrangement on a TR set with no immersed switch would involve an external air switch that is utilized as a disconnect and ground. Another arrangement might involve disconnect switches in the bus for electrical isolation. The complexity of the switch arrangement will vary depending on whether full wave-half wave rectification is used and/or the degree of desired bus section isolation. The switches should be locked and a part of the sequenced, key-interlock system to avoid being actuated under load. All switches and switch components should be inspected for signs of corrosion or pitting due to electrical arcing. Hand cleaning, filing, and/or wire wheel cleaning may be required. Efforts should be made to verify that connections are tight and that the switch blades mate properly in clip positions to provide a positive electrical connection. Cleaning and switch operation verification may require actuating the switch. This may be difficult to schedule with the switches in a locked position for ESP entry. It may have to be done early in the entry procedure or later in the outage once internal work is completed and prior to the ESP being returned to service.

Related Topics:

- TRs

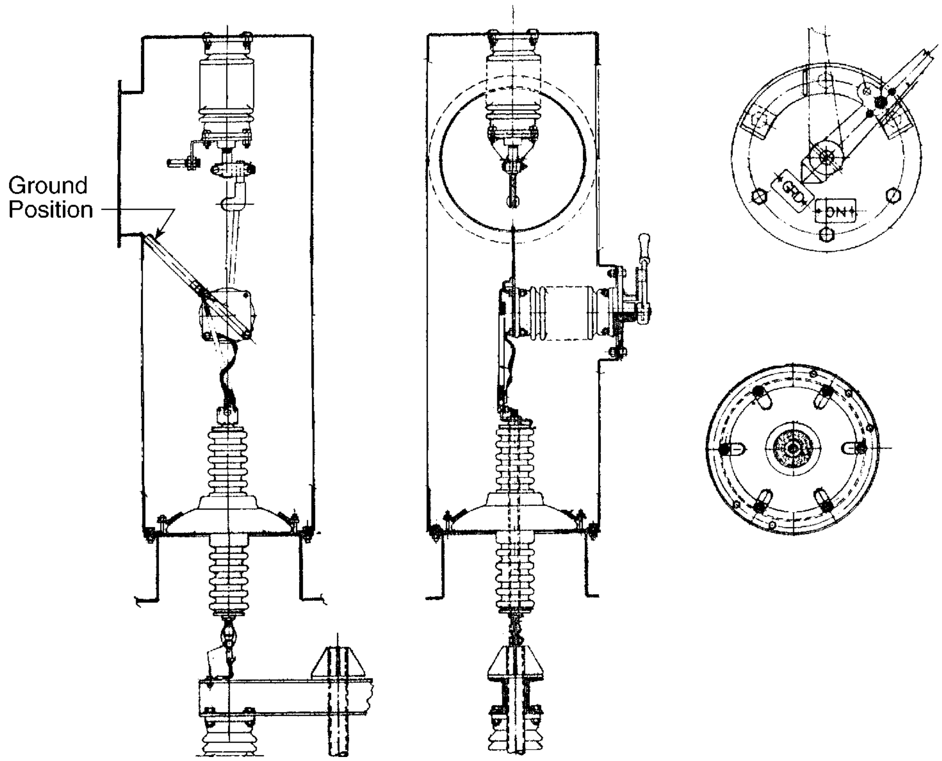


Figure 4-42
An External Air Switch in the Bus Duct That Is Utilized as a Disconnect and Ground

4.2.4 High Voltage Support Assembly and Support Insulators

Each electrical bus section has a separate HV frame that is suspended by hanger rods from support insulators located overhead in either an insulator compartment or penthouse. Two- or four-point suspension is utilized, depending on the size of the HV frame. The major component of the HV support assembly is the support insulator, which is used to support the discharge electrode HV frame and isolate the frame from the grounded, ESP casing. Most often, cylindrical or conical shape support insulators are used. Some designs utilize convoluted (stand-off) insulators. HV support assembly design differs by manufacturer. Other components of the HV support insulator assembly may or may not include base plate(s), corona shield(s), gaskets, cover plate (flange), support nut, springs, a coupling with an attached insulated rapper rod, and a rapper. A typical, HV support assembly arrangement is shown in Figure 4-43.

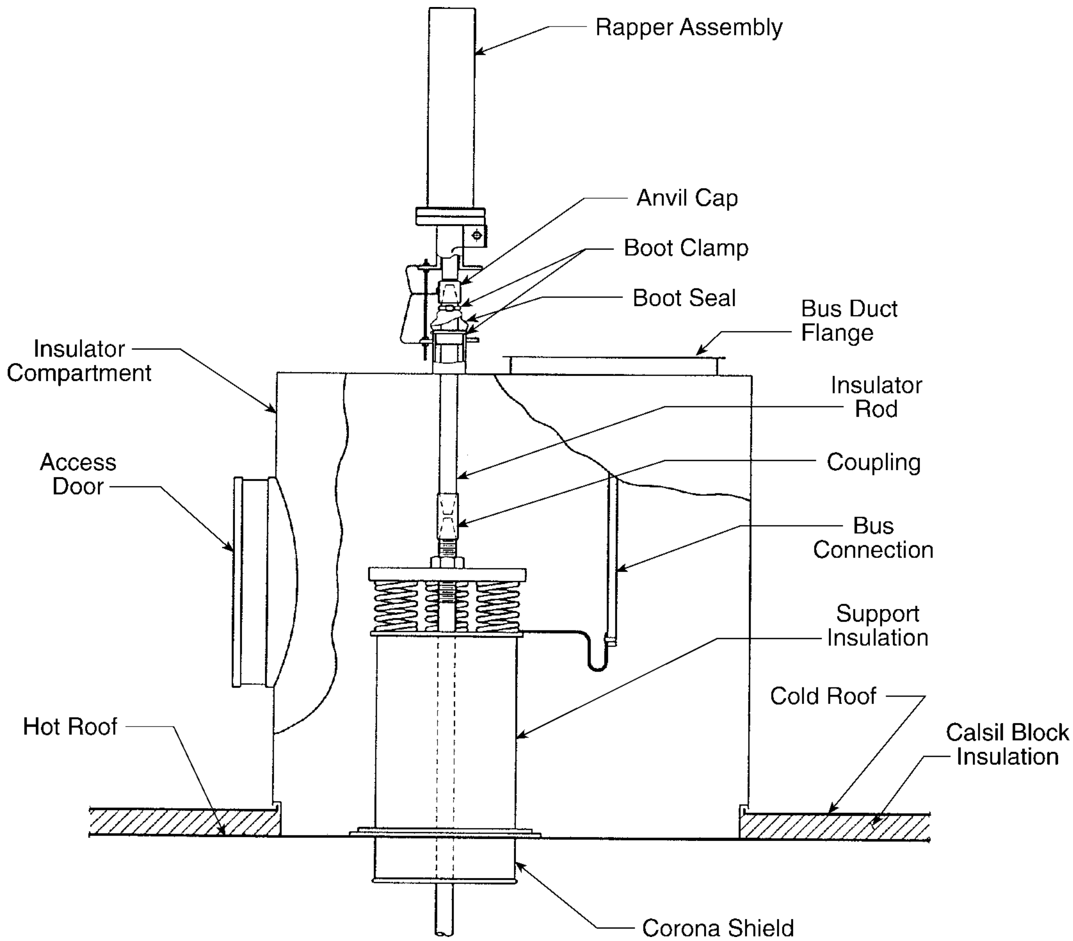


Figure 4-43
Typical High Voltage Support Assembly in an Insulator Compartment

Many manufacturers use base plates under the support insulators to provide a means to level the support insulators on the precipitator hot roof so that weight distribution on the insulators is uniform. The base plate(s) is shimmed to assure a plumb and level support insulator. Base plates also provide a means to adjust the discharge electrode to collecting plate alignment, laterally or perpendicularly. Once positioned, the base plate is often seal welded to the hot roof to prevent purge-air leakage or gas out-leakage. If the base plate is not seal welded, it should have a gasket underneath and/or the base plate should be sealed around the edges with high temperature caulking. The advantage to not welding is that it allows for future re-alignment if necessary. A preferred arrangement is a double base plate, where the lower plate is stationary and the upper plate can be shifted with jackscrews as needed to adjust alignment (see Figure 4-44). Gaskets are used between the plates to create a seal. Base plates are usually of thicker material than the ESP hot roof. Use of base plates is preferable to support insulators mounted directly to the ESP hot roof.

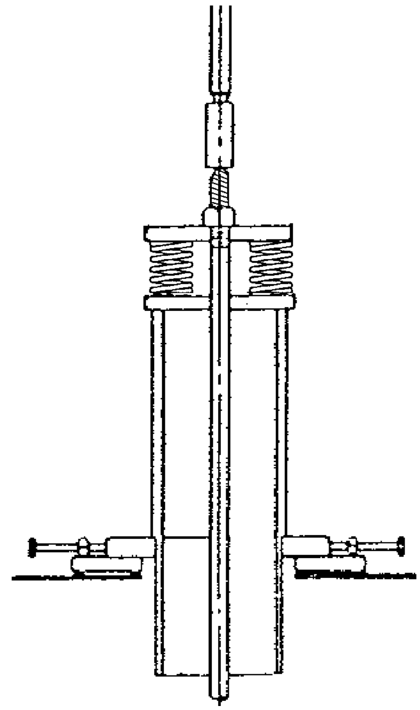


Figure 4-44
Dual Support Insulator Base Plate with Jack Screws for Alignment Adjustment

Corona shields are usually used on the underside of the support insulators to provide a smooth, curved transition where the HV frame support rod penetrates the cutout in the ESP hot roof so as to reduce the potential for spark over. The corona shields may have a conical shape or a hyperbolic shape. The hyperbolic shape is used in some designs to also create a venturi effect inside the insulator to help keep it clean. The condition of corona shields should be checked during off-line inspection of the ESP to make sure no holes have developed and/or excessive material buildup has occurred. Holes can develop as a result of cool purge-air flow across the shield, condensation formation, chemical corrosion, and reduced electrical clearances. The sharp, jagged edges of holes in the corona shields can reduce the spark-over voltage and result in reduced power levels. Damaged or deteriorated corona shields should be replaced.

Gaskets are typically used on the top and bottom edges of the cylindrical and conical type support insulators to provide a gas tight seal. A steel cover plate/support flange with nut is used at the top of the insulator, from which the HV frame support rods are suspended. The cover plate/support flange typically has holes in it for the introduction of purge air to keep the inside surfaces of the support insulators free of material buildup and to prevent particulate-laden flue gas from entering (see Section 4.2.5 - Purge Air Systems and Heaters). Blast heaters and/or band or ring heaters around the base of the insulator are used to prevent condensation formation. The cover plate/support flange may also have removable cover plates that allow inspection and aid cleaning of the inside surface of the support insulators from above the ESP hot roof. The large nut on the HV frame support rods that supports the weight of frame can be used for alignment purposes when there is misalignment at the bottom of a field. Once alignment has been achieved, some type of keeper should be used on the nut to prevent any future movement.

Some HV support assembly designs utilize springs on top of the support insulators to control movement of the HV frames and aid rapping energy transmission. Those that do not use springs often have frame designs that promote rapping energy transmission by some other means. The desire is to direct rapping to the HV frames and minimize rapping energy losses through the support structure.

American-design ESPs that use cylindrical and conical type HV support assemblies usually have a coupling attached to the HV frame support rod that mates with an insulated rapper rod and some type of externally mounted rapper. The couplings may be of a bolted clamp design or a dual taper type that fits over a tapered support rod and accepts a tapered insulator. Care must be taken with clamped porcelain or ceramic rapper-insulator rods to avoid damage and subsequent failure of the rod due to loose clamp bolts, over-tightened bolts, and/or misalignment of the insulator rods in the clamps that cause them to crack under impact of the rapper. The rapper insulator rods and coupling connections need to be checked during maintenance outages. They should be tight to assure good rapper transmission. European-design ESPs may or may not have a rapping mechanism mounted directly on top of the support insulators.

Key Technical Point

Care must be taken with clamped porcelain or ceramic rapper-insulator rods to avoid damage and subsequent failure of the rod due to loose clamp bolts, over-tightened bolts, and/or misalignment of the insulator rods in the clamps that cause them to crack under impact of the rapper.

Insulated rapper rods are usually manufactured of porcelain or some type of plastic resin (fiberglass reinforced plastic [FRP]). These are typically rated for a 270 to 350°F (132 to 177°C) operating range. Higher temperature applications might use ceramic (alumina) insulators. Care must be taken with both porcelain and alumina rapper rods to avoid binding, misalignment, or over-rapping that could lead to mechanical failure. The insulated rapper rods need to be checked during every maintenance outage. Also check for evidence of electrical tracking, water penetration from the rapper boot seal, or condensation formation. Cracked, damaged, deteriorated, or tracked insulators need to be replaced.

4.2.4.1 Support Insulators

Support insulators are usually of the cylinder or conical type and are available in a variety of sizes. However, there are some manufacturer support assembly designs that do not use these types of insulators. Instead, the HV frame support assembly uses stand-off/post insulators, one at each end of a steel beam from which the HV frame support rod is suspended (see Figure 4-45).

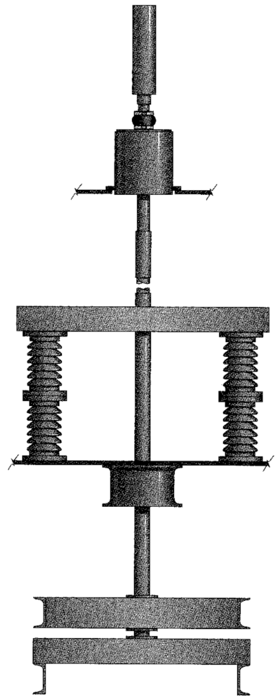


Figure 4-45
Post Insulator HV Support Assembly

Support insulators are manufactured of porcelain or ceramic material. Porcelain support insulators are widely used in applications where temperatures are in the 300 to 400°F (149 to 204°C) range. Alumina (ceramic) support insulators however, have since become the industry standard because of their superior mechanical and electrical properties. According to the Alumina Ceramic Manufacturers Association, to be classified as a high-alumina ceramic, the aluminum oxide content of the insulator should be in excess of 80%. There are however insulators available, often referred to as *alumina-based porcelain* or *high-strength porcelain*, which contain 35 to 48% alumina. Although these are superior to the porcelain insulators, they do not have the same properties of the high-alumina ceramic insulators.

Key Technical Point

There are however insulators available, often referred to as *alumina-based porcelain* or *high-strength porcelain*, which contain 35 to 48% alumina. Although these are superior to the porcelain insulators, they do not have the same properties of the high-alumina ceramic insulators.

Insulators are available glazed or unglazed. Because of its porous nature, porcelain is usually supplied with a glaze coating for the precipitator application in order to seal the insulator body against absorption of liquids or gasses. Some of the precipitator manufacturers and parts suppliers argue against the use of glaze on the alumina insulators. They argue that the dense, non-porous nature of alumina (80+%) does not require a glaze coating and that application of a glaze lowers the overall electrical resistivity of the insulator because the glaze has inherently lower electrical properties than the alumina body.

Key Technical Point

Some of the precipitator manufacturers and parts suppliers argue against the use of glaze on the alumina insulators. They argue that the dense, non-porous nature of alumina (80+%) does not require a glaze coating and that application of a glaze lowers the overall electrical resistivity of the insulator because the glaze has inherently lower electrical properties than the alumina body.

Support insulators in the dry, coal-fired ESP utility application are usually fairly reliable and failure is infrequent. This is not always the case in an oil-fired application. A high rate of failure needs to be investigated. Common causes of support insulator failure include:

- Material buildup or the presence of moisture on the insulator surface that results in electrical tracking and subsequent fracture of the insulator
- Thermal shock due to extreme temperature fluctuations
- Misalignment of the insulator or other condition that introduces mechanical stress due to uneven load distribution
- Inadequate provisions for thermal expansion that lead to stress related failure

Maintenance of the support insulators should include a thorough inspection and cleaning of the insulator surfaces (inside and out). Cleaning should be done with a dry rag and, if needed, water or some other electrically neutral cleaner. A mix of water and vinegar or water and ammonia works well. The support insulators should be inspected for evidence of electrical tracking, ash buildup, or cracks. Tracking can cause support insulator failure by concentrating excessively high temperatures on the surface. Ash buildup on the insulators can allow the tracking to occur during operation if the dew point temperature is sufficiently high.

A well-designed system will have little-to-no ash buildup on the inside surfaces of the support insulators. However, it is not uncommon to find a small amount of dry ash on the surface of the insulators unless they have been recently cleaned. The ash layer should be thin and regular in appearance. If the ash contains a significant amount of carbon (that is, it appears blacker than the rest of the ash) or if the ash is wet from either moisture or acid condensation, the problem must be investigated and corrected: check for problems with the purge-air system, air in-leakage, and problems with the insulator heaters. Deposits of high-carbon ash or moist ash will lead to insulator failure and poor ESP performance.

Tracked or badly cracked and damaged support insulators need to be replaced. Several support insulators should always be kept in the spare parts inventory. Plants that experience a high rate of failure should have more on-hand, or a reliable source that can provide them with a reasonably short lead-time. Support insulators that have only a vertical hairline crack from top to bottom do not necessarily require immediate replacement. Support insulators are very strong in compression. The condition of the insulator should however, be monitored during future outages.

Key O&M Cost Point

Several support insulators should always be kept in the spare parts inventory. Plants that experience a high rate of failure should have more on-hand, or a reliable source that can provide them with a reasonably short lead-time. Support insulators that have only a vertical hairline crack from top to bottom do not necessarily require immediate replacement.

When replacing an insulator, it is good practice to also replace any associated gaskets. Also assure that the weight-bearing surfaces of the insulator, base plate, insulator cover plates/flanges, and gaskets are clean and free of any debris so as to avoid introduction of any stresses that could promote cracking of the insulator. Replacement of a support insulator can disturb the discharge electrode to collecting plate alignment. Unless there has been a catastrophic failure where the support insulator is collapsed, it is a good idea to make a mark(s) indicating the relative position of the HV frame prior to removing the damaged insulator. Once alignment has been achieved, some type of keeper should be used on the HV frame adjustment nut to prevent any future movement. These keepers are normally welded in place. It is important that the insulator be covered or protected against weld splatter. Welding slag can become imbedded on the insulator surface and could compromise the electrical integrity of the insulator. In extreme cases, the heat of the welding slag hitting the insulator surface might cause it to crack and fail. Be aware that any time welding is done on the HV frame or support assembly, the connection to the TR should be lifted to prevent the possibility of feedback that could damage the transformer and switch.

Related Topics:

- Penthouse/insulator compartments
- Purge systems and heaters

4.2.5 Purge Air Systems and Heaters

Purge air systems and heaters are used to ventilate and heat the HV suspension insulators housed in the insulator compartments/penthouse. They are important to maintaining the structural and electrical integrity of the insulators. Failure, or inadequate delivery, can lead to electrical tracking, ash buildup, or cracking of the support insulators, which can be detrimental to performance.

Purge air is intended to provide a constant flow of clean, dry air across the insulator surface where the HV frame support rods penetrate the ESP hot roof to prevent flue gas contamination of the insulator and the penthouse/insulator compartment enclosures. Dust deposition on the insulator surface can lead to electrical tracking and subsequent failure of the insulator. Generally, only a small amount of air is required to accomplish this. Most manufacturers specify 50 to 100 cfm (0.024 to 0.047 cms) of purge air per insulator. The upper flanges/cover plates on the top of the barrel/cylindrical type support insulators commonly have holes in them of various diameters to achieve the desired flow. During an outage, these openings should be checked for blockages. Buildup in excess of 0.25 in. (6.35 mm) on the inside surface of the insulator may indicate problems.

Purge air can be delivered one of two ways: either with a fan/blower or by natural draft. Purge-air blowers are used on positive-pressure systems to provide airflow across the insulators and to pressurize the insulator compartment/penthouse enclosures above the operating pressure of the precipitator proper. It is common to find these also on negative-pressure systems for the same purpose since it is unlikely that negative-draft systems are negative under all operating conditions. Startup, shutdown, low load, and/or boiler upset conditions may cause the precipitator to go positive, in which case the insulator compartments/penthouse would be contaminated. Some negative-draft systems rely on the natural draft of the I.D. fan to introduce purge air. Openings or vents in the insulator compartment/penthouse allow ambient air to be drawn across the insulators under the negative draft of the fan. Again, it is important that these openings be clear.

Heat is another component that is important to maintaining the integrity of the insulators and enclosures. The need for heat is largely governed by operating temperatures and design. Condensation of water or other condensable material in the flue gas can occur without adequate heat that promotes electrical tracking, contamination, and accelerated corrosion. Lack of heat can also lead to thermal shock of the insulators. The extent of condensation varies by site and is dependent on moisture content and temperature of the flue gas, moisture content and temperature of the air being introduced, the temperature in the insulator compartment/penthouse (as a result of heat loss through the roof), and the rate of purge air being introduced. If condensation, or evidence of condensation (such as hardened buildups or widespread corrosion of the insulator enclosure), is present during inspection, heat or additional heat is warranted. The most critical need for heat is during boiler startup, when surfaces are cold and heat losses may result in condensation.

Key Technical Point

If condensation, or evidence of condensation (such as hardened buildups or widespread corrosion of the insulator enclosure), is present during inspection, heat or additional heat is warranted. The most critical need for heat is during boiler startup, when surfaces are cold and heat losses may result in condensation.

Heaters are generally of two types: blast heaters that work in combination with the purge-air blower to provide heated air to the insulator compartments/penthouse, and direct heaters (such as band or ring heaters) that are furnished for each support insulator. In spite of the increased operating costs, the combination heater and blower purge-air system is preferable to the blower with direct insulator heaters or the natural-draft system with or without direct insulator heaters. Those systems risk problems with the introduction of cold, moist ambient air. It is not uncommon to find natural-draft systems with no filtering devices at the enclosure vents. These systems have the additional risk of introducing outside contaminants if the ambient environment is not clean. Some systems utilize both a combination purge-blower/heater system and direct heaters on each insulator.

The combination purge-blower/heater systems are usually thermostatically controlled and include circuitry to prevent blast heater operation in the event of blower failure to avoid burning up the heaters. Purge-air systems should also include provisions for annunciating blower failure.

Temperatures in the penthouse/insulator compartments should also be monitored. Where use of purge-air systems are critical to reliable ESP operation, such as with positive-pressure systems, it is not uncommon to find a backup system that is automatically actuated in the event of failure of the primary system. Control schemes can become quite elaborate depending on the complexity of the system and the desired levels of monitoring and control.

4.2.5.1 Inspection and Maintenance

Given the importance of the purge-air and insulator heating systems, it should be inspected regularly while in service to insure that it is operating properly. Blower intake filters should be checked and cleaned or replaced as necessary.

During maintenance outages the entire heating and ventilating system should be inspected, cleaned, and serviced. Fans/blowers, motors, heaters, dampers, thermostats, and switches should be cleaned and checked for proper operation. Fans and motors should be lubricated as recommended by the manufacturers' instructions. Defective heaters should be replaced.

Inspection of the penthouse/insulator compartment will provide clues as to the effectiveness of the purge-air and heater systems. Excessive dust contamination, corrosion, and/or condensation in the insulator penthouse/insulator compartment areas, or buildup on the inside surfaces of support insulators, might indicate problems such as:

- Heater failure or insufficient heat due to a lack of or undersized heaters; too much purge air; or the introduction of cold, moist ambient air.
- Blower failure, or insufficient purge airflow. Insufficient purge airflow might be due to a dirty filter, a lack of or an undersized blower, improper blower rotation, or pressure losses. Pressure losses can result from oversized purge holes in the support insulator cover plates, or from losses that occur at other locations that should be sealed. It is not uncommon for pressure losses to occur at the support rod penetration of the support insulator due to an oversized, unsealed opening. These openings should be sealed off. This can usually be done by wrapping gasket material around the HV frame support rod to close off or restrict the opening size. Of course, any holes in the insulator enclosures, other than purge vents, should be sealed.

  It is also important to verify that the purge air delivered to the inside surface of the insulator is effectively directed. Many purge holes have pipe elbows or sleeves on the underside of the support insulator flanges/cover plates to orient purge airflow.

Some less obvious situations that maintenance personnel might encounter during inspection that relate to the heater/blower system include:

- Corrosion of the penthouse floor (ESP hot roof) directly underneath the blower discharge. This area is subject to corrosion due to the continuous introduction of air if there is no deflector baffle. A deflector should be installed under the blower discharge to guard against this and to distribute purge air throughout the penthouse.
- Freewheeling of the blower. This can happen under high, negative conditions that exceed the blower capacity and can damage the motor. This problem can be investigated with vane anemometers. It may indicate an undersized blower and/or a need to restrict air movement across the support insulators.
- Corrosion of the upper HV support frames. Too much purge airflow is occasionally a problem that is indicated by corrosion of the HV frame directly underneath the support insulators.

There are some manufacturer designs that do not use the cylindrical or conical (flower pot) support insulators. Instead, the HV frame support assembly uses stand-off insulators: one at each end of a steel beam from which the HV frame support rod is suspended. These arrangements often have a large diameter hole in the precipitator hot roof through which the HV frame support rod passes. This large opening makes it difficult-to-impossible to pressurize the associated insulator compartment. Therefore, it is not uncommon to find the entire insulator compartment contaminated. A solution is to install a short, split-cylindrical insulator around the hole with a split cover plate that sandwiches the support rod (see Figure 4-48).

Key Technical Point

This large opening makes it difficult-to-impossible to pressurize the associated insulator compartment. Therefore, it is not uncommon to find the entire insulator compartment contaminated. A solution is to install a short, split-cylindrical insulator around the hole with a split cover plate that sandwiches the support rod.

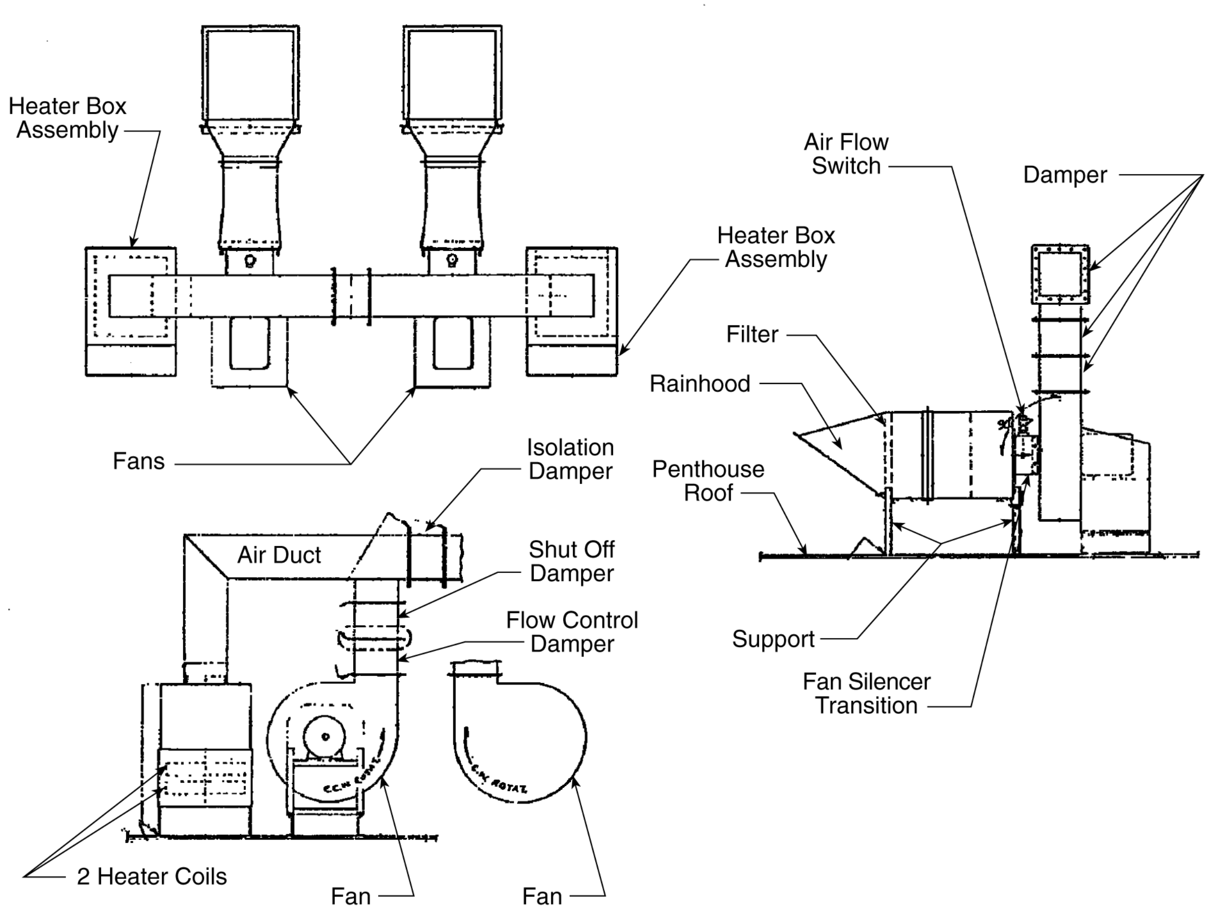


Figure 4-46
Combination Purge Blower/Heater System with Back-Up System

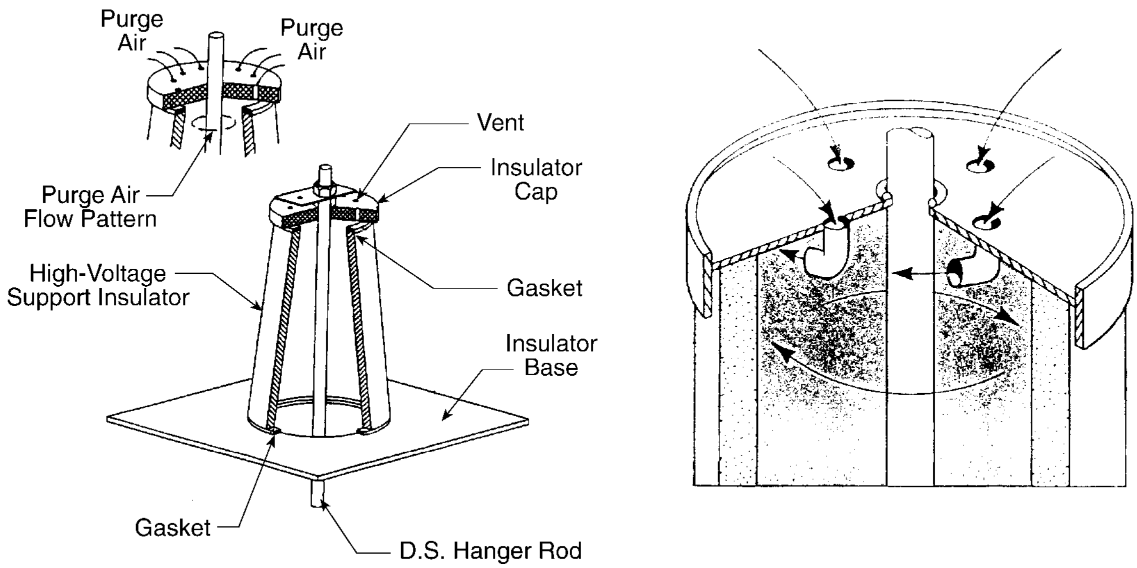


Figure 4-47
Purge Air Is Intended to Provide a Constant Flow of Clean, Dry Air Across the Insulator Surface Where the HV Frame Support Rods Penetrate the ESP Hot Roof to Prevent Flue Gas Contamination of the Insulator and the Penthouse/Insulator Compartment Enclosures. Dust Deposition on the Insulator Surface Can Lead to Electrical Tracking and Subsequent Failure of the Insulator. Generally, Only a Small Amount of Air Is Required to Accomplish This. Most Manufacturers Specify 50 to 100 cfm (0.02 to 0.05 cms) of Purge Air Per Insulator. The Upper Flanges/Cover Plates on the Top of the Barrel/Cylindrical-Type Support Insulators Commonly Have Holes in Them of Various Diameters to Achieve the Desired Flow.

