REPORT SUMMARY

Electric Motor Predictive and Preventive Maintenance Guide

Electric motor failure could result in lost capacity as well as excessive repair and maintenance costs. This guide provides information on establishing an effective maintenance program to help prevent unexpected motor failures, costly downtime, and unnecessary maintenance costs. Specifically, the guide summarizes technical data relative to four basic power plant motor types and associated components.

INTEREST CATEGORIES

Nuclear plant operations and maintenance
Plant electrical systems and equipment
Engineering and technical support
Industrial

KEYWORDS

Electric motors
Induction motors
Electrical equipment
Electrical testing
Maintenance
Bearings

BACKGROUND Maintenance recommendations proposed by electric motor vendors have sometimes encouraged many overly conservative maintenance practices. These practices have led to excessive maintenance activities and costs that have not provided an extra margin of operability. Current work was prompted by a need to determine appropriate maintenance techniques and tasks for specific applications based on the type and size of electric motors and components.

OBJECTIVE To provide utilities with guidance for establishing an effective motor maintenance program, which should prevent unexpected failures through planned motor maintenance efforts.

APPROACH EPRI relied on supply and repair facility personnel as well as the Nuclear Plant Reliability Data System to evaluate the operational history and failure modes of various motor types and sizes. They reviewed numerous electrical test and inspection methods, determining how effectively each method revealed the operating condition of electric motors. Then they compiled these methods and matched them with appropriate motor types based on their use in performing motor evaluations. The analysis evaluated motor components as well as the entire motor unit to detect signals that could provide trending information.

RESULTS This guide summarizes technical data on the four basic types of power plant motors and their components; it correlates failure causes, symptoms, and modes. The guide further addresses the significant causes of motor failures and outlines methods to optimize service life and minimize maintenance costs through appropriate preventive maintenance programs. Test and maintenance recommendations for different motor sizes and types are arranged to allow clear comparison of motor reliability with function and cost effectiveness. Throughout the guide, easy-to-read charts and tables chronicle the data.

On the basis of information provided in this guide, maintenance personnel in nuclear and fossil plants can customize their programs for specific motors according to service applications and operating conditions. To assist in this effort, the guide includes a glossary of terms, regreasing guidelines for motors with antifriction bearings, and oil-monitoring guidelines for electric motors with oil bath bearings.

EPRI PERSPECTIVE This guide provides a foundation for an effective electric motor maintenance program with simple, but viable, testing routines that increase assurance of efficient motor operation. In all, the guide simplifies selection of predictive and preventive maintenance tasks to help maintenance personnel plan motor repairs during scheduled outages and avoid costly unexpected failures. Related EPRI reports include GS-7352, *Manual of Bearing Failure and Repair;* NP-3357, *Condition Monitoring of* Nuclear *Plant Electrical Equipment;* and CS-5328, *Signature Analysis, Rotating Equipment Monitoring.*

PROJECT
RP2814-35

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Electric Motor Predictive and Preventive Maintenance Guide

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ABSTRACT

Electric motor performance is vital to the reliable and efficient operation of power plants. The failure of one or more critical motors could cause lost capacity and excessive repair and maintenance cost. However, existing maintenance recommendations proposed by vendors for electric motors have sometimes encouraged many overly conservative maintenance practices. These practices have lead to excessive maintenance activities and costs which have provided no extra margin of operability.

EPRI has sponsored RP2814-35 to develop a guide which provides power plants with information and guidance for establishing an effective maintenance program which will aid in preventing unexpected motor failures and assist in planning motor maintenance efforts. The guide includes a technical description which summarizes technical data relative to the four basic types of motors and their components in general use in power plants. The significant causes of motor failures are investigated and described in detail and methods to optimize service life and minimize maintenance cost through appropriate preventive maintenance and conditioning program are presented.

This guide provides a foundation for an effective electric motor maintenance program and simplifies the selection of predictive and preventive maintenance tasks. Its use will enable maintenance personnel in nuclear and fossil plants to plan motor repairs during scheduled outages and avoid costly unexpected failures.

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Section 1.0

Introduction

1.0 Introduction

1.1 Scope and Purpose of Guide

A nuclear power plant utilizes large numbers of electric motors ranging in size from fractional horsepower to many thousands of horsepower. Unanticipated failure of motors in critical service may result in equipment damage and affect plant availability. Motor failures can be substantially reduced by applying proper predictive and preventive maintenance techniques.

The purpose of the guide is to provide nuclear power plant licensees with information and guidance for establishing an effective maintenance program for primary system and balance of plant electric motors.

The guide outlines the most probable failure modes and provides information on the available methods to optimize service life and minimize maintenance cost through effective preventive maintenance and condition monitoring. The guide concentrates on establishing the maintenance program. It briefly describes effective tests and identifies the effectiveness of each test. Trending of tests is discussed. References are provided for further detailed technical information on tests and test procedures. Test and maintenance recommendations for different types and sizes of motors have been designed to ensure motor reliability commensurate with functions and cost effectiveness.

Data is laid out in easy to read tables and charts. Based on the information available in this guide, personnel responsible for maintenance can customize their maintenance program for specific motors according to service application and operating conditions.

While the recommendations in this guide are applicable to all motors in general, 10 CFR 50.49 (Reference 6.20) motors in a nuclear power plant may have additional maintenance and testing requirements. These plant-specific requirements are not covered in this guide. In addition, electric motors for motor-operated valves are not included due to the limited amount of maintenance performed on these types of motors.

Recommendations in this guide have been developed using Reliability Centered Maintenance (RCM) techniques. Data sources included:

- Discussions with power plant maintenance personnel
- Discussions with motor repair shop personnel
- Motor manufacturers' experience
- Discussions with diagnostic test equipment manufacturers
- IEEE, NUREG, and other technical publications
- Nuclear Plant Reliability Data System and other industry databases

A complete listing of reference source material is provided in Section 6.

1.2 Organization of Guide

This guide is organized in six sections and three appendices as follows:

- Section 1, Introduces and summarizes the scope and purpose of the guide and describes its organization.
- Section 2, Technical Description, summarizes technical data relative to the four basic types of motors and their components in general use in power plants.
- Section 3, Component Failure Analysis, covers the significant causes of motor failures and the observable conditions associated with these failures.
- Section 4, Preventive/Predictive Techniques, details technical factors to be considered when preparing a preventive maintenance plan and maintenance trends to be used to establish predictive maintenance.
- Section 5, Recommendations, describes the recommended predictive tests and preventive maintenance tasks for power plant motors and discusses how to apply these various techniques.
- Section 6, References, presents a list of related materials used either in the development of this guide or referenced for further detailed information.
- Appendix A is a glossary of terms used in this guide.
- Appendix B presents regreasing guidelines for motors with antifriction bearings.
- Appendix C presents oil monitoring guidelines for electric motors with oil bath bearings.

Section 2.0

Technical Description

2.0 Technical Description

This section includes technical descriptions of the types of motors used in power plants and the components important for consideration in maintenance programs.

- Section 2.1, Motors
- Section 2.2, Motor Components

The purpose of these sections is to give an overview of the different types of motors generally used in nuclear power plants. For detailed description, refer to EPRI Publication EL-5036, Volume 6: Motors (Reference 6.1)1. Appendix A, Glossary of Terms, provides additional definitions of motor types and related components.

2.1 Electric Motors

The principle function of an electric motor is to convert electric energy into mechanical energy. The conversion is accomplished by two main component- the stator and rotor. Regardless of the type and application of an electric motor, all motors will be made up of these two main components. The stator is the stationary component and the rotor is the rotating component. These components are separated by a small air-gap clearance to avoid mechanical rubbing.

The stator is generally made up of a winding, the frame, and the laminated steel punchings (core iron). The stator coils can be random wound (loops of wire) or form wound (pre-formed diamond shape) coils of magnet wire.

The rotor is usually made up of laminated steel punchings (core iron), coils or rotor bars, shorting rings and a shaft.

Electric motors can be broken into three main categories: induction, synchronous, and DC. Each of these categories can be further sub-divided as follows:

Induction Motors: Squirrel-cage, Wound rotor

Synchronous Motors: Cylindrical rotor or Salient pole

DC Motors: Shunt wound, Series wound, or Compound wound

The following descriptions do not list all the available combinations of motor types but highlight only major types used in the power industry. Most of the motors used in power plants are of the squirrel cage induction type. Squirrel cage induction motors employ the simplest and most rugged construction. They are generally the most economical

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[1] Much of the book covers induction motors. Section 6.12, page 6-158 relates to synchronous motors and Section 6.13, page 6-160 discusses DC motors.

in terms of initial and maintenance costs. They also have a proven record for long term reliability. Of the many types of motors used in power plants, this section describes various applications, classifications, and construction features of four basic types of motors in general use.

2.1 .1 AC Squirrel Cage Induction Motors

The rotor winding of a squirrel-cage motor is usually embedded in slots near the outer surface of the rotor. For larger motors, the winding is made up of uninsulated copper, copper alloy, or other suitable bar or rod material embedded in the slots of the rotor punchings. The rotor bars or rods extend beyond the ends of the rotor punchings and are connected together by shorting rings to provide closed-loop current paths. (See Figure 2-1).

Die cast aluminum rotors perform similar to copper bar rotors and are used because of their economic advantage in fabrication cost. In either design, it is the rotor bar conductivity and shape, coupled with the stator winding design, that determines the motor starting and running characteristics.

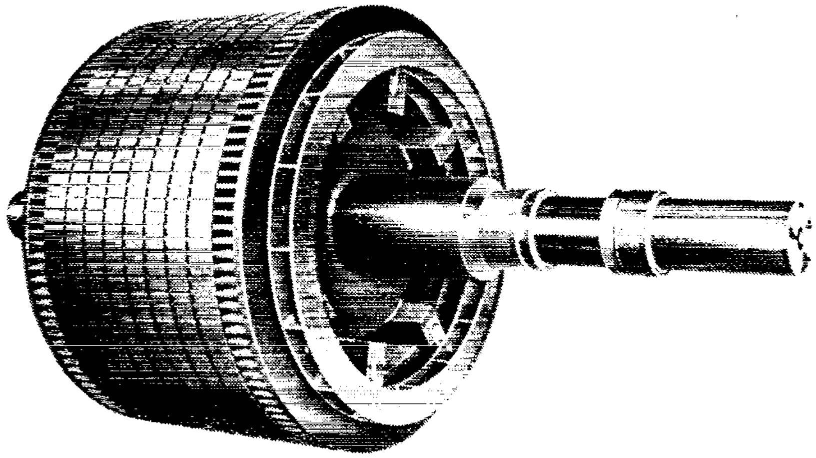

FIGURE 2-1
DETAIL OF ROTOR FOR SQUIRREL CAGE MOTOR

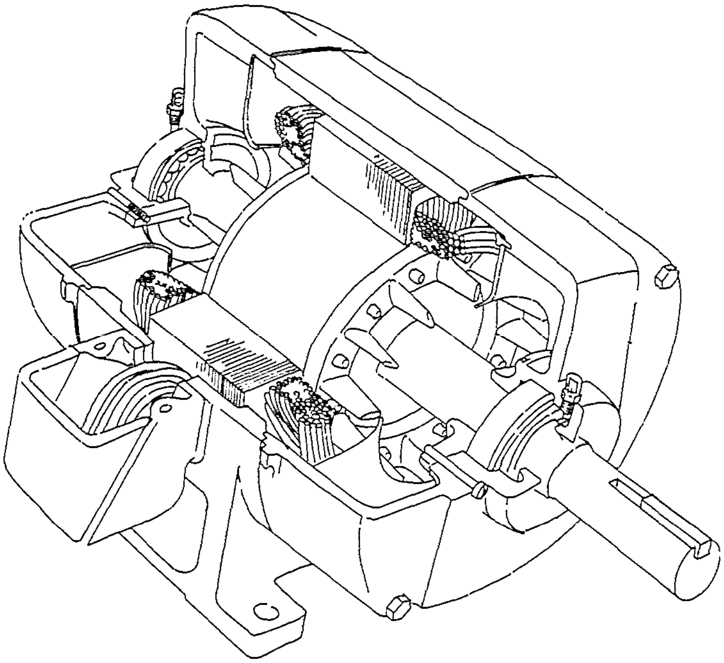

FIGURE 2-2
CUTAWAY DRAWING OF OPEN, DRIP-PROOF
SQUIRREL CAGE INDUCTION MOTOR

Technical descriptions of squirrel cage induction motors for various horsepower ratings are given below:

Horsepower ratings 200 hp and below. These motors normally covered by NEMA Standard MG-1, typically have voltage ratings below 600 volts. They generally have die-cast type rotors and random-wound stators. Enclosures for these motors are:

- Open, drip-proof
- Totally enclosed, fan-cooled
- Totally enclosed, air-over

NOTE: Some vendors offer TEFC motors rated above 200 HP.

A cutaway drawing of squirrel cage induction motor with a cast iron, open drip-proof enclosure is shown in Figure 2-2. The motor has antifriction bearings and a die cast aluminum rotor with integrally cast fan blades.

Horsepower ratings above 200 hp. These motors, typically categorized 4,000 volts and above, have form-wound stator coils and fabricated copper or alloy bar rotors. The enclosures for these motors are:

- Open, drip-proof
- Weather protected I
- Weather protected II
- Totally enclosed, water-cooled
- Totally enclosed, pipe ventilated

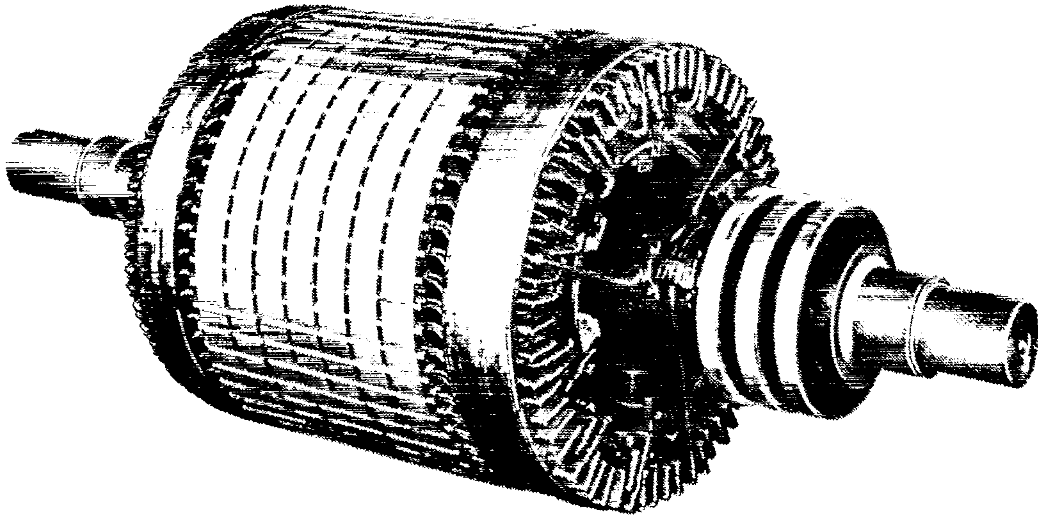

FIGURE 2-3
ROTOR FOR WOUND-ROTOR INDUCTION MOTOR

2.1.2 AC Wound-Rotor Induction Motors

The rotor winding of a wound-rotor motor consists of coils of insulated magnet wire placed in the slots of the rotor (see Figure 2-3). The coils are connected in a three phase arrangement. The lead ends of the winding are connected to insulated, rotor-mounted collector rings. A rotor-current path to an external rotor circuit is completed through carbon brushes. The external circuit usually contains resistance. By adjusting the value of the external resistance, certain operational characteristics of the motor can be controlled (i.e. torque, current, and speed) within limits.

Wound-rotor induction motors used in power plants are generally less than 200 horsepower and 600 volts. These motors are used in a few applications that require speed control or special torque considerations. The stator of a wound-rotor induction motor is the same as the stator of a squirrel cage induction or synchronous motor.

2.1.3 AC Synchronous Type Motors

The stator of a synchronous motor is the same as that of an induction motor. The rotor of a synchronous motor differs in that it has two windings. One winding, called a damper winding, is similar in construction to a squirrel-caged motor. It is utilized during starting to create asynchronous torque. It is also used to damp out oscillations resulting from load fluctuations during normal operations. The second winding, called a field winding, provides excitation, using an external DC source. It produces a magnetic field on the rotor to facilitate synchronous operation. The field winding is usually formed of magnet wire shaped to fit around salient-poles (see Figure 2-4). The synchronous motor with brushless excitation system (see Figures 2-4) has an exciter mounted on the shaft. The design of the rotor is such that alternate north and south poles complete the magnetic circuits of the motor. The rotor has the same number of poles as the stator. The magnetic field of the rotor locks in step with opposite-polarity of the rotating magnetic field of the stator and thus, the rotor revolves at the same (synchronous) speed determined by the number of poles in the stator and rotor. Synchronous motors are often used for large, low speed circulating water pumps and aid in auxiliary system power factor correction. These motors are often vertically mounted and have voltage ratings above 4,000 volts.

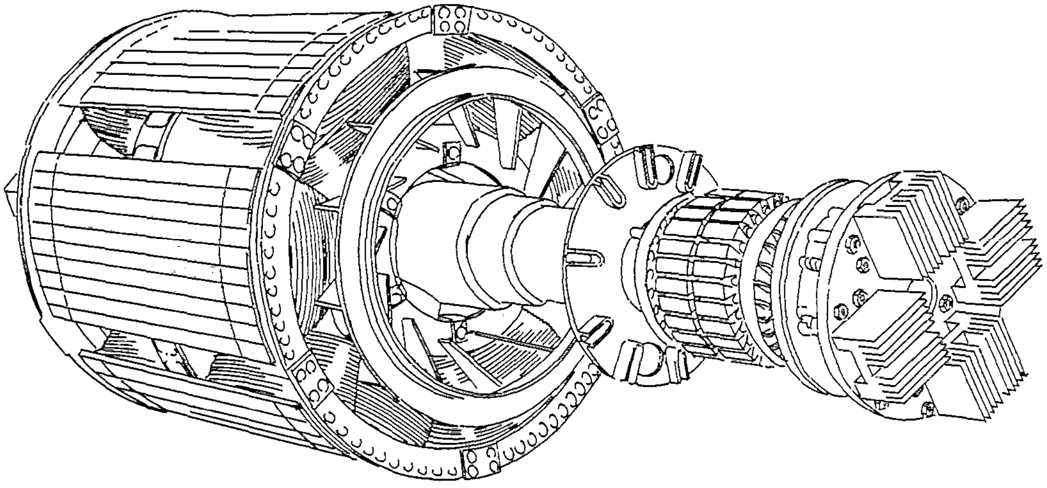

FIGURE 2-4
ROTOR FOR SYNCHRONOUS MOTOR

2.1.4 DC Motors

DC motors are energy conversion devices which convert direct current energy into mechanical energy. These motors are used as constant-speed or adjustable-speed motors. The special speed-torque characteristics of these motors are suited for applications which require acceleration and deceleration rates; controlled speed changes over varying speed ranges; speed matching, and controlled torque and tension limits.

DC motors have a rotating and a stationary element just as other electric motors. The stator of the DC motor is called the field frame or yoke. The stator is constructed of salient field poles bolted to the inside of the field frame. The rotor or armature is the rotating element of the DC motor and is constructed of windings in a laminated steel core mounted on the shaft. Each coil of the winding is connected to an insulated copper bar in the commutator that is mounted on the rotor shaft. Another essential component of the DC motor is the carbon brushes. The function of carbon brushes and commutator arrangement is to produce a constantly changing magnetic field polarity in the armature with respect to the polarity of the stator field that results in motor torque. DC motors are primarily used as drives for emergency or standby service that require battery backup power for high reliability. While this service is essential, under normal operating conditions these motors are seldom run, except for routine testing Another application of DC motors is emergency motor operated valves, not covered by this guide.

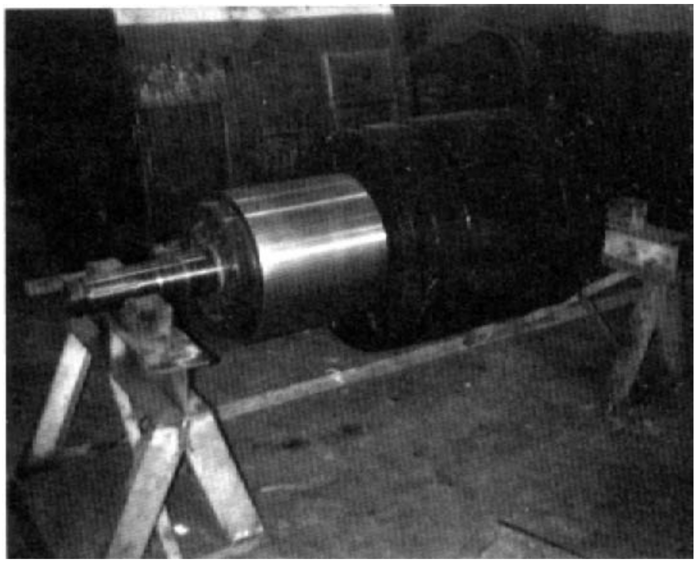

FIGURE 2-5
ROTOR FOR DC MOTOR

2.1.5 Construction Features and Application

Tables 2-1 and 2-2 identify the construction features of the different types of motors and their usual application in a power plant.

TABLE 2-1
CONSTRUCTION FEATURES

Features	Squirrel Cage	Synchronous	Wound Rotor	DC Motors
Slip Rings		X	X	
3-Phase Stator	X	X	X	
Salient Pole Stator				X
Die-Cast Rotor	X			
Fabricated Rotor Bars	X		X	
Salient Pole Rotor		X		
3-Phase Rotor			X	
Commutator				X
Excitation System		X	X	

TABLE 2-2
COMMON APPLICATION CHART

Application	Motor Types			
	Squirrel Cage	Synchronous	Wound Rotor	DC Motors
Most Pumps and Fans	X			
Circulating Water Pumps	X	X		
Cranes and Hoists			X	X
Emergency DC Service				X
Compressors	X	X		X

2.2 Motor Components

There are three essential components that make the operation of the electric motor possible. The windings, which receive current from an electrical supply system, the active iron (stator and rotor cores) which provides a path for magnetic flux, and the stator housing with structural support elements, make up the electric motor.

The motor components of concern for motor maintenance programs are discussed in this section:

- Section 2.2.1 summarizes the features of the motor components by motor type.
- Section 2.2.2 discusses bearing systems and applications.
- Section 2.2.3 summarizes lubricants and lubrication systems.

2.2.1 Motor Components Overview

The stator housing protects and supports the stator core and windings. The support structure for most electric motors consists of two endbells (bearing housings), and a stator frame. The stator frame and endbells are often made of cast iron, fabricated steel or in some instances cast aluminum. With horizontal motors, the stator housing with mounting feet usually doubles as the mounting system for the motor. Vertical motors are usually anchored or supported by a lower mounting flange on the bottom endbell. Rotor shafts are usually carbon or special steel alloy.

The stator frame houses the stator core which is made of stacked insulated laminated punchings, with slots which allow for winding placement. The stator frame also provides support for brackets and rings for the endturns of the windings. The endbells contain the bearings which allow for correct positioning of the rotor with the respect to the stator. Correct positioning of the rotor will maintain a sufficient and uniform air gap between stator and rotor. Often enclosures of large motors contain air baffles which aid in the ventilation of the core, windings and bearings.

The stator windings receive the applied voltage and are so arranged to produce a rotating magnetic field within the confines of the stator. These windings are made of magnet wire which is formed to make coils. The magnet wire is coated with an insulating material which provides the turn-to-turn and phase separation. The coils are further insulated by layers of insulating material which provide electrical isolation from the stator core iron. The coil ends are brought out, connected and insulated to form the required series or parallel circuits.

Both stator and rotor cores are made of low loss insulated laminations that are stacked, aligned and clamped. Thin laminations are used to reduce hysteresis and eddy current losses to minimize core heating. When the motor is fully assembled, the rotor core is inside the stator core and the two are separated by an air gap. Magnetic flux passes across the air gap to complete the magnetic circuit. The magnetic flux reacting with the induced current in the rotor conductors produces torque, causing the rotor to rotate.

AC MOTORS - Nema Type, Squirrel Cage Induction Motors, Up To 200 Horsepower, 600 Volts And Lower (References 6.22 and 6.33). Design features include:

- **Stator**
  - Winding: Three-phase winding consisting of various insulating materials. Conductors are made from insulated magnet wire.
  - Core: Stacked laminations, insulated with iron oxide, enamel, aluminum phosphate, or other insulating material.
- **Rotor**
  - Winding: Die-cast or fabricated
  - Shorting Rings: Die-cast or fabricated
  - Core: Similar to stator core material
  - Shaft: Carbon steel or special steel alloy
- **Bearings:** Antifriction (ball or roller) or, occasionally, sleeve bearings.
- **Frame**: Cast iron, die-cast aluminum or sheet steel
- **Fan**: Molded plastic, sheet metal or cast metal alloy

Figure 2-6 shows an exploded view of a NEMA type squirrel cage induction motor with random-wound stator, die cast aluminum rotor and antifriction bearings. This is a totally-enclosed, fan-cooled motor. The external fan and fan cover are shown.

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[2] Pages 2-1, 2-2, and 2-3 show details of small motors.

[3] Pages 2-1 through 4-1 show details of small motors including winding arrangements.