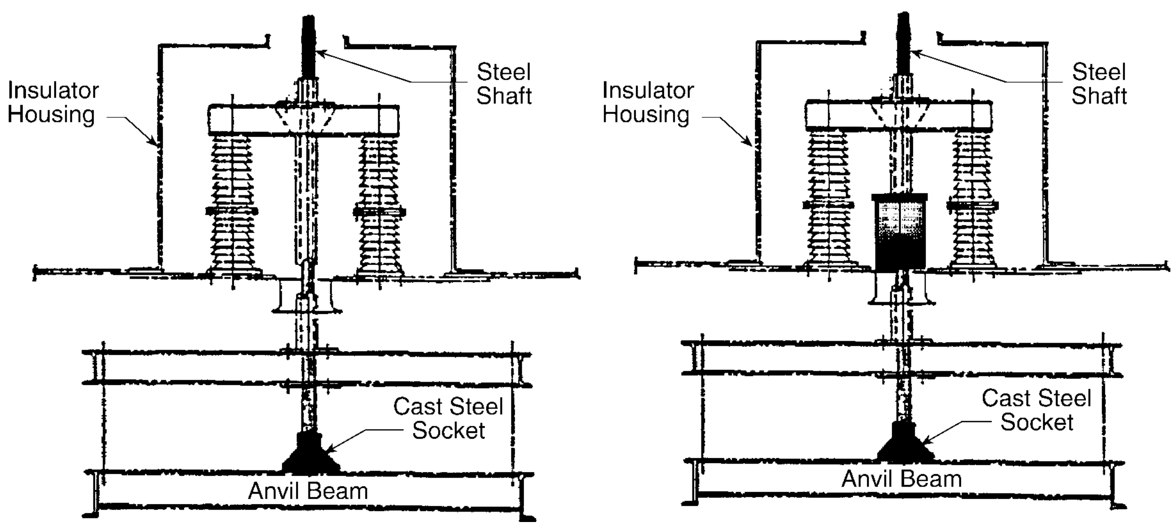


Figure 4-48
The HV frame Support Assembly (Left) Uses Stand-Off Insulators: One at Each End of a Steel Beam from Which the HV Frame Support Rod Is Suspended. This Arrangement Leaves a Large Diameter Hole in the Precipitator Hot Roof, Through Which the HV Frame Support Rod Passes. This Large Opening Makes It Difficult-to-Impossible to Pressurize the Associated Insulator Compartment, so It Is Not Uncommon to Find the Entire Insulator Compartment Contaminated. A Solution Is to Install a Short, Split-Cylindrical Insulator Around the Hole with a Split Cover Plate That Sandwiches the Support Rod (Right).

Related Topics:

- Penthouse/insulator compartments
- HV support assembly and support insulators

4.3 Hopper Area

Hoppers collect the ash dislodged by rapping from the collecting plates and discharge electrodes, and deliver it for discharge to an ash removal system. Sections 4.3.1 through 4.3.6 discuss the hoppers and ash removal and their importance to effective ESP operation. Also discussed are the typical problems that are encountered in this area of the precipitator system, some measures that can be taken to avoid problems, and inspection and maintenance requirements.

4.3.1 Hoppers

Hoppers collect the ash dislodged by rapping from the collecting plates and discharge electrodes. The hoppers used in the utility application are mostly of an inverted-pyramid shape that converges to a round or square discharge. Some industrial-type, power-boiler ESPs might utilize trough hoppers. Regardless, the sides of the hoppers must be steep enough (typical valley angles are 55 to 65 degrees +) to promote material flow to the hopper outlet and minimize the potential for buildup on the hopper walls. The outlet opening of the hopper must also be appropriately sized to promote material flow and easy removal by the ash removal system.

Sizing of a hopper should give consideration to the loading and the rate of material removal. For instance, since the inlet field collects the largest percentage of the dust, sizing of the hopper should reflect this. Hoppers should be structurally designed to withstand a full dust load and to support the loads imposed by the ash removal system. Sizing may also be influenced by the time for which the material might be stored. However, since the major problem with hoppers is pluggage, it is not good practice to use the hoppers for storage purposes. Ash should be removed from the hoppers as continuously as possible so that the ash remains hot and flows easily.

Key Technical Point

However, since the major problem with hoppers is pluggage, it is not good practice to use the hoppers for storage purposes. Ash should be removed from the hoppers as continuously as possible so that the ash remains hot and flows easily.

Baffles are often placed in the hoppers to minimize gas sneakage below the ESP collection zone and are typically always used when the hopper spans two fields in the direction of the gas flow. Hoppers are usually equipped with accessories such as strike plates for manual rapping of the hopper walls, poke holes to help unclog the hopper outlets, vibrators or fluidizing stones to promote material flow, heaters to prevent condensation formation and ash caking, and level detectors to monitor ash levels.

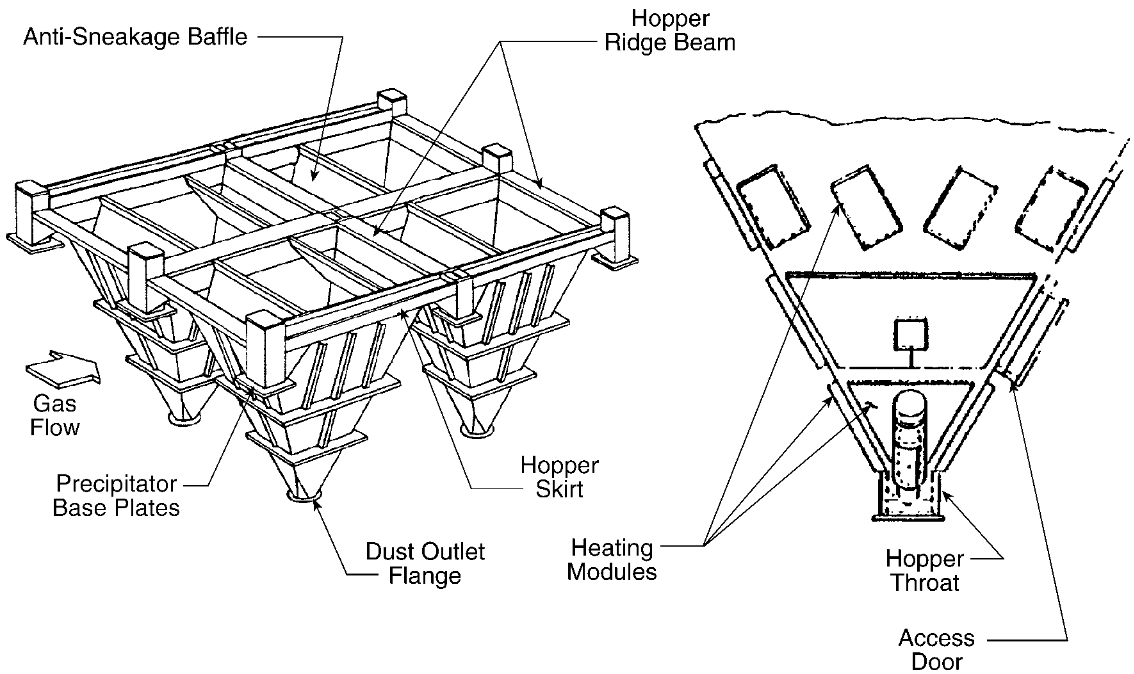


Figure 4-49
Pyramid Hoppers

4.3.1.1 Typical Problems

Hopper plugging is the major concern. It can lead to both short- and long-term ESP performance problems that imperil compliance. Unfortunately, hopper pluggage can be difficult to diagnose because its effect on the precipitator TR meter readings is not apparent until the hopper is nearly full. Once the ash level extends into the HV frames of the fields overhead, heavy sparking typically develops that results in reduced power levels. It may also lead to a ground-like condition. The TR may or may not trip off in response due to under-voltage or over-current protection in the control circuitry. Regardless, the collection efficiency in the associated fields is significantly impaired. Buildup in the hoppers that extends into the lower HV frames and collecting plates can also lead to permanent damage of these components. If this happens, performance in the effected fields may remain diminished by misalignment, even after the hopper is cleared.

The primary causes of hopper plugging are the following:

- **Insufficient heat or insulation –** This can lead to cooling of the hopper wall or throat surface (discharge transition) that will promote condensation and ash buildup on the wall and throat areas. The hoppers need to be well insulated and should have heaters at the lower apex to maintain hopper wall surface temperature above a minimum of 250°F (141°C). A windbreak may also be helpful. Subsections 4.3.3 and 4.3.5 discuss criteria for hopper heaters and insulation.

- **Air in-leakage –** This can cause material to cool rapidly and harden to form material bridges or clinkers that impede material flow. It can also cause collected material to ignite, resulting in reentrainment of collected material and accelerated corrosion of the hopper walls. Common sources of air in-leakage are access doors, worn valve seals at the outlet discharge, and any holes that may have developed.
- **Design oversights and internal obstructions –** Poor hopper design that does not provide sufficient slope or opening at the outlet flange will promote hopper plugging. Hopper walls should be sloped at 55 degrees or greater, and have an outlet flange opening of 12 in. (304.8 mm) minimum. Baffles should not extend so close to the outlet flange opening that they narrow the passage for material movement. Corner configurations, internal struts, and ladders can also contribute to buildup.
- **Use of hoppers for dust storage –** The use of the hoppers for this purpose invites problems. Continuous evacuation of the hoppers will help to avoid pluggage problems.

Some means of level detection should be employed to indicate hopper buildup at a level that allows a timely response before the buildup affects ESP operation. Once detected, high priority should be given to clearing the hopper. Poke-holes are often used for this purpose. They should be oriented downward to prevent personnel from extending a long steel rod out pipe or air lance toward the HV frame. A flexible ground strap should be attached to the lance. It is prudent to shut down the rappers for a short time while working to clear a hopper to avoid adding to the dust load in the hopper. If power readings indicate that buildup has already reached the HV frame, the TR should be shut down if it has not already tripped, and it should be locked out until the hopper is judged clear.

Key Technical Point

Some means of level detection should be employed to indicate hopper buildup at a level that allows a timely response before the buildup affects ESP operation. Once detected, high priority should be given to clearing the hopper.

Hopper pluggage problems persist in spite of the use of hopper accessories such as vibrators, strike plates, heaters, baffles, level detectors and poke holes, and hopper designs that incorporate large outlet discharges and steep hopper walls that are meant to reduce the problem. Hopper accessories and their purpose are discussed in detail in Sections 4.3.2 through 4.3.6. Some of these accessories can actually create or compound pluggage problems.

Corrosion and air in-leakage are other related problems that can plague the hoppers. As mentioned, air in-leakage can contribute to hopper pluggage, but it can also accelerate corrosion, cause damage to internal components, and cause material reentrainment that adversely affects ESP performance. Efforts need to be made to identify and eliminate sources of air in-leakage in this area. Access doors, poke-hole pipes, and ash removal system valves are common sources of leakage.

Corrosion may be a problem when SO_3 levels are high, such as when firing medium- to high-sulfur coal, over-conditioning with SO_3, or using SCR NO_X catalyst. This is especially true during boiler cycling and low-load operation when gas temperatures may be lower. The dead gas region located towards the top of the hopper is most susceptible to premature corrosion, particularly at the outlet. The importance of a good insulation layer and adequate heating of the hopper sidewalls cannot be overstressed

Key Technical Point

The importance of a good insulation layer and adequate heating of the hopper sidewalls cannot be overstressed.

4.3.1.2 Inspection and Maintenance of the Hoppers

Inspection and maintenance of the hoppers revolves primarily around preserving a smooth inner surface with no ledges or obstructions, and keeping the hoppers gas-tight.

Hoppers should be emptied before inspection. Unusual buildup in the hopper corners or at obstructions will usually still be evident after hopper evacuation. When opening hopper doors for inspection, maintenance personnel need to be extremely careful to avoid being potentially burned by hot ash and/or being overcome by ash that may be impounded in the hopper. Do not rely solely on hopper level detectors. If possible, visually verify that the hoppers are clear of material prior to opening. This can often be done from side access walkways located above the hoppers, or some other point of access located overhead. If not, the door (inner door if applicable) might be tapped with a hammer. A hollow ring would be indicative of an empty hopper whereas, a thud would indicate material buildup behind the door.

All hopper doors should be equipped with safety chains or latch mechanisms that can be used to prevent complete opening of the door upon release. This can slow the loss of ash from the hopper and prevent personnel from being suddenly overcome in the event of accidental opening of a full hopper. Most hopper doors will have both an inner and outer door. The inner door will usually have features to determine if there is material impounded behind it. If not, some of these can be easily installed. A pipe coupling in the inner door with a plug that can be removed provides a simple means of visually verifying whether there is buildup behind the door. The inner door may also have a latching mechanism that allows it to be backed-off to create a gap between the seal and jam. The partial release would allow accumulated dust to flow out of the gap and indicate a potentially full hopper without jeopardizing personnel.

Key Human Performance Point

All hopper doors should be equipped with safety chains or latch mechanisms that can be used to prevent complete opening of the door upon release. This can slow the loss of ash from the hopper and prevent personnel from being suddenly overcome in the event of accidental opening of a full hopper.

If, after supposedly emptying, there is still ash in the hopper, there is clearly a problem. It could indicate a problem with the ash removal system, or it may be the result of clinker formation that impedes ash flow or rat-holing of the accumulated ash. Note the problem and then manually empty the hopper and continue the inspection.

During inspection, the structural condition of the hoppers should be checked, as well as looking for signs of leaks, dust buildup, corrosion, and erosion. Exterior inspection should focus on the condition of the insulation and lagging, and on any area that may not be gas-tight or that might create a heat sink. Interior inspection may require the installation of some type of scaffolding to gain access. Care must be taken in most hoppers to avoid falling. A harness should be used when necessary to assure safety of personnel.

Any debris, such as fallen wires and weights, needs to be removed. If there are unusual buildups or a known history of hopper plugging, look for obstructions that may exist that could impede material flow or promote buildup. These might include a baffle that extends too far into the hopper, struts or supports that are low in the hopper, ladder rungs on a hopper wall, or even the use of fluidizing air nozzles/stones in the bottom of the hopper. These may need to be modified or removed. Localized buildups and/or corrosion on the hopper wall surface might be found opposite a heat sink such as a strike plate.

Identifying and eliminating sources of air in-leakage in the hopper area is important to preventing hopper plugging, material reentrianment, corrosion, and deformation of the precipitator internals. Ash caking and *wind trails* in the ash can help identify sources of air in-leakage. Pay special attention to hopper valleys and upper flanges, as these are areas of great structural stress concentrations, especially in hot-side precipitators. Access doors are a frequent source of air in-leakage. It is good practice to replace the gaskets after the door has been opened to help assure a good seal on closing. Another common source of air in-leakage are the ash removal system valves at the outlet flange of the hopper. These need to be checked when inspecting the ash removal system.

Key Technical Point

Access doors are a frequent source of air in-leakage. It is good practice to replace the gaskets after the door has been opened to help assure a good seal on closing.

Interior corrosion may indicate air or moisture in-leakage, or it may be related to low temperatures. Corrosion of the hopper wall girder/beam at the precipitator outlet is a location where corrosion frequently develops due to lower temperatures. Areas where there is corrosion and erosion damage should be noted and repairs made as needed.

It is good practice to leave the hopper heaters on and the access doors in a closed position during an outage where there is no intent to clean the ESP internals. This will help to keep whatever ash residue is in the ESP from picking up moisture. The ash removal system should be in operation any time the rappers are running. The hopper heaters and ash removal system will need to be turned off for entry into the hopper. They should be energized at least eight hours prior to startup.

Key Technical Point

It is good practice to leave the hopper heaters on and the access doors in a closed position during an outage where there is no intent to clean the ESP internals. This will help to keep whatever ash residue is in the ESP from picking up moisture.

Hoppers frequently provide the only means of access for inspection of the lower HV frames and the bottom of the collecting plates, which means some sort of scaffolding must be installed to gain access for inspection and repairs. On large units with many hoppers, this may require a significant amount of outage time. At a minimum, the hoppers and lower ESP components should be visually inspected from the access doors. Where evidence suggests that there may be a problem, the appropriate temporary access should be installed to investigate further. Power readings taken before an outage may help to identify areas where hopper access should be given priority to help identify a problem. If there is to be a complete change of wire discharge electrodes during an outage, planning should include the material and manpower to install and remove temporary access, as well as the wire electrodes.

The placement of pipe or angle stiffeners across the hopper (if not already installed) can aid the quick installation of scaffold boarding. These stiffeners need to be located such that they do not promote buildup or impede material removal. Ladder/hand rungs should be available inside and outside of each hopper door to aid safe entry and exit. Rungs located along the hopper wall should be at least 10 in. (254.0 mm) off the hopper wall to discourage formation of buildup along the wall.

Key Human Performance Point

The placement of pipe or angle stiffeners across the hopper (if not already installed) can aid the quick installation of scaffold boarding. These stiffeners need to be located such that they do not promote buildup or impede material removal.

Related Topics:

- Hopper level detectors
- Hopper heaters
- Hopper accessories
- Hopper insulation

4.3.2 Hopper Level Detectors

Level detectors, which measure the level of fly ash within a hopper, are commonly used on precipitator hoppers. It is desirable to know how full the hoppers are to avoid performance problems and potential damage to internal components of the ESP. Even if hoppers are near continuously evacuated, hopper level detectors are useful because they will provide an indication of a hopper that is not being properly emptied.

Level detection devices can utilize gamma radiation, sound, capacitance, pressure differential, temperature, or paddle-wheel methodology for the detection of excess buildup. Those that do not require components within the hopper are generally the more reliable. The equipment should be designed for the intended use and be as rugged as possible. Even so, the harsh environment around the bottom of a precipitator can subject any type of level detection to a high rate of failure or faulty readings. Hopper level detectors have not enjoyed a history of high reliability. The radio frequency and radiation methods are the more common and reliable methods of detection in use today.

The radio frequency, level-detection system operates by radio frequency oscillation, which is dampened by a high ash level, producing a proportionate ac signal. The detector actuates a relay or a set change in a 4 to 20 mA signal, which can be used to operate an alarm. The probe is mounted on the hopper sidewall with the electronics located somewhere in the hopper area away from high temperatures. The detector should be able to ignore coatings on the sensing element, hopper wall buildup, and suspended dust particles, so the system reacts only to a true high-level condition. When a center baffle is used in the hopper, it is recommended that a detector be installed on each side of the baffle. This is not necessary when a nuclear level detector is utilized.

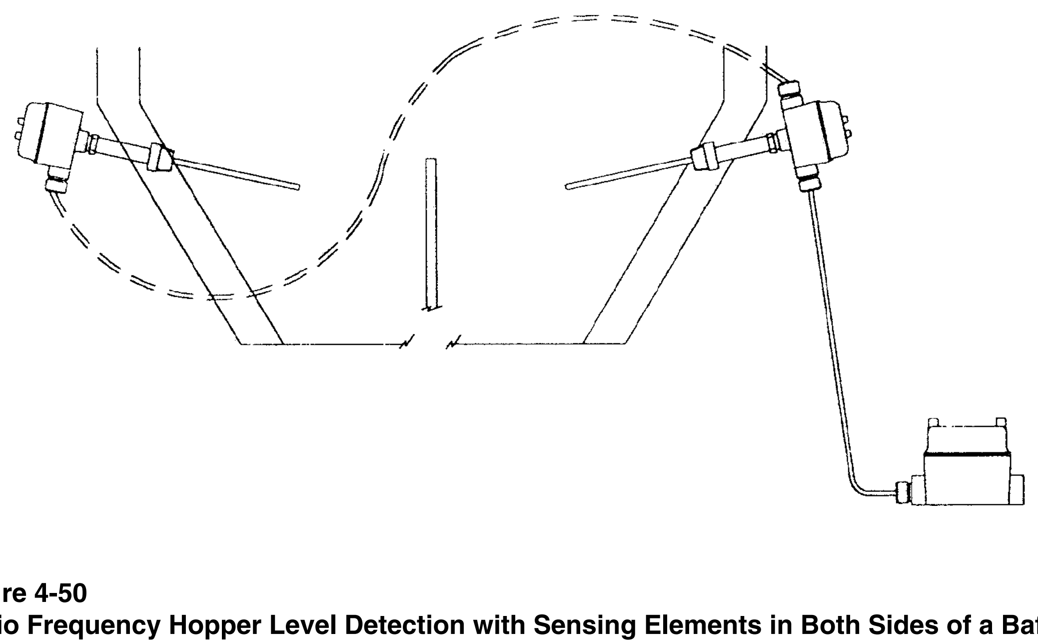


Figure 4-50
Radio Frequency Hopper Level Detection with Sensing Elements in Both Sides of a Baffled Hopper

Nuclear level detectors utilize a radioactive source mounted on one side of the hopper, with a detector on the other side. The presence or absence of dust between the source and the detector is indicated by the amount of radiation that reaches the detector. On that basis, a signal actuates an alarm relay. This type of level detector can be sensitized to tolerate a fair amount of buildup on the hopper walls because the buildup is small compared to the width of the hopper. However, regulatory requirements must be observed using nuclear level detectors and any work done on the equipment requires specially trained and licensed personnel. This has caused their use on new installations to fall out of favor in recent years. The shutter on the radiation source must be incorporated into the ESP key-interlock system so that access cannot be gained to the hopper unless the radiation has been shuttered.

Key Human Performance Point

However, regulatory requirements must be observed using nuclear level detectors and any work done on the equipment requires specially trained and licensed personnel. This has caused their use on new installations to fall out of favor in recent years. The shutter on the radiation source must be incorporated into the ESP key-interlock system so that access cannot be gained to the hopper unless the radiation has been shuttered.

The location of the hopper level detectors should reflect the type of ash removal system (continuous, manual, automated cycle), the loading, and the size/geometry of the hopper. Particle size distribution and maintained temperature at the hopper apex may also influence placement. To minimize frequent detector alarms, the level detectors should be located high enough above the ash levels that accrue when the ash-removal system is operating normally. At the same time, hopper level detectors should be located at an elevation that alerts plant personnel with a margin of time to respond to ineffective ash removal before the ash reaches a level where it adversely affects the ESP or makes removal difficult.

With a continuously evacuated ash- removal system, such as that typically found on a trough hopper, the level detectors in a tightly monitored system might be placed only 2 to 3 ft (0.6 to 0.9 m) above the apex since that is the location where the weight of the ash will compress and increase potential problems. The sooner the abnormal height is detected, the sooner a response can be made. On a manually evacuated system, the hoppers are essentially being used for storage and the effective location of level detectors would need to reflect the storage capacity of the hopper and the normal interval between evacuations.

Most utility installations use vacuum and pressurized ash removal systems that operate cyclically from inlet to outlet. Ash is usually pulled longer or cycled more frequently at the inlet row of hoppers than at the outlet, reflecting the heavier loading from inlet to outlet. Level detectors are usually set at the same elevation on all hoppers. However to provide the most benefit, the inlet hopper detector should be located higher than on the rest of the hoppers, reflecting the large amount of material collecting in the inlet. One method used to locate the hopper level detector height on a tightly monitored system is to place the inlet hopper detectors at a level that reflects the amount of ash that would be stored in the hopper for double the normal ash removal cycle time. The remaining hoppers would then be located at 2/3 to 1/2 of the height of the inlet level detector. Problems with this arrangement can arise when, for instance, low NO_x burners are installed and carbon carryover increases the loading to fields downstream of the inlet. This may require adjustment of the evacuation cycle and/or relocation of the level detectors to avoid buildup problems. Also, if the system is too tight, false alarms can occur when the hoppers are quickly filled with material during POR cycles.

Maintenance, troubleshooting, and repair of hopper level detection equipment will vary by type and manufacturer. The operation and maintenance manual furnished by the equipment supplier should be consulted as to the specific requirements. For the most part, the equipment should maintenance-free and require no periodic recalibration. Probes and other equipment should be cleaned during a maintenance outage.

Experience with a level detection system may or may not allow personnel to develop confidence with the reliability of the system. Level detectors should be thought of as a maintenance tool and not the definitive indicator of a full or empty hopper. That should always be kept in mind when opening hopper access doors.

Key Human Performance Point

Level detectors should be thought of as a maintenance tool and not the definitive indicator of a full or empty hopper. That should always be kept in mind when opening hopper access doors.

4.3.3 Hopper Heaters

Lack of proper insulation and insufficient heat input, especially at the bottom apex and throat of the hopper, accounts for a large percentage of hopper problems. The hoppers need to be well insulated and should have heaters at the lower apex to maintain hopper-wall surface temperatures above a minimum of 250 to 300°F (121 to 149°C) to avoid condensation formation on the hopper walls. Heaters that cover the throat area and the lower third of the hopper height on pyramidal hoppers have proven to be of benefit in reducing corrosion and maintaining efficient ash removal.

Key Technical Point

The hoppers need to be well insulated and should have heaters at the lower apex to maintain hopper-wall surface temperatures above a minimum of 250 to 300°F (121 to 149°C) to avoid condensation formation on the hopper walls.

Heaters are sometimes of the tubular type, but more commonly are of the low watt-density modular-panel or blanket type. These blankets or panels mount directly to the exterior steel surface of the hopper. It is advantageous to utilize a panelized insulation barrier to allow easy access to the heating elements if replacement is needed. Running the wiring leads from the heater elements to a common junction box on each hopper with individual terminations can provide a means to verify operation of the individual panels. Visual means, such as electric current meters on groups of hopper elements, can also be used to monitor heater operation. Derating the surface heat density of the element increases the operating life and reliability of the heating elements. However, this requires more heater capacity per area.

Control of the hopper heaters should be on a per-hopper basis. Thermostat control is desirable (set for 250 to 300°F [121 to 149°C] at the exterior hopper wall surface), but the heater element should be capable of continuous operation without failure due to high temperature. A temperature probe to alarm low-temperature conditions might also be considered.

A good control arrangement might utilize a dual set temperature controller in a local panel that receives input from a thermocouple or a resistance temperature detector (RTD). One set point is used to control the temperature of the heaters and the other set point is used for a low temperature alarm. The control panel cycles the heaters on and off to maintain the desired temperature through contactor opening and closing, and provides a *Control ON*, *Control OFF*, and *Low Temperature* indicator, as well as a temperature display for each hopper. The panel could also provide a trouble alarm for remote use.

Maintenance of the hopper heater system involves periodically confirming the integrity of the heater circuits and the insulation cover. It is good practice to keep the hopper heating system in service at all times except when inspection or maintenance requires hopper entry. Heaters that have been off for an extended period of time should be energized at least eight hours prior startup.

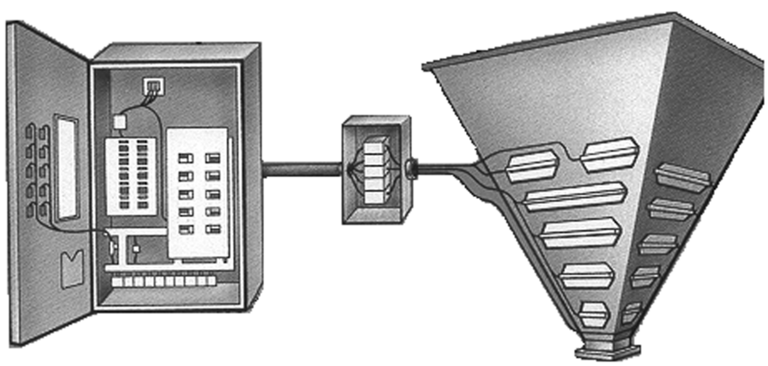
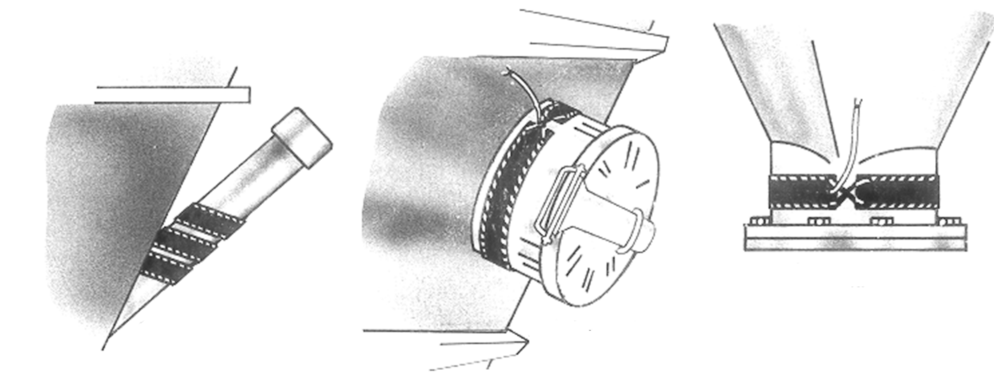


Figure 4-51
Hopper with Modular Panel/Strip Heaters. Running the Wiring Leads from the Heater Elements to a Common Junction Box on Each Hopper with Individual Terminations Can Provide a Means to Verify Operation of the Individual Panels.



Section Through Hopper to Show Poke Tube Heater | Pictorial View to Show Manway Heater | Front View to Show Throat Heater

Figure 4-52
Blanket Heaters on the Hopper Extremities (Poke Hole, Manway, and Hopper Throat)

4.3.4 Hopper Accessories – Vibrators, Strike Pads, Poke Hole Pipes, and Fluidizing Stones

Hoppers are usually equipped with accessories such as strike plates for manual rapping of the hopper walls, poke hole pipes to help unclog the hopper outlets, and vibrators or fluidizing (aeration) stones to promote material flow. Some of these accessories can actually create problems so there needs to be an awareness of their limitations and how to use them most effectively.

4.3.4.1 Strike Pads/Plates

Strike pads, located on the sidewalls of the hopper, can be useful for dislodging dust bridges and buildup that have attached to the hopper wall. Use of strike pads on all four sides of the hopper is the most effective arrangement. The strike pads protrude through the insulation layer so that they can be manually struck with a small hammer or sledge. The pads should be located about 5 to 6 ft (1.5 to 1.8 m) above the hopper apex and safe access to them should be available.

Personnel using the strike plates will eventually learn to tell by sound whether the hopper is free of material in the lower half. Avoid hitting directly on the hopper walls or the hopper throat, as the impact may cause damage that creates a location for future hopper bridging or pluggage.