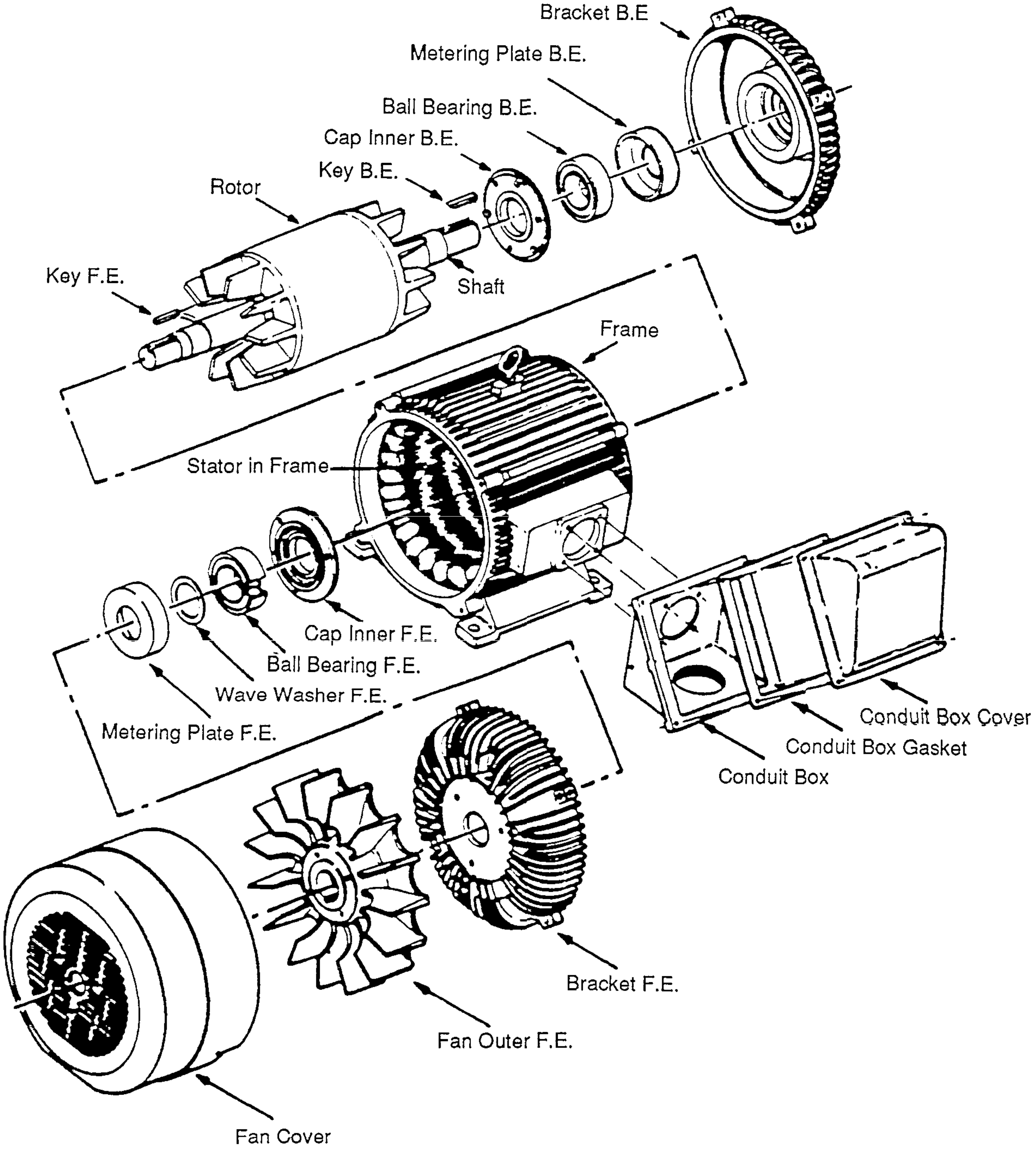

FIGURE 2-6
EXPLODED VIEW OF AC MOTOR

AC MOTORS - Above 200 Horsepower, 4000 Volts And Higher. Design features include:

- **Stator**
  - Winding: Three-phase winding consisting of insulated formed coils. Several resin treatments exist for these systems (vacuum-pressure impregnation, resin-rich, etc.).
  - Core: Laminated electrical grade steel sheets, insulated
- **Rotor**
  - Winding. Rotor bars of fabricated conductors made of copper, alloy, or aluminum
  - Core: Same as stator core.
  - Shaft: Carbon steel or special steel alloy
- **Bearings:** In some cases, antifriction bearings are used in motors up to 2000 hp. Ring lubricated sleeve bearings are used for most horizontal motors. Vertical motors often use plate or pivoting shoe type thrust bearings.

  Oil-lubricated bearings may have cooling coils in the oil reservoir. Water is circulated through cooling coils to reduce oil temperature.
- **Frame**: Usually fabricated from carbon-steel plates or cast iron.

Wound-Rotor Induction Motors. Stator winding, stator core, rotor core, shaft, and bearings are similar to squirrel cage induction motor components. Other design features include:

- **Rotor Winding**: Insulated conductors formed into a 3-phase winding
- **Slip Rings**: Steel, brass or bronze rings connected to a 3-phase winding
- **Carbon Brushes and Brush Rigging:** Carbon brushes fitted with flexible copper wire cables called pigtails are mounted in brush holders with springs and some have tension adjusting devices. Carbon brushes ride on slip ring surfaces to conduct rotor current to the controller.

Figure 2-7 shows a cutaway drawing of a NEMA size wound rotor induction motor. This is an open, drip-proof motor with internal fans, slip rings and antifriction bearings.

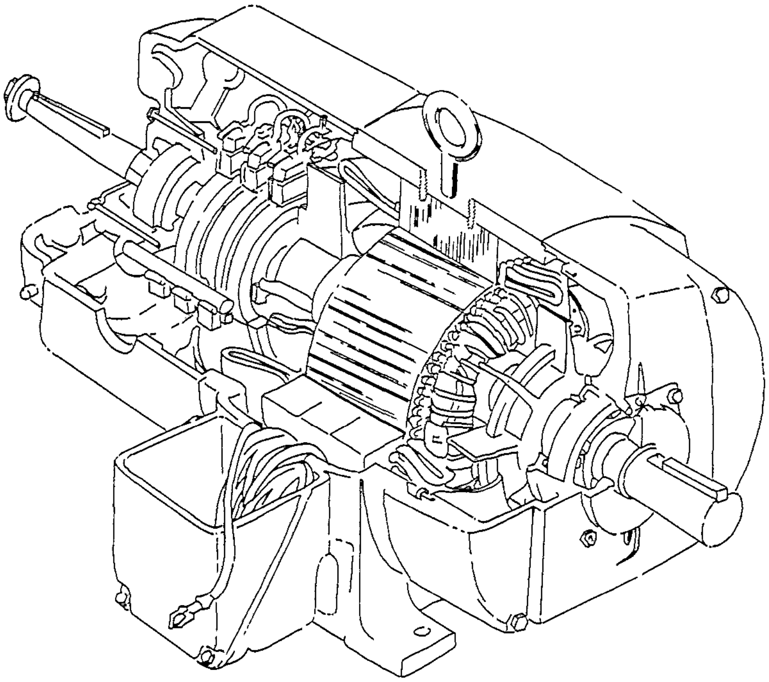

FIGURE 2-7
WOUND-ROTOR INDUCTION MOTOR

AC MOTORS - SYNCHRONOUS TYPE. Stator components are the same as for AC induction motors 1000 hp and above. Other design features include:

- **Rotor**
  - Winding: The synchronous motor has an insulated rotor winding consisting of copper conductors in a concentrated salient pole field coil. It also has a damper winding that is used for starting the motor.
  - Core: The synchronous motor has salient poles that are attached to a central rim by bolts or dovetail connections.
  - Shaft: Carbon steel or special steel alloy
  - Slip Rings: Steel or bronze slip rings are mounted on and insulated from the rotor shaft, with electrical connections to the insulated field windings.
- **Rotating, Brushless Exciter:** Instead of slip rings, the motor may have mounted on its shaft, a rotating alternator with rectifier diodes to supply the insulated field winding with field current.
- **Carbon Brushes:** Where slip rings are furnished, carbon brushes, and brush holders are used to supply the insulated field winding with field current.
- **Bearings:** Bearings for these high horsepower, low rpm, vertical type motors are oil-lubricated, usually of the sleeve type for guide bearings and disc or pad type for thrust bearings.
- **Frame:** Usually fabricated from carbon steel plate.

Figure 2-4 shows a horizontal synchronous motor rotor with laminated rotor pole pieces, damper winding with shorting rings, journals for sleeve bearings and brushless exciter.

Figure 2-8 shows a horizontal synchronous motor with solid steel pole pieces, bolted-on pole caps, ring-lubricated sleeve bearings, brushless exciter and totally-enclosed, water-cooled (TEWC) construction.

DC MOTORS. DC motors in power plants are usually rated below 100 horsepower. Design features include:

- **Stator**
  - Winding Windings on the stationary part of the motor are referred to as field windings. They are made of magnet wire and are insulated from the field poles with insulating material.
  - Core and Poles: Can be either solid steel or laminated steel.

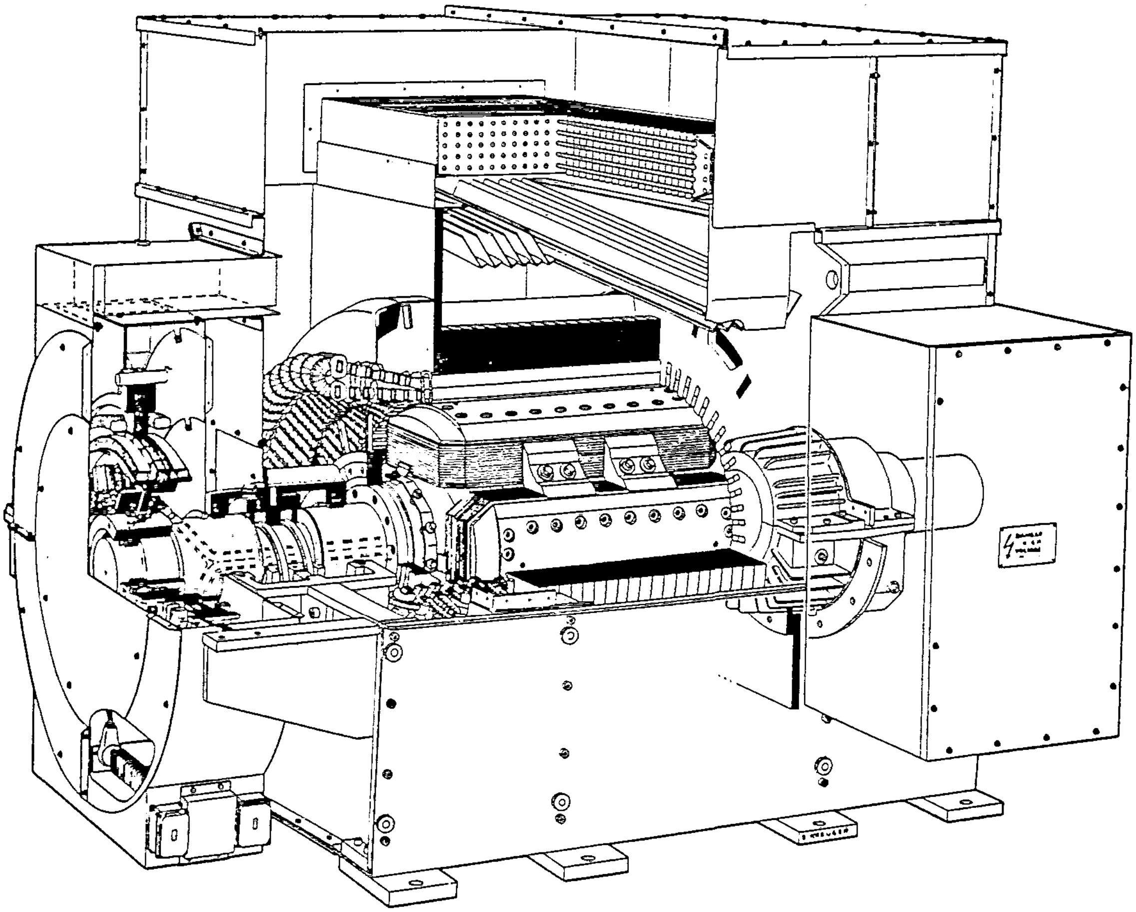

FIGURE 2-8
SYNCHRONOUS MOTOR DETAILS

- **Rotor**
  - <u>Winding</u>: Windings on the rotating portion of the motor are referred to as amature windings. They are made of insulated magnet wire.
  - <u>Core:</u> Stacked laminations, insulated with iron oxide, enamel aluminum phosphate or other insulating material.

    <u>Shaft:</u> Carbon steel or special steel alloy
- **Commutator:** Insulated wedge shaped copper conducting elements formed into a cylinder. Copper segments are insulated from the shaft and from each other, and are connected to armature conductors.
- **Carbon Brushes and Brush Rigging:** Carbon brushes supported by brush rigging transfer current to the rotating commutator
- **Shaft:** Carbon steel or special alloy steel
- **Bearings:** Antifriction bearings

Figure 2-8 shows an exploded view of a DC motor of less than 100 hp rating. This is an open, drip-proof motor with internal cooling fan and antifriction bearings. The rotating armature has a commutator. The field poles are in the stationary stator frame.

2.2.2 Bearing Systems

Bearings are a crucial element in the reliable operation of an electric motor. Bearings fall into three major categories: sleeve (see Figure 2-10), antifriction (see Figure 2-12A-D), and thrust bearings which can be either antifriction bearings or plate type bearings (see Figures 2-12E and 2-13). The type of bearings used in a motor depends on the service requirements of the motor. Small motors typically use antifriction bearings. Large motors often use babbit bearings; however, motors up to 2000 HP have been designed with antifriction bearings. In addition, large vertical motors incorporate a thrust bearing in their design. However there are exceptions to these generalities and it is important for maintenance personnel to recognize bearing types and their orientation (Reference 6.19).