Key Human Performance Point

Personnel using the strike plates will eventually learn to tell by sound whether the hopper is free of material in the lower half. Avoid hitting directly on the hopper walls or the hopper throat, as the impact may cause damage that creates a location for future hopper bridging or pluggage.

Since the strike pads protrude through the insulation layer, they can act as heat sinks and create a localized area inside the hopper where material may attach to the wall and/or corrosion may develop. If the hopper area is enclosed, or the protrusion of the insulation lagging is well sealed, this may not be a problem. If inspection reveals that it is a potential problem, removable insulated covers can be fabricated to cover the strike plates when they are not being used.

4.3.4.2 Poke Hole Pipes

Poke hole pipes are often furnished with the hopper, or added after experiencing hopper difficulties, to help facilitate the removal of material. The 2 to 4 in. (50.8 to 101.6 mm) diameter pipes are typically located at the apex of the hopper and oriented downward to allow for clearing of a blockage at the hopper discharge. A rod or air lance is inserted in the pipe to try to clear the blockage. When not being used, the pipe is capped to prevent air or moisture in-leakage.

For safety reasons, all poke hole pipes should be oriented downward and installed at an elevation to prevent any personnel from inserting a long rod or lance towards the high voltage frame overhead of the hopper. There is little danger in using the downward oriented poke holes to clear the hopper discharge while the associated field is energized. However, if TR power readings indicate a full hopper and the TR has not already tripped, the TR should be deenergized and locked-out until the hopper is judged to be free of material. In all cases, a flexible ground strap should be attached to the steel rod or lance that is inserted. When using a poke hole, also be aware of the possibility that when a large amount of material is dislodged some of it may be forced out of the pipe opening, depending upon the static pressure. A small adapter plug in the cap or flange, used to seal the end of the pipe, can sometimes be advantageous to check for dust or static pressure conditions prior to opening the larger diameter.

Key Human Performance Point

For safety reasons, all poke hole pipes should be oriented downward and installed at an elevation to prevent any personnel from inserting a long rod or lance towards the high voltage frame overhead of the hopper.

Many poke hole pipes are threaded at the ends and a threaded pipe cap is used over the end to seal the pipe when not in use. Poke holes pipes can provide a means for air or water in-leakage that can compound pluggage problems. It is not uncommon for operators to only loosely thread a pipe cap back on after being used. Sometimes, leakage may occur at the thread itself. Hinged, spring-loaded sealing caps can be used to assure a better seal at locations where operators frequently need to use the poke holes. Poke hole pipes should be checked during routine inspections for air in-leakage. It may be audible under the draft of the fan.

4.3.4.3 Vibrators

Vibrators are sometimes used on hoppers to encourage dust flow. The vibrators may be of the pneumatic or electromagnetic-reciprocating type. Be aware that vibrators can cause as many problems as they may solve. They can create or compound pluggage problems by compacting the collected ash in the hopper. They can also damage the hopper wall. It is not uncommon to find vibrators that have torn away the hopper wall.

Hopper vibrators can be operated manually or automatically. Either way, they should only be operated when the hopper is nearly empty of material (vacuum break or end-of-venting cycle) and there are safeguards in place to prevent their operation with dust buildups of a couple of feet or more in the hopper. The risk otherwise is overloading the apex of the hopper and/or compacting the ash. This is especially true with fine-sized material, coupled with a small discharge opening at the bottom of the hopper. In reality, vibrators are most effective on hoppers that are in a continuous mode of evacuation, such as a trough hopper. They can be more problematic on pyramid type hoppers where evacuation tends to be on an automated cycle from inlet to outlet based on time or pressure. This can allow for material to accumulate in the hopper between cycles, which makes it important that vibrator use coincide with the evacuation cycle.

Two smaller vibrators on opposite sides of the hopper are preferable to one large vibrator. The intensity and duration of vibration should initially be set at minimal levels. Adjustments can be made later as needed. Remember that too high intensity vibration and too long a duration can lead to ash compaction and damage to the hopper wall. The vibrators should be mounted at the baffle line to avoid formation of rat holes, or slightly above the halfway mark of the hopper, as measured on the wall surface.

Key Technical Point

Two smaller vibrators on opposite sides of the hopper are preferable to one large vibrator.

Electromagnetic-reciprocating vibrators should be periodically checked to verify operation and intensity. The strike plates tend to wear with use and may require adjustment to maintain the desired intensity. Replacing strike plates and repairing defective vibrators can be labor intensive and it may be more cost effective to replace them when they fail or become noticeably weak.

Air operated vibrators should be checked at least semi-annually. Automatic lubricators should be checked for proper oil levels. Air pressure should be set for the most efficient operation. All air connections should be checked and filters cleaned. Tighten any bolts that have loosened. If the vibrators are to be shut off for long periods of time (such as an extended outage), the interior should be well lubricated.

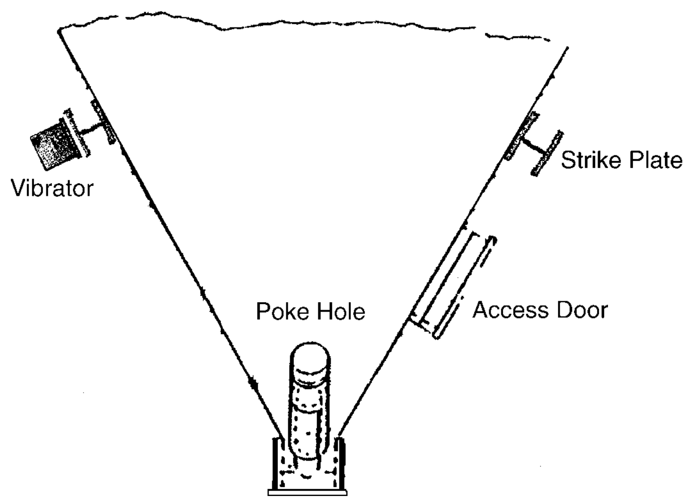


Figure 4-53
Hopper with Strike Plate, Vibrator, and Poke Hole Pipe

4.3.4.4 Fluidizing Stones

Fluidizing stones, or aeration stones and diffusers as they are sometimes also called, are sometimes used in the lower part of the hoppers to fluidize the dust by air injection. Their use can actually contribute to pluggage problems rather than help avoid them. Located near the bottom of the hopper, they may actually create an obstruction that closes off open areas of the hopper. The injection of any air into the hoppers can also create difficulties. It is important that the fluidizing stones be supplied with dry, heated air. A high quality dryer is needed to remove the moisture and oil from the air supply, and the air must be heated so it will not cool the dust in the hopper.

During a maintenance outage, the fluidizing stones should be checked for buildup on the diffuser surface, for breaks or cracks, and for air leaks. The diffuser surface should be cleaned or replaced if necessary. Diffuser surfaces may be checked by applying low-pressure air to the system and placing a handful of dry fly ash on the diffuser. The ash should immediately flow off of the diffuser. All gaskets should be inspected and replaced as necessary. Air connections should be checked, and all filters cleaned or replaced. The air supply should be clean, dry, warm, and at the proper pressure.

4.3.4.5 Air Cannons and Sonic Horns

Air cannons and sonic horns have seen some limited use in the industry to encourage material flow in the hoppers. Similar to the vibrators, these devices can create problems if used or installed incorrectly. Like vibrators, sonic horns can compound pluggage problems by compacting the collected ash in the hopper if they are not operated in sync with the ash removal cycle. Air cannons can cause reentrainment spiking if set too aggressively and can promote or aggravate hopper fires as a result of the added oxygen.

Key Human Performance Point

Like vibrators, sonic horns can compound pluggage problems by compacting the collected ash in the hopper if they are not operated in sync with the ash removal cycle. Air cannons can cause reentrainment spiking if set too aggressively and can promote or aggravate hopper fires as a result of the added oxygen.

Like other pneumatically actuated devices, these devices require a clean, dry air supply delivered at the proper pressure. Valves, regulators, solenoids, and air piping/hoses need to be maintained.

4.3.5 Hopper Insulation

Insufficient heat or insulation can lead to cooling of the hopper wall or throat surface (hopper discharge transition) that will promote condensation formation and ash buildup on the wall and throat areas. This can lead to problems with hopper pluggage and/or accelerate corrosion. The exterior surfaces of the hoppers need to be well insulated to retain heat generated from the precipitation process and the hopper heaters. The surface temperature of the hopper walls and throat should be maintained above the dew point (250 to 300°F [121 to 149°C] range). Insulation of a hot-side ESPs needs to be sufficient to prevent cold spots and to protect plant personnel from exposure to hot areas that could cause burns.

Insulation should be at least 5 to 6 in. (127.0 to 152.4 mm) thick if it is placed against the wall, or 3 to 4 in. (76.2 to 101.6 mm) thick with at least a 4 in. air space. The latter is the more preferable arrangement. The entire hopper should be insulated and there should be no opening at the bottom insulation termination to allow a chimney effect to take place. Chimney stops should also be used as part of the insulation barrier. An insulation barrier with removable insulation panels can make for easier access to hopper heating elements in the event one of them needs to be replaced.

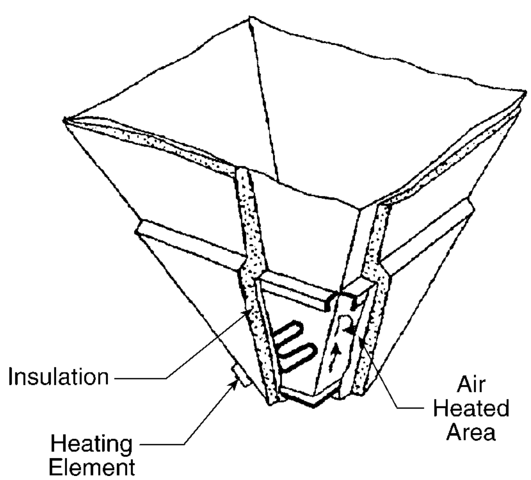


Figure 4-54
Hopper Insulation with Air Space for Heat Distribution

All penetrations in the hopper insulation barrier, such as for support stanchions, thermocouples, strike plates, poke hole pipes, and vibrator supports, should be sealed at the point of penetration with foam or caulking to help minimize heat losses. Some of these may need to be fitted with removable insulation coverings if they prove to be heat sinks that promote corrosion or buildup problems.

A wind barrier or enclosure of the hopper area can also enhance heat retention. It is not uncommon for hopper pluggage problems to develop on the windward side of an ESP during the colder months of the year. In many cases, erecting a wind barrier or enclosing the hopper area to reduce the cooling effects of the prevailing winds can correct this.

Key Technical Point

It is not uncommon for hopper pluggage problems to develop on the windward side of an ESP during the colder months of the year. In many cases, erecting a wind barrier or enclosing the hopper area to reduce the cooling effects of the prevailing winds can correct this.

Inspection of the hopper insulation should note any missing or damaged insulation. Internal inspection of the hoppers will provide an opportunity to evaluate the effectiveness of the insulation layer. Special attention should be paid to the hopper area of the precipitator outlet. This hopper is generally subject to cooler temperatures due to less contact with the hot gases and minimal dust buildup in the hopper. The outer wall is also frequently exposed. It may be necessary to provide additional insulation and heat if condensation inside the hopper is to be avoided and corrosion and blockages prevented. An infrared survey may be useful in evaluating the effectiveness of the hopper insulation layer if corrosion or frequent pluggage is a problem.

Maintenance of the hopper insulation involves replacement of any missing or damaged insulation and sealing all siding penetrations.

4.3.6 Ash Removal System

Ash in the precipitator hoppers is removed by an ash handling system, which transports the material from the outlet flange of the hopper to the final destination in the plant for disposal. All the ash handling equipment located below the hopper outlet flange, including valves, piping, expansion joints and vacuum or pressure sources, is normally supplied by the ash handling manufacturer and not the precipitator manufacturer. Maintenance requirements will vary by manufacturer and the type, size, and complexity of the system. It is not uncommon to have a separate maintenance group assigned to the ash handling system while another is responsible for the ESP. Regardless, whoever is responsible for the ash handling system should understand that troubles that occur on either the collection or removal side of the hopper can have the same net effect on the precipitator. It is imperative that ash in the hoppers be removed as continuously as possible so that the ash remains free flowing.

The operation and maintenance of an ash removal system is beyond the scope of this manual. An earlier EPRI technical report, *In-Plant Ash-Handling Reference Manual*, CS-4880 (now out of print), provides guidance on this subject. There are, however, some common problems with the ash handling system that can affect the precipitator of which maintenance and operating personnel should be aware. The figures and descriptions that follow illustrate and describe these problems.

In large systems, such as those found in the utility application, ash is removed from the hoppers via a pressure or vacuum ash system, or a combination of both. A screw conveyor might be used for this purpose on a small industrial power boiler with a trough hopper. Regardless, an air seal is required at each hopper discharge to provide a positive seal. Pressure systems are equipped with air locks and slide gates for this purpose, whereas vacuum systems typically have electric valves and slide gates. Conveyors might use a rotary or tipping valve. These valves/gates can be the source of many problems. Poor sealing and/or poor synchronization of these valves/gates degrade the performance of the ash removal system.

The valves and connections that attach to each hopper should be routinely checked and carefully inspected during maintenance of the ash removal system. Periodic adjustment for the seating of the gate valves may be required as fly ash can produce erosion of the gate and seat surfaces. The compressed air supply for the gate valve actuators also needs to be dry and clean. All transport piping, flanges, and expansion joints should be routinely checked for cracks or leaks and repairs made as needed. If sections of the main transport piping indicate the need for replacement, it is best to do this during an outage. Time-consuming repairs of this nature made during operation create the potential for hopper difficulties from excessive buildup of dust in the hoppers.

As mentioned, pneumatic ash removal systems are the primary means of evacuation in the utility application. Use of the vacuum system is limited by the configuration of the discharge system and the altitude above sea level. When the limits for a vacuum system are exceeded, pressure systems are applied. A vacuum is produced either hydraulically or by use of mechanical vacuum pumps. Pressure systems utilize positive displacement blowers. Air intake for the compressors or blowers should be obtained from a clean source.

The original design layout of the ash removal system should strive for parallel vacuum or pressure sources, as well as transport systems. The ability to transfer dust to alternate depositories and availability of a backup blower/compressor should also be considered.

Problems unique to the pneumatic systems are addressed in Sections 4.3.6.1 and 4.3.6.2.

4.3.6.1 Vacuum Systems

Vacuum system ash removal is fairly straightforward. A valve at the hopper discharge opens to allow material in the hopper to be pulled into the transport piping for removal.

Possible Problems:

- Problems have surfaced with the adjustment of the regulator at the termination of the piping system that regulates conveying velocity (vacuum) by the degree to which it is opened or closed. Too open and ash may not be effectively removed; too closed or blocked and ash may be too aggressively drawn from the hopper, creating a rat hole or small opening through the center of the hopper buildup. This can provide a foundation for more ash to accumulate along the hopper walls to a problematic level. Too much time between evacuation cycles can also contribute to rat holing of the ash, especially in cold weather and inadequate heat at the hopper apex.
- A poorly sealed or malfunctioning valve on a hopper with transport piping in-line with another hopper that is being pulled will reduce the vacuum and the effectiveness of the ash removal system. Cooling will also occur as a result of such leakage and can promote the material to harden and become an obstruction.

4.3.6.2 Pressure Systems

Pressure systems involve more components and are equipped with air locks and slide gates, pressure vessels, and equalization venting for ash delivery from the hopper outlet to the transport piping. A typical arrangement is shown in Figure 4-55, as well as a description of normal evacuation from an individual hopper.

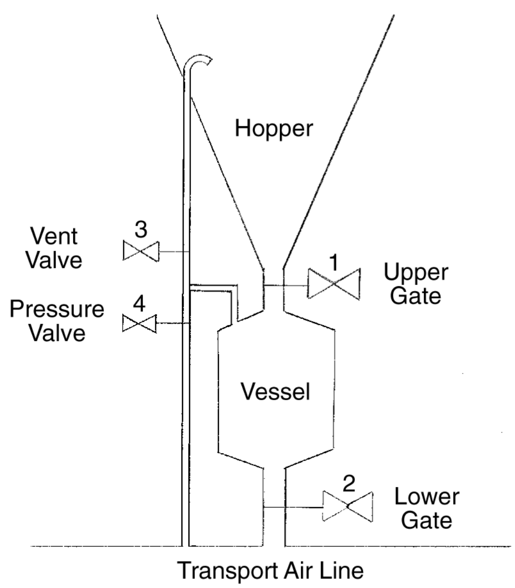


Figure 4-55
Ash Removal Pressure Evacuation Sequence

The ash removal pressure evacuation sequence is as follows:

1. Valves 1 and 3 *OPEN* with valves 2 and 4 *CLOSED* and material in the hopper fills the vessel.

2. Valves 1 and 3 *CLOSE*

3. Valves 2 and 4 are *OPENED* to pressurize the vessel and discharge the contents to the transport air line.

4. Valves 2 and 4 *CLOSE*.

The process is repeated each time the ash removal control systems cycles through the evacuation sequence. Frequently, valves 3 and 4 are combined into a 3-way valve that is referred to as a pressure equalization valve.

Possible Problems:

- Poor sealing of valves can promote hopper pluggage and lead to ash reentrainment that can adversely affect ESP performance. For instance, if valve 1 in the figure did not seal properly, when the vessel is pressurized (valves 2 and 4 *OPEN*) air could leak past valve 1 causing material reentrainment and promoting cooling of material. If valve 2 is leaking, the vessel will not fill and material reentrainment will occur when valves 1 and 3 *OPEN*.

  It is fairly common to find erosion of the equalization vent piping due to leakage at valve 3. Evidence of this occurrence can typically be found in the hopper by holes in the peak of the vent piping. Once a hole develops, there is potential for material reentrianment. An indicator that leakage at valve 3 is occurring is if the vent piping heats up when the pressure vessel is being evacuated (valves 2 and 4 *OPEN*). A recommended design that minimizes reentrainment caused by problems with equalization valves is to utilize a common vent header to the precipitator inlet.

- Pluggage of equalization vent piping is another potential problem that can interfere with evacuation. That is why the vent piping usually penetrates the hopper wall fairly high up. However, if a hopper is over-filled, pluggage can occur.

- Poor sealing of the valves can allow the transport air to enter a hopper on the same transport line with valves that do not seal well, causing an increase in emissions by reentrainment of hopper ash.

- Another problem with some pressurization systems has occurred when the bottom orifice is not large enough to accommodate lumps or hardened chunks of material that may be encountered during startups. The transport piping itself can usually handle this type of material.

4.3.6.3 Evacuation Cycle and System Evaluation

Most utility installations use vacuum and pressurized ash removal systems that operate cyclically from inlet to outlet (batch removal). Ash is usually pulled longer or cycled more frequently at the inlet row of hoppers than at the outlet, reflecting the heavier loading from inlet to outlet. Hopper sizing/geometry may or may not change from inlet to outlet. Problems with this arrangement can arise when, for instance, low NO_x burners are installed and carbon carryover increases the loading to fields downstream of the inlet. This may require adjustment of the evacuation cycle to avoid buildup problems. Buildup in the outlet fields can lead to material reentrainment and opacity spiking.

The effectiveness of the vacuum and pressure ash removal system can be evaluated using vacuum and pressure charts, if available. (Examples are shown later in this section.) However, if the evacuation cycle is such that two hoppers are pulled simultaneously, the charts can be more complicated to interpret and less useful. Valves and air locks should have contacts available to indicate the open and closed positions for use with the ash handling controls system to aid evaluation. Hopper level detectors, vibrators, and fluidizing stones that are installed on the hoppers to promote or monitor material flow should also have spare input/output contacts for this purpose.

The pressure or vacuum feedback should be used to indicate when the hopper is nearly empty (vacuum break or end-of-venting cycle) for purposes of firing vibrators or sonic horns so as to avoid overloading the hopper apex and/or compacting the ash. This is the best and safest way to utilize these devices on an automated system.

4.3.6.4 Other Concerns

Evacuated material from the ash removal system is usually transported to a silo. Silo venting is another important consideration in the ash removal process. Typically, the silo is vented to the inlet of the ESP. If the volume is significant, it can adversely affect ESP operation in ways similar to air in-leakage: localized condensation and corrosion, and a slight increase in gas volume.

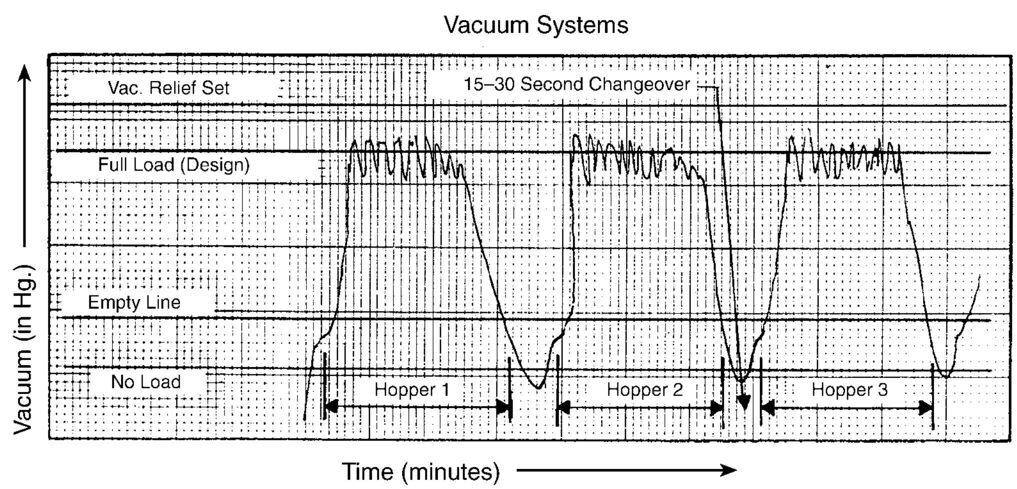


Figure 4-56
Normal Cycling System Vacuum-Time Trace

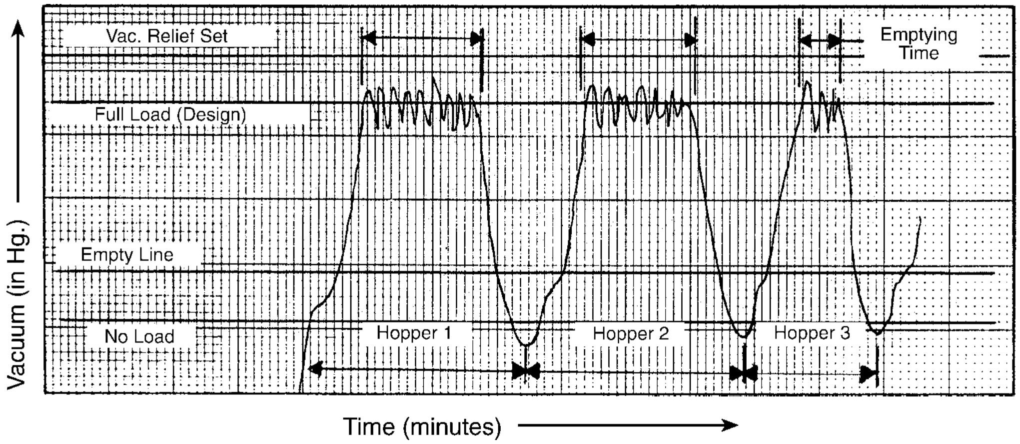


Figure 4-57
Reduced Emptying Time, Indicating Rat Holing

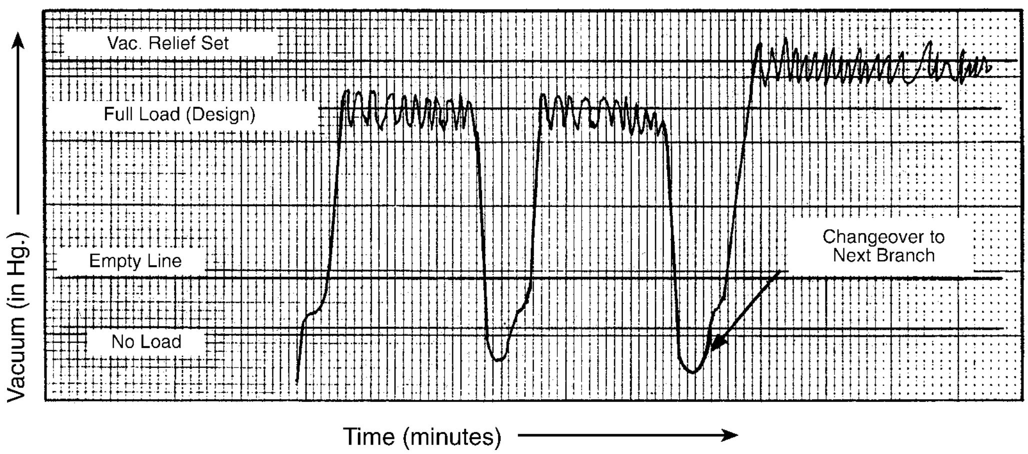


Figure 4-58
Branch Line Gate Fails to Open

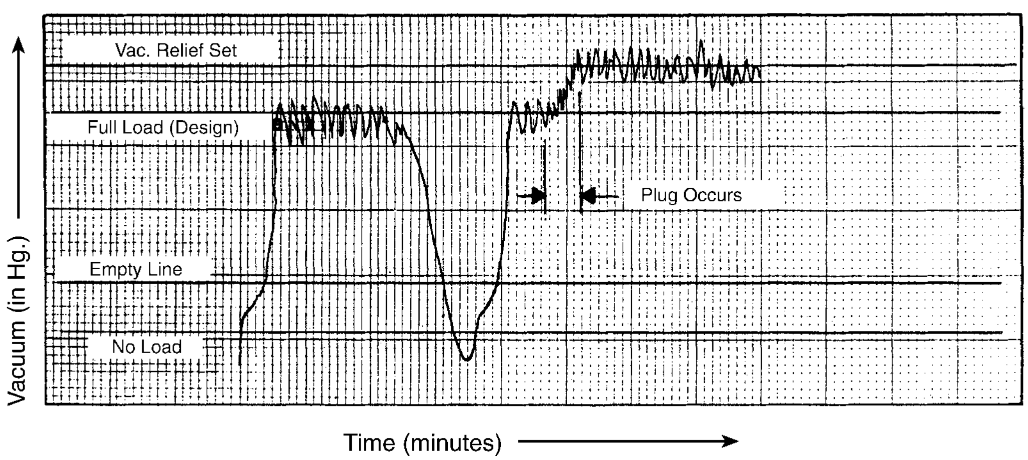


Figure 4-59
Plugged Conveyor Line

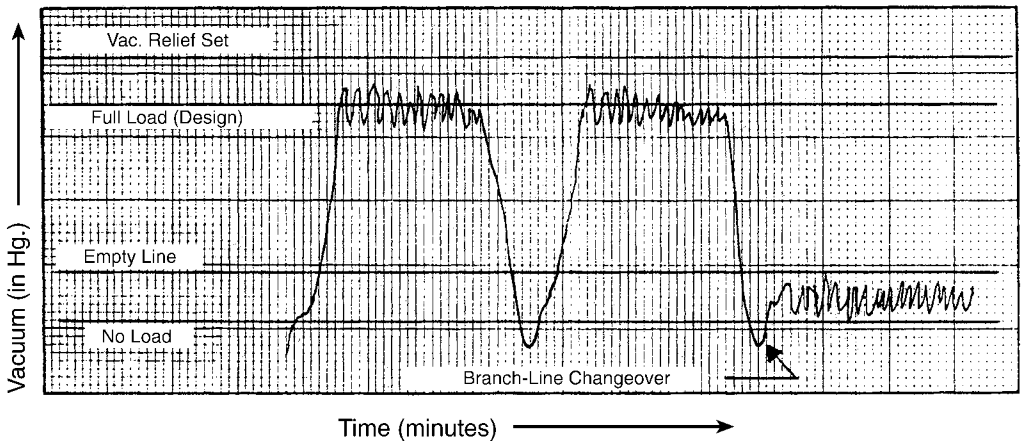


Figure 4-60
Branch Line Fails to Close

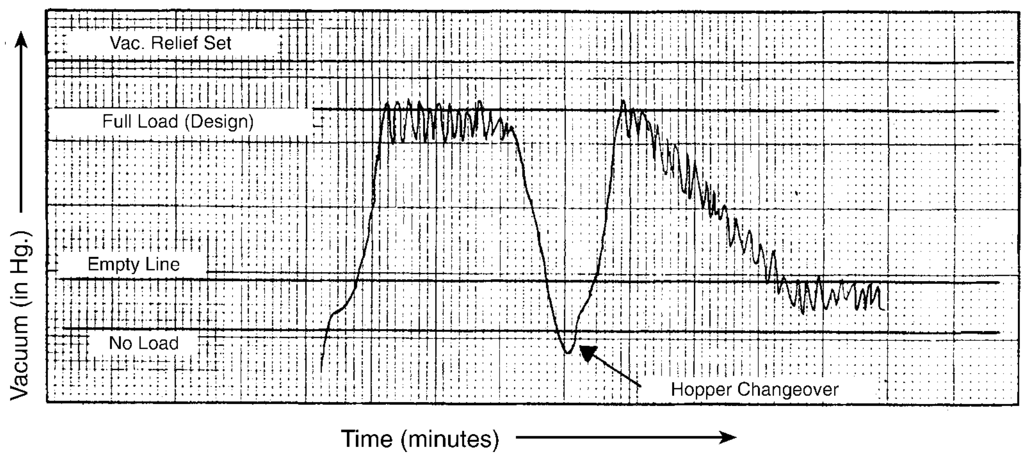


Figure 4-61
Plugged Collection Hopper

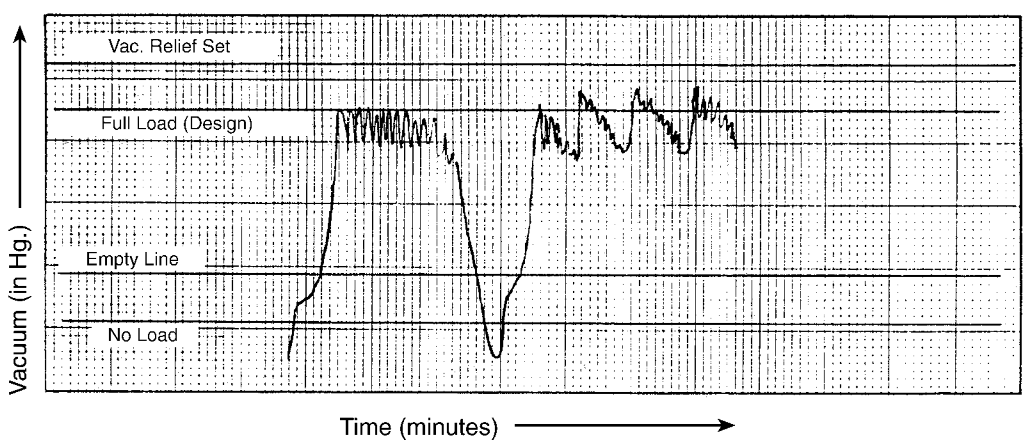


Figure 4-62
Partially Plugged Line or Intake Leak

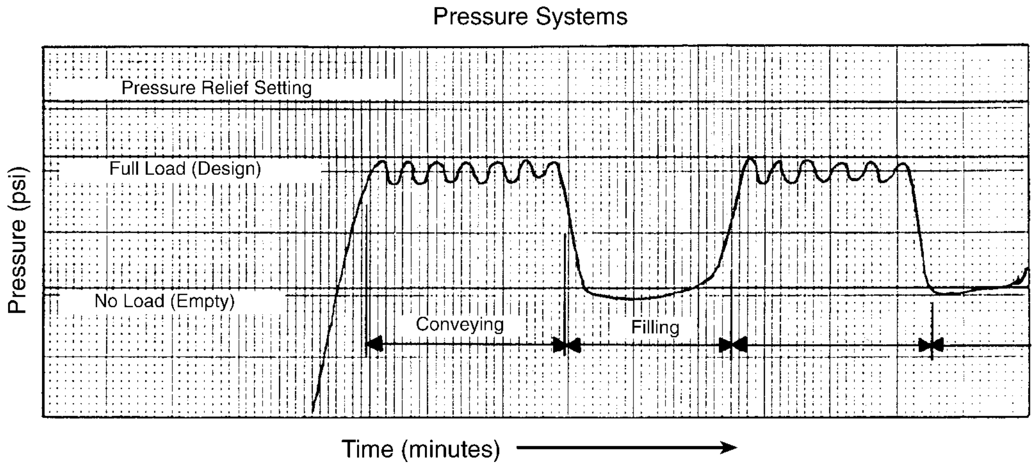


Figure 4-63
Single Air Lock Alternately Filling and Emptying

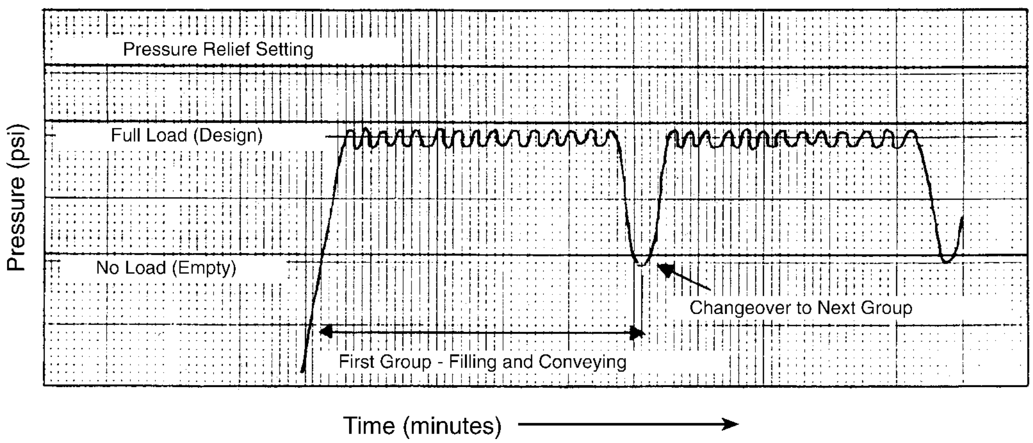


Figure 4-64
Air Locks Operating in Groups (Same Branch)