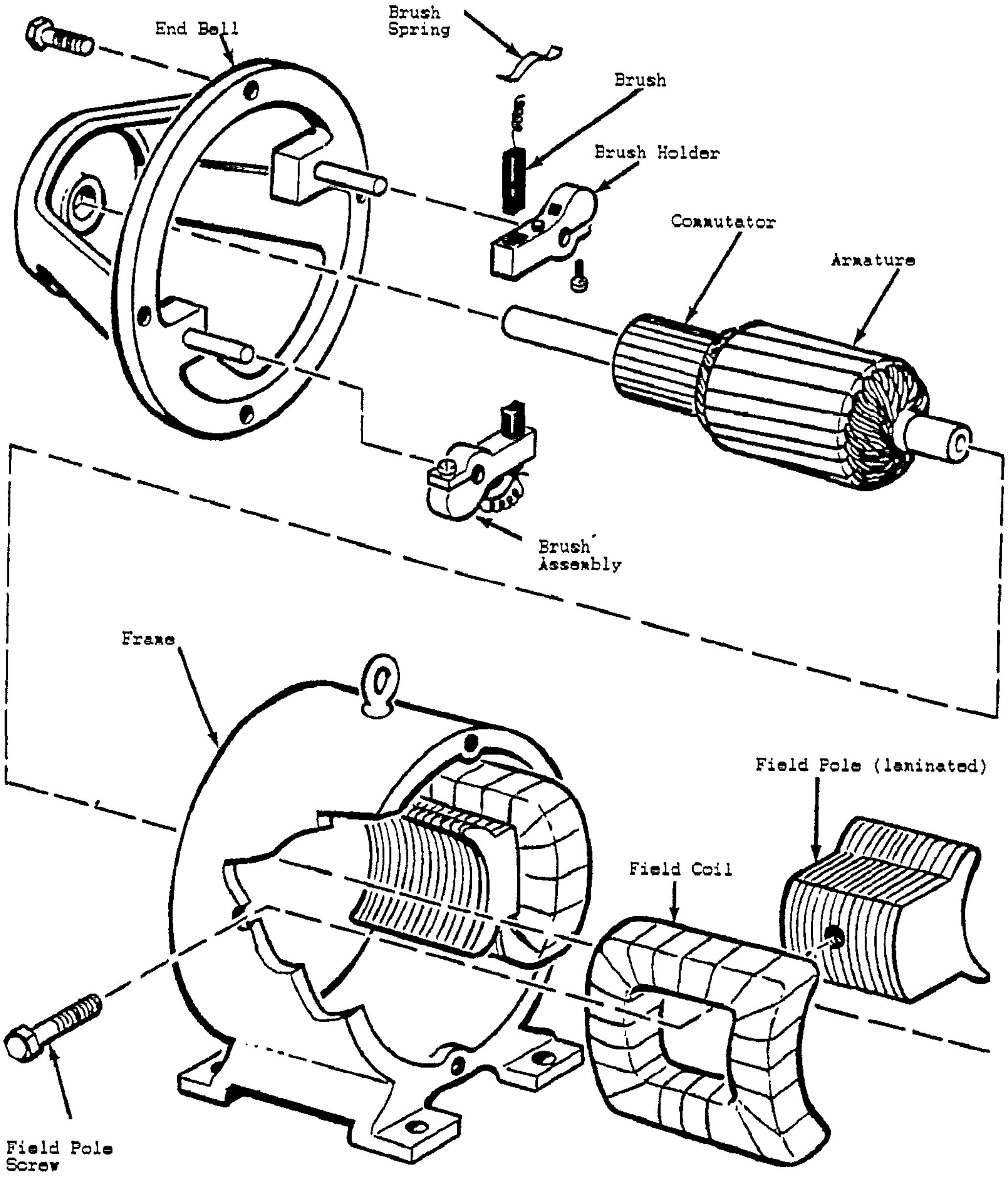

FIGURE 2-9
EXPLODED VIEW OF DC MOTOR

Predominant motor components by motor type are summarized in Table 2-3.

TABLE 2-3
PREDOMINANT MOTOR COMPONENTS SUMMARY

Motor Type[a]	3Ø Stator	3Ø Rotor	Random Wound Stator	Form Wound Stator	Random Wound Rotor	Form Wound Rotor	Sleeve Bearing	Antifriction Bearings	Oil Lubricated	Grease Lube	Horizontal	Vertical	Salient Pole Stator	Salient Pole Rotor	Die Cast Rotor Bars	Fabricated Rotor Bars
SCIM Up to 200 hp	X		X				X	X	X	X	X	X			X	X
Above 200 hp	X			X			X	X	X	X	X	X			X	X
WRIM Below 200 hp	X	X	X	X	X	X	X	X	X	X	X	X				
SYNCH Above 200 hp	X			X			X	X	X	X	X	X		X		
DC Below 200 hp					X	X		X	X	X	X	X	X			

(a) SCIM = Squirrel cage induction motor
WRIM = Wound rotor induction motor
SYNCH = Synchronous motor
DC = Direct current motor

Bearings are the major cause of failure for electric motors (see Section 3). All motor bearings are intended to have some form of lubrication. Bearing life is dependent on correct and adequate lubrication. Choice of lubricants depends on the following factors:

- Type and size of bearing
- Operating temperature
- Bearing load
- Bearing fit to shad and end-bell
- Motor speed
- Environment (humid, hot, dirty, high radiation, etc.)
- Motor operating mode (continuous or standby)

Under continuous operation and normal load conditions, most antifriction bearings have an average life expectancy of 5 to 10 years (Reference 6.14) whereas sleeve and thrust bearings are considered to have indefinite life, if properly maintained. However, the factors listed above can have significant effect on bearing life expectancy. Over-lubrication can be as detrimental to the bearings as under-lubrication. Forcing too much grease or adding too much oil into a bearing reservoir will lead to overheating of the bearing and may lead to incursion of the lubricant into the motor, resulting in damage to the windings. Therefore, it is important that correct type, amount, and frequency of lubrication be determined for each motor.

Large motors use oil-lubricated bearings as bearing size and speed exceed the limits for grease. These bearings can be either antifriction or babbitted bearings. Many of the identified bearing failures relate to grease lubricated bearings.

Bearing types and applications are discussed below. Bearing types are related to bearing application considerations rather than to motor types.

BEARING TYPES. The two principal types of self-lubricated bearings used are antifriction (rolling element bearings) and babbitted bearings. Most horizontal motors in the 1 to 500 hp size range, and some motors up to 2000 hp. use antifriction bearings. This type of bearing is lubricated by an oil reservoir or grease which acts as an oil reservoir, gradually releasing oil to the bearing surfaces. Larger horizontal motors usually have oil-film babbitted sleeve bearings (see Figure 2-10). These bearings have an oil reservoir from which oil is drawn by oil rings (see Figure 2-11), which rotate on the shaft and dip into the oil reservoir. The rings deposit oil on the shaft and the bearing surfaces. Some large motors have force-fed lubrication supplied from a separate shaft-driven or motor-driven pump.

The bearing types for horizontal and vertical motors are discussed in more detail below:

- **Antifriction Bearings.** The basic difference in antifriction bearings is the type of rolling element used in the bearing. The following types of rollers are in wide use today: balls, cylindrical rollers, spherical rollers and tapered rollers. Small direct-coupled horizontal motors use ball bearings. Horizontal motors using antifriction bearings that drive their loads with V-belts use ball and roller bearings. Roller bearings are capable of higher side thrust loading than ball bearings and sleeve bearings.

- **Sleeve Bearings.** The sleeve bearing for horizontal motors is normally a simple babbitt-lined steel cylinder. Oil rings, usually made of bronze or brass, ride on and rotate with the shaft to carry oil up from a sump beneath the bearing, letting it flow down onto the journal to spread oil between journal and bearing surfaces. Sleeve bearings are in wide use on the larger motors in power plants. Sleeve bearings should be avoided in belt drive applications.

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[4] Bearings and lubrication are extensively discussed in Section 6.9, pages 6-103 through 6-123.

Since there are no statistical, standardized relations between load and life, sleeve bearings unlike the antifriction type, are often expected to last indefinitely. Experience has shown, however, that degradation of lubrication systems, vibration and poor shaft alignment can lead to sleeve bearing wear and eventual failure.

- **Thrust Bearings.** Thrust bearings of most vertical motors having large diameters and rotor weight, such as circulating water pump motors, use oil-lubricated disc or tilting pad bearings that have babbitted surfaces. Vertical motors rated up to 2000 hp may use antifriction bearings as thrust bearings in single, double, or triple arrangements depending on thrust loading.

Bearing Application. Table 2-4 shows how bearings are usually applied by horsepower.

TABLE 2-4

BEARING APPLICATION

	Horizontal Direct Connected			**Horizontal Belt Connected**			**Vertical**		
Bearing Type	200 hp and Below	200 hp to 2000 hp	Above 2000 hp	200 hp and Below	200 hp to 2000 hp		200 hp and Below	200 hp to 2000 hp	Above 2000 hp
Antifriction Ball Type	X	X		X			X	X	
Antifriction Roller Type				X	X			X	
Sleeve Bearing Ring Lubricated	X	X	X						
Sleeve Bearing Oil Bath							X	X	X
Sleeve Bearing/Forced Lubrication		X	X						
Thrust Bearing Antifriction, Ball Oil-Lubricated		X	X	X	X		X	X	
Thrust Bearing Antifriction, Ball Grease Lubricated	X			X			X		
Thrust Bearing Tilting Pad								X	X
Thrust Bearing Disc Type								X	X

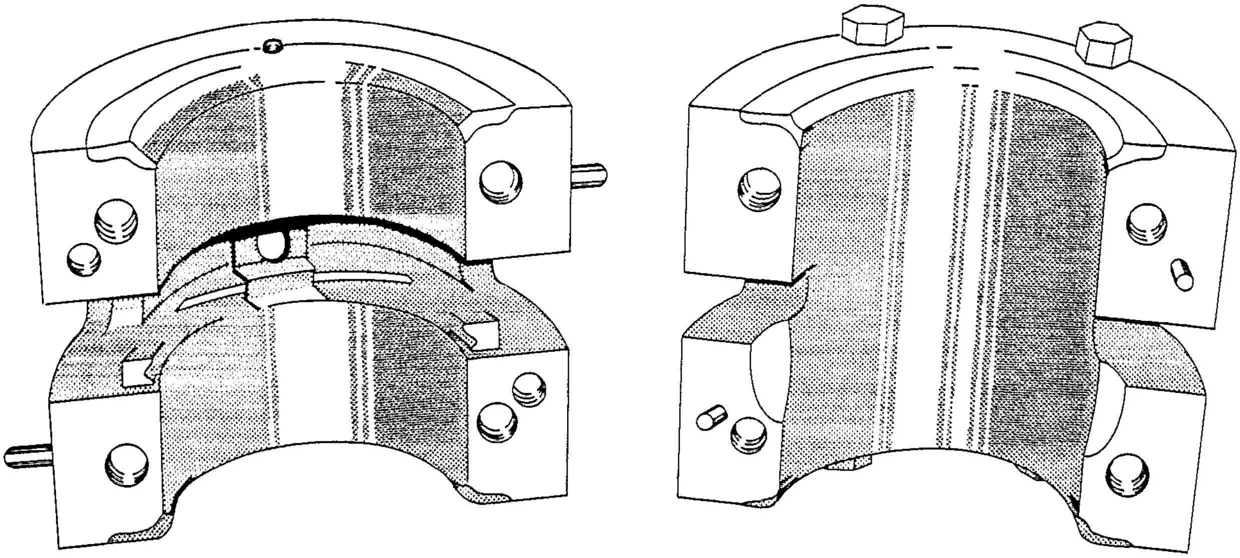

FIGURE 2-10
SLEEVE BEARING DETAILS

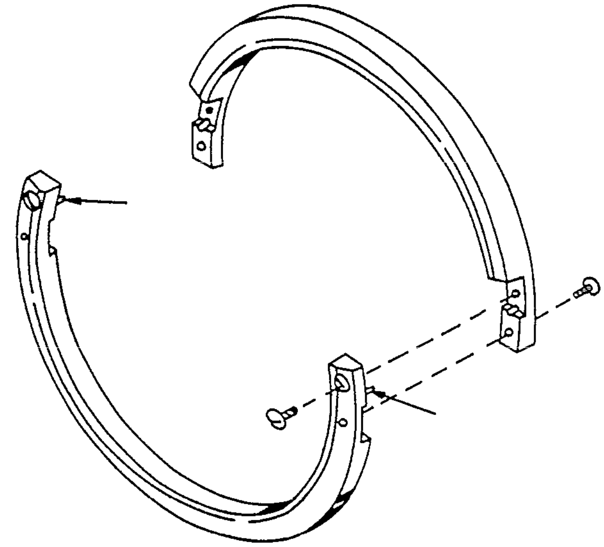

FIGURE 2-11
OIL RING DETAIL

Ball bearings are provided in a variety of configurations for requirements of load, speed, thrust and lubrication design.

- Sealed bearings prevent foreign material entry into the bearing. These bearings are not usually designed to be relubricated. The bearing has a prebilled grease level in its enclosed reservoir. (Figure 2-12A)

- Single row, deep-groove, double-shielded bearings combine the bore and outside diameter of single row bearings with the width of double row bearings for wider area in contact with shaft and housing. This style is often used with aluminum housings. Extra width provides extra grease capacity. Deep-groove ball bearings tolerate moderate thrust loads. (Figure 2-12C,D)

- Single row maximum type bearings are designed for heavy radial loads at moderate speeds. A filling slot is milled into the inner and outer rings of the bearing. They are used with or without shields, depending on the application. Because of the filling slot these bearings have little thrust capability. (Figure 2-12B)

- Angular contact ball bearings carry a combination of radial and single direction thrust loads. To carry thrust loads in both directions, these bearings are mounted in pairs with opposed contact angles. (Figure 2-12E)

- Ball bearings for axial thrust loads can handle relatively high thrust loads where no radial loads are present.

Bearings with pivoted shoes, also called tilting pads, are used in both horizontal shaft and vertical shaft applications. Figure 2-13A shows a runner for tilting pad bearing. Figures 2-13C and 2-13D show a six-shoe tilting pad thrust bearing with and without the runner. The all steel runner is fixed to the rotating shaft and it rides on the six shoes with babbitted surfaces. The pads tilt to allow an oil wedge to form on its surface that supports the weight of the shaft assembly via the runner. Figure 2-13B shows schematically how the individual thrust bearing shoes provide an equalized support system.

2.2.3 Lubrication Systems

All motors have lubrication systems for bearings. Bearing life is primarily limited by the adequacy of the lubricant. The type and quality of the lubricant are dependent upon bearing type size, operating temperature, load, and motor speed. Bearings may be self-lubricated or force-feed lubricated.

OIL LUBRICATION. Oil lubricated bearings are either submerged in an oil bath for vertical motor applications or use a slinger or oil rings to coat the bearing with oil. Oil viscosity selection is based on bearing loading. Vertical motors with antifriction thrust bearings use fairly low viscosity oil. A heavily loaded spherical roller thrust bearing will use higher viscosity oil. High operating temperatures will promote oil deterioration. Some motors use cooling coils to limit bearing operating temperatures and retard oil dew radation. Oil analysis should be used to periodically monitor the lubricant for degradation of physical properties and/or the presence of bearing wear. Equipment manufacturers should be consulted when determining the correct oil (i.e., viscosity, additives, etc.) for each application. However, where this information may not be accessible, equipment qualification reports and lubricant companies are also good sources for lubrication information.

GREASE LUBRICATION. Grease provides the following functions:

- It maintains a film of oil between the rotating and stationary surfaces within the bearing, thus minimizing friction between them.
- It cools those surfaces so that friction heat does not damage the parts or the lubricant.
- It aids in flushing out microscopic particles broken away from bearing parts by wear or high surface stress.
- It prevents corrosion.
- It limits dirt or chemical contamination.

LUBRICANT REQUIREMENT. The amount of lubricant needed to maintain an oil film on bearing parts is extremely small. At the proper viscosity, less than one-thousandth of one drop of oil can properly lubricate a ball bearing on a 2-inch shaft running at 3,600 rpm. In setting up grease lubrication maintenance programs for motors, it is important to understand the workings of the following types of antifriction bearings:

- **Unshielded Bearings** (see Figure 2-12C)

  These are used when the lubricant system is arranged for flow-through greasing. In the system shown, grease enters one side of the bearing and leaves from the other. This is intended to aid discharge of old grease from the bearing during lubrication. The wide inner cap fit along the shaft helps keep grease from being forced into the motor interior. (See Figure 2-14)

- **Shielded Bearings** (see Figure 2-15 and 2-12D)

  - Single-Shielded Bearings - Shield Facing Outside of the Motor.

    This assembly is common when an inner bearing cap is used to hold the bearing in place. The cap acts as a grease seal to prevent leakage, and the side of the bearing that is left open facing the cap allows the bearing to purge excess grease into the cap reservoir. Unfortunately, over-greasing will fill-up the cap reservoir and cause the grease to be forced between the cap and the shaft and to the inside of the motor.

  - Single-Shielded Bearings - Shield Facing the Motor Interior.

    This bearing is customarily used when there is no inner cap. The shield is needed to help prevent internal grease leakage.

- Double-Shielded Bearings (Figure 2-12D)

  These bearings are used when there is a need to retain the lubricant in the bearing more efficiently and to minimize the intrusion of contaminants into the bearing. Regreasing this type of bearing arrangement is more difficult because the grease cannot be pushed into or forced out of the bearing as easy as in the case of an open or single-shielded bearing. Because of this, regreasing intervals are usually longer and the amount of lubricant added to the grease cavity is less. In a non-hostile environment, with a proper greasing program, a double-shielded bearing should have approximately the same useful life as an open or single-shielded bearing.

- **Sealed Bearings** (Figure 2-12A)

  These bearings are made to prevent lubricant (and dirt) inflow as well as lubricant escape. These bearings are not usually designed to be relubricated. The use of sealed bearings should be evaluated on a case by case basis. This evaluation should take into account motor characteristics, operating environment and accessibility.

Grease Fill

The most common recommended grease fill percentage in a bearing grease cavity is 50%, although there are published ranges from 25 to 75%. The partially filled cavity allows for thermal expansion of the grease without it being forced into the motor through clearances between the shaft and the inner bearing cap.

The fill plug and drain plug of 90 percent of bearing housings are located on the same side of the beating (usually the side of the bearing facing away from the motor). This design usually employs shielded bearings. See Appendix B for regreasing guidelines.