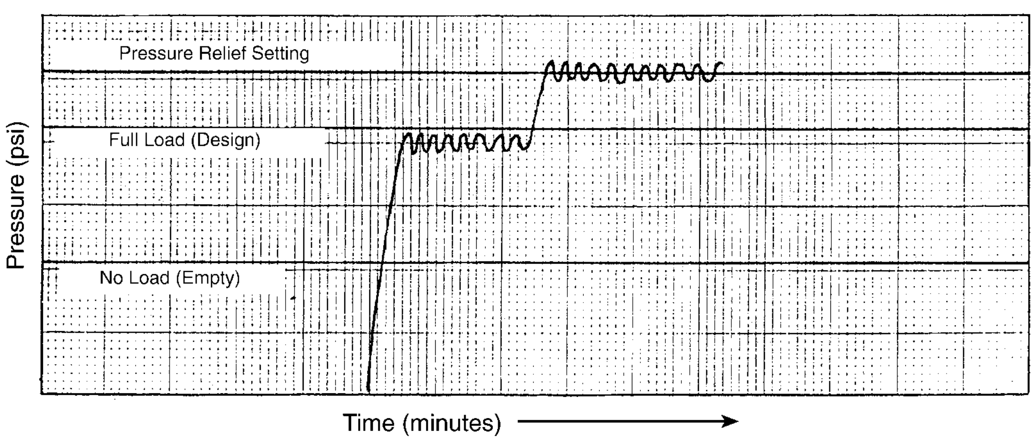


Figure 4-65
Plugged Conveyor Line

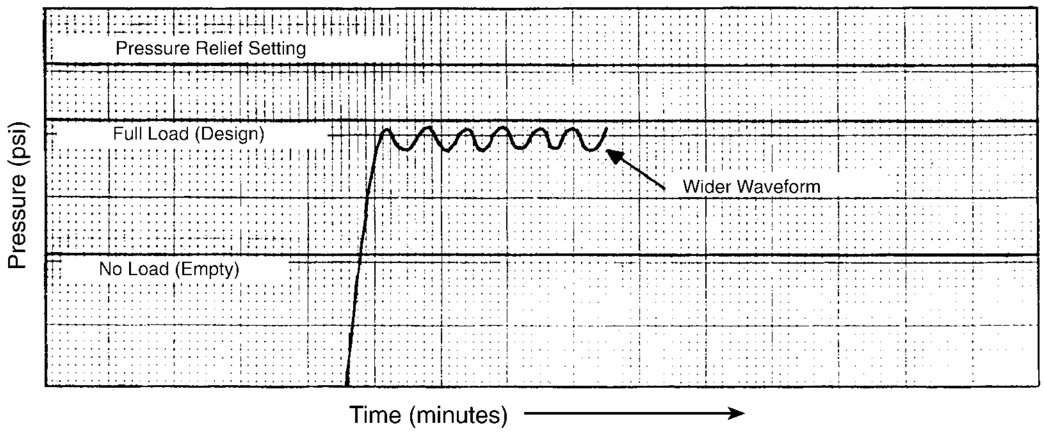


Figure 4-66
Feed From Air Lock (Too Fast)

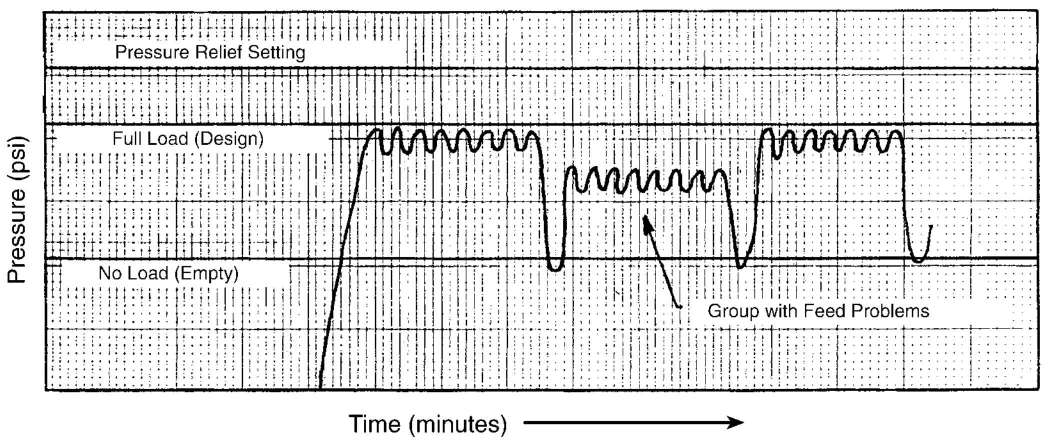


Figure 4-67
Feed Problem in One Air Lock (or Group)

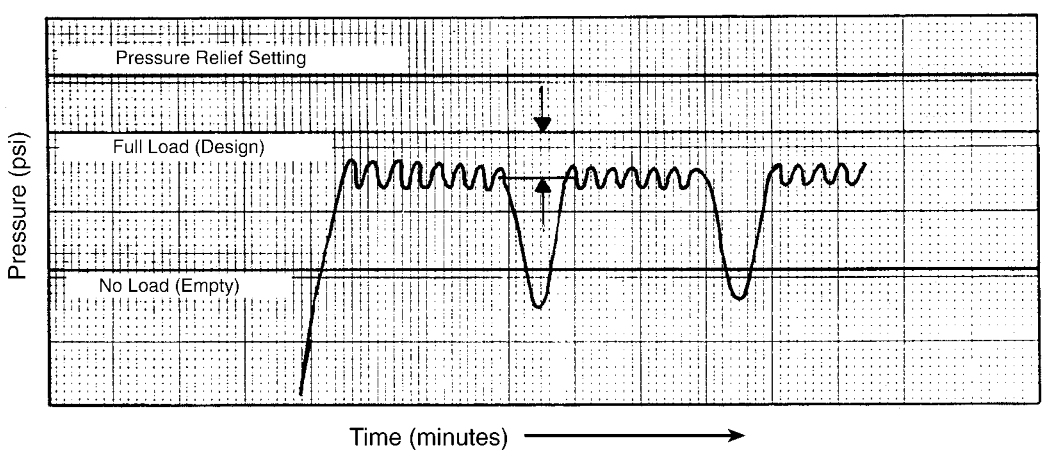


Figure 4-68
Inadequate Pressurizing Differential

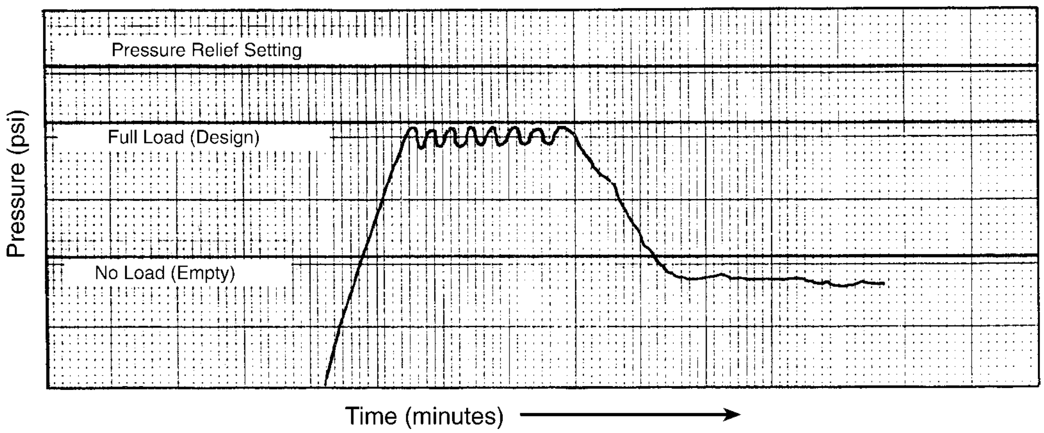


Figure 4-69
Major Motor/Blower Malfunction or Air Line Leak

4.4 Casing and Ductwork

The primary maintenance concern regarding the precipitator casing and ductwork is air in-leakage. Air in-leakage can be extremely detrimental to both the condition and performance of the ESP. It is almost exclusively a problem of systems that operate under the negative draft of an I.D. fan, but it can occasionally occur in positive pressure systems when load and/or gas velocity through the ESP is low. Under these circumstances the negative draft of the stack may exceed the positive pressure of the F.D. fan. This is most likely to occur towards the precipitator outlet.

Air in-leakage promotes corrosion and leads to deterioration of ESP components that may ultimately compromise performance. In addition to causing corrosion, air in-leakage can have an adverse affect on ESP performance by increasing the gas volume and gas velocity, reducing treatment time, modifying temperature (resistivity), distorting gas distribution, and/or promoting material rentrainment. Efforts need to be made to identify and eliminate sources of air in-leakage. Air in-leakage is often audible under the negative draft of the fan during on-line operation. Common sources/locations of air in-leakage include expansion joints, flanges, dampers/slide gates, access doors, and other casing penetrations such as rappers, test ports, and ash removal systems. It is particularly important to prevent air in-leakage in the hopper area because of the potential for rentrainment of collecting material and hopper plugging.

Routine maintenance should include periodic on-line walkdown of the ESP system to identify sources of air in-leakage. Unless the design calls for the admission of ambient air for a specific purpose, as in the case of purging the support insulators, any locations where air in-leakage is identified should be sealed. On-line repairs or temporary sealing with high temperature caulking can sometimes be made. If not, the area(s) should be marked for inspection and more permanent repair during a future outage. A routine check of O_2 level and temperature in combustion flue gas can be a useful indicator of in-leakage. A marked increase in O_2 and corresponding decrease in temperature would be indicative of air in-leakage.

Key Technical Point

A routine check of O_2 level and temperature in combustion flue gas can be a useful indicator of in-leakage. A marked increase in O_2 and corresponding decrease in temperature would be indicative of air in-leakage.

If SCR technology is being installed for NO_x control on and existing system, substantial reinforcement of the ESP casing (including the penthouse) and ductwork is usually required. The effect on the precipitator of implementing this technology is discussed in Section 6.3.

4.4.1 Access Doors

Access to the inlet and outlet ductwork and transitions, the precipitator, the hoppers, and to HV areas such as the insulator compartments/penthouse, is usually gained through hinged access doors. In some instances or locations, bolted cover plates may be used. Precipitator manufacturers offer are a variety of sizes, shapes, and access door designs. Several access door designs are shown in Figure 4-70. The access door assembly may include both a hinged outer door and a removable inner door. Hinged access doors to areas where high voltage is present during ESP operation usually have locks that are part of a sequenced key-interlock system designed to prevent personnel entry to HV areas prior to deenergization and grounding of high voltage components.

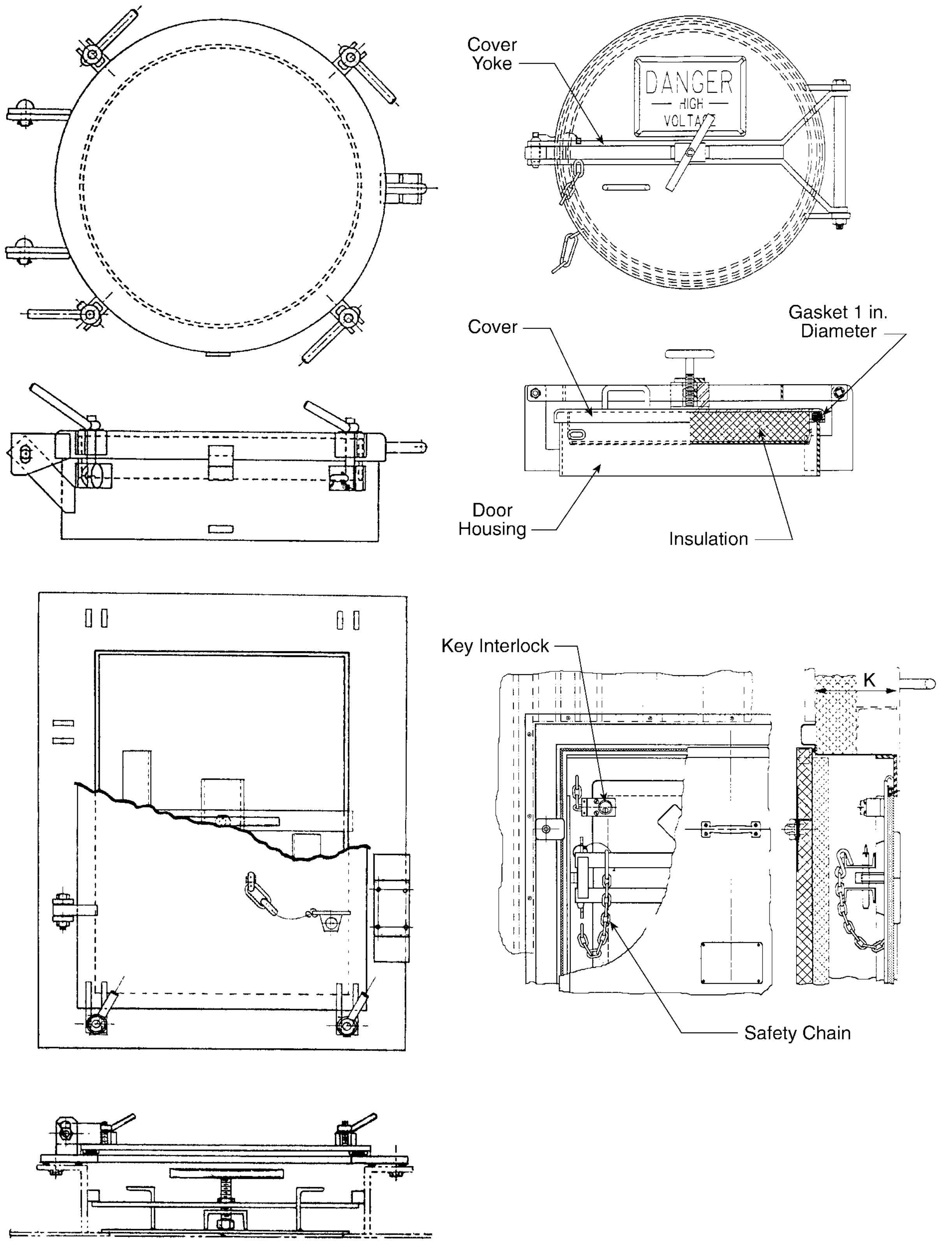


Figure 4-70
ESP Access Doors

Access doors are a frequent source of air in-leakage, which can accelerate corrosion and have an adverse affect on precipitator performance. They also often create a heat sink that promotes corrosion. When properly fitted and maintained, the access doors in the ductwork and casing should seal to prevent air in-leakage (or gas leakage where operating pressure is positive). Maintenance personnel should check the access doors periodically while the ESP is on-line, particularly after the doors have been opened. Air in-leakage is often audible under the negative draft of the fan. On positive pressure systems, gas leakage is often visible or can be smelled. Sealing the doors often requires no more effort than tightening the door lugs. If that does not do the trick, a temporary seal can often be obtained using some type of high temperature sealant (for example, silicone). Permanent repairs can be made during an outage.

Key Technical Point

Access doors are a frequent source of air in-leakage, which can accelerate corrosion and have an adverse affect on precipitator performance.

Key Technical Point

Air in-leakage is often audible under the negative draft of the fan. On positive pressure systems, gas leakage is often visible or can be smelled.

Whenever doors are opened, the gasket seals should be checked and deteriorated door gaskets should be replaced. During a maintenance outage, the entire door assembly, including the doorframe, coaming (tunnel), and inner and outer doors should be checked for deterioration. Any material buildup in the door coaming/tunnel should be removed. Corroded door components should be repaired or replaced as needed to restore the seal integrity of the door. Door lugs and hinges should be lubricated.

In addition to being potential sources of air in-leakage, access doors often create heat sinks that lead to condensation formation and subsequent corrosion and deterioration. This occurs because the outer surface of the door is exposed to ambient conditions, while the inner surface is at, or near, gas temperature. This frequently is the result of not being insulated and/or due to a lengthy door coaming/tunnel that extends beyond the insulation layer. Removable exterior insulation covers are recommended for access doors to reduce corrosion. This is preferable to insulating the inner surface of the door as is done in some designs. A door modification or replacement design that places the door surface closer to the casing wall (that is, reduces coaming/tunnel length) and exterior insulation is recommended if heavy door corrosion is a problem.

Key Technical Point

A door modification or replacement design that places the door surface closer to the casing wall (that is, reduces coaming/tunnel length) and exterior insulation is recommended if heavy door corrosion is a problem.

Particular care should be taken when opening access doors to the hoppers to avoid being potentially burned by hot ash. If possible, visually verify that the hoppers are clear of material prior to opening. This can often be done from side access walkways located above the hoppers. If not, the door (inner door if applicable) might be tapped with a hammer. A hollow ring would be indicative of an empty hopper whereas, a thud would indicate material buildup behind the door.

When closing access doors, care should be taken to assure the door is seated properly to obtain a good seal. Play in the hinges will sometimes prevent or interfere with good gasket contact and compromise the seal. Carefully examine the door seal as the ESP is closed up after inspections or maintenance. Extra care in closing the doors can minimize future repair costs.

4.4.2 ESP Casing/Shell

The precipitator shell or casing is designed to confine the flue gas within a specific collection zone, and it must provide structural support for the discharge and collecting electrode systems, rapping systems, gas distribution system, and other precipitator components. The precipitator shell is usually constructed of fabricated steel panels fitted with columns, beams, and stiffeners and is designed so that the final assembly provides a gas-tight unit able to withstand both internal and external loading. The term *casing* generally includes the inlet and outlet transitions (nozzles/plenums), the precipitator side and chamber walls, penthouse, insulator compartments, hot and cold roofs, and hoppers/bottom. Figure 4-71 illustrates a typical casing construction. Design of the casing should be gas- and water-tight and encourage drainage. The casing sits on a network of support steel.

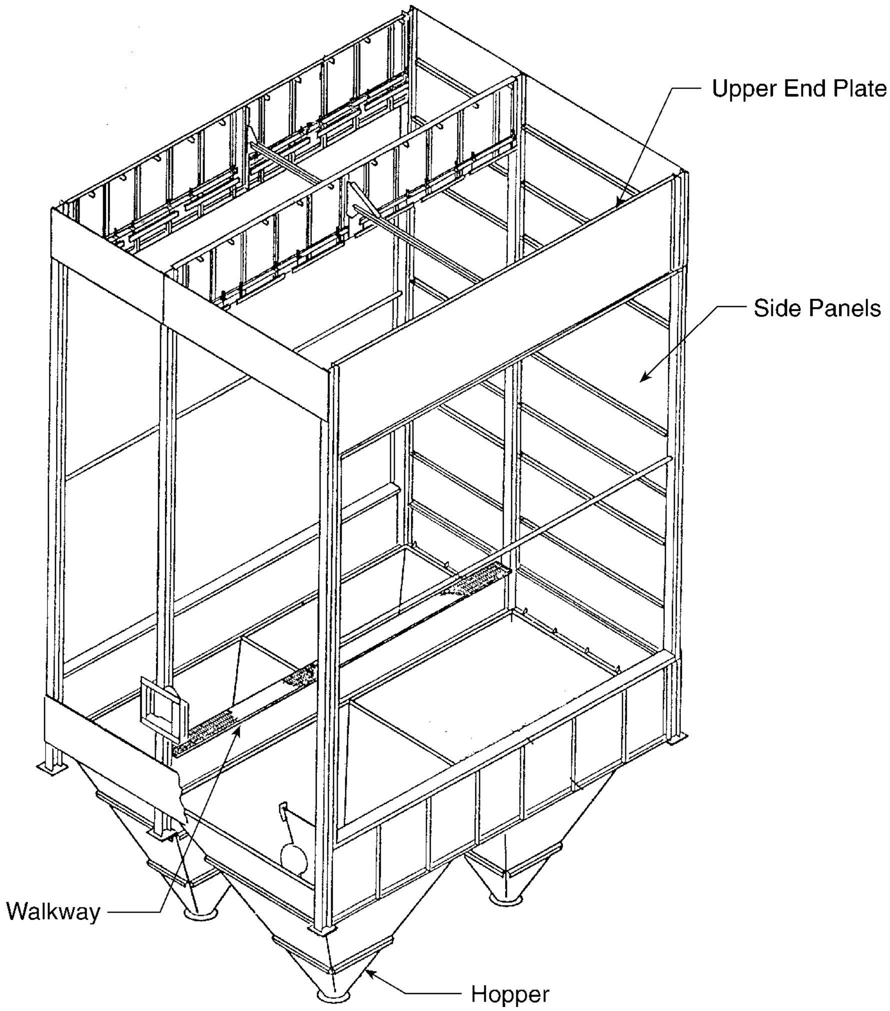


Figure 4-71
Typical Casing Construction

Lagging and heat insulation of the precipitator casing and connecting ductwork are necessary to conserve heat, to prevent corrosion due to condensation of moisture and acid on the internal parts, and to minimize stresses due to differential temperatures. The precipitator roof assembly usually consists of an inner (hot) and outer (cold) roof assembly, with insulation between the two. Penthouses or insulator compartments are typically used to house the HV support assemblies.

Access to the precipitator casing for internal inspection and maintenance is gained through access doors located in the roofs, the hoppers, and/or the ESP sidewalls. A sequenced key-interlock system prevents access while the precipitator is energized. Access walkways, platforms, stairs, and ladders are attached to the casing at various internal and external locations. Some manufacturers' designs are more maintenance friendly than others in terms of the number and location of access points and the available space to perform maintenance.

A weather enclosure over the precipitator casing roof helps to protect roof mounted equipment such as TRs, rappers and controls, purge-air systems, and insulator compartments, and facilitates routine inspection and maintenance, particularly in adverse climates.

4.4.2.1 Inspection/Maintenance

Check the casing and internals for leakage, which can take the form of in- or out-leakage, depending on the operating pressure of the ESP. In the case of out-leakage, the cause is usually a structural failure resulting in the discharge of flue gas and ash into the surrounding area. Such leakage can cause secondary deterioration of lagging, rappers, and controls. Moreover, out-leakage of high concentrations of SO_2 poses a safety hazard to plant personnel.

In-leakage can occur with just air or a combination of air and water. Both are detrimental to precipitator operation and reliability. Air in-leakage, if in sufficient volume, can cause corrosion that takes years of service from the life of downstream internals in a period of weeks. In-leakage near the bottom of an ESP poses added potential for problems because airflow into the ESP casing near the collected ash can reentrain some of that ash, thereby increasing emissions as well as causing ash caking from moisture condensation. Water (primarily rainwater) in-leakage can plug hoppers, thus resulting in electrical shorts if the discharge electrodes contact overflowing ash, plus accelerated corrosion even more severe than that caused by air in-leakage.

Conduct a detailed inspection of all areas prone to leakage. As needed, clean off any remaining ash residue to get a clear view of component surfaces and note any distortions, abnormal flexing, or any changes in appearance that could indicate thin metal.

Be sure to include the following:

- **Access doors -** When properly fitted and maintained, the gaskets sealing the access doors in the ductwork and casing will not allow air leakage. If the doors are not properly sealed, air in-leakage can cause cold spots, with consequent condensation and eventual corrosion. The problem self-perpetuates as damage increases with time, causing the holes to get larger and thereby allowing more leakage. Eventually, leakage increases to the point that the gas distribution in the ESP is affected. The capability of the I.D. fans to draw the flue gas through the ESP may also become a problem, resulting in unit derating. (Obviously a derate would occur only after a long time, but there have been door seal leaks which eventually formed holes about 1 ft^2 [0.093 m^2] in size!) Carefully examine the door seal as you close the ESP after inspections or maintenance. Extra care as the doors are closed can minimize repair costs in the future.
- **Corners near the inlet mouthpiece and outlet nozzles -** These are prone to cracking and tears.
- **Vertical columns, horizontal beams, turning vanes (that is, any structural element completely immersed in flue gas) -** These are particularly prone to cause punctures in the adjoining casing. This is because these members expand and contract with temperature changes at a faster rate than the exterior casing. This relative movement pushes against the casing wall like a piston until the wall finally yields.

- **Support stanchions, walkway anchors, conduit struts, and other casing attachments -** These are heat sinks that produce a relatively cold spot on the interior of the casing wall. If conditions favor acid condensation, these areas will become perforated in time, allowing flue gas to escape or air and rainwater in-leakage.
- **Slide plates on the stub columns -** If the plates do not move as they should (for example, because of grit in the sliding area or retainer [guide] bars not functioning properly), the seal welds at the hopper attachment areas can tear.
- **Intentional holes or pass-throughs (such as those for opacity meters or sampling ports) -** Make sure that seals are in good condition and there is no corrosion of the surrounding casing.

One source of intentional air in-leakage provides purge air through the HV support insulators to help keep their inside surfaces free of material buildup. Ideally, heated air is introduced for this purpose with a combination purge blower/heater system (see Section 4.2.5 – Purge-Air Systems and Heaters). Some insulator compartments and penthouses on negative-draft systems have openings or vents that draw ambient air under the negative draft of the fan for this purpose. During an outage, these openings should be checked for blockages. This type of purge system can introduce cold air and moisture that leads to corrosion of the penthouse/insulator compartment and components housed within. It can also lead to failures. As a rule, natural draft purge systems should be replaced with forced-draft combination heat and purge blowers whenever possible.

4.4.3 Structural Support Steel

The precipitator casing is typically supported from structural steel that ties to the foundations at grade. Slide bearings are often used between the support steel and ESP casing columns to allow for thermal growth of the casing steel. Slide bearings should be inspected annually to insure they are intact, functioning properly without interference, and show no signs of deterioration. These bearings may be subject to rotational forces for which they were not designed, or other directional forces that exceed their design. Forces that exceed design expectations can lead to bearing damage and to tearing of the ESP casing.

Grounding of the ESP structure is critical to optimum ESP performance. There should be intact grounds/bonding jumpers between the ESP casing and the structural support steel. At a minimum, there should be such a ground jumper across the slide bearing at each of the four corners of the ESP. There should also be an intact ground jumper between the structural support steel and the ground grid at grade at all four corner columns. Upgrading the grounding may be necessary when older voltage controls are replaced with newer microprocessor-based controls, which are much more sensitive to noise interference.

Key Technical Point

Grounding of the ESP structure is critical to optimum ESP performance. There should be intact grounds/bonding jumpers between the ESP casing and the structural support steel. At a minimum, there should be such a ground jumper across the slide bearing at each of the four corners of the ESP.

Support steel is usually exposed and should be painted with a protective coating. Any areas where the coating has peeled or otherwise deteriorated should be recoated to inhibit corrosion.

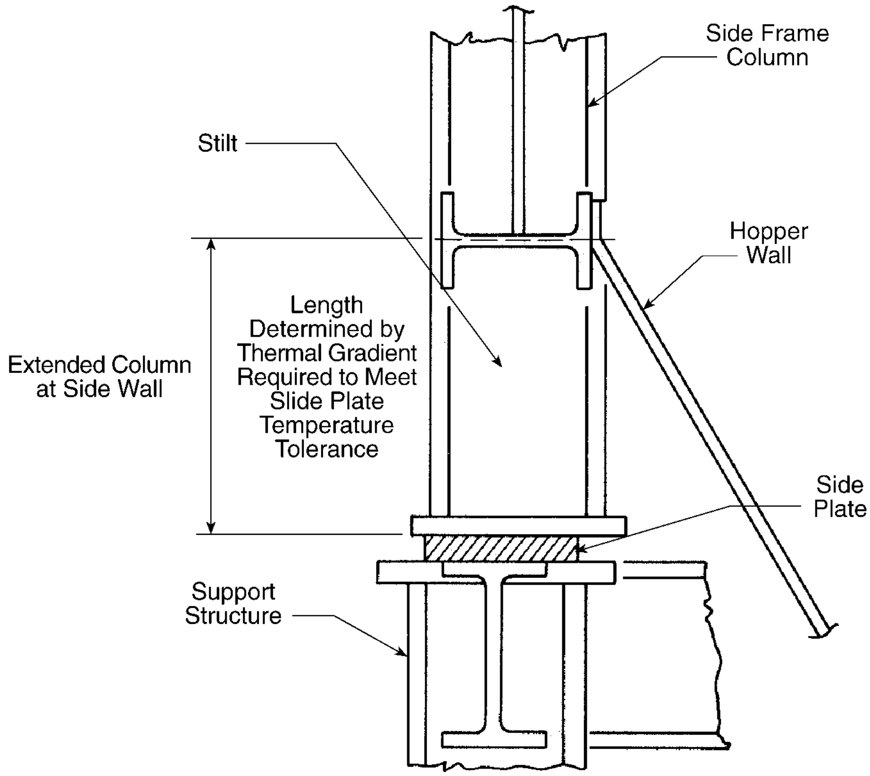


Figure 4-72
A Typical Slide Bearing

4.4.4 Ductwork

The ductwork to and from the inlet and outlet transitions of the precipitator should be gas tight and configured to enhance gas distribution by providing the desired velocity profile. It is not within the scope of this guide to discuss ductwork design criteria, however, maintenance personnel should be aware that abnormal deposits of material fallout in the ductwork may be indicative of problems that need to be investigated. Deposits may be the result of a duct configuration that forces abrupt changes in gas flow direction without adequate turning media or sufficient length of duct downstream of the turn to allow the gas to fill the duct. These types of deposits would tend to be localized, whereas more uniform and widespread accumulation might be the result of operating at low load with a reduced fan speed. Deposits that are allowed to accumulate can eventually hinder gas distribution. At the outlet, they can also lead to material reentrainment.