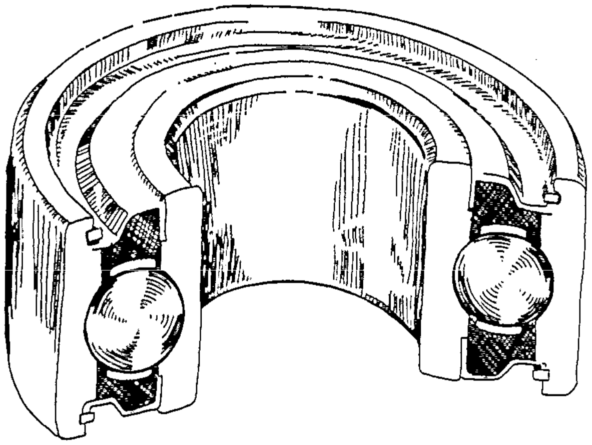

FIGURE 2-12A
SINGLE ROW, DOUBLE SEALED
BALL BEARING

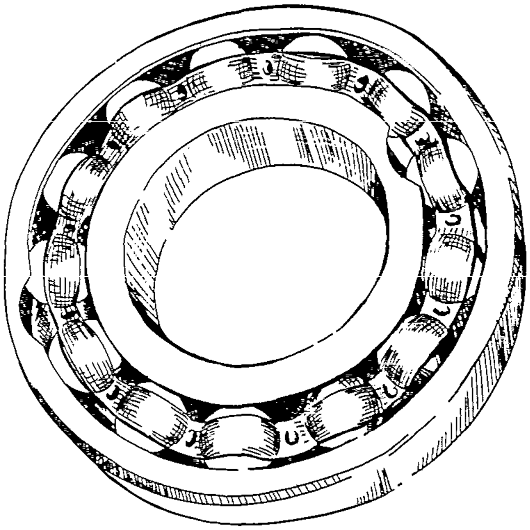

FIGURE 2-12B
SINGLE ROW, MAXIMUM TYPE
BALL BEARING

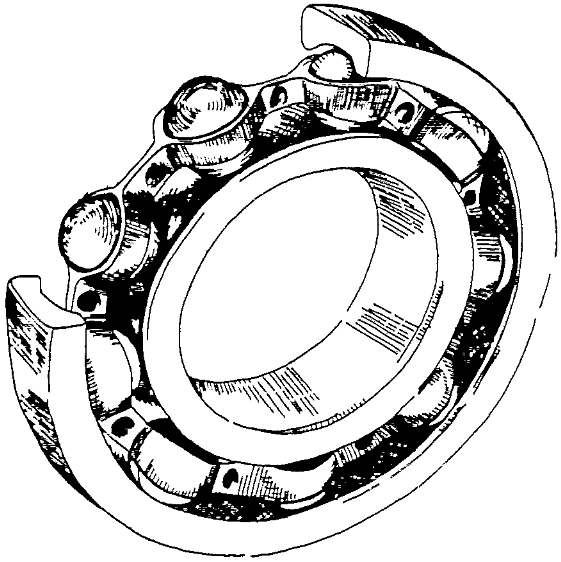

Figure 2-12C
SINGLE ROW, OPEN ENCLOSURE, DEEP
GROOVE BALL BEARING

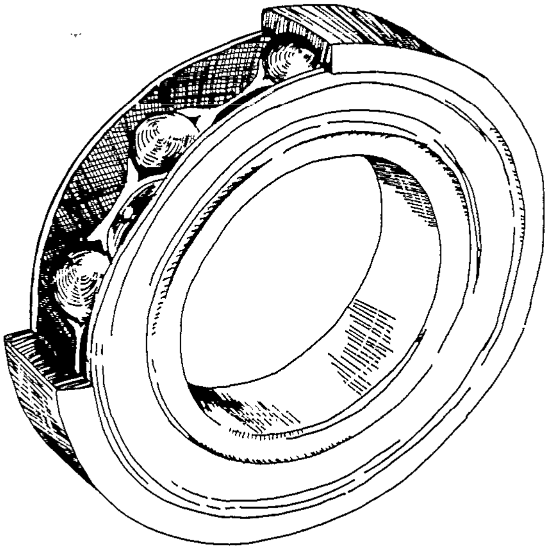

Figure 2-12D
SINGLE ROW, DOUBLE SHIELDED
BALL BEARING

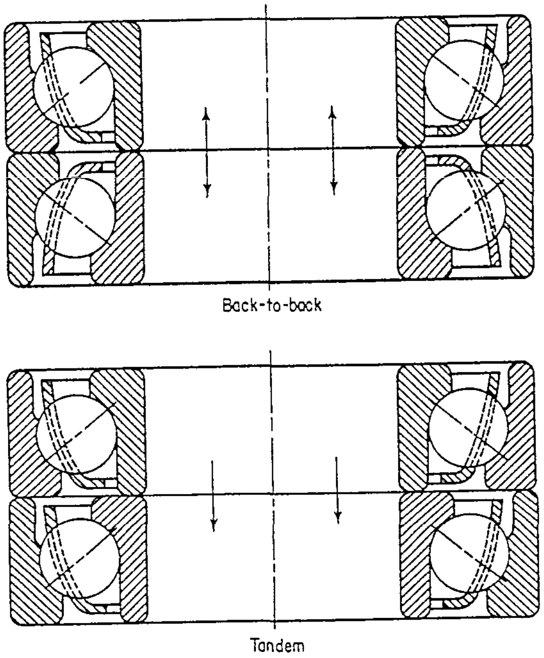

FIGURE 2-12E
MOUNTING ARRANGEMENTS FOR ANGULAR-CONTACT
BALL BEARINGS

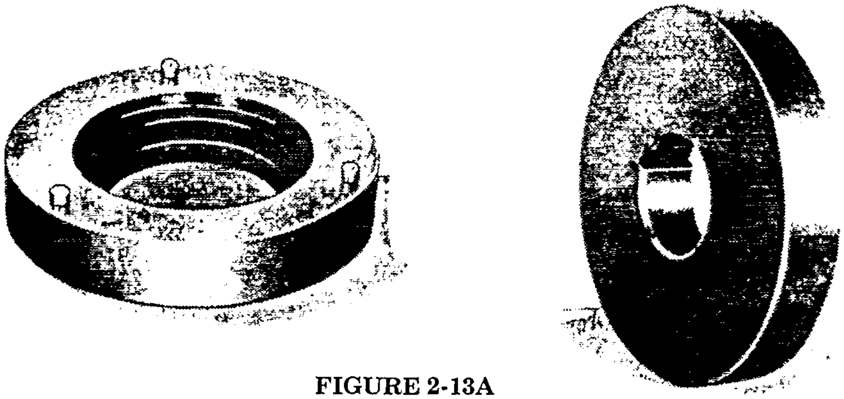

FIGURE 2-13A
TILTING-PAD JOURNAL BEARING

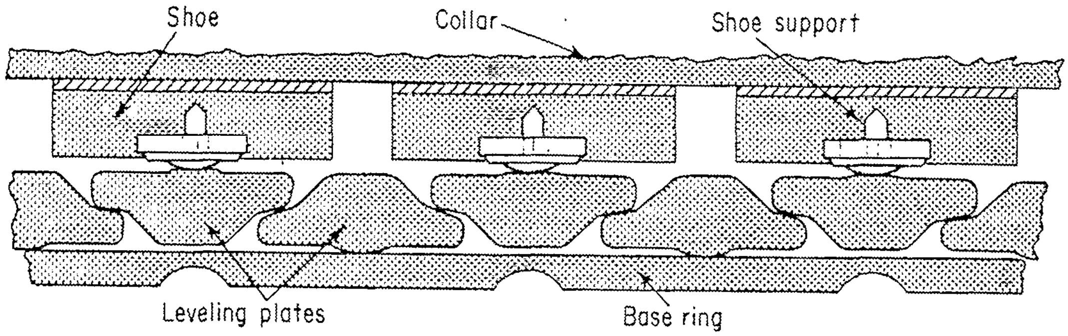

FIGURE 2-13B
EQUALIZED SUPPORT OF THRUST BEARING
SHOES

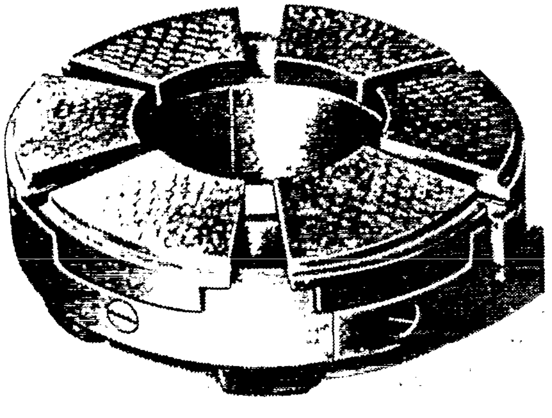

FIGURE 2-13C
ASSEMBLY OF SE-SHOE
THRUST BEARING

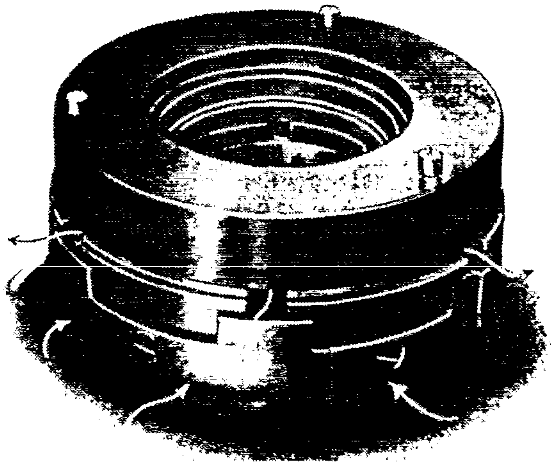

FIGURE 2-13D
VERTICAL RUNNER ADDED SIX-SHOE
THRUST BEARING

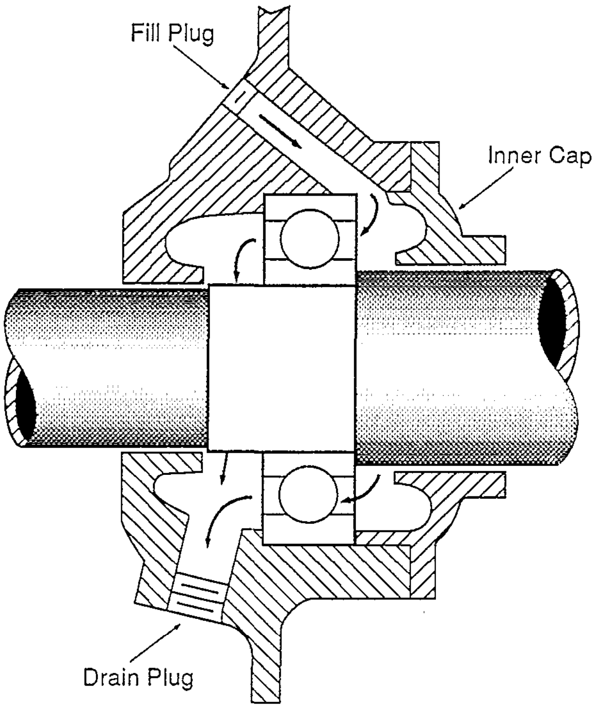

FIGURE 2-14
FLOW-THROUGH LUBRICATION SYSTEM

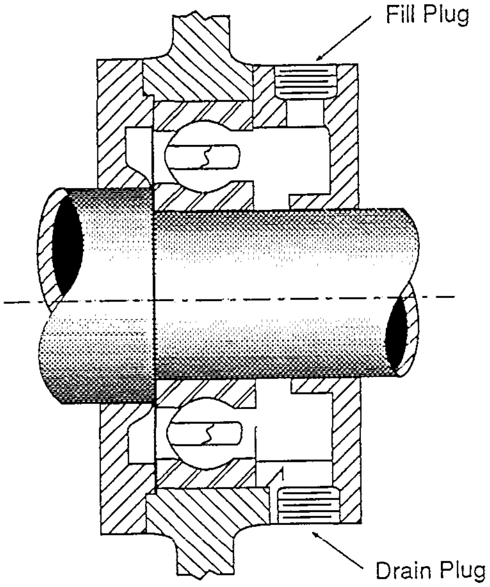

FIGURE 2-15
LUBRICATION SYSTEM USED FOR SHIELDED
BEARINGS

Section 3.0

Component Failure Mode Analysis

3.0 Component Failure Mode Analysis

To initiate a cost-effective preventive maintenance program, the motor components that are most likely to cause motor failure need to be identified and analyzed.

- Section 3.1, Industry Surveys - summarizes industry surveys relative to motor failures, pinpointing the motor components that, according to survey data, have tended to fail most often.
- Section 3.2, Failure Mode Analysis - describes the causes of failure associated with these components and summarizes, in matrix form, the causes, symptoms, and failure modes of electric motors.

3.1 Industry Surveys

Recent industry operating assessments sponsored by the IEEE (Reference 6.4) and EPRI (Reference 6.5) show that most motor failures are related to a few major components. These components, and the approximate percentage of the total failures attributed to each, are listed in Table 3-1.

TABLE 3-1
PERCENT OF FAILURES BY MAJOR COMPONENTS

Cause	IEEE Survey	EPRI Report
Bearing related	44	41
Stator related	26	36
Rotor related	8	9
Other	22	14

The IEEE survey and the EPRI report identified several failure mechanisms. The significant failure mechanisms from the IEEE survey are listed in Table 3-2 along with the approximate percentage of total failures attributed to each. The failure mechanisms are divided into failure causes and related observed conditions.

TABLE 3-2
MOTOR FAILURES BY SIGNIFICANT CAUSES
(IEEE SURVEY RESULTS)
(Note 1)

Cause of Failure	Percent of Total Failures	
	Bearings	Windings
Overheating	12	21
Insulation Breakdown	2	37
Mechanical Damage	50	10
Electrical Fault	4	11

Notes:

1. Reference 6.4, summarized in Reference 6.6, page 5.

Another data source that was reviewed for motor failure listing was the Nuclear Plant Reliability Data System (NPRDS) (Reference 6.7). This is an industry wide database for monitoring the performance of selected nuclear power plant components that are important to safe and reliable plant operation.

Evaluation of the NPRDS database up to March 1991 showed 1,330 motor failures broken down as follows:

Sudden and complete failure	439
Degraded	741
Incipient	148
Unknown	2
	1,330

Of the failures, recorded in NPRDS, 795 were mechanical, 399 were electrical, 134 were human related, and 2 did not have failure modes identified.

The NPRDS analysis shows a much higher percentage of mechanical failures (60%) as compared to electrical failures (30%). All three studies show that the motor components most likely to result in failures are:

- Bearings (Reference 6.19)
- Stator windings (including connections)

To be effective, predictive maintenance programs should contain trending factors that will address degradation of these components. (See Section 4.1)

Surveys such as the IEEE and EPRI studies broadly identify the motor components that fail without revealing the precise mechanism of failure of the component. The NPRDS data provides more information on the reason for equipment failure, but it does not get down to the exact mechanism for component failures. It is not possible to determine from surveys and databases the precise cause of motor failure, because in most cases it is not known by those reporting. For instance, consider a stator winding failure that requires a rewind. Often the actual failure mechanism is difficult to determine because the root cause is masked by subsequent damage. If the "as found condition" of the motor is recorded before it is sent out for repair, later, a more accurate type and cause of failure can be assigned. The condition of the motor at failure should be evaluated by a qualified person for proper disposition. Further, it may not always be possible to determine if the failure was from a latent defect, normal wear, switching surge, or other cause. The failure data as presently recorded in NPRDS does not yield straightforward trends for most failures. After investigating the narrative information and combining different search criteria, the data seems to indicate that with the exception of electrical system disturbances, most of the failures of electrical motors reported in NPRDS are from normal wear, repair related or from operational errors.

To help understand symptoms, causes of failure and failure modes, Section 3.2 has been assembled from references, commonly used practices in analyzing motor failures, recommendations of motor manufacturers, repair shops and suppliers of test equipment for rotating machinery. Causes of failures are described in Section 3.2.1 and are related to components in Table 3-3.

3.2 Failure Mode Analysis

This section discusses the causes, symptoms, and failure modes of the key components.

3.2.1 Causes of Failure

Most conditions that cause electric motor failure will be manifested in the form of vibration or excessive temperature.

Vibration can be caused by conditions which are electrical as well as mechanical. When an open bar develops in the rotor winding or a short happens in the stator winding, the effect on motor operation may show up as a slightly higher vibration reading. More often than not, the cause of vibration can be contributed to misalignment or bearing wear/defect. Some times motors can be damaged in handling or have a manufacturing defect which will appear as a vibration problem over a period of time because of residual stress.

In some rare occasions, the foundation arrangement can be defective and contribute to a shaft or frame vibration problem. Shipping damage or installation practice can cause vibration problems with a motor at or after initial startup.

Failures seemingly not related to vibration can develop because of, or in conjunction with, vibration in an electric motor. Bearing damage, insulation abrasion, excessive brush wear, commutator or collector ring burning, and winding fatigue can all result from vibration.

Temperature is also a good indicator of problems with a motor. Again, high temperature, can result from electrical or mechanical problems. As an example, often, the first indication of bearing trouble will be high bearing temperature. Temperature increase can be caused by such conditions as high ambient temperature, voltage imbalance, excessive load, dirty windings or blocked air intakes.

Protecting the motor winding from moisture is a major concern. When the motor is in use, condensation is usually not a problem. However when idle, the motor winding needs to be kept dry (i.e. heaters). If there is any moisture in the groundwall insulation of the winding, it should not be energized since this could cause gross failure of the windng. Often a wet winding can be dried out by applying external heat or by circulating low level DC current through the windings (Reference 6.12). Indication of a wet winding can often be found by insulation resistance testing. Additional discussion on causes of failures are as follows:

Corrosion: Corrosion can cause serious damage to motor parts. Conduit boxes, motor feet, bearing fits, air deflectors, screens, and assembly bolts can be destroyed. Oil cooling coils can develop pitting and holes from corrosion.

Excessive Moisture. Excessive moisture causes failures in motor winding insulation and in motor leads. It can also cause loss of lubrication capability in bearing oil systems and deterioration of motor parts, both electrical and mechanical.

Excessive Starts. Large squirrel cage induction and synchronous motors have limited capability for repetitive starts which is defined by the motor manufacturer. Exceeding these repetitive starting limitations can lead to failure of rotor bars, rotor short circuiting ring, or stator winding.

High Ambient Temperature. Stator windings, armature windings, field windings, bearings and lubricants have limitations on maximum temperature. If these limitations are exceeded, the useful life of these components may be shortened. High ambient temperature, when added to the rated temperature rise of the component, can cause the temperature limit to be exceeded. Some motors have cooling coils in the oil reservoir. These coils act as heat exchangers by using water to remove heat from the oil reservoir. If the water flow rate is too low or the coil leaks, bearing damage could result from high temperature.

Inadequate Lubrication. Reliable operation of bearings depends on adequate lubrication. Both oil-based and greased-based systems can fail from degradation, contamination, lack of lubricating medium, or over-lubrication.

Manufacturing Defect/Design. There have been winding failures attributable to design defects and manufacturing defects, particularly in the form wound stator coils of large motors. Occasionally, blow holes are found in die cast aluminum rotors. Motors have also been found with inadequate core or winding material.

Misalignment. Shaft misalignment is one of the causes of shaft vibration and can cause in bearing failure.

Misapplication. Motors need to be applied within their horsepower rating and designed load carrying capabilities. Excessive loading results in high temperature and deterioration of electrical insulation. Bearings and shaft materials are carefully selected for the loading demands of the shaft system (i.e. side loaded VS direct coupled). Care should be taken to ensure that replacement bearings retain the original design load carrying characteristics.

Normal Deterioration with Age. Because of the special demands of the application, the design life of Class HE motors is the same as that of the insulated windings. Balance-of-plant motors have windings that are typically designed for a life of 20 years or longer, if properly maintained. Anti-friction bearings generally have a 5- to 10-year life. The expected life of sleeve bearings is considered to be indefinite with correct application and care.

Oil and Dirt. Oil and dirt have a detrimental effect on insulated stator and rotor windings. Oil tends to dissolve insulation systems and makes them more susceptible to the deteriorating effects of moisture. Oil attracts dirt which reduces heat transfer from the winding surface and plugs ventilating passages causing overheating Dirt in lubrication systems will lead to eventual bearing failure.

Persistent Overload. Persistent overload causes overheating of windings and bearings which can lead to damage and eventual failure.

Poor Ventilation. Ventilation can be adversely affected by foreign material including oil, dirt, paper, and rags. Also, structural columns, pipes, building walls, and low ceilings can restrict air flow to or from motors. Some motor ventilation designs allow recirculation of hot discharge air from the motor itself or adjacent motors.

Repair Related. Motor failures can result from improper repair procedures and techniques. Defects can result from, but are not limited to, poor rewind techniques, stator core damage from burn-out oven procedures, improper installation of new bearings, damage from dropping major components, and inadequate efforts to exclude foreign material.

Repetitive Surge. Some circuit breaker designs have caused switching surges that adversely affect motor winding dielectric capability.