The inlet and outlet ductwork should be inspected prior to any cleaning to evaluate gas flow and ash-buildup patterns. Excessive buildup in a localized area indicates a low-flow zone, and distribution devices should be assessed for effectiveness. Abnormal buildup needs to be removed and the entire ductwork system inspected. Examine the corners, seams, and access doors for tears and corrosion, especially if there was a significant buildup in the area. Loose or damaged turning vanes, expansion joints at the inlet and outlet flanges, and connections should be noted so appropriate repairs can be made.

Also check for holes in the ductwork. In many instances, leaks in the ducts and expansion joints can be determined from an external inspection of the duct while the unit is in service. However, some holes may be too small to be visible from the outside or may be blocked by insulation and lagging on the ducts; these holes can sometimes be detected from the interior of the duct by turning off all of the lights inside and observing the entry of sunlight. It is also helpful to check the ducts for water leakage if it happens to rain during the outage.

4.4.5 Expansion Joints

Expansion joints are used in the ductwork and at the inlet and outlet flanges as needed to allow for thermal expansion. The number and location of the joints will vary from site to site. Expansion joints are manufactured from a variety of materials, including fabric and metal types. Choice of expansion joints is governed by temperature and pressure, resistance to vibration or movement, duct geometry, and chemical/oil, abrasion, and weather-resistance requirements. Expansion-joint subassemblies and accessories might include retaining rings, baffles, flanges, angles, insulation pillows, and shrouds.

Expansion joints need to be inspected with the inlet and outlet ductwork and transitions. Leaks in the expansion joints can often be detected by external inspection while the precipitator is in service. Periodic on-line inspections of the entire system, including the expansion joints and ductwork, should be made to determine if any leaks have developed. Permanent or temporary repairs should be made if possible; otherwise the area(s) should be noted for inspection and repair during an outage. Small holes may be difficult to see from the outside, or may be obscured by material buildup in the joint bellows and/or by any insulation and lagging of the ductwork. Accessibility to the joints may also make this difficult.

During an outage, the structural integrity of the expansion joints should be verified. Also note any corrosion, erosion, or dust buildup. Fabric-type expansion joints should be inspected for tears or punctures. Less obvious holes can often be detected from the interior of the duct by turning out all the lights inside and observing the entry of sunlight. It is also helpful to check the expansion joints for water penetration if it happens to rain during the outage. Make repairs or replace the joint as needed. Any material that has accumulated in the joint should be removed to limit condensation and chemical attack. Protective shrouds and packing bladders are often furnished to prevent ash accumulation in the joint bellows on horizontal duct runs. They are also sometimes furnished where the particulate is highly abrasive. Protective external shields are recommended for expansion joints on horizontal duct runs where there is risk of debris or material accumulating on the joint.

Expansion joints are often directly exposed to the elements and the surrounding area, particularly the steel flanges and adjacent duct steel, can act as heat sinks where corrosion is accelerated. On units with a continuous operating temperature of 400 to 500°F (204 to 260°C), where excessive dew point corrosion of the areas adjacent to an expansion joint is a problem, consideration might be given to insulating the joint to limit exposure and retain some heat. At a minimum, consider a weather shield around the perimeter of the joint. It is always a good idea to discuss insulating the expansion joint with the supplier prior to doing so. If an insulation barrier is installed, it cannot impede proper functioning of the joint. An outer insulation barrier that is fixed on only one side (see Figure 4.73), or an overlapping arrangement can be used to avoid this. High-temperature expansion joints (above 500°F [260°C]) should not be insulated. Figure 4-74 provides some guidelines for expansion joint use.

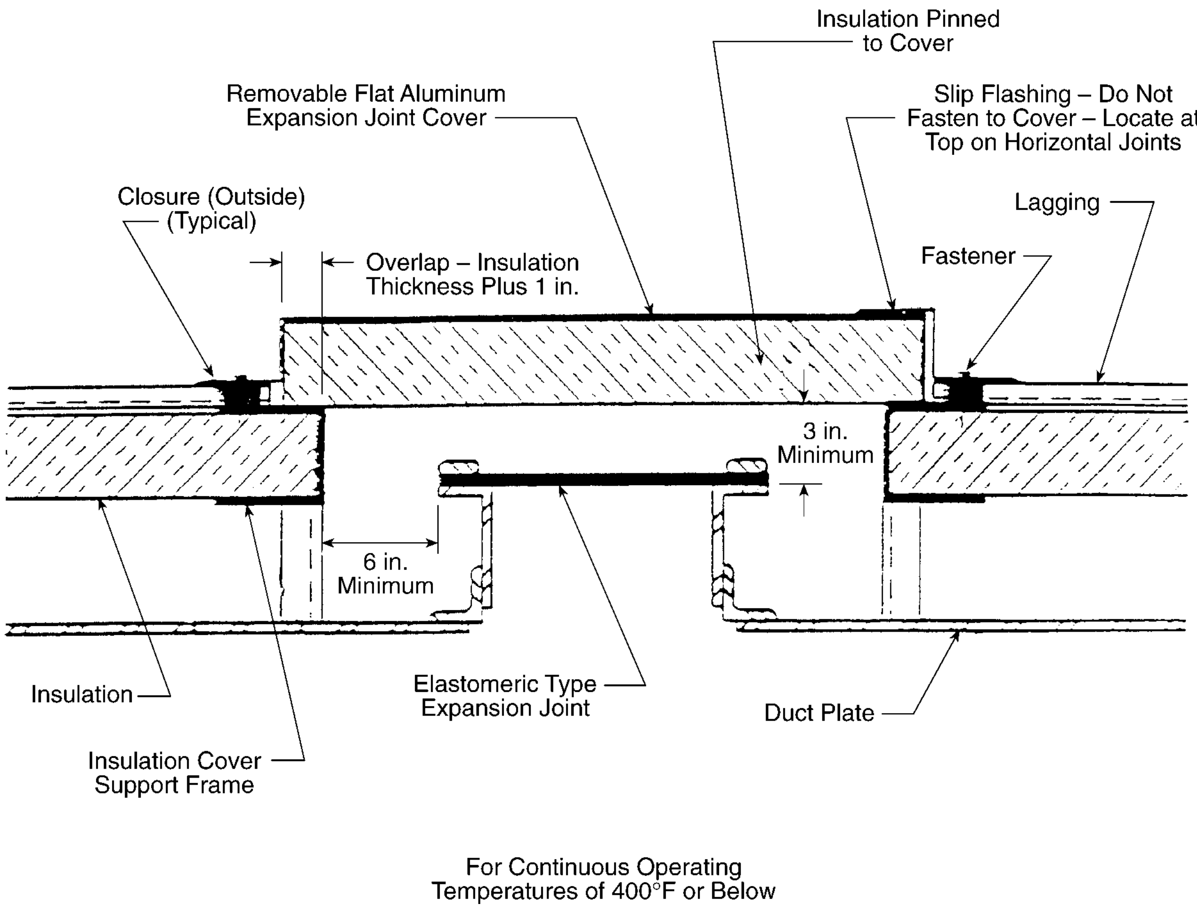


Figure 4-73
Insulation of an Expansion Joint

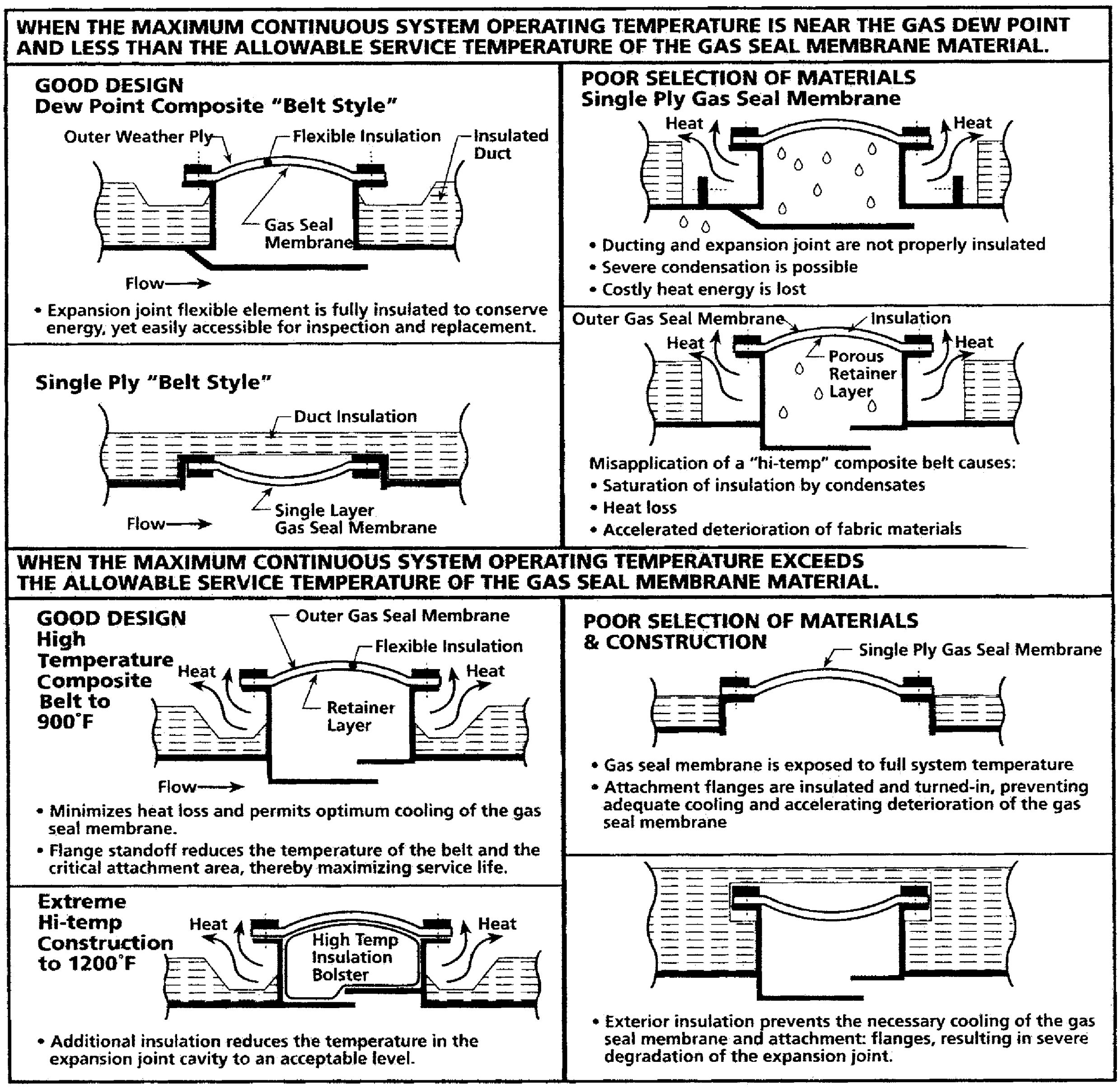


Figure 4-74
Different Expansion-Joint Configurations

4.4.6 Test Ports and Other Duct Penetrations

Test/sampling ports and other duct penetrations such as for temperature probes, conditioning analyzers/lances, opacity meters, and the like must be properly located in the duct to be effective. They should not be located directly downstream of any abrupt changes in duct configuration or direction, or any internal members (that is, structural) or obstructions that might obscure readings. Guidelines for establishing test-/sampling-port locations can be found in the *Standards of Performance for New Stationary Sources*, Code of Federal Regulations CFR 40 Part 60.

Maintenance personnel should pay attention to any penetrations of the ductwork and inlet and outlet plenums during inspections. The condition of any probes and rapper mechanisms should be verified. The test ports and other penetrations are potential heat sinks and sources of leakage and water penetration. Make sure that these locations are effectively sealed and there is no corrosion of the surrounding steel. It is not uncommon to find test port caps that have not been properly replaced or tightened after testing, or flexible rapper boot seals that have deteriorated. It is also not uncommon to find that these penetrations are not properly insulated and that the lagging around these penetrations is not sealed. This creates a heat sink and allows water penetration of the insulation layer that will accelerate corrosion of the duct. Efforts need to be made to minimize this. Removable insulation plugs, covers, or top-hat configurations can sometimes be fabricated to place over the penetrations to retain heat and prevent water penetration. Blanket insulation can used to retain heat.

4.4.7 Dampers

There are two types of damper devices that might be found in the precipitator ductwork: control dampers and isolation dampers. Control dampers, such as butterfly or louver dampers, are primarily used for flow control by regulating gas flow by degree of closure. Isolation dampers, such as guillotine dampers, slide gates, and disc-style gates are used to isolate a precipitator chamber from process gas. Figure 4-75 shows several damper designs. A motorized, single-blade guillotine damper is the most common variety. These generally offer low leakage and provide zero leakage in a negative-pressure system. Positive-pressure systems might utilize zero-leak dampers at the precipitator inlet. These gates often utilize two plates with a cavity between them that is pressurized by a blower such that any leakage across the gate in the closed position is eliminated. Or, zero leakage might be obtained by pressurizing a sealed air chamber located around the periphery of the closed blade with ambient seal air. Isolation dampers should not be used as a means to regulate gas flow on a permanent basis.

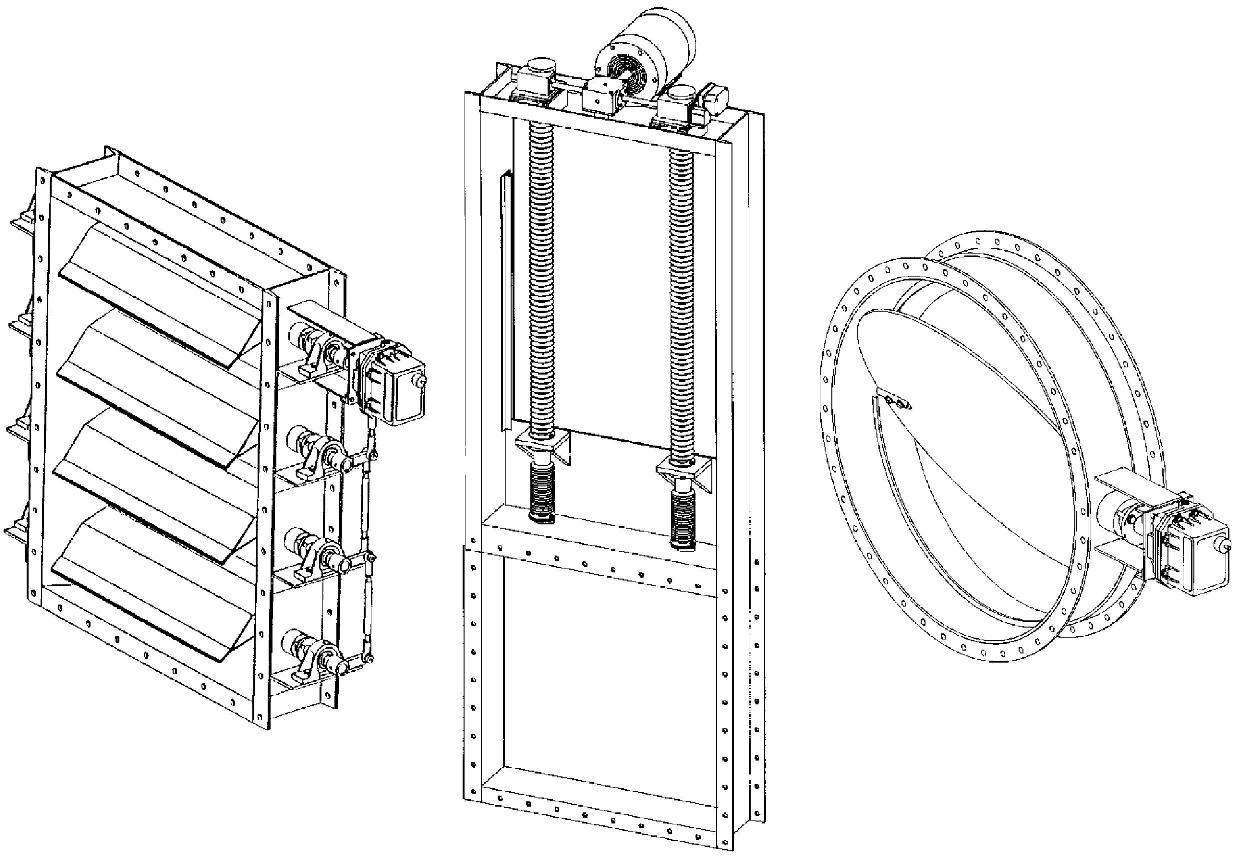


Figure 4-75
Louver Damper, Guillotine Damper, and Butterfly Damper

Isolation dampers may or may not have a protective bonnet around the exposed portion of the damper frame that is not in the gas stream. Bonnets are recommended on high-temperature or positive-pressure applications. The bonnet will reduce the thermal shock of bringing a cold blade into a hot duct in high-temperature applications, and eliminate gas leakage to the atmosphere on positive-pressure installations. Although a bonnet is not necessarily needed on negative-pressure systems, it is still recommended. A sealed bonnet will help prevent any atmospheric in-leakage.

Key Technical Point

Bonnets are recommended on high-temperature or positive-pressure applications. The bonnet will reduce the thermal shock of bringing a cold blade into a hot duct in high-temperature applications, and eliminate gas leakage to the atmosphere on positive-pressure installations.

Damper design and material requirements are dictated by gas-stream operating temperature, maximum temperature (design) and time duration, gas stream pressure (normal and design maximum), maximum pressure against which the damper is required to open/close, and gas-stream characteristics.

Dampers should be checked annually for dust buildup, corrosion, erosion, and structural damage. They are a frequent source of air in-leakage and/or water penetration. Isolation dampers should be checked to ensure that they seal properly. Re-tension or replace damper seals as needed and check bearings for proper lubrication. Dampers that have remained stationary for long periods of time should be exercised during the maintenance outage. Actuator and limit-switch operation should be verified.

4.4.8 Insulation Barrier

The insulation barrier should provide a water-tight layer that minimizes heat losses. Like air in-leakage, heat losses can cause a reduction in gas temperature that can alter resistivity. ESP over-sizing, poor gas distribution, or poor insulation barriers are among the conditions that can lead to poor heat distribution, or localized areas within the ESP where temperatures are lower than elsewhere. A temperature gradient can lead to differences in particle resistivity within zones of the same electrical field, causing the whole field to be adversely affected. This is often evident in gas passages adjacent to the outside casing walls of an ESP. The effects of heat loss are usually magnified in an outlet field because of heat loss through the steel structure and the normal reduction of particle loading from inlet to outlet. Upgrades should include the evaluation or possible replacement of the existing insulation barrier. The insulation layer should utilize chimney stops for heat distribution. All penetrations in the insulation barrier, such as support stanchions, walkway anchors, conduit struts, rapper shafts, hopper poke holes, access openings, and other casing attachments, should be sealed at the point of penetration to minimize heat loss.

> **Key O&M Cost Point**
>
> **The effects of heat loss are usually magnified in an outlet field because of heat loss through the steel structure and the normal reduction of particle loading from inlet to outlet. Upgrades should include the evaluation or possible replacement of the existing insulation barrier.**

Precipitator insulation and lagging should be inspected on an annual basis. Any wet or damaged insulation should be replaced immediately. An infrared survey of the insulation may be useful in identifying areas of damage or improperly installed insulation. Gutters and downspouts should be checked for obstructions.

4.5 ESP Internals

4.5.1 Collecting Surfaces/Electrodes and Support Assembly

4.5.1.1 Component Description

Gas flows horizontally in a precipitator through individual gas passages formed by the collecting plates. The collecting plates are suspended from the top of the precipitator, parallel to and in proper alignment with the discharge electrodes. As dust particles pass through the electrostatic field, they are charged negatively, or opposite in polarity to that of the collecting surfaces, and are attracted to the collecting surfaces where they adhere until removed.

Precipitator collecting electrodes and their support systems must be strong enough to support the weight of the collected particulate and durable enough to withstand the rapping forces used in cleaning. They must be designed in such a way that they transmit rapping impact as uniformly as possible, and thereby facilitate uniform dust removal.

Collecting plates are typically fabricated of light gauge, roll-formed metal and suspended only from the top so as to allow for thermal expansion. Most designs incorporate stiffeners, guides, and vertical baffles to provide structural stability to maintain alignment. The plate proper is usually fabricated from 16- to 18-gauge material. The stiffeners are typically a heavier gauge metal, and fabricated as formed shapes that attach to the top and bottom of the collecting plate. Baffle shapes vary greatly among precipitator manufacturers. Collecting plates are typically an assembly of individual panels. In some designs, these panels are integrally attached to one another, while in other cases the individual panels merely abut one another. There are advantages and disadvantages to each design. Collecting plates generally range from 20 to 50 ft (6.1 to - 15.2 m) in height and 3 to 18 ft (0.9 to 5.5 m) in the direction of gas flow.

Various types of commercially available collecting plates are illustrated below. In spite of the variation in design, the functional characteristics of the plates do not vary substantially.

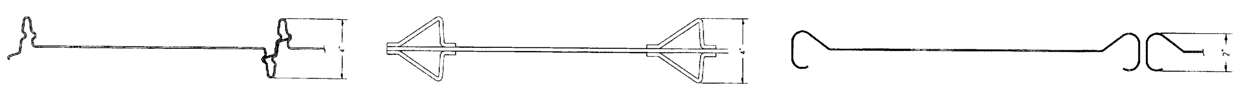


Figure 4-76
Profiles of Collecting Plates. The Collecting-Plate Designs at Left and Center are Integral Plate Designs. The Collecting-Plate Panel on the Right is a Segmented-Panel Plate.

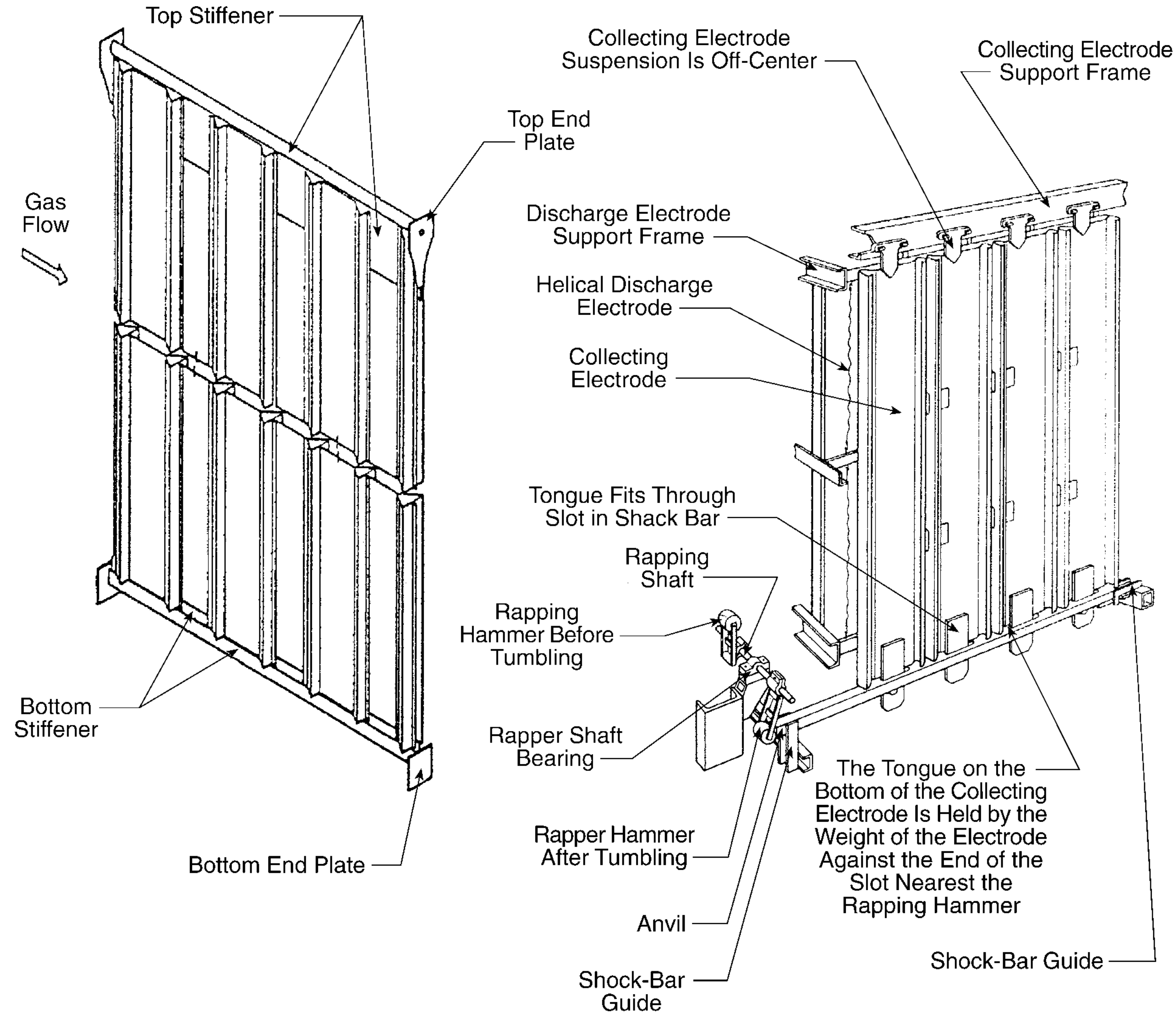


Figure 4-77
Left-Integral Collecting Plate Design, Right-Panel Collecting Plate Design

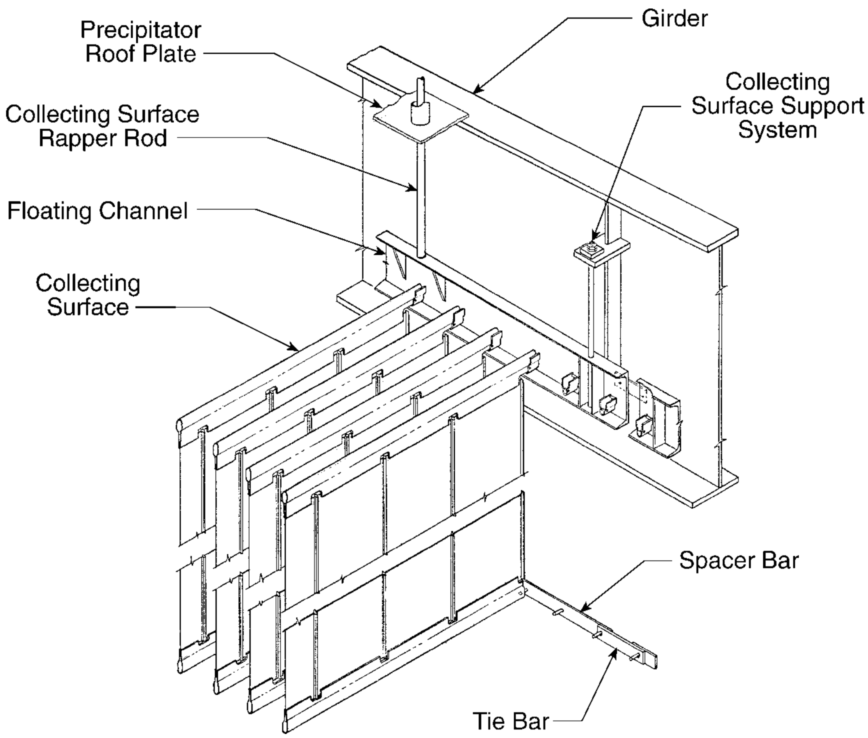


Figure 4-78
Collecting Plate Support Assembly – Integral Collecting Plates Supported by Channels at the Leading and Trailing Edges of the Plate

4.5.1.2 Maintenance/Inspection of Collecting Plates

If the ESP is properly installed, operated, and maintained, little to no maintenance of the collecting plates is required during normal operation. However, a precipitator's life expectancy is limited by its collecting plates, which will degrade over time. The collecting plates should be inspected during maintenance outages to evaluate the condition of the plates, the collecting plate to discharge electrode alignment, and to make corrections if possible to extend the life of the plate(s) and maintain optimum ESP performance.

Inspection of the collecting plates during a dirty inspection of the ESP can reveal patterns of ash buildup, which provide insight into gas-flow distribution and rapping adequacy. Areas of high gas flow are indicated by the absence of ash buildup and possible scouring of the steel. In contrast, low-flow or low-temperature zones would be characterized by localized areas where buildup is heavier than elsewhere. Normally, a pattern of heavier to lighter buildup should be observed from inlet to outlet. Expect to see some variation in dust thickness from top to bottom of the plate, influenced by the point of rapper impact. Excessive buildup of material, particularly in the outlet fields, can lead to material reentrainment that results in increased opacity and/or opacity spiking. The level of buildup may indicate a need to adjust the rapping frequency or intensity. Heavy material residue on the collecting plates and discharge electrodes should be removed during an outage. The locations of unusual levels of buildup should be recorded, and the rapping system serving those sections should be carefully checked.

Key Technical Point

Inspection of the collecting plates during a dirty inspection of the ESP can reveal patterns of ash buildup, which provide insight into gas-flow distribution and rapping adequacy.

Particulate buildup on the collecting surface can have substantial effects on electrical readings. A thin resistive layer can cause a spark-sensitive precipitator. If not resistive, material buildups of 1 to 2 in. (25.4 to 50.8 mm) thickness can often occur without an electrical breakdown of the remaining space. It is practically impossible to operate with collector electrodes in a completely clean condition. Normally 1/8 to 1/2 in. (3.2 to 12.7 mm) buildups will be found on the collecting surface. Unfortunately, the higher resistive material will tend to have better cohesive forces holding the particles together on the surface of the collector. The case where thick buildups occur can also produce changes in the voltage-current readings. Even though the voltage gradient may be similar to that of the wider spaces, the increase in gas velocity through the narrowed passage will decrease the overall precipitator efficiency. The indicated voltage will generally be less for the narrowed passages in an affected field. The point to remember is that normal precipitators will operate with varying degrees of both collecting and discharge electrode buildup. Whether this buildup is meaningful can often be judged by comparing electrical readings of adjacent fields or cells. With a successful precipitator, buildups will generally show some uniformity. When observations indicate great differences in buildup from top to bottom and side to side in specific fields, this might indicate poor gas distribution exists.

Key Technical Point

Particulate buildup on the collecting surface can have substantial effects on electrical readings. A thin resistive layer can cause a spark-sensitive precipitator. If not resistive, material buildups of 1 to 2 in. (25.4 to 50.8 mm) thickness can often occur without an electrical breakdown of the remaining space. It is practically impossible to operate with collector electrodes in a completely clean condition.

Depending on the level of buildup, cleaning may be required in order to make a more thorough inspection of the collecting plates, and/or to make repairs. When inspecting the condition of the collecting plates, the plates need to be evaluated both individually and as an assembly. Any abnormalities and their locations should be noted. During inspection, look for the following:

- The collecting plates are straight and structurally intact. There should be no bowing, warping, or other deformation of the plate.
- Cracks or tears at stress points such as the upper supporting connections, the area where rapper impact or vibration occurs, the spacer/tie bars along the lower leading and trailing edges of the plates, and so on.
- Holes/perforations/penetrations in the collecting plates that create sharp edges.
- Corrosion and erosion damage.

- On panel plates, check that the individual panels comprising the plate are in-line with one another and that they are properly positioned in retainer clips and alignment rakes (see Section 4.5.3 - Alignment of Collecting Plates and Discharge Electrodes).
- The collecting-plate-to-discharge-electrode alignment is within acceptable tolerances, and that no close clearances exist (see Section 4.5.3 - Alignment of Collecting Plates and Discharge Electrodes).

Misalignment, close clearances, and other plate deformations that lower the spark-over voltage can lead to low power levels and reduced ESP performance. Efforts should be made to determine and eliminate or compensate for the cause.

4.5.1.3 Typical Problems and Repair Methods

Damage to the collecting plates can result from temperature excursions, fires, explosions, over-filled hoppers, inadequate provisions for thermal expansion, corrosion from chemical attack and air in-leakage, and repeated localized spark over/arc over due to the existence of close clearances. It is not possible to discuss every conceivable collecting plate anomaly that maintenance personnel may encounter. The important thing to remember regarding making repairs is that the goal is to attain good clearances between the collecting plates and the discharge electrodes, and to eliminate and avoid creating sharp edges that can promote sparking at lower spark-over levels. Assuming that the damage is not so severe and widespread as to warrant complete replacement, some of the options available to repair collecting plates and improve electrical clearances include the following.

4.5.1.3.1 Warped or Bowed Collecting Plates

Warped or bowed collecting plates usually result from a temperature excursion, over-filled hopper, air in-leakage (localized cooling), or inadequate provision for thermal expansion. Some degree of warping can be expected to occur naturally over the course of the life of the plates as residual stresses are relieved. The concern is with plate anomalies that reduce the clearance between collecting plate and discharge electrode by more than 0.5 to 1 in. (12.7 to 25.4 mm).

Most mildly-bent or warped collecting plates can be repaired by either hot or cold methods. Each has its place in the arsenal of possibilities. The most common hot method is shrinking, a procedure that involves annealing a very small spot on the *too close* side of the plate and allowing it to air cool or cooling it with a water spray. Experienced personnel are best to perform this technique, but plant staff can become fairly skilled at straightening plates in a short time. Shrinking is considered to be a permanent fix as long as the original cause for the bowing is rectified.

Key Human Performance Point

The most common hot method is shrinking, a procedure that involves annealing a very small spot on the *too close* side of the plate and allowing it to air cool or cooling it with a water spray. Experienced personnel are best to perform this technique, but plant staff can become fairly skilled at straightening plates in a short time. Shrinking is considered to be a permanent fix as long as the original cause for the bowing is rectified.

Cold straightening, while more limited in application, can produce faster results. The most common form is crimping. Crimping involves twisting the seam, or rib, at various elevations with a long-handled slotted tool. The disadvantage of this approach is that every successive correction progressively weakens the rib.

An alternative to hot- or cold-straightening procedures is to install stiff spacer bars to reestablish the proper clearances. Bars of various designs are available from many suppliers. The spacer bars must often be installed in areas other than the damaged area because the corrections depend on the stiffness of the plate metal to maintain the corrections after straightening. The primary disadvantage of these devices is that they may distribute rapping energy across a greater number of plates, since they tie plates together. Such plate clusters generally include more area than each rapper was designed to clean, and thus the resultant assembly is frequently not cleaned properly, resulting in ESP performance degradation. For plate straighteners to be affective, near-perfect longitudinal alignment must be present or electrode-to-straightener sparking may result.

If repairs are not successful or not practical and the ESP has compliance capacity to spare, it may be possible to operate the damaged section at reduced power levels, or to not operate the section at all. If the extent of the damage to the plate(s) is limited to only a few plates or portions of plates in a field, it may be possible to operate the damaged field or section at improved power levels by removing select discharge electrodes adjacent to damaged plates where clearances are significantly reduced. Up to 5 to 10% of the discharge electrodes can be removed with little impact on performance as long as they are not concentrated in an area or gas passage.

4.5.1.3.2 Cracks and Tears in Collecting Plates

Cracks or tears in the collecting plates typically occur at stress point locations such as the upper supporting connections, the area where rapper impact or vibration occurs, the spacer/tie bars along the lower leading and trailing edges of the plates, and the like. In some cases, these deformities are initiated or augmented by corrosion degradation or wear. Excessive rapping impact can also contribute to collecting plate damage. Tears or cracks that result from inadequate provision for thermal expansion may be the result of poor design, or more likely, improper welds, spacer/tie bars, guides, alignment rakes, etc., that restrict movement of the plates. These tears and cracks often originate at the upper and lower corners of the plate at the junction of the top and bottom stiffeners with the vertical baffle/stiffeners at the ends of the plates. They do not always affect electrical clearances.

It is important that efforts be made to stabilize the plate and to inhibit progress of the crack or tear. Drilling a hole at the end of the crack and welding a connection between the detached stiffeners can diminish progress of the crack. If the cause is thought to be related to restricted growth, drawings of the original installation may need to be reviewed, welds may need to be cut, or modifications may need to be made to correct the problem. The spacer bars used along the lower leading and trailing edges of the collecting plates and the connection between the spacer bars and the casing walls are often the source of problems. Rapper shock bars and anvils are other locations where problems may originate.

4.5.1.3.3 Holes/Perforations/Penetrations and Corrosion/Erosion Damage

Holes, perforations, and penetrations in collecting plates and corrosion damage can result in sharp, jagged edges that promote sparking. Spark over will occur at lower voltages to a sharp or jagged edge than to the smooth surface of an undamaged plate. To maintain high average power levels, it is important that these be eliminated, or compensated for. Holes, perforations, penetrations, and corrosion can develop as a result of air in-leakage, low temperatures, chemical attack, repeated localized spark over/arc over, or careless blast cleaning. Erosion is usually the result of high velocities and/or the nature of the particulate. It may also result from localized repetitive spark over.

Holes, perforations, or penetrations in the collecting plate that are determined to be problematic and are of reasonable diameter can be repaired by installing patch plates to restore a smooth surface. This is most effectively done by sandwiching the damaged area and plug welding the plates. Some of the area surrounding the hole may have to be cut away to allow the damaged area to be effectively patched. If time or manpower constraints during a maintenance outage preclude patch plating, the sharp edges of the hole should be cut back to create as smooth a surface as possible and/or the adjacent discharge electrode removed or modified. A wire electrode can easily be removed. The corona emitters opposite the hole on a rigid electrode can be cut off and the rest of the electrode left as is.

Corrosion damage of the collecting plates can be confined to a particular area, or can be widespread, depending on the cause. If corrosion is severe and widespread, it may warrant a complete replacement of the collecting plates (rebuild). It is to be expected that the collecting plates will eventually degrade over time and ultrasonic thickness testing can be done periodically to help predict the service life of the unit. Attention should be paid to the bottoms of the collecting plates in the outlet, as plate wastage usually begins here due to lower temperatures at the ESP outlet. However, corrosion of the plates can be accelerated by air in-leakage, and chemical attack resulting from low temperature operation such as can occur with low load operation (below acid dew point) or over-injection of SO_3. Firing on gas can also promote corrosion due to water being a byproduct of the combustion process. If the damage is severe, replacement will be necessary. Cutting off the damaged part and welding on a new, straight portion in its place can replace a badly corroded plate bottom. Entire strips of collecting plates can be replaced if the new parts can be moved into the collecting area, either by inserting them through the hopper access doors or a slot cut in the roof of the ESP near the area where the damage has occurred. Sometimes other internals have to be temporarily removed to allow the plate replacement to proceed.

Erosion damage of the collecting plates is usually the result of zones of high velocity and/or the nature of the material. It can also result from localized repetitive spark over or careless blast cleaning. Repairs can be made in a similar manner as those suggested above. The cause of the erosion needs to be determined as any repairs will be subject to similar conditions. Oftentimes erosion damage is indicative of poor flow distribution.

4.5.1.3.4 Other Concerns

As previously stated, one of the primary goals of inspection is to identify areas of the collecting plate system where clearances promote spark over at reduced voltages. The inspector needs to be aware of more than just the obvious. For example, in some designs window plates are used. Window plates are panels or sections of a panel that are missing from a plate to allow the HV discharge electrode frame to pass through it. These locations can be a source of spark over if clearances are not adequate, or there has been wear that results in a sharp edge. Spark over is also common between the discharge electrodes and the top and bottom collecting-plate stiffeners if discharge electrode wires are unshrouded, or the top and bottom emitters are in too close proximity to the edge of the stiffener.

4.5.1.4 Upgrade Options

When rebuilding or replacing collecting plates, consideration might be given to installing plates fabricated from a heavier gauge material. Most collecting plates are fabricated from18-gauge steel. Replacing the plates with plates fabricated from 16-gauge steel would provide an increased corrosion allowance, if needed. Consideration must be given to the additional weight that this will add to the ESP structure, however, since this is dead load, it is often possible to do this without the need for modifications or structural reinforcement. Heavier gauge steel can also be used when replacing the bottom sections of collecting plates that have been damaged from corrosion.

Key O&M Cost Point

When rebuilding or replacing collecting plates, consideration might be given to installing plates fabricated from a heavier gauge material.

Another improvement can be gained by using turnbuckle or clevis connections at the casing wall. Some collecting plate assemblies have connections between the spacer bars along the leading and trailing edges and the casing wall that do not allow for adequate thermal expansion either because they are too rigid, or they become rigid with material buildup. Installing turnbuckles can alleviate this problem.

Related Topics:

- Alignment of collecting plates and discharge electrodes
- Discharge electrodes and high-voltage support assembly

4.5.2 Discharge Electrodes and High-Voltage Support Assembly

4.5.2.1 Component Description

ESP discharge electrodes are designed to produce strong, uniform coronas while maintaining the proper distance and alignment with respect to the collecting electrodes. Discharge electrodes are held at a high electrical potential during precipitator operation to ionize the flue gas and establish electric fields for particle charging.

Discharge electrode systems are divided into discrete sections, each being energized by a separate TR set. Sectionalization is important in matching the required corona currents and voltages to the electrical ratings of a T/R set and in promoting reliability and stability under sparking/arcing conditions.

Discharge electrodes are found in a variety of shapes and sizes as illustrated in Figure 4-79. The shape of the electrode will influence the voltage-current characteristics. Methods of supporting the electrodes differ among different precipitator manufacturers. One method is to suspend the electrodes from an overhead support structure and to maintain their position with weights and guides at the bottom. Another approach is to provide a frame or tubular support for the electrodes. Discharge electrodes normally belong to one of the following classifications (see Figure 4-80):

- **Weighted wire -** Weighted wire discharge electrodes consist of vertically hung wires that span the full height of the collecting electrodes. Electrode diameters typically range from 0.10 to 0.15 in. (2.5 to 3.8 mm). Wire discharge electrodes have been fabricated from single-strand round wire, dual-strand-twisted round wire, square wire and barbed wire. *In situ*, the wires are supported from overhead by frames of various designs, and a steadying frame that is equipped with guides maintains their position at the bottom. Figure 4-81 illustrates one type of weighted wire electrode system, including the connections to the top frame and the weight at the bottom. Wires may be subjected to localized sparking in the regions of high field strength. Shrouds are often used to provide a larger diameter, and hence low field strength, in critical regions near electrode ends to reduce the potential for spark over in these areas where clearances are close.
- **Rigid frame -** This design, also referred to as the *bedspring type*, uses a stiff structural frame to support the discharge electrodes. The electrodes themselves can be of a variety of shapes. They may be circular, square twisted, formed strips, or they may be designed in special shapes, such as spiral wires, that yield a desired current-voltage relationship. The electrodes are strung through intermediate horizontal cross members fastened to the rigid frame. The distance between supports is usually 3 to 7 ft (0.9 to 2.1 m).
- **Rigid mast -** A mast-type discharge electrode system utilizes a stiff structural member to support the individual electrodes. Support members, usually tubes, are fastened rigidly to the top support frame. The electrodes themselves may be circular, square twisted, or some other special shape. The electrodes are strung through cross arms fastened to the central support member. The distance between supports is from 3 to 7 ft (0.9 to 2.1 m).

- **RDE -** Rigid discharge electrodes consist of formed sheet or structural members rigidly fastened to a support frame at the top. The length spans the height of the collecting plates and is kept in place at the bottom by an alignment frame. The electrodes are typically fabricated from 16-gauge material. In order to enhance corona generation, they have studs, protrusions, or other sharp emitter shapes spaced over the length of the electrode. Figure 4-79 provides illustration of typical rigid electrode designs. Since the mid-1980s, the rigid electrode design has largely replaced the weighted wire design in new installations.

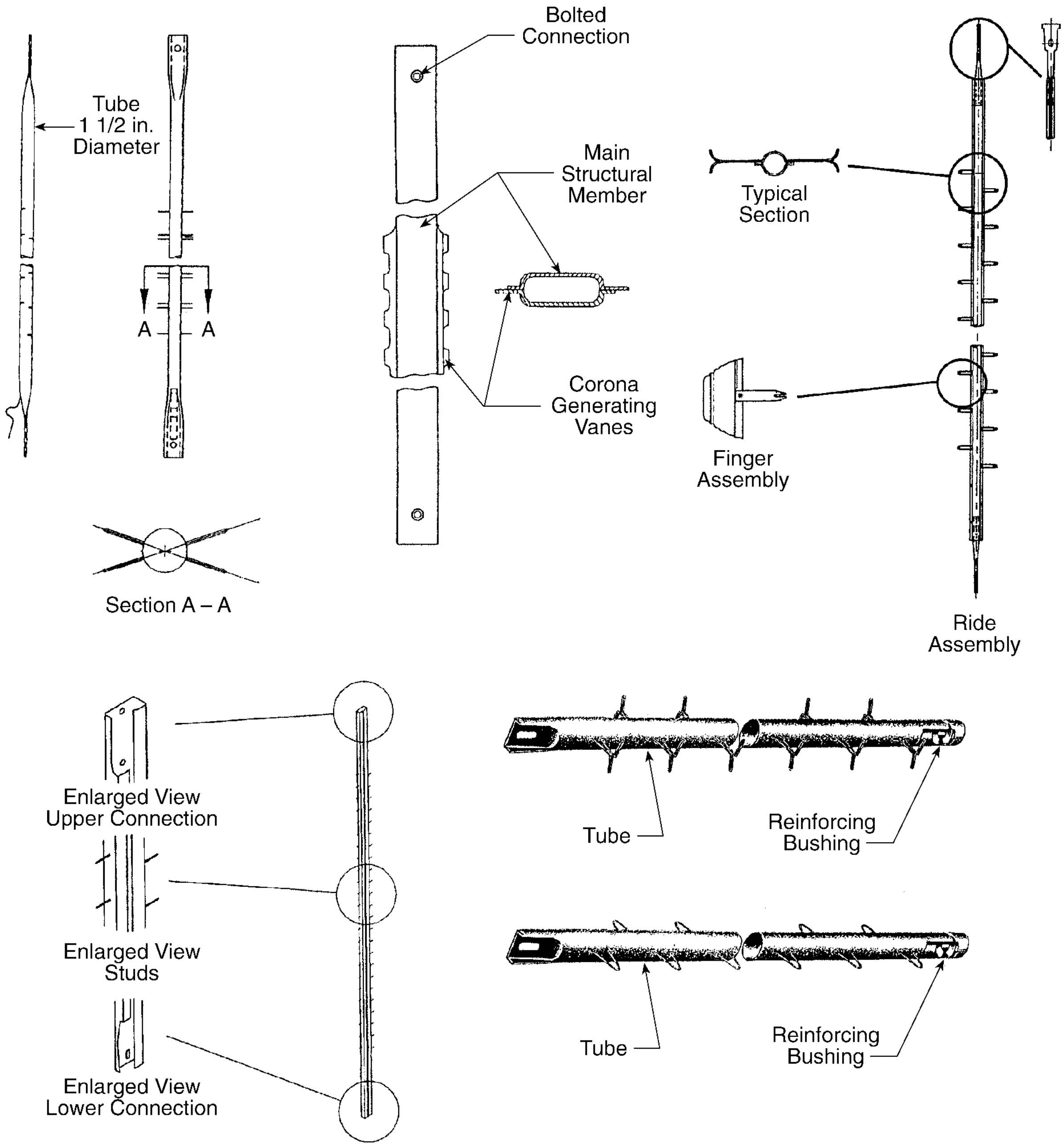


Figure 4-79
A Variety of Rigid Discharge Electrode Geometries. The Electrode Geometry Will Influence the Voltage-Current Characteristics.

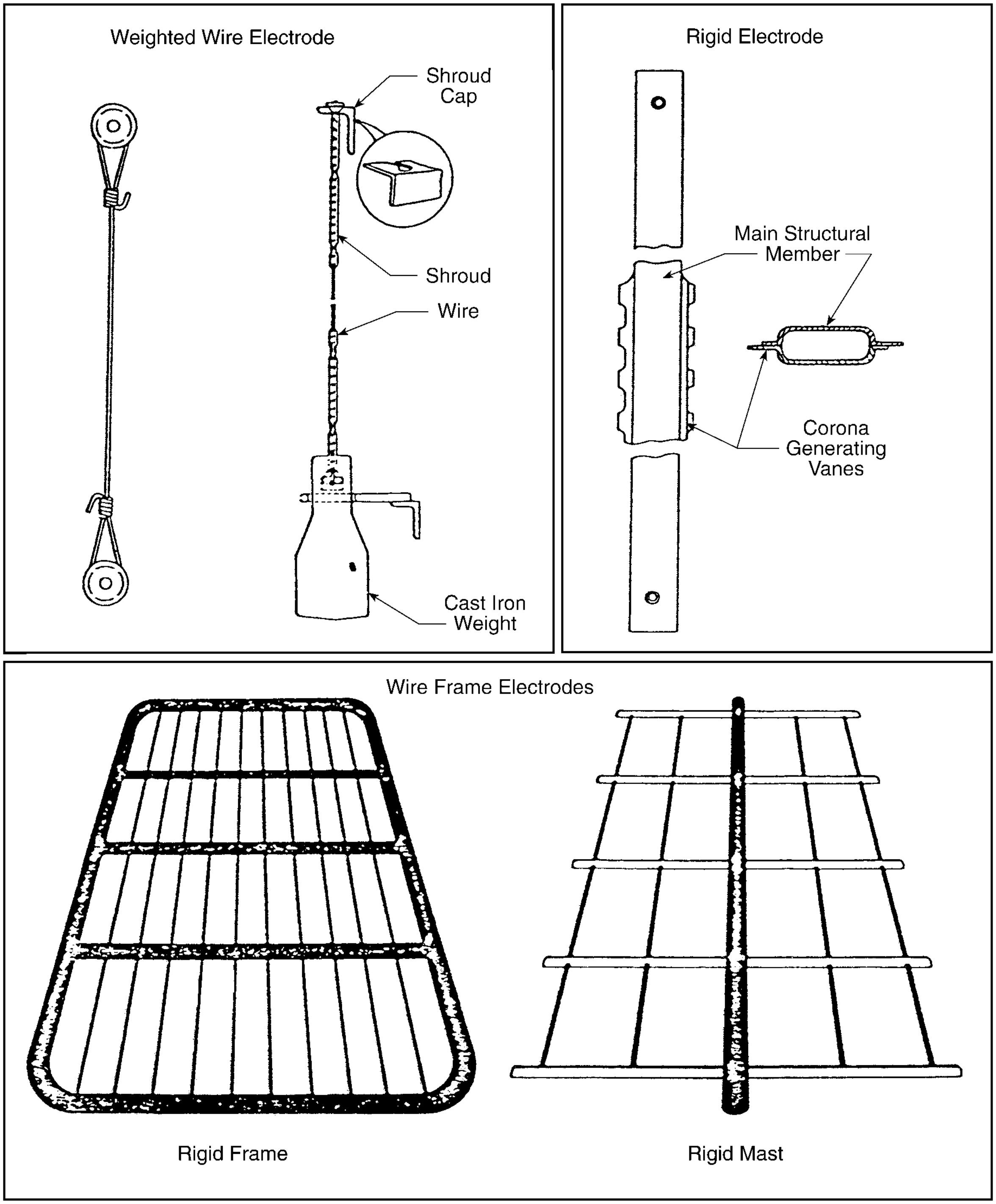


Figure 4-80
Clockwise From Top Left – Weighted Wire, Rigid Electrode, Rigid Mast, and Rigid Frame

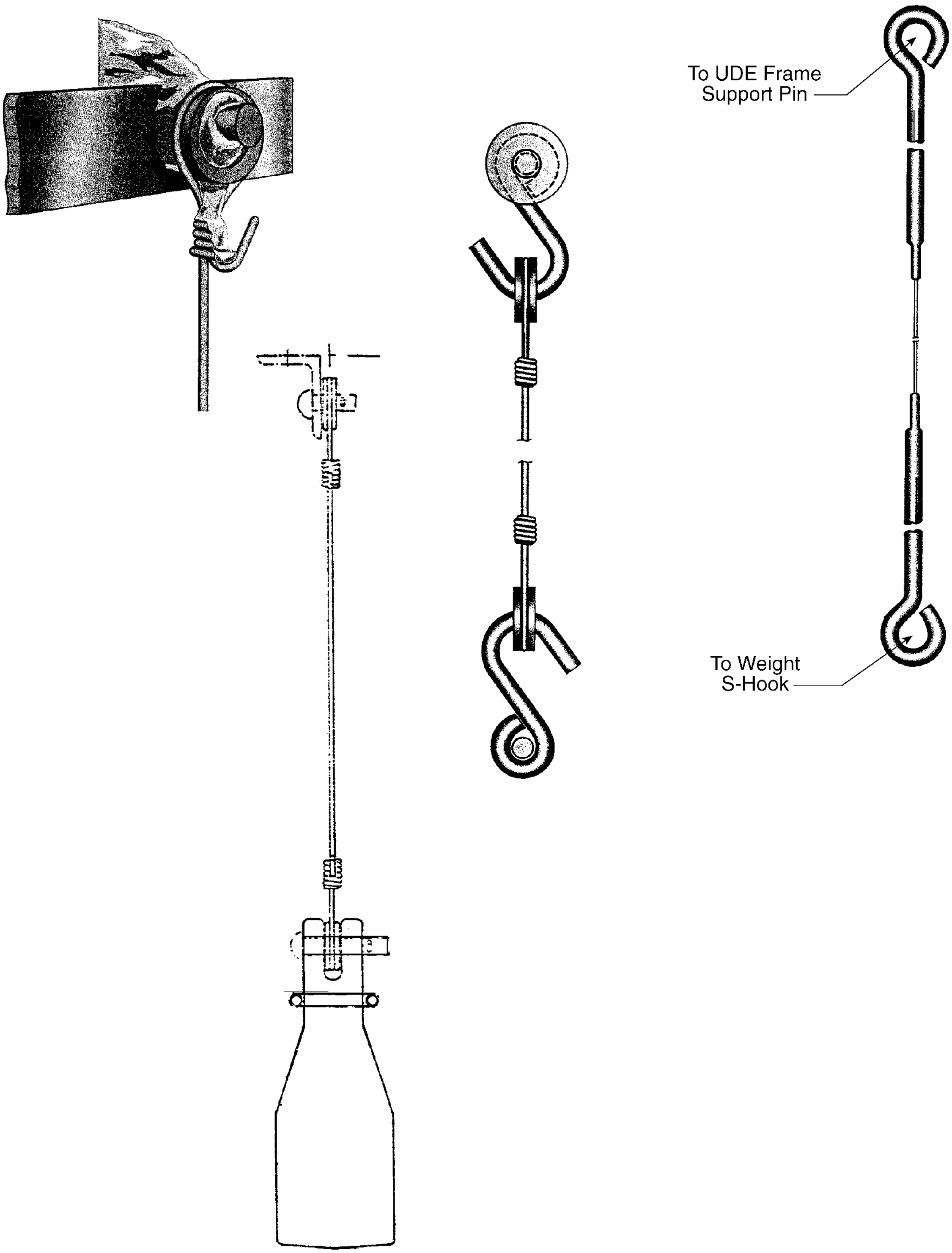


Figure 4-81
Weighted-Wire Electrode Showing Connection to the Top Frame and the Weight at the Bottom. The Electrode at the Far Right is a Shrouded-Discharge Electrode. The Shrouds at Top and Bottom Provide a Larger Diameter, and Hence Low Field Strength, in Critical Regions Near Electrode Ends to Reduce the Potential for Spark Over in These Areas Where Clearances Are Close. The Unshrouded Wire at Left Is Subject to Spark Over Where It Enters and Exits the Collecting Plates Opposite the Top and Bottom Plate Stiffeners.

Historically, American precipitator manufacturers have favored the weighted wire and rigid electrode design, while European manufacturers have favored the rigid frame and mast designs. There are advantages and disadvantages to each design, but that discussion is beyond the scope of this manual.

Discharge electrodes are supported from a HV support assembly. Designs vary among different precipitator manufacturers. Regardless, the discharge electrode support assembly has two primary functions: to provide the necessary HV electrical isolation and to give mechanical support to the discharge electrode frame. Several types of support systems are illustrated in Figure 4-82. In all cases, the discharge electrode frames are supported from roof level by porcelain or alumina insulators that are housed in a relatively low temperature zone that is comparatively free of contaminants – either an insulator compartment or penthouse. Note from the illustrations that some discharge electrodes and frames extend above and below the collecting plates, while others are immersed between the collecting plates.

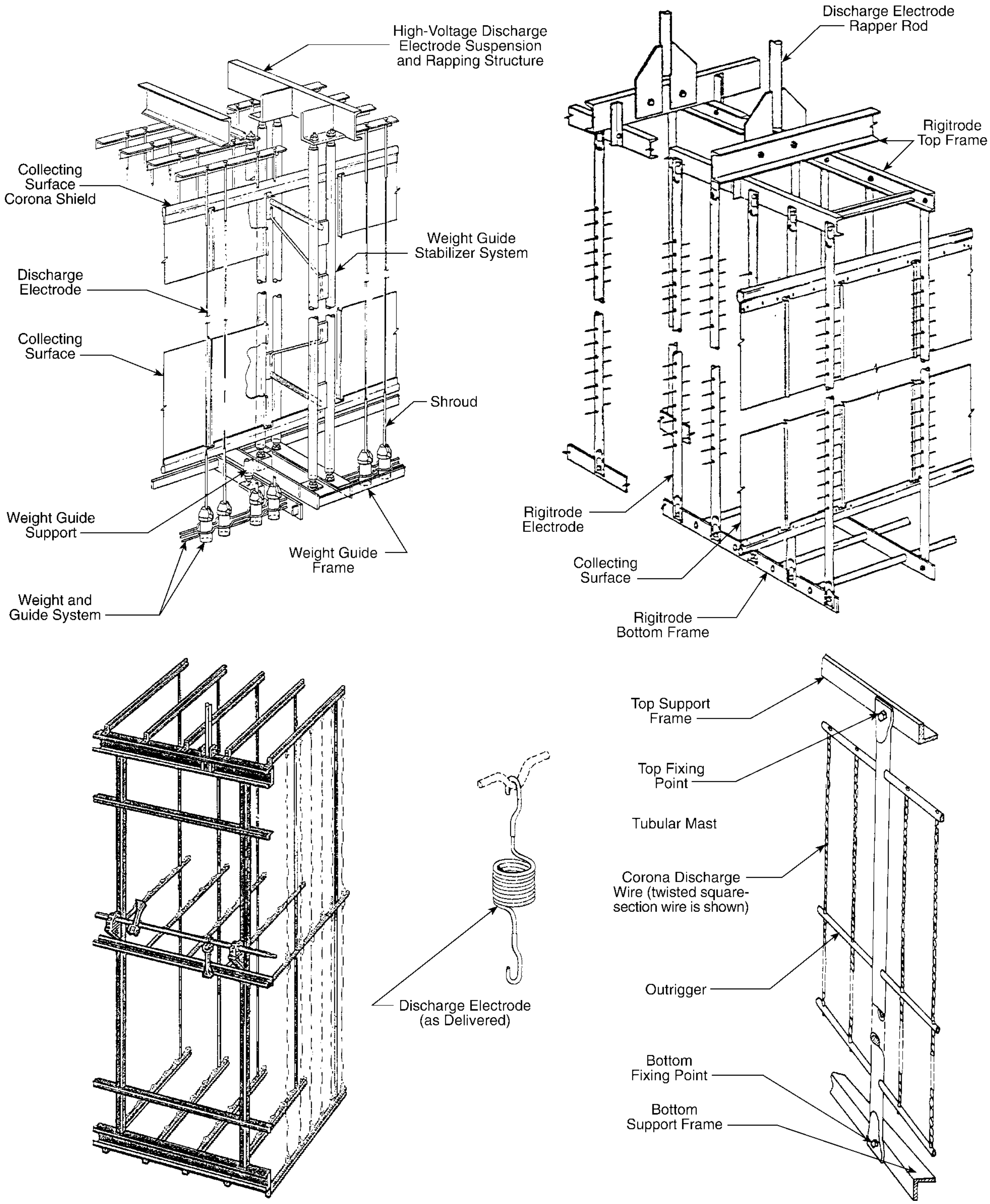


Figure 4-82
Discharge Electrode Support Frames; Clockwise From Top Left – Weighted Wire, Rigid Electrode, Rigid Mast and Rigid Frame

4.5.2.2 Maintenance/Inspection of Discharge Electrode System

Electrodes should be inspected annually for proper alignment, tension, excessive dust buildup, and signs of arcing or other deterioration. When inspecting the discharge electrodes, it should be kept in mind that all discharge electrodes of an electrical bus section are operated at the same high potential. Since a bad clearance or discontinuity in even a single electrode will reduce the performance of that electrical section, it is important that no electrodes be overlooked. Initial attention should be paid to those sections that have exhibited poor electrical readings prior to the outage.