Shaft Currents. Large motors have one or two insulated bearings to prevent the flow of current from motor frame to motor shaft through the bearing. These currents can damage bearings, if allowed to flow. The integrity of the insulation can usually be confirmed by checking the resistance path between the oil reservoir and the bearing housing

3.2.2 Summary of Failure Causes

Electric motor component failure causes are summarized in Table 3-3. This table is organized in four sections:

- **Major components** - likely components of a motor to experience failure
- **Symptoms** - conditions that can be observed by inspections/tests
- **Failure causes** - most likely failure causes for the observed symptoms
- **Failure mode** - most likely failure mechanisms resulting from one or more of the failure causes

TABLE 3-3
CAUSES SYMPTOMS, AND FAILURE MOVES OF ELECTRIC MOTORS

Component	Symptoms	Failure Causes															Failure Mode or Result								
		Corrosion	Excessive Moisture	Excessive Starts	High Ambient Temp.	Inadequate Lubricant	Manufacuturing Defects	Misalignment\Imbalance	Misapplication	Normal Deterioration	Oil and Dirt	Persistent Overload	Poor Ventilation	Repair Related/Maintenance	Repetitive Surge	Shaft Current	Broken Rotor Bars	Broken shaft (or Part)	Commutator Damage	Damage to Antifriction Bearing	Damage to Sleeve Bearing	Dielectric Breakdown	Failed Connection	Reduced Component Life	Slip Ring Damage
Stator Winding	Overheated			X	X		X		X		X	X	X	X			X					X		X	
	Ground fault	X	X	X			X			X				X	X							X	X		
	Turn-to-turn fault		X	X			X			X		X		X	X							X	X		
	Loose bracing			X			X	X		X				X				X				X		X	
	Incrs. in insul. voids						X			X				X	X							X			
	High leakage current	X	X							X	X	X		X	X							X		X	
	Low Megger[1] reading	X	X								X											X		X	
	Low polariz. index	X	X							X	X											X		X	
	High resistance	X	X				X			X				X					X			X	X	X	
	High stator current					X	X		X			X		X			X			X	X	X	X	X	
Bearing	Overheated	X			X	X	X	X	X	X	X	X	X	X		X				X	X			X	
	High vibration	X				X	X	X		X				X		X	X	X		X	X			X	
	Oil qual. degradation		X			X	X	X		X	X			X		X				X	X			X	
	Grease related		X			X				X	X			X						X				X	
	Oil level/pressure					X	X				X			X						X	X			X	
Rotor	High vibration			X		X	X	X		X	X		X	X		X	X	X		X	X			X	X
	Carbon brush sprking	X	X				X	X		X	X	X	X	X					X					X	X
	High current sidebands			X			X	X		X				X			X	X		X	X			X	
Lube System, Lube Cooling Coil	(See Bearings)																								
Ventilation Sys	Overheated	X			X		X		X		X		X	X								X	X	X	
Stator Core	Overheated	X			X		X			X	X		X	X								X		X	
Frame	High vibration	X					X	X	X					X				X		X	X			X	

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[1] Megger is a registered trademark of James G. Biddle company.

Section 4.0

Preventive/Predictive Techniques

4.0 Preventive/Predictive Techniques

A motor preventive maintenance program must employ the appropriate technical measures to identify and address degraded conditions prior to impact on motor operation. Based on the results of this program there will be occasions when corrective actions may be necessary. This program should effectively address reliability, cost, and schedule considerations as well as the causes of motor failures known to be most prevalent. When applying any of the tests or inspections discussed in this section, it is important to compare the results with established baseline data for each motor. It is equally important to have an understanding and knowledge of design parameters of these motors. Preventive maintenance activities available to monitor motor reliability are outlined in the three sections below.

- Section 4.1, Trendable Tests
- Section 4.2, Inspection Techniques
- Section 4.3, Other Diagnostic Tests

The goal of these activities is to detect an unsatisfactory condition well before it results in motor failure.

4.1 Trendable Tests

With this guide's goal of promoting reliability centered maintenance methods, emphasis is placed on implementation of condition monitoring through trendable tests. Trendable tests are listed in Table 4-1 (References 6.8[1], 6.9[2], 6.1[3]).

The trendable tests listed in this section are time proven and are accepted by most electric motor maintenance specialists. Because of the variety of failure modes that are possible, a number of tests can be applicable, each addressing a different failure symptom.

Trending of equipment history combined with maintenance recommendations made in Section 5 can provide the basis for an effective maintenance program.

Further information on motor condition can be obtained from the recommended tests that explore the condition of the winding and other components of the motor (Reference 6.1[4]):

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[1] Pages A-2 through A-17 describe most of these tests.

[2] Section 5 has additional information on tests.

[3] Pages 6-92 through 6-102.

[4] Provides detailed technical information on these tests.

- **Supply Voltage:** Motor standards allow operation within a voltage range of ±10% of rated motor voltage. Operation on the low end of the range increases the temperature of the stator and rotor windings. Operation at the high end of the range reduces the temperature of most motors. An exception is low speed induction motors which can experience a high increase in magnetizing current at the higher voltage. Allowable voltage unbalance is about 1% for low voltage motors (NEMA MG-1-14.35) and not to exceed 5% for large motors (NEMA MG-1-20.56).

- **Running Current:** Measured current values should be nameplate rated amperes or less, although motors with service factor ratings can operate to service factor levels. The three phase currents should be balanced to within a few percent. Current pulsations at slip frequency can be an indication of broken rotor bars. Baseline currents should be recorded at full unit load. Winding temperature is proportional to the square of running current. Thus, a five percent increase in running current results in a 25 percent increase in winding temperature. Excessive winding temperature causes electrical insulation degradation.

- **Speed**: For induction motors, motor speed reflects motor load. As motor load increases, its speed of rotation decreases slightly. Motor speed measurement, compared to rated motor speed or baseline motor speed, verifies that the motor is operating within its rating.

- **Bearing Temperature:** For high horsepower motors, bearing temperatures may be measured by RTD, thermocouple or bulb type thermometer. For motors not equipped with devices, bearing temperature is measured by a portable thermometer on the outside of the bearing housings. High bearing temperature, compared to baseline value, indicates deterioration of the bearing. High bearing temperature may be related to vibration, lube oil performance, grease deterioration or bearing deterioration.

- **Winding Temperature:** It is widely accepted that motor insulation life is reduced by 50 percent for each 10°C that the insulation temperature exceeds rated temperature. Thus, it is important that the motor operate within its rated temperature. Large critical motors are usually equipped with RTDs to measure insulation temperature. Random wound motors are rarely equipped with temperature measuring devices. For these motors, portable clamp-on ammeters are used to measure current or portable tachometers are used to measure speed to determine if the motor is operating within its rating. It is important that air discharge and inlet openings not be blocked. Blocking air flow would restrict cooling air flow to the motor. Also discharge air should not be allowed to recirculate air to the inlet. Ambient air should not be above rated ambient air for the motor design, normally 104°F. Winding temperature may be related to supply voltage, running current, speed, cooling air temperature, or lack of cooling air.

- **Insulation resistance:** This is the condition of insulation between conductor and ground. Low values indicate moisture, dirt or damaged insulation. Test voltage should be higher than rated voltage, e.g. 500 volt or 1000 volt DC test for a 480 volt motor, and 5 kV to 10 kV DC for a 4000 volt motor. This test is applicable to both operating motors and motors in storage.

- **Polarization Index:** This test provides additional information on condition of insulation between conductor and ground (for motors rated 4000 volts and higher). Polarization index is the ratio of the insulation resistance for a ten-minute test and that of a one-minute test. A ratio of 2 or higher indicates suitability for service. This test is used to determine if a winding is wet.

- **Current Analysis:** Analysis of stator current with special Fast Fourier Transform analysis technique can yield side band harmonic information to show presence of cracked or broken rotor bars. It is recommended that initial benchmark tests be made to establish the presence or absence of manufacturing defects. Reactor recirculating pumps, or reactor coolant pumps with heavy flywheels, may develop rotor winding problems because of long accelerating time with high starting currents. This test is more significant for these motors than for most of the low inertia pumps in the power plant. If indications are found, test interval should be shortened.

- **DC Spot**: A more searching test on condition of insulation between conductor and ground. Effective for motors rated 4000 volts and higher. Is also recommended on motors rated 575 volts and less to determine if it is safe to apply the surge comparison test. IEEE step voltage method is recommended because it controls the charging current in a uniform manner to allow the test operator to stop the test if indication of impending failure develops during the test. It is recommended that a trained operator perform the test because of safety considerations and because of the possibility of causing a winding failure.

- **Vibration** Monitoring of vibration levels of an operating motor over a period of time can provide valuable baseline information on motor condition. Changes in vibration indicate bearing deterioration, misalignment, damaged parts, electrical imbalance, and other conditions which are associated with the rotation of the machine.

- **Oil analysis:** Analysis of bearing oil can provide evidence that oil has correct properties, or that deterioration of lubricating properties has taken place. Also, bearing babbitt particles may indicate development of bearing failure or cooler leak.

- **Grease Analysis:** Analysis of grease can provide evidence of deterioration of lubricating properties as shown by hardening, chemical breakdown or excessive amount of dirt.

- **Winding Resistance (including feeder cables):** Using a Kelvin bridge which is more accurate than a Wheatstone bridge, resistance measurement can detect high resistance connections before they develop into a connection or winding failure. This also will identify imbalances between phase windings.

- **Ultrasound:** Changes in ultrasonic frequency from 24 KHz and 50 KHz in a bearing give warning of bearing deterioration long before such indicators as heat and vibration.

TABLE 4-1
TRENDABLE TESTS

Test	Description	Application	Effectiveness $^{(a)}$	Reference
Supply Voltage	Measure bus voltage	Stator heating Rotor heating	Effective for trending	Ref 6.1, page 6-60
Running Current	Measure stator amperes	Stator heating	Determines overload	Ref. 6.8
Speed	Measurement of shaft rpm	Shaft Speed	Determines overload. Effective for trending	Ref. 6.9, page 5-32
Bearing Temp.	Measurement of bearing, bearing housing, or bearing oil temperature	Applies to all bearings, oil lubricated and grease lubricated	Effective for trending. Must account for effect of ambient temperature	Ref. 6.1, page 6-118
Winding Temp.	Indirect measurement of winding temperature	Applies to motors with built-in RTDs or thermocouples	Effective for trending. Must account for effect of ambient temperature	Ref. 6.9, page 6-8
Insulation Resistance	Measures resistance of insulation between conductor and ground (R)	To detect wet or dirty insulation and dielectric integrity	Effective for trending if corrected for temp. Adequate scale range needed.	Ref. 6.8, page A-2 Ref. 6.11
Polarization Index	Ratio of 10-minute IR to 1-minute IR	To detect wet or dirty insulation and dielectric integrity	Effective for trending for motors rated 4,000 volts and higher. Should have adequate scale range	Ref. 6.8, page A-3 Ref. 6.11
Current Side-Band Analysis	Fast Fourier Transform analysis of stator current	To detect broken rotor bars or short circuiting rings	Effective for trending	Ref. 6.9, page 5-32
DC Hipot	Overvoltage	Line to ground test; measures leakage current	Step voltage method; effective for trending	Ref. 6.8, page A-6
Motor Vibration	Shaft or bearing housing vibration	Direct on bearing housing or prox. to shaft	Effective for trending	Ref. 6.8, page B-3
Oil Analysis	Analysis of oil for lub. characteristics and wear particle concen.	Oil lubricated motor bearings	Effective for trending	Ref. 6.1, page 6-117
Grease Analysis	Appearance, smell, grit, content of grease sample	Grease lubricated motor bearings	Effective for trending	Ref. 6.1, page 6-111
Winding Resistance (including cables)	Measures winding resistance	Stator windings and motor terminations	Effective for trending; use Kelvin bridge. Correct for temperature	Ref. 6.8, page A-18
Ultrasound	Ultrasonic noise from antifriction bearings	Early warning of bearing	Effective for trending	Ref. 6.18 page 6-117

(a) Reference 6.9, pages 5-2 through 5-6, discusses effectiveness, advantages and disadvantages of many of these trendable tests.

4.2 Inspection Techniques

Motor maintenance is often thought of in only terms of operating equipment. In addition to operating motors, there are spare motors in storage that require routine maintenance to ensure availability for service. Periodic inspection of motors is important. Moisture and dirt buildup can be observed directly. Unusual noise, leaking oil seals, or high vibration can often be detected. Oil level gages can be monitored.

Periodic inspection can be these types:

- **External Inspection.** Observation of the external condition of the motor should include verification of oil level in sight glasses, a check for signs of oil leakage at bearings, verification that air inlets are not plugged, a check for abnormal sounds or smells, and addition of grease at predetermined intervals. (See Appendix B for regreasing guidelines.)

  Motors in storage should also have external inspections performed. Filling the oil reservoir or occasional rotation of the shaft and verification of space heater operation are important items to be included in maintenance procedures.

- **Borescope Inspection.** Observation of endwinding condition with a borescope with motor out of service. This inspection may reveal conditions of winding ties and evidence of loose coils, such as dusting at coil support points. Partial disassembly may be required.

- **Disassembly and Inspection of Components.** Decision to dismantle a motor for visual inspection is an expensive and operationally disruptive one. Therefore, decision to dismantle should be carefully evaluated based on the analysis of trendable tests, any abnormal noise or odor, unexplained operation of protective relays, and industry experience with similar motors. In addition to cost, a disadvantage of motor disassembly is the possibility of damage to components by mishandling and improper reassembly. However, in certain cases, visual inspection is an accepted means of evaluating physical condition of stator windings, rotor windings and magnetic cores.

  A simple visual inspection will not provide information that is available from tests such as insulation resistance, polarization index, or partial discharge. However, a visual inspection will reinforce findings of these tests and also provide root cause for the problems encountered. An inspection will also reveal presence of dirt, oil or moisture, damage from foreign material, broken or cracked components, loose winding ties or abraded insulation. Visual inspection may also reveal effects of corona discharge in 13.2 kV windings. Heat caused deterioration of windings may show up as a change in color of paint, varnish or resin. Damage from abnormal current paths caused by broken rotor bars will also be evident by darkened or burned pieces of the rotor. Radiation can also darken varnish or resin and makes it more brittle.

- **Regrease:** Refer to Appendix B for details.
- **Alignment Check:** Verify that the shaft of the motor and the shaft of the driven equipment have correct alignment. This is done when replacing the motor or driven equipment on its foundation or if abnormal vibration is measured.
- **Driven Equipment Inspection:** Inspection of the driven equipment, looking for solutions to motor problems. Checking for system resonant frequency may yield clues to vibration problems.