Under normal operating conditions, most of the particulate is collected on the collecting plates and relatively little collects on the discharge electrodes. However, while the discharge electrode is the source of energization, it too can develop a coating of particulate. It is not unusual to observe buildups of 1 to 3 in. (25.4 to 76.2 mm) in diameter on groups of wires, and also at different sections of the electrode. Large buildups on wires and rigid discharge electrodes may or may not be critical to the electrical characteristics. That is more dependent on the nature of the coating. For example, an irregular buildup that forms the shape of beads over the total length of the wire will not basically alter the meter readings or precipitator performance because the corona discharge will occur between the beads at the wire surface. However, if a uniform buildup of fine particulate coats the electrode so that it simulates a wire of larger diameter, higher voltages will be required to initiate corona current, and corona distribution will be poor. This condition can lead to a voltage-sensitive precipitator in which spark over occurs, because the voltage gradient is too great for the physical spacing.

The barbed wire, punched plate and rigid type discharge electrodes provide a corona discharge by use of evenly spaced physical points, thus reducing the effect of material buildup on the electrical characteristics and providing a uniform corona distribution. In these cases, only the tips of the emitters need be clean. Maintenance personnel need to become familiar with what constitutes a normal level of buildup in their particular ESP. Excessive and problematic buildup on the discharge electrodes may be indicative of inadequate rapping or may be related to over-conditioning, low-temperature operation, fuel characteristics, poor gas distribution, boiler tube leaks, or a host of other reasons. Locations of unusual dust deposits should be recorded.

Key Human Performance Point

Maintenance personnel need to become familiar with what constitutes a normal level of buildup in their particular ESP. Excessive and problematic buildup on the discharge electrodes may be indicative of inadequate rapping or may be related to over-conditioning, low-temperature operation, fuel characteristics, poor gas distribution, boiler tube leaks, or a host of other reasons. Locations of unusual dust deposits should be recorded.

Inspection of the discharge electrodes should focus on identifying reduced clearances and discontinuities that reduce performance and trying to determine the cause, while maintenance should be directed towards corrective or compensatory action. Modes of failure and other problems with discharge electrodes, as well as corrective measures, are discussed in the next section.

4.5.2.3 Typical Problems, Modes of Failure, and Corrective Measures

Many of the typical problems with discharge electrodes, modes of failure, and corrective measures are unique to the type of electrode designs discussed above. Failed/broken discharge electrodes need to be removed. Badly deformed electrodes need to be straightened or removed. A failed or broken electrode can result in an electrical short that grounds the associated bus section, removing it from service. Deformed electrodes reduce the electrical clearance between the electrode and collecting plate, which lowers the spark-over voltage and can reduce the power levels of the associated bus. These conditions jeopardize compliance.

4.5.2.3.1 Weighted-Wire Designs

There are many weighted-wire precipitators still in service in the utility industry. The most common problem with the weighted-wire design is wire breakage/failure. There are a number of conditions that can contribute to excessive wire failure. These include:

- Mechanical/fatigue failure
- Electrical erosion from repetitive localized spark over
- Corrosion and age-related wear

Mechanical failures generally occur near points of attachment and are due to excessive movement of electrodes in a manner that results in excessive cold working and subsequent fatigue failure. Visually, this type of failure appears as a fracture surface, with no necking, perpendicular to the wire. On shrouded wires, this often occurs at the crimp where the ends of the wire penetrate the shrouds. If this happens with widespread frequency, it may be indicative of poor electrode fabrication.

Electrical failures by concentrated sparking can occur because of misalignment or localized high-field regions due to sharp surfaces, distortions, or protrusions on the collecting electrode. Concentrated sparking and subsequent wire failure may also occur by swinging of the electrode (which reduces the inter-electrode spacing), by lack of proper shrouding, or by spit sparking. It may also result from distortions in the wire itself, such as kinks in the wire that are introduced during careless installation or cleaning.

The nature of the electrical failure can often be determined by visual examination of the failed electrode. For the type of failure associated with a sharp protrusion or other cause of a high electric field at the collecting plate surface, the wire surface is generally round and smooth on one side, whereas the region directly exposed to the arc/spark is flat and rough. The length of an affected zone is usually 3 to 4 in. (76.2 to 101.6 mm) This type of failure is commonly found near the top or bottom of an electrode, at a location corresponding to the top or bottom edge of the collecting plate. In such cases, arcing occurs from the edge of the collecting plate or the bottom of a plate baffle and can be corrected by rounding the plate edges, using shrouded wires, or cutting away a portion of the baffle. This type of failure can also occur at other locations, particularly if plate baffles are welded or if there is another sharp point or other rough surface on a collecting plate. One common cause of this type failure is improper alignment of the electrodes due to faulty erection, foundation shifts, or other causes that permit the discharge electrode to be spaced closer than normal to the collecting electrode, particularly near the bottom. Kinked or crimped wires can also lead to this type of failure. They should be removed or reoriented so that the kink is oriented in the direction of gas flow as opposed to towards the collecting plate.

A second type of electrical failure generally occurs near the middle of the electrode. The reduced section of the failed electrode can extend over several feet and is circular in cross section, tapering to a point at the fracture face. Failures of this type are commonly due to plate bowing, or electrode swinging that usually results from poor gas-flow distribution, a resonant condition, or inadequate wire weights. Swinging wires can also result from wires that have bottomed out in the weight guide retainer on the lower guide frame and lost tension. This may be the result of the wires having relaxed and/or inadequate provisions for thermal expansion. In this case, the lower weight guide frame may need to be lowered slightly, or the tensioning weights freed in their guides. Wires or cables used to support the lower weight guide frames can also slacken and oscillate in the gas stream if there is variation in weight distribution of the lower frame. These need to be re-tensioned. As a general rule of thumb, wires should be tensioned with weights weighing 1 lb/ft of wire length to avoid swinging/oscillating wires. However, there are many ESPs that operate without problems with a less weight per foot ratio. Where high velocities exist, high secondary voltages are required, or when large diameter wires are used, more than 1 lb/ft of weight may be required.

Spit sparking often occurs at the connection of the wire electrodes to the upper support frame (Figure 4-83), at the weight connection at the bottom of the electrode, or between the wire weight and the weight guide frame. Spit sparking results from slight differences in electrical potential due to inadequate electrical connections. Erosion of the electrode, the support frame, and/or the weight guide frame is often indicative of its occurrence. Improving the integrity of the connection and/or adding shunt straps can be done to eliminate potential differences and prevent the occurrence of spit sparking.

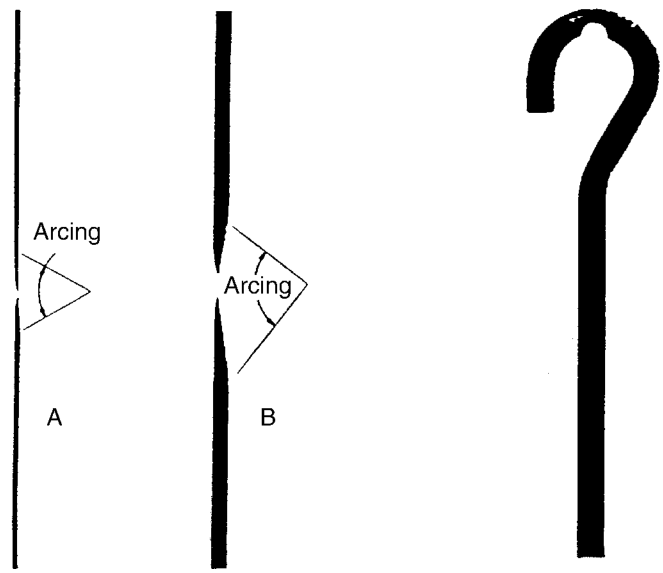


Figure 4-83
Left - Illustration of Electrical Erosion Failure of the Wire Electrode With Damage Restricted to a Very Short Length of Wire. Right – Illustration of Partially Failed Discharge Electrode Wire Shroud, the Result of Electrical Erosion From Spit Sparking and/or Mechanical Erosion From Movement.

Corrosion failures can occur in a variety of locations and in a variety of ways. Some discharge electrodes are fabricated from more exotic materials than the standard carbon steel wire to resist corrosion. Metallographic examination along with analysis of the corrosion product can generally be used to identify this type of failure.

Locations of failed and missing wires should be documented. The location of wire failure should also be recorded. Efforts should be made to try to determine the cause of failure and, if possible, correct the condition causing the failure. Failed discharge electrode wires need to be removed. There is some debate over replacing failed wire electrodes. It is not a clear-cut issue. Some suggest that broken or missing weighted wire electrodes should be replaced unless a pattern of consistent failure at a single location is identified. The authors of this guide argue that, in general, a failed or missing wire electrode should not be replaced, unless the source of failure has been identified and eliminated and the entire bus section of wires is being replaced. A new wire, installed in place of the failed wire, will likely fail again if the cause of failure has not been removed. Additionally, a new wire installed in place of the failed wire will exhibit different electrical characteristics when energized than the other wires in the same bus section that have been in operation for an extended period of time. Wear will have reduced the diameter of the failed wire or dulled the corona emitters on a barbed-type wire. Since all of the wires in the same bus section are energized by the same power source, replacement with a new wire can adversely influence the overall power to that section. A small number of randomly missing wires, less than 5 to 10% of the total, will not adversely affect the performance of the ESP. The larger the SCA of an ESP, the more randomly located wires that can be removed with impunity.

Key Technical Point

A small number of randomly missing wires, less than 5 to 10% of the total, will not adversely affect the performance of the ESP. The larger the SCA of an ESP, the more randomly located wires that can be removed with impunity.

Corrosion- and age-related wear of the discharge electrodes will occur over the service life of the electrodes. Corrosion and subsequent failure will be accelerated by air in-leakage, low temperature operation (below the dew point), moisture exposure, and chemical attack. Trying to anticipate failure or the useful life of the electrodes is difficult because of the many variables that can affect wire life. In utility applications where load is relatively steady, it is not uncommon for wires to last 10 to 15 years or more. The situation to be avoided is one where frequent wire failures jeopardize opacity compliance. Close inspection of the wires during an outage can help to avoid this situation and/or anticipate the need for future wire replacement. For example, it is not uncommon to find thinning of unshrouded wire electrodes where they enter and exit the collecting plates. If there is widespread evidence of this occurrence, plans should be made for wire replacement to avoid the inevitable problem. When that is done, shrouded electrodes should be installed as the replacement to prolong wire life and reduce sparking.

4.5.2.3.2 Rigid-Frame and Mast-Electrode Designs

Rigid-frame and mast-discharge-electrode systems may use wire electrodes, rigid, or semi-rigid electrodes between the cross braces. Due to shorter discharge electrode lengths, the rigid-frame and mast discharge electrode systems are generally free from breakage, although there have been notable exceptions to this rule, often due to an installation problem or other deficiency. Spark erosion can also destroy the attachment integrity of the discharge electrodes to the frames; consequently, some systems are equipped with attachment shunt straps to prevent sparking at the point of support. Finding broken electrodes on a rigid frame design can sometimes be difficult because when there is no electric field to pull them toward the collecting plate they may remain in position in the frame. Shaking the frame may help to audibly determine the location. Once determined, the failed electrode should be removed.

Tensioning of the discharge electrodes needs to be periodically checked. The electrodes are often pre-tensioned prior to installation, but they can slacken or become loose in use. When this happens, they need to be re-tensioned or, in some cases, replaced to avoid repetitive localized spark over and subsequent electrode failure. The attachment integrity of the electrodes to the frames also needs to be checked to determine if a problem is developing. Often this takes the form of spark erosion, whereby each spark vaporizes a small portion of the electrode, eventually causing failure.

Close inspection of the frames should be made in the vicinity of rapper impact. The repetitive impact of rapping can lead to weld failures or fatigue cracking. Repairs need to be made to restore the integrity of the frame and to assure good rapper transmission. As with the collecting surfaces, any repairs that are made should avoid creating reduced clearances or sharp edges that promote spark over.

Rigid frames can warp for reasons similar to those that would bend the collecting plates. Straightening them can also be accomplished by heating and bending or crimping, as described for the collecting plates (see Section 4.5.1.3). Replacement of badly damaged sections should be considered. Often where collecting plates are severely damaged, the discharge electrode system will also be damaged.

Entrance access for replacements can often be obtained by cutting a slot in the roof or moving replacement pieces in through the hopper. As with plates, be sure to consider longitudinal as well as vertical misalignment, and investigate the root cause to ensure the long-term efficacy of the repair or replacement procedure.

The frame-restraining grid is often held in place by an insulator attached to the hopper wall. The insulator maintains electrical isolation for the discharge electrodes and prevents the entire discharge electrode assembly from shifting or swaying due to either gas flow or electrical forces. This insulator should be replaced if it is damaged or broken.

4.5.2.3.3 Rigid Discharge Electrodes (RDE)

The advantage of RDE is that they seldom break. In the unlikely event of a failure, they should be replaced (or possibly repaired) and the cause of the failure investigated. The decision to repair or replace RDEs depends on the mode of failure, the severity of failure, and the number of failed units. The electrodes can often be removed and replaced through the hopper.

Inspection of RDEs should focus on any deformations that might exist that reduce the clearance to the adjacent collecting plates and promote spark over. These include bent or improperly located corona-emitter pins and bowing of the electrodes. If shunt straps are installed at the lower frame connection to avoid sparking at that point, they also need to be checked.

The emitter pins are spaced at intervals over the length of the discharge electrodes and come in a variety of shapes (pins, scalloped, or perforated edges, and the like), sizes, and orientations that influence the voltage-current characteristics. Ideally the emitter pins should be vertically aligned with one another over the length of the electrode body. There is usually some tolerance allowed by the manufacturers as to how far off center individual emitter pins can be bent over towards adjacent collecting plates. Typically, any emitter pin bent beyond the body of the electrode should be corrected. The emitter should be bent back into position or removed. Bent emitters are usually the result of careless installation or being disturbed during cleaning, inspection, or maintenance repairs.

There should be adequate clearance between the top-most and bottom-most emitter pins of the discharge electrodes and the top and bottom stiffeners of the collecting plates. This is an often overlooked detail, particularly in rebuild situations. Spark over will occur if there is not sufficient clearance. A general rule of thumb is that the clearance between the top-most and bottom-most emitters and the edge of the stiffener should be one-and-one-half times the cross-gas-flow clearance. For example, where collecting plate spacing is 12 in. (304.8 mm) and the discharge electrodes are properly positioned between the plates, the cross-gas-flow clearance is 6 in. (152.4 mm) The clearance between the top-most and bottom-most emitter pins on the electrodes should be approximately 9 in. (228.6 mm) from the edges of the collecting plate stiffeners (a sharp edge). If they are not, the emitters should be removed or bent against the body of the electrode. In some instances, this may shorten the treatment zone of the ESP and baffle extensions may have to be added to avoid gas bypass.

Key Technical Point

There should be adequate clearance between the top-most and bottom-most emitter pins of the discharge electrodes and the top and bottom stiffeners of the collecting plates. This is an often overlooked detail, particularly in rebuild situations.

Bowed discharge electrodes can result from overfilling the hoppers, a temperature excursion, fire, or inadequate provision for thermal expansion. Bowed electrodes that compromise the alignment need to be straightened or removed. Electrodes that are bowed across gas flow can often be straightened by crimping the body of the electrode, or by shimming the electrode at the top and/or bottom connection to introduce a counter-bow. RDEs that are bowed in the direction of gas flow are often less of a problem, unless the extent of the bow is such that the electrode is in close proximity to the vertical baffles on the collecting plate. If that is the case, the electrode will likely need to be removed.

4.5.2.4 Upgrade Options

When replacing all the weighted wires in a precipitator, or all the wires in an entire electrical field, make sure the new wires are equipped with shrouds at the top and bottom where the wires pass the edges of the collecting plates. These shrouds will minimize sparking and extend the life of the wire. Adequate tensioning of the wires might require the installation of heavier weights. When adding additional weight, a structural review and an assessment of the physical condition of the ESP cold roof and HV support assembly should be made.

Key Technical Point

When replacing all the weighted wires in a precipitator, or all the wires in an entire electrical field, make sure the new wires are equipped with shrouds at the top and bottom where the wires pass the edges of the collecting plates.

If widespread corrosion of the discharge electrodes is a problem, consideration might be given to replacing the existing electrodes with electrodes fabricated from a material that is more corrosion resistant. Choice of material will be dependent on process conditions.

Increasing the electrical sectionalization of a precipitator is a way to minimize the impact of broken discharge electrodes on ESP performance. In some cases, this can be done relatively easily by separating or splitting existing HV frames and adding additional TRs. In other cases it may be more complicated and require the addition of support points or a full scale rebuild (collecting plates and discharge electrodes) of the ESP. The arrangement of the existing discharge electrode supports will largely determine the ease and practicality of doing this.

If a complete rebuild of the precipitator is planned, upgrade options include converting to other discharge electrode designs. For instance, weighted-wire and rigid-and mast-frame designs could be converted to a rigid electrode design. In the case of wire electrodes, this eliminates the problems associated with broken wires. Conversion of the rigid and mast frame designs with internal rapping (European design) to a rigid electrode design with external rapping (American design) can sometimes provide a means to increase the specific collecting surface area.

Related Topics:

- Alignment
- Anti-sway insulators
- Collecting surfaces

4.5.3 Alignment of Collecting Plates and Discharge Electrodes

Proper alignment of the collecting plates and discharge electrodes is critical to ESP performance. Misalignment can result in low secondary voltages and increased current, creating a situation that promotes sparking at lower-than-optimal power levels. The result is a reduction in overall power and performance capability in the affected section(s) of the ESP. Alignment usually refers to the position of the collecting plate assembly relative to the discharge electrode or HV assembly as a whole. As previously discussed, anomalies in the collecting plates and discharge electrodes that create reduced electrical clearances can compromise the overall alignment. Since a bad clearance or discontinuity in even a single collecting plate or discharge electrode will reduce the performance of the associated electrical section, it is important that no plates or electrodes be overlooked when inspecting the ESP. There is usually some adjustment capability when the relative position of the collecting plates and discharge electrode assemblies need to be improved. Localized close clearances need to be addressed on an individual basis.

Ideally, the discharge electrodes should be centered between the collecting plates in each gas passage of the field. In reality, this is nearly impossible to achieve because of construction tolerances and other factors. Cross gas-flow alignment within 0.25 in. (6.4 mm) is desirable for an ESP with 9 to 10 in. (228.6 to 254.1 mm) plate spacing. Misalignment by more than 0.5 in. (12.7 mm) warrants correction. ESPs with wider plate spacing (12 to 16 in. [304.8 to 406.4 mm]) can tolerate a greater degree of misalignment. With the wider plate spacing manufacturers typically allow for ± 0.5 in. (12.7 mm) tolerance; misalignment by more than 1 in. (25.4 mm) would warrant correction. Problematic misalignment is often visibly apparent, but a ruler or template (Figure 4-84) should be used to evaluate alignment clearances. Pay special attention to areas exhibiting unusually high or low ash deposits in the dirty inspection; poor clearances could be the cause.

Key Technical Point

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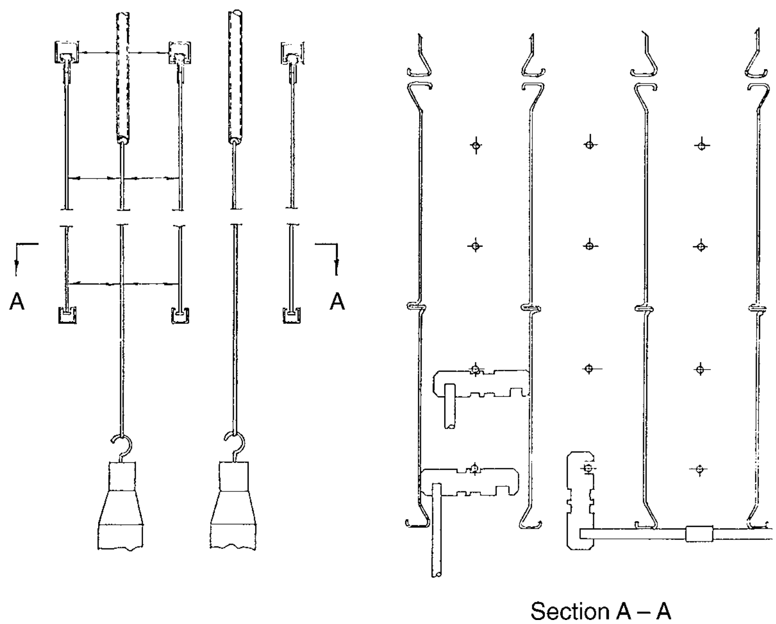

Figure 4-84
Example of Template Used for Checking Collecting-Plate-to-Discharge-Electrode Alignment

Most personnel performing precipitator inspections are accustomed to looking for misalignment across the direction of gas flow. However, it is also important to look for misalignment occurring in the direction of gas flow, often called longitudinal misalignment. The discharge electrodes should also be reasonably well centered between the vertical stiffeners/baffles on the collecting plates, though some manufacturers position their electrodes slightly forward or back of center depending on the shape of their baffles. A general rule of thumb is that the clearance between the corona emitters on the electrode and the collecting plate baffles should be approximately 1½ times the ideal cross gas-flow clearance (Figure 4-85). Areas with improper clearances should be marked directly on the component and on a map of the internals.

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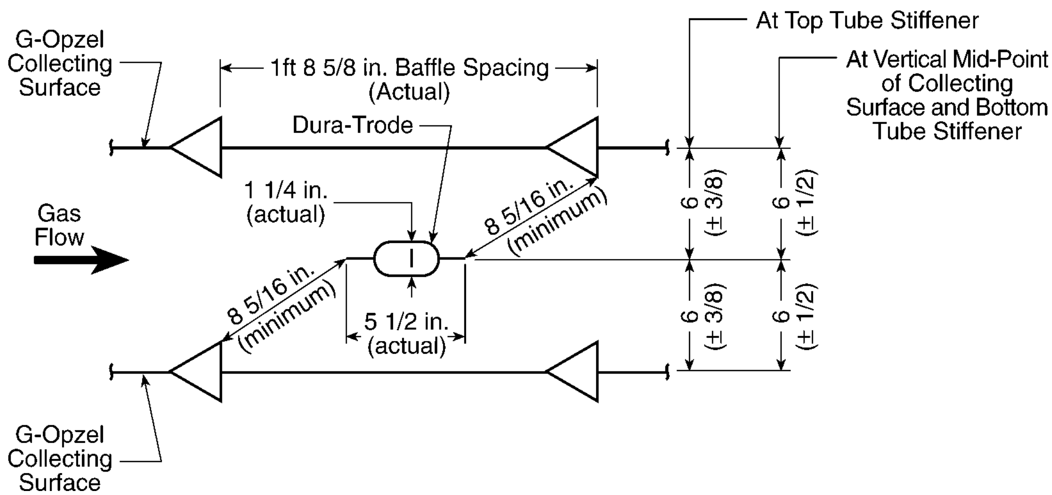


Figure 4-85
Example of Alignment Tolerances

Whenever possible, efforts should be made to determine the cause of misalignment. Alignment may have been disturbed during replacement of a support insulator, or may have shifted at the bottom as a result of a missing retainer for the large nut on the HV frame support rod. Causes of misalignment are many and include support insulator failure, deformation of the collecting plates or discharge electrodes, material buildup breaching the hoppers, excessive buildup on the electrodes, failure of a structural slide plate, and deformation of ESP structural members, among others. Less common is live misalignment, which is a dynamic condition that arises from a conflict in expansion forces. It is unobservable during inspections, as it only occurs while components are at operating temperatures.

When possible, efforts should be made to restore the collecting plate to discharge electrode alignment. Assuming the initial installed alignment was reasonably good and there has not been irreparable damage, this can usually be done by adjusting the elevation of the discharge electrode frame, shifting the HV support assembly, or adjusting/shifting the collecting plates. There is wide variation in the degree to which this can be successfully done from one manufacturer's design to another. In some designs, the alignment is relatively fixed at initial installation.

When cross-gas-flow alignment is consistently off at the bottom of the field but acceptable at the top, adjusting the elevation of the upper HV frame that supports the discharge electrodes can correct this. It takes very little movement at the top to have a large pendulum affect at the bottom. In some cases, it might be more appropriate to adjust the bottom of the plates in one direction or the other in order to obtain improved clearances. If the discharge electrodes are too far forward or back of the collecting plate vertical stiffeners/baffles or alignment rakes at the bottom elevation only, this can be corrected by raising or lowering the leading or trailing edge of the collecting plates if that adjustment is available.

If the alignment at both the top and bottom elevations is skewed, the discharge electrodes are too far forward or back of the collecting plate vertical stiffeners/baffles or alignment rakes, or the discharge electrodes in each gas passage are consistently close to one side the collecting plates, the HV frames can sometimes be shifted slightly to correct or improve the alignment. Some manufacturer designs use support-insulator base plate arrangements that allow the HV assembly to be easily shifted (Figure 4-86). Others weld the base plate to the ESP hot roof after initial alignment is attained. In that case, the base plate must be cut free in order to make adjustments. Still others provide no means at all. Where possible, shifting the collecting plates can provide some additional latitude.

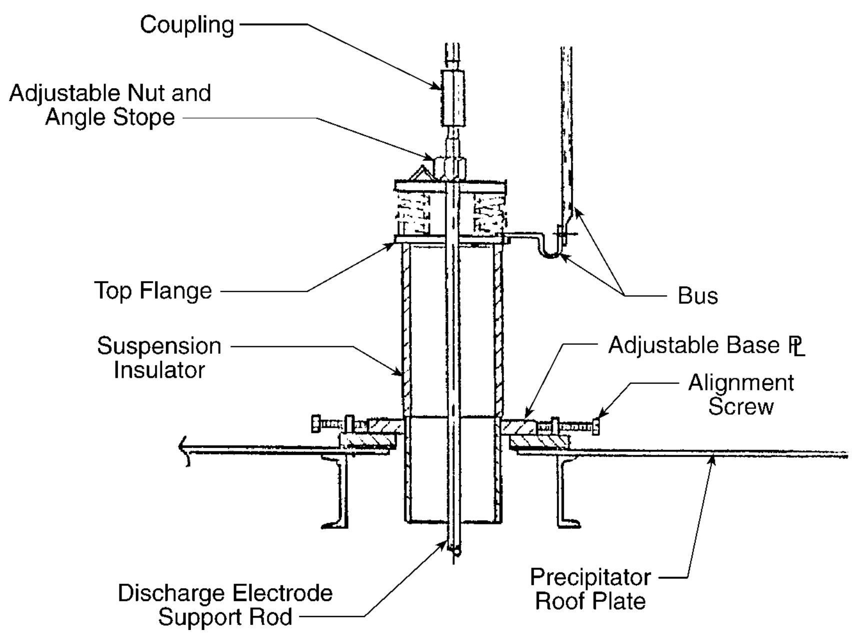


Figure 4-86
This Support-Insulator Base Plate Arrangement Allows More Latitude in Alignment Adjustment Than Designs That Use Only a Single Support-Insulator Base Plate.

Another component of alignment is where the HV frame that supports the discharge electrodes penetrates the ESP hot roof. The support rods usually pass through a hole that needs to be of sufficient diameter to avoid spark over, and the rod should be reasonably well centered in the hole. Most often, there is a transitional piece (corona shield) at the penetration that provides a curved surface to discourage spark over. The corona shields need to be inspected during annual outages. If they develop holes, they promote sparking and need to be replaced. In all cases and in all locations, the HV frames need adequate clearance to any grounded surface (collecting plates, ESP structure, and the like) to avoid spark over.

Close clearances or discontinuities in the collecting plates and/or discharge electrodes will promote premature spark over and a reduction in power levels regardless of the best alignment efforts. They need to be eliminated by making repairs and modifications, or compensated for by the removal of individual discharge electrodes. This will usually improve operating voltages and currents and reduce electrode wear or failure. About 5 to 10% of the discharge electrodes can be removed with little impact on performance, as long as they are not concentrated in an area or gas passage. If damage to a collecting plate(s) is such that it is not immediately repairable or replaceable, and the problem is limited to a small number of gas passages in a field (for example, because of a few warped plates), it may be prudent to remove all the wires in the gas passage. If this is done, it is recommended that the associated gas passages be blanked off to force gas flow into other active passages and prevent it from passing through the ESP untreated. When damage extends to more than a few randomly located or adjacent gas passages and affects most or all of a field, removing discharge electrodes is not a stopgap option.

Correcting and optimizing ESP alignment and eliminating close clearances will benefit performance. This is particularly true in marginally sized ESPs and those that operate in a high resistivity range. Any anomalies have a greater effect on spark-over voltages under high resistivity conditions.

Related Topics:

- Collecting surfaces
- Discharge electrodes
- Anti-sway insulators

4.5.4 Anti-Sway Insulators

Anti-sway insulators are often used to maintain the position of the lower HV discharge electrode frames (weight guide frames, attachment grids, and the like). The insulators maintain electrical isolation of the discharge electrodes and prevent the entire discharge electrode assembly from swaying either due to gas flow or electrical forces. Swaying can lead to repetitive spark over that reduces average power levels. It is important that these insulators be checked for cleanliness and damage, including signs of electrical tracking. Maintenance personnel should replace damaged or broken insulators and remove dust accumulations. It should be noted that although the anti-sway insulators maintain the aligned position of the collecting plates to the discharge electrodes, they should not be used to attain that alignment. The insulators should not be bound in any way that introduces mechanical forces that might cause them to break. The insulator assemblies should allow for thermal expansion. Failure of anti-sway insulators is usually the result of mechanical forces or electrical tracking. Tracking across the insulator can create a high resistance condition that adversely affects power levels of the associated field.

Anti-sway insulators are usually of either a bar or post (rod) type and made from Teflon, porcelain, or alumina. Of the three, alumina has the superior mechanical and electrical characteristics. The anti-sway insulator assemblies (Figure 4-87) are typically positioned in one of two ways. One method is to attach the insulator between the lower HV discharge-electrode frame and the hopper or casing wall. The other is to attach the insulator assembly between the collecting plates and the lower HV discharge electrode frame. The latter method is preferable, although there are many successful installations using the other arrangement. If deformation or unequal thermal expansion of the casing or hopper walls occurs where the insulator attaches, it can change the position of the discharge electrodes relative to the collecting plates. Attachment between the collecting plates and discharge electrode frames maintains the relative alignment.