As a result of electrical tests, vibration or visual inspection of components, it may be desirable or necessary to refurbish motor components. Components that may need refurbishment or replacement are as follows:

- Stator windings
- Rotor windings
- Antifriction bearings
- Carbon brushes
- Brush holder springs
- Space heaters
- Bearing seals
- Gaskets
- Collector rings
- Commutators
- Sleeve Bearings
- Bearing Journals

Damaged or worn sleeve bearings can be rebabbitted. Journals can be lapped to assure trueness. End-bell to frame fits may need to be renewed as well as antifriction bearing to end-bell fits.

4.3 Other Diagnostic Tests

Other tests that may be used in manufacturing or diagnostics are listed in Table 4-2.

A short discussion of the effectiveness of these diagnostic tests is given for general understanding of the applicability of each test:

- **AC Hipot Test:** This test applies a high alternating voltage to the insulation that lies between the conductor and the outside of the coil. With coil installed in the machine, the outside of the coil is grounded and the test voltage is applied between conductor and ground. This is a reliable time proven test, usually conducted by the manufacturer prior to shipment of new equipment. The test voltage for new motors is 2E + 1000 volts, where E is the rated line-to-line voltage. This test has also been adapted to determine service suitability of large generators. Voltage used for generator tests vary from 1.1E to 2/3 (2E+1000) volts. This test can be used for testing plant motors, but the equipment is not as portable as that for the DC Hipot test. Also, DC Hipot tests usually provide a "warning" from increased leakage current prior to failure, but AC Hipot may result in an abrupt failure.

- **Power Factor Test:** This test measures the power factor of the insulation that lies between the conductor and the outside of the coil. Since the insulation is capacitive in nature, the power factor is very low. This is an excellent test for use in quality comparison testing for new coils rated 13.2 kV and higher. For testing motors in a maintenance program it provides no more information than the DC Hipot test, but the test equipment is not as portable as that used for the DC test.

- **Dissipation Factor and Capacitance Tests:** These tests are similar in nature to the Power Factor Test. The Dissipation Factor Test measures the tangent of the loss angle and its value is close to that of the Power Factor Test. The Capacitance Test measures the capacitance of the insulation that lies between the conductor and the outside of the coil. These tests have the same applicaton and evaluation as discussed above for the Power Factor Test.

- **Partial Discharge (PD):** This test measures the level of activity of high frequency discharges formerly referred to as corona. The discharges may be internal to the insulation lying between the conductor and the outside of the coil or the discharges may be on the surface of the coil. This test is favored by Ontario Hydro research engineers for detecting corona inception and void discharges in high voltage (13.2 kV) windings. It has not received any significant acceptance in the U.S. at this time for power plant motors, but it may become accepted with passage of time as engineers become familiar with the significance of measured PD levels.

- **EL-CID:** This is a low power test for shorted laminations in stator cores. It requires special equipment and is useful where core damage is expected. Requires removal of the rotor.

- **Growler:** This test makes use of an AC electromagnet placed against the surface of a rotor to check the integrity of the rotor windings. Mainly used in motor repair shops.

- **Surge comparison test:** Tests turn-to-turn insulation and conductor-to-ground insulation. Compares the simultaneous response of two winding sections (phases) to a capacitor discharge-produced surge voltage. Difference in the response as observed on an oscilloscope determines the presence or absence of turn-to-turn shorts. Most effective on random wound motors rated 575 volts and less. Should be preceded by DC Hipot. With care, this can be a trendable test according to some experts.

TABLE 4-2
OTHER TESTS

Test	Description	Application	Effectiveness	Reference
AC Hipot	Overvoltage test to measure leakage current	Line-to-ground	Go-no-go test; not effective for trending	Ref. 6.8, page A-6
Power Factor	AC Test to measure insulation power factor	Line-to-ground	Applicable to 13.2kV motors. Can be trended. Effective in manufacturing	Ref. 6.8, page A-9
Dissipation Factor	AC test to measure dissipation capacitance	Line-to-ground	Effective on single coils during manufacturing of 13.2kV motors	Ref. 6.8, page A-9
Capacitance	AC test to measure insulation capacitance	Line-to-ground	Effective on single coils during manufacturing of 13.2kV motors	Ref. 6.8, page A-9
Partial Discharge	AC test to measure partial discharge (corona)	Line-to-ground	Trendable test. Requires experienced operator	Ref 6.8, page A-14
EL-CID	Test for shorted stator core laminations	Stator core of disassembled motor	Go-no-go test; not effective for trending	Ref. 6.9, page 5-37
Growler	Tests rotor winding integrity (laminations)	Rotor Core of disassembled motor	Go-no-go test; not effective for trending	None
Surge comparison test	Impulse Voltage	Test turn-to-turn insulation	Effective for motors rated 600 volts or less	Ref. 6.8, page B-3

4.4 Summary Of Tests And Inspections

Table 4-3 summarizes the applicable tests/inspections for observed symptoms discussed in this section. This Table is organized in 5 sections:

- **Major Components:** Likely components of a motor to experience failure
- **Symptom**: Conditions that can be observed by inspections/tests
- **Trendable Tests:** Condition monitoring tests most likely to identify failure symptoms when compared against baseline data
- Inspections: Activities likely to support assessment and/or refurbishment of a motor's condition
- Other Tests: Tests that provide additional motor diagnostic/ troubleshooting capability

TABLE 4-3
APPLICABLE TESTS/INSPECTIONS FOR OBSERVED SYMPTOMS

Components	Symptoms	Trendable Tests														Inspections						Other Tests							
		Supply Voltage	Running Current	Motor Speed	Bearing Temperature	Winding Temperature	Insulation Resistance	Polarization Index	Current Analysis	DC Hipot (Step)	Motor Vibration	Oil Analysis	Grease Analysis	Winding Resistance	Ultrasound	External Inspection	Borescope Inspection	Disassemble/Inspection	Regrease	Alignment Inspection	Driven Device Inspection	AC Hipot Power Factor	Power Factor	Dissipation Factor	Capacitance	Partial Discharge	EI-CID	Growler	Surge Comparison
Stator Winding	Overheated	x	x			x			x					x		x	x	x			x								
	Ground fault	x					x	x		x				x		x	x	x				x	x	x	x	x	x		x
	Turn-to-turn fault													x															x
	Loose bracing																x	x											
	Incrs in insul voids									x																x			
	High leakage current									x				x								x	x						
	Low megger[1] reading						x	x														x	x	x	x	x	x		
	Low polariz. index						x	x														x	x	x	x	x	x		
	High resistance		x			x								x															
	High stator current	x	x			x			x												x								
Bearing	Overheated	x	x		x						x	x	x		x	x		x	x	x	x								
	High vibration			x	x				x		x	x	x		x	x		x	x	x	x								
	Oil qual degradation				x						x	x						x	x	x	x								
	Grease related				x						x		x		x			x	x	x	x								
	Oil level/press			x	x						x	x				x		x	x		x								
Rotor	High vibration				x				x		x							x		x	x								
	Carbon brush sprking		x	x		x					x			x		x		x											
	Broken bars & endrngs	x	x	x					x		x							x										x	
Lube Sys Lube Cooling Coil	(See bearings)											x																	
Vent. Sys	Overheated					x										x	x	x											
Stator Core	Overheated	x	x			x	x			x						x	x	x									x		
Frame	High vibration										x					x		x		x	x								

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[1] Megger is a register trademark of James G. Biddle Company.

Section 5.0

Recommendations

5.0 Recommendations

The recommendations summarized below for predictive and preventive maintenance tests for nuclear power plant motors are based on industry studies and failure histories identified in Section 3 and inputs from:

- Power plants
- Repair shops
- Industry experts
- Motor manufacturers
- Diagnostic test equipment manufacturers

These recommendations are intended to provide cost-effective methods to address potential failures most likely to affect motor reliability.

- Section 5.1, Overview; generally summarizes the basis for recommendations presented in this section.
- Section 5.2, Recommended Tests/Inspections and Associated Performance Frequencies; introduces the recommended activities and their frequencies.
- Section 5.3, Non-Periodic Tests/Inspections, discusses tests that do not sufficiently meet the selection criteria established in Section 5.1.

5.1 Overview

The information provided in this Guide allows the user to formulate a motor maintenance program based on their maintenance/reliability goals, resources, experiences, and failure history.

The recommendations presented in this Guide are for most motors, but may not apply to special motors. Motors covered by 10 CFR 50.49 (Reference 6.20) may have additional maintenance and testing requirements to maintain qualifications. These additional requirements which are specific to each plant are not included in this Guide.

Recommended tests or inspections and their frequencies of performances are based on their effectiveness to improve motor reliability. Characteristics of the tests include applicability to failure modes, cost effectiveness, non-intrusive methods and proven capabilities.

- **Equipment Reliability -** By testing motors with the recommended tests with a schedule of approximately as suggested, it will be possible to determine that a motor is operating in a reliable manner and trouble is not to be expected. Test values selected suggest continued operating reliability of the motor.

- **Applicability to Component Failure modes** - The tests that have been selected for recommendation in the Guide are oriented to component failure modes identified in Chapter 3.
- **Cost Effectiveness** - The tests selected are reasonable in cost and most can be performed by technicians. The most significant potential cost item is disassembly of motors for inspection, particularly those in containment. Motor disassembly, when recommended, has been with concern for motor reliability. The cost of any work proposed in this Guide must be offset with the cost of an unpredicted motor failure that results in loss of power production.
- **Non-Intrusive Nature of Test** - Some tests can be performed with the motor in service, some with the motor out of service. Only the dismantling for inspection option is truly an intrusive test.
- **Proven Tests and Inspection Methods** - All of the tests and inspection methods recommended in the Guide for predictive and preventative maintenance are time proven.

Maintenance recommendations in this section are presented in a series of tables. Tables 5-1 through 5-6 cover recommended predictive and preventive maintenance tasks for Nuclear Safety Related and Balance of Plant motors. Each table covers a specific type of motor with recommendations for trendable and non-trendable tests/inspections. Recommended tests/inspections satisfy most, but not all, of the above selection criteria.

5.2 Recommended Tests/Inspections and Associated Performance Frequencies

5.2.1 Trendable

- **Supply Voltage** - This data is useful to determine abnormal motor performance and winding overheating conditions. Although routine voltage verification is not required, baseline voltage data should be recorded under normal operating conditions and is recommended to be checked from 24-48 months. This information can be used for comparison during future abnormal events.
- **Running Current** - Recorded values of running current are useful to determine overload or other abnormal operating conditions. Baseline currents should be recorded for all three phases and trending values at 6 to 12 month intervals for continuously operated motors or 12 to 24 month intervals for intermittently operated motors.
- **Motor Speed** - This information serves as a backup to running current as a measure of motor load. Baseline data should be recorded and checked again at 24 to 48 month intervals for continuously operated motors.
- **Bearing Temperature** - This information is recorded to determine if the bearings are performing in the manner in which they were designed to operate for

long bearing life. For continuously operated motors, bearing temperatures should be recorded on 6 to 9 month periods.

- **Winding temperature** - This data is analyzed for excessive temperature which results in premature aging of the winding insulation. The recommended period for recording is 6 to 12 months. Data should be correlated with running current, voltage, inspection and vibration level.

- **Insulation resistance** - This simple test provides basic information e.g. if the insulation is clean and dry. It tests motor cables, motor leads and winding. Recommended test periods are 24 to 36 months for low voltage motors and 12 to 18 months for medium voltage motors.

- **Polarization Index** - This data is recorded in conjunction with the insulation resistance test for medium voltage motors. The test interval is the same, 12 to 18 months. A polarization index of 2 or higher is usually considered to demonstrate suitability for service or as a prerequisite for the DC step voltage hipot test.

- **Current Analysis** - This test indicates the presence of broken rotor bars or short circuiting rings in squirrel cage rotors. The recommended time for performing this test, after the initial benchmark tests, is 36 to 60 months for medium voltage motors and 60 to 72 months for low voltage motors. The longer period for low voltage motors results from their use of die cast aluminum rotors, which when driving pumps, are not likely to develop rotor problems. This test can be used to investigate difficult to explain rotor vibration problems caused by cracked rotor bars or short circuiting rings that only produce vibration under load.

- **DC Hipot (Step)** - This test is recommended for medium voltage motors on a 36- to 60-month schedule. The minimum recommended test value is l. l x 1.7 x (rated line-to-line voltage) or 1.9 (rated line-to-line voltage). This test value is to assure that the motor has enough voltage-withstand capability to survive a line-to-ground failure of another motor on the same bus. A line-to-ground failure can raise the neutral voltage of other motors (and the line-to-line voltage of two phases). Multiple motor failures can result from a single line-to-ground fault if the motors have weak windings.

- **Motor Vibration** - Because of the importance of maintaining low vibration level for motor well-being, because of the relatively high incidence of bearing failures cited in Section 3, and because of the sensitivity of rotor vibration to indicate bearing problems, misalignment, damaged parts and electrical imbalance, it is recommended that motor vibration be checked on a 6- to 9-month interval .

- **Oil Analysis -** Oil analysis can be a useful tool in determining bearing performance and possible deterioration. Periodic checks for oil color, Visocity, and acidity can aid in preventing or anticipating bearing failure. Appendix C covers oil analysis in more detail.

- **Winding Resistance** - Winding resistance can be taken at the same time as the insulation resistance measurement is made - on a 12- to 18-month interval for medium voltage motors. This test is more significant for motors subject to an atmosphere that fosters corrosion of motor connections, such as outdoor motors.

5.2 2 Non-Trendable

- **External Inspection** - Should be performed on a 12- to 18-month schedule.

- **Borescope Inspection** - Where