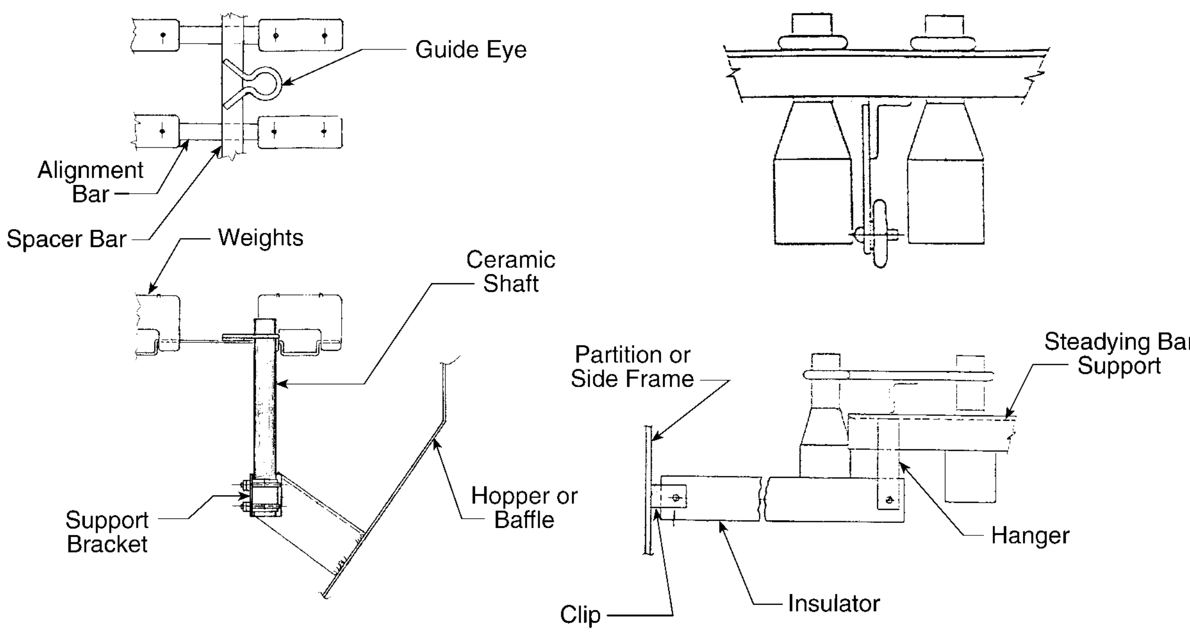


Figure 4-87
Anti-Sway Insulator Assemblies. Anti-Sway Insulators Are Usually of Either a Bar or Post (Rod) Type and Made From Teflon, Porcelain, or Alumina. Of the Three, Alumina Has the Superior Mechanical and Electrical Characteristics. The Anti-Sway Insulator Assemblies Are Typically Positioned in One of Two Ways. One Method Is to Attach the Insulator Between the Lower High-Voltage-Discharge-Electrode Frame and the Hopper (Above Left) or Casing Wall (Above Right). The Other (Below) Is to Attach the Insulator Assembly Between the Collecting Plates and the Lower High-Voltage-Discharge-Electrode frame. The Latter Method is Preferable, Although There Are Many Successful Installations Using the Other Arrangement.

Related Topics:

- Discharge electrodes
- Alignment

4.5.5 Walkways and Internal Access

Many precipitators have internal walkways to provide access for inspection and maintenance. Prior to entering the precipitator, relevant safety considerations should be made and grounds should be in place. Maintenance personnel should visually inspect the walkway from the access door prior to entry to determine that it is intact. Large accumulations of material buildup need to be removed.

Lower walkways are typically located between fields and mounted on the upper flange of the girders that form the hopper walls. In some cases, the walkway may be nothing more than the upper flange of the girder. In oil burning units that have a wet bottom, the walkways may be mounted on the between field baffles. Walkways are often grated to allow material to pass through them. Large accumulations of material on the walkways can lead to material reentrainment and elevated opacity or opacity spiking. Material accumulation or the lack thereof can be indicative of the gas distribution profile. The elevation of the walkway/hopper wall should be high enough that it is above the treatment zone of the ESP to avoid gas sneak-by. This is sometimes overlooked, particularly in a conversion from a weighted wire to rigid electrode design, and can lead to opacity problems. Another oversight that is often made is the clearance proximity of the walkway to the adjacent discharge electrodes. Corona emitters on rigid electrodes located directly opposite the edge of the walkway may need to be removed to avoid sparking.

In addition to lower walkways, some units also have upper walkways. These may be suspended from the ESP roof, or access may be across some internal structural member. Often times there are ladders between the upper and lower access, or ladder rungs on structural members to access different elevations. There is great variation in accessibility for inspection and maintenance among the many manufacturer ESP designs. Care needs to be taken when moving around and working within the precipitator.

Related Topics:

- Gas-distribution media

4.5.6 Inlet and Outlet Nozzles/Plenums

The inlet and outlet, be they of a nozzle or plenum design, aerodynamically transition gas flow to and from the precipitator. They are usually considered a part of the precipitator casing and are subject to the same concerns regarding in-leakage/out-leakage, corrosion, and erosion. They are treated separately here because of their role in gas distribution and gas velocity as it relates to gas treatment time and effective precipitation.

The inlet, and quite often the outlet, transitions are equipped with gas-distribution media, including diffuser plates and directional vanes to straighten the gas flow such that it has a distributed horizontal profile as it enters the treatment zone of the precipitator. The design should also minimize the potential for material buildup. Flat spots and ledges should be avoided. There are a variety of common transition designs, such as nozzles and bottom and top inlet and outlet plenums (see Figures 4-88 and 4-89). Some designs are more prone to gas distribution and buildup problems than others. The design configuration at a particular site is often the result of space requirements/limitations and, therefore, may not be the most effective design for achieving the desired results. Good use of gas distribution media and directional vanes within the ductwork and transitions can often overcome these obstacles.

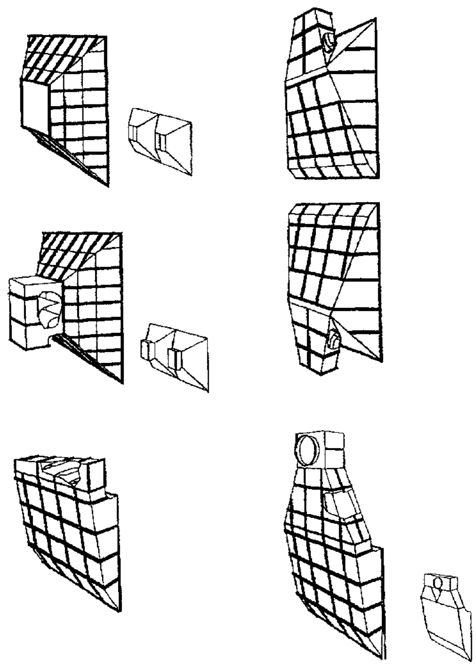


Figure 4-88
Typical Inlet and Outlet Transition Configurations

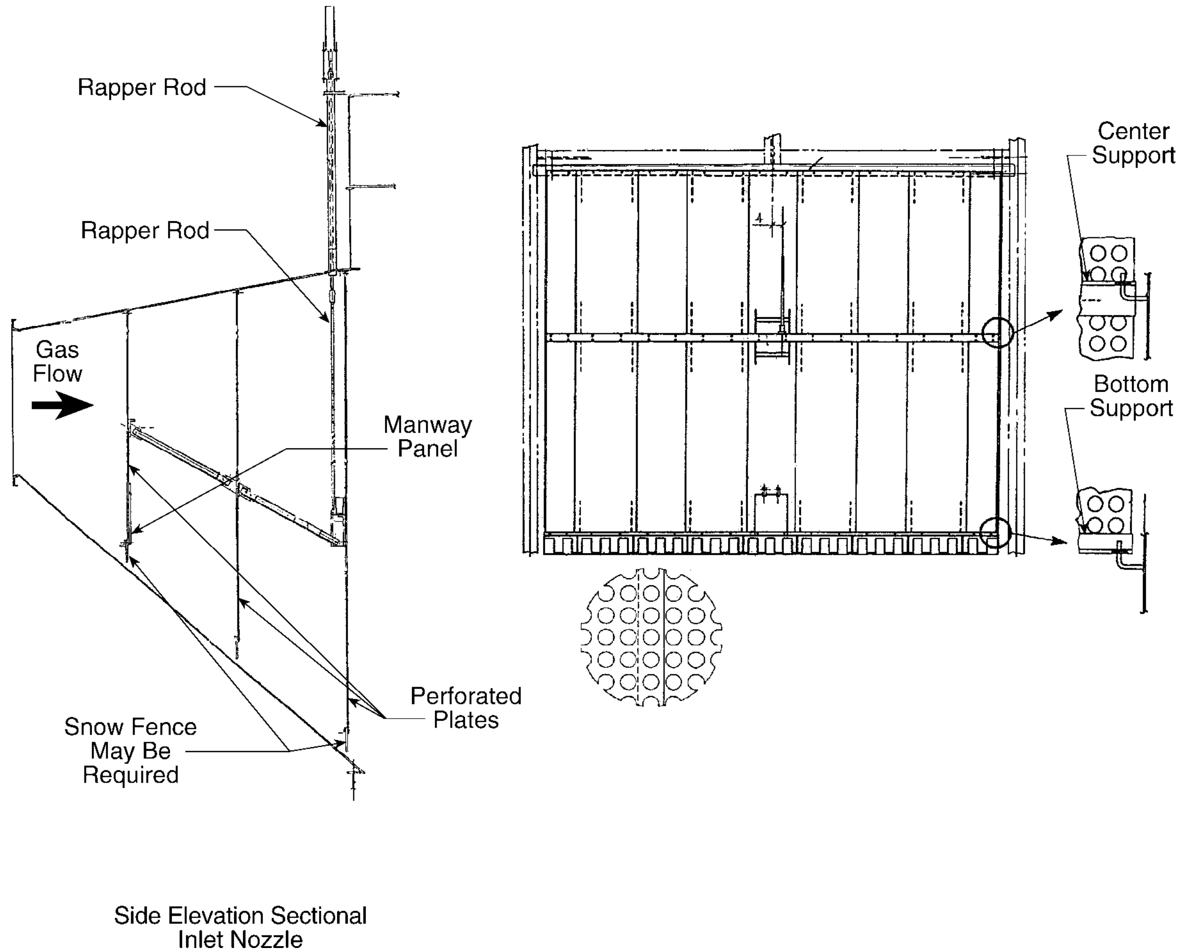


Figure 4-89
Inlet Nozzle Transition and Perforated Gas-Distribution Plate With Snow Fence

4.5.6.1 Inspection/Maintenance

During maintenance outages, the inlet and outlet transitions should be inspected inside and out. Like the ESP casing they should be checked for structural integrity as well as for signs of leaks, dust buildup, corrosion, and erosion. Some nozzle and plenum designs are more accessible for inspection than others. A thorough inspection and any repairs may require the installation of scaffolding.

Holes, tears, and cracks resulting from structural failure, corrosion, and/or erosion can lead to in-leakage or out-leakage, depending on the operating pressure of the ESP. Once this occurs, it can lead to accelerated corrosion, structural and equipment deterioration, and/or ESP performance loss. Erosion is often prevalent in the inlet because this is where the gas is transitioned from a relatively high velocity in the ductwork to a relatively low velocity at the inlet face of the precipitator treatment zone. In the transition areas, pay obvious attention to areas where corrosion/erosion or evidence of air in-leakage is present or tends to occur. Special attention should be paid to areas such as:

- **Access doors or covers -** When properly closed and maintained, the gaskets sealing the access doors should not allow air in-leakage or out-leakage. Even when a good seal is obtained, the door assembly can act as a heat sink if not properly insulated and corrosion may develop.
- **Corners near the inlet and outlet flanges of the ESP where the transitions attach -** These areas are prone to cracking and tears if there is any expansion interference or structural movement beyond that anticipated by design.
- **Turning vanes, vertical columns, horizontal beams, cross-members (that is, any structural element completely immersed in flue gas) -** These are particularly prone to cause punctures in the adjoining casing. This is because these members expand and contract with temperature changes at a faster rate than the exterior casing. This relative movement pushes and pulls against the casing wall until the wall finally yields.
- **Dampers, expansion joints, and casing attachments (such as support stanchions, walkway anchors, conduit struts, test ports, and rapper-rod pipe sleeves) -** These are or can be heat sinks that produce a relatively cold spot on the interior of the casing wall. If conditions favor acid condensation, these areas will become perforated in time, allowing flue gas to escape or air and rainwater to leak in. Proper insulation or weather shielding of these areas is important. Where penetrations in the siding exist, they should be adequately sealed to retain heat and prevent water penetration.
- **Intentional holes or pass throughs (such as those for opacity meters, thermocouples, sampling ports, or rapper penetrations) -** Make sure that seals are in good condition and there is no corrosion of the surrounding area.
- **Areas of heavy material buildup -** Material should be removed and inspection made of the areas beneath the built up area for corrosion. Fly ash buildup provides a medium for moisture collection and a place for corrosion to develop.

Widespread corrosion of the inlet and outlet transitions may be indicative of a poor insulation layer and may be the result of acid or moisture condensation from low temperature operations. This is likely to be more prevalent at the outlet where temperatures tend to be lower.

4.5.6.2 Corrective Measures/Upgrades

Any structural damage, holes, tears, or cracks in the inlet and outlet transitions need to be repaired and sources of in-leakage and out-leakage need to be eliminated. Any missing, deformed, detached, or badly eroded gas-distribution media needs to be repaired or replaced. Heavy corrosion of the casing steel may warrant ultrasonic testing to determine the thickness of the remaining steel as a means of predicting future repair or replacement requirements. This can often require scaffolding and the removal of insulation to investigate.

If a dirty inspection reveals a need to improve gas distribution, this may need to be done if there are compliance issues. If patterns are well defined, corrections can sometimes be made on the basis of field observation and trial and error. In other cases, measurement and modeling may be warranted. It is impossible to cover the multitude of scenarios that one might encounter in the field, and it is beyond the scope of a maintenance guide to discuss the design criteria of ductwork and transitions. A list of typical problems that occur in the inlet and outlet, and some solutions follow:

- **Heavy material buildup at the bottom of perforated gas distribution plates -** A common problem when the perforated plate extends to the floor and inhibits dust from flowing into the inlet field hopper. It is not uncommon to see units where the bottom of the plate has been cut off to prevent buildup; however, this creates a high velocity zone that may further lead to hopper sweepage. A better solution is the installation of a *snow fence*. A snow fence can be installed at the bottom of the distribution plate(s) to create slotted openings that are spaced to maintain the same open area of the plate itself. That allows dust movement without changing the velocity profile across the distribution plate.

Key Technical Point

It is not uncommon to see units where the bottom of the plate has been cut off to prevent buildup, however; this creates a high velocity zone that may further lead to hopper sweepage. A better solution is the installation of a *snow fence*.

- **No diffuser or perforated plate at the outlet -** Many ESPs do not have any kind of diffuser or perforated plate in the outlet transition. If gas distribution problems exist, installation of a plate at the outlet is a means of correcting the problem.
- **Flat spots or ledges -** Some ESP inlet and outlet transition designs have flat spots or ledges that promote excessive buildup. A sloped false floor can sometimes be installed to prevent buildup and promote material removal. In other cases, installation of a dropout hopper may be warranted.
- **Erosion resistance -** Ceramic tile can be applied to some surfaces to provide erosion resistance. If structural members in the gas stream are eroding because they present too great a surface exposure to abrasive particulate (such as round pipe, turning vane stiffeners), angle can be welded to the surface, oriented teepee-like to help deflect the material and present a reduced surface area.
- **Corrosion resistance -** Corrosion may be the result of a poor, missing, or inadequate insulation barrier. Missing insulation should be replaced and inadequate insulation enhanced. Removable insulated covers for access doors/covers will help to preserve the door area, which is a natural heat sink. This is preferable to an insulation pan or layer on the inside surface of the door.

Covering expansion joints with weather shielding will help protect them from exposure. In some instances, where operating temperatures are below 400 to 500°F (204 to 260°C) it may be advisable to insulate the expansion joint to retain heat and prevent dew point corrosion of the flanges and surrounding steel. If this is done, it must not interfere with expansion of the joint. An overlapping lagging/siding arrangement can avoid this.

All penetrations of the insulation siding, such as for casing attachments, need to be sealed as well as possible to retain heat and prevent water penetration.

Related Topics:

- Gas-distribution media
- ESP casing

4.5.7 Gas Distribution Media/Anti-Sneak Baffles

Gas-distribution media such as turning vanes, diffusers/perforated plates, and baffles are used to maintain and improve gas flow distribution, and along with anti-sneak baffles, keep gas flow within the treatment zone of the precipitator. Proper gas distribution and avoidance of gas bypass of the ESP treatment zone are critical to optimum ESP performance. Poor gas distribution can lead to zones of high velocity that can cause material reentrainment and/or allow gas to pass through the ESP virtually untreated. It can also cause erosion of internal components and lead to material accumulations that may further distort flow and elevate opacity.

Gas-distribution media is generally found in the ductwork and inlet and outlet transitions (nozzles/plenums) of the precipitator. The media are custom designed and configured through model studies, however the design effectiveness of the media to provide the desired gas distribution should be evaluated in the field following a period of normal operation. There have been many instances where implementation of the model has not had the desired results. There are many varieties of gas-distribution media. Their use and placement vary by system configuration, and device designs may vary by manufacturer. Examples of several types of gas distribution media are shown Figure 4-90. Louver-type dampers may be used to achieve gas flow proportioning in multiple chamber ESPs.

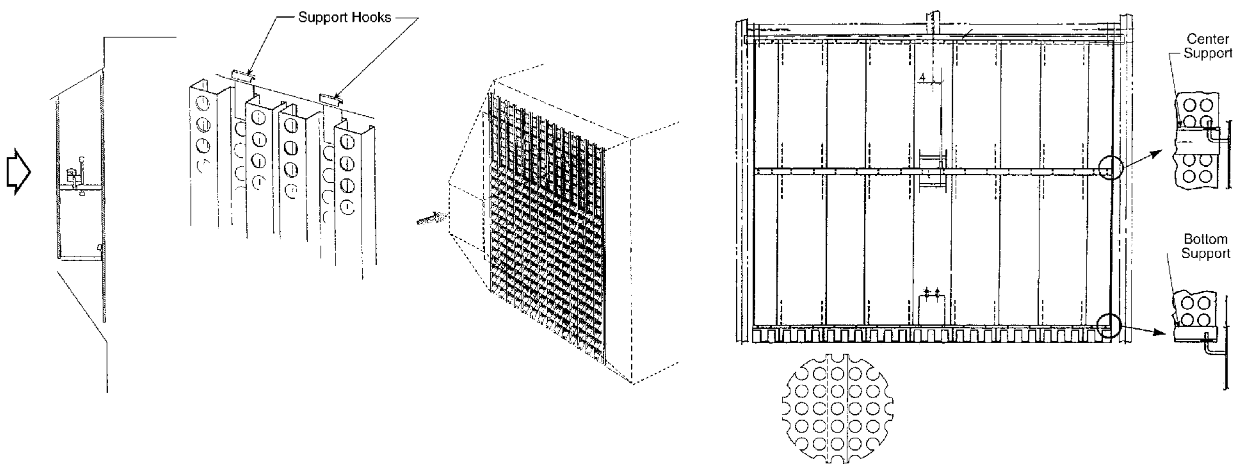


Figure 4-90
Gas-Distribution Media at the ESP Inlet

Anti-sneak baffles are used within the precipitator to prevent flue gases from bypassing the treatment zone. Vertical baffles are typically used along the casing walls at the leading and/or trailing edge of the fields to prevent gas flow in the dead space between the casing or chamber wall and the adjacent collecting plate. Baffles are also used between fields at the top and bottom to prevent gas passage above and below the treatment zone. These are typically formed by structural members or extensions to them, such as the upper girders and the lower girders that form the hopper wall. These baffles need to extend up and down far enough into the gas stream that gas flow is maintained within the active treatment zone. This is sometimes overlooked, particularly in a conversion from a weighted wire to rigid electrode design, and can lead to opacity problems. This is particularly important at the bottom where gas sneak-by can also cause hopper sweepage and material reentrainment (see Section 4.5.5 - Walkways and Internal Access). Baffles are often used in the hoppers themselves to help further prevent this.

Inspection should verify that gas distribution media and baffles are intact, and they should be checked for dust buildups, pluggage, corrosion, erosion, or structural damage. During a dirty inspection buildup patterns, or the lack thereof, can provide clues to evaluate gas distribution. Areas of high gas flow are indicated by the absence of ash buildup and possible scouring of the steel. Ash buildup may be excessive in areas of low gas flow. In many cases where problems are indicated, these visual patterns show the direction of gas flow and corrective modifications can be made, such as the addition of turning vanes, to correct flow or reduce buildups on the basis of these observations. Actual measurements and modeling are sometimes necessary to identify a quantitative pattern to help implement solutions to poor gas distribution.

Large accumulations of material on or between gas-distribution media should be removed during maintenance outages and efforts made to determine the cause. Frequent operation at low gas velocities will cause dust to settle and accumulate. The deposit may not be swept away at higher velocities and may result in an increasing depth of deposit with time of operation. If the deposit covers a significant portion of the gas-distribution baffles, misdistribution of flue gas in the ESP will follow. Further, reentrainment of the fly ash may overload the precipitator, reducing collection efficiency. False floors in the nozzle areas, dropout hoppers in the inlet nozzles or ductwork, the addition of snow fence rakes at the bottom of the perforated plates, or some other redesign may be required.

Pluggage or blockage of gas-distribution media may be caused by poor gas distribution, or acid or moisture condensation as a result of process upsets (for example, tube leaks or over-conditioning), low temperature operation (low load), air in-leakage, or a poor insulation layer. Plugging of the gas distribution devices can also occur without condensation if the dry fly ash is unusually adherent. These conditions can further distort gas flow distribution and/or accelerate corrosion. It is important that distribution plates be as clean as possible. Perforated plates and other diffuser media that are rapped may not be being rapped effectively

Erosion on the other hand is the result of an abrasive particulate and/or high velocity conditions. Structural damage and deformation is usually the result of a high temperature excursion, over-rapping, or inadequate provisions for thermal growth. Any missing, deformed, detached, or badly eroded gas-distribution media needs to be repaired or replaced.

Related Topics:

- Inlet and outlet nozzles – plenums
- Dirty inspection

4.6 Safety System

4.6.1 Key Interlock System and Ground Straps

A sequenced key-interlock system or locking procedure should be employed to assure that the ESP has been deenergized before any personnel can enter the ESP or gain access to the HV distribution system. The key-interlock system involves a sequential transfer of keys to electrically and/or mechanically lock out HV equipment in order to free the captured keys necessary to gain access to areas where high voltage is present during normal operation. The keys used to lock out the high voltage become captured until access keys are returned to position and the sequence is reversed to close the ESP for safe reenergizing. Where nuclear level detectors are used on the hoppers, they are usually incorporated into the key-interlock sequence also. The primary purpose of the key-interlock system is for safety of personnel, but it also helps to prevent damage to equipment. For instance, the locking sequence usually prevents on-line switching of the TRs.

Key Human Performance Point

A sequenced key-interlock system or locking procedure should be employed to assure that the ESP has been deenergized before any personnel can enter the ESP or gain access to the HV distribution system.

The key-interlock system is custom designed for each precipitator installation and the complexity will be influenced by factors such as the number of chambers, the number of TRs, and the number of access doors. The sequential transfer of keys for a sample key-interlock system is described and illustrated in Figure 4-91. Maintenance personnel should be familiar with the key-interlock system for their precipitator. The key-interlock system should be maintained and never be bypassed.

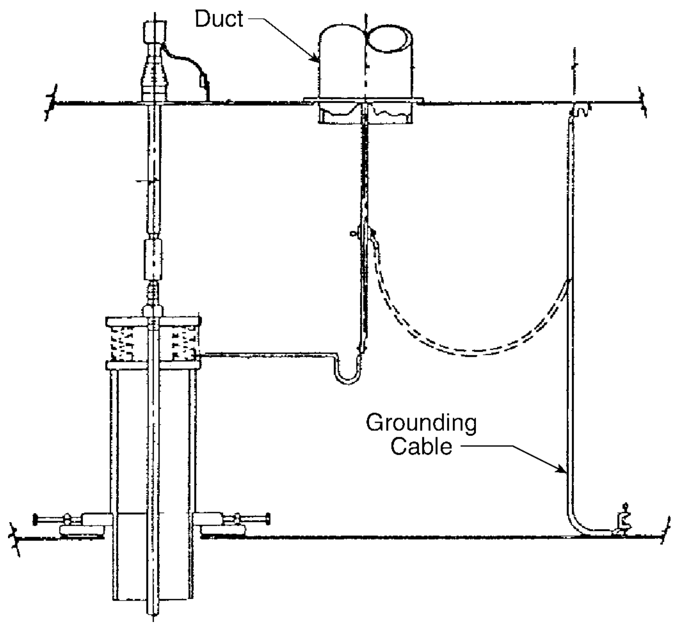


Figure 4-91
Example of HV Bus With Ground Strap Attached to ESP Casing

The key-interlock system is designed to provide positive lock out of the TR main breaker and electrical isolation and grounding of the TRs. Both the switch position and ground contact can be visually verified on TR sets that have air switches with view windows. However, this is not the case with TR sets that utilize internally immersed switches. Because the switch is not visible, its position cannot be visually verified. In all cases, physical grounds should be used for entry to the precipitator and HV distribution system.

In addition to the more obvious hazards associated with the live HV equipment, maintenance personnel should be aware of the hazards posed by the fact that the precipitator acts like a large capacitor that discharges slowly. Ground straps with one end attached to the grounded ESP casing should be available for use at all points of access to prevent potential electrical shock (live or static). The other end of the strap should be attached to the HV distribution system nearest the point of entry and clamped or hooked in place.

Key Human Performance Point

In addition to the more obvious hazards associated with the live HV equipment, maintenance personnel should be aware of the hazards posed by the fact that the precipitator acts like a large capacitor that discharges slowly. Ground straps with one end attached to the grounded ESP casing should be available for use at all points of access to prevent potential electrical shock (live or static). The other end of the strap should be attached to the HV distribution system nearest the point of entry and clamped or hooked in place.

4.6.1.1 Maintenance

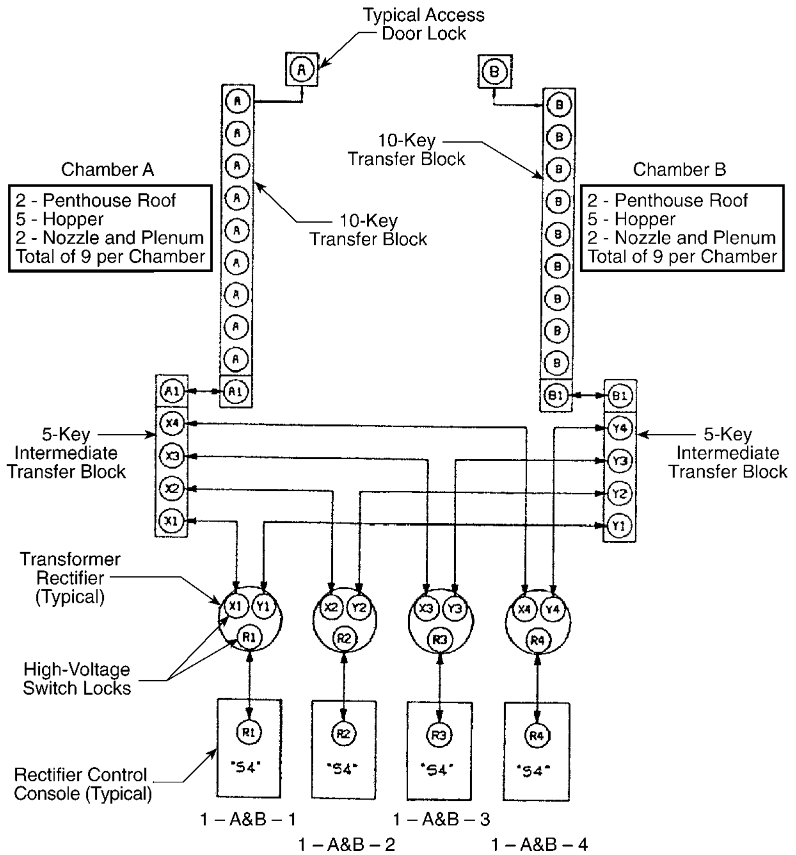
The key-interlock system should be inspected and lubricated on a monthly or quarterly basis. Insert flaked or liquid-suspended graphite solution into each lock cylinder and work it into the slot with the key. During a maintenance outage, the locks should be purged by injecting light mineral spirits and compressed air to clean out the lock interior. The locks should then be re-lubricated with graphite.

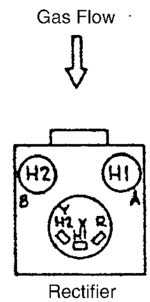
Never lubricate a lock cylinder with oil or grease. Oil acts as a sticky base that allows particulate matter to build up in the lock. When oil is left for long periods of time, a film sets up on the lock component and introduces a frictional load that makes the lock mechanism difficult to actuate.

If the surrounding environment is corrosive, the bronze exteriors of the locks should be maintained with a protective paint. Always keep lock caps in place so that dust or other contaminants will not foul lock mechanisms.

Whenever a lock mechanism or key must be replaced, it should be obtained directly from the precipitator manufacturer to avoid duplicate locks and keys.

The condition of ground straps should be routinely checked to verify continuity and that the insulated component of the ground strap (for example, fiberglass or wooden handles) is not damaged.





Switch Orientation

Bushing Number	Switch Positions				
	I	II	III	IV	V
H1	GRD	FW	FW	HW	GRD
H2	GRD	GRD	FW	HW	FW

Figure 4-92
Typical Key Interlock System

To gain access to chamber A (or chamber B):

1. De-energize the TR for chamber A (or chamber B) at their respective rectifier control console. Remove the R keys from the S4 switch lock.

2. Use the R keys in the respective TR HV switch lock and turn the switch to position No. 5 to obtain the X keys (or position No. 2 to obtain the Y keys). Return the R keys to the S4 switch lock on the rectifier control consoles to re-energize the opposite chamber.

3. Use the X (or Y) keys in the respective five-key intermediate transfer block to release the A1 (or B1) key.

4. Use the A1 (or B1) key in the respective 10-key transfer block to obtain the A (or B) keys.

5. Use the A (or B) keys in the various access door locks to gain access to the grounded chamber.

6. To re-energize the grounded chamber, follow the reverse procedure of steps 1 through 5.

To Gain Access to Complete Precipitator

1. De-energize the TRs at their respective rectifier control console. Remove the R keys from S4 switch lock.

2. Use the R keys in the respective TR HV switch locks and turn the switches to position No. 1 to obtain the X and Y keys. This will hold the R keys captive.

3. Use the X and Y keys in their respective five-key intermediate transfer blocks to release the A1 and B1 keys.

4. Use the A1 and B1 keys in their respective 10-key transfer blocks to obtain the A and B keys.

5. Use the A and B keys in the various access door locks to gain access to the grounded precipitator.

6. To re-energize the grounded precipitator, follow the reverse procedure of steps 1 through 5.

Note 1: The double half-wave TR HV switch has five positions as shown. The B key cannot be removed from the TR HV switch in position No. 2 (or position No. 5) or between positions. The rectifier control console switch lock S4 locks out the primary power when the R key is removed for use on the TR high-voltage switch.

Note 2: Do not rely entirely on the key interlock for complete protection from high voltage: Use a portable grounding cable.

Note 3: It is essential to follow the key sequence. Short cuts or bypassing a necessary step may endanger the operator's life or damage expensive equipment.

Key Human Performance Point

Note 2: Do not rely entirely on the key interlock for complete protection from high voltage: Use a portable grounding cable.

Note 3: It is essential to follow the key sequence. Short cuts or bypassing a necessary step may endanger the operator's life or damage expensive equipment.

Target:

Fossil Maintenance Applications Center (FMAC)

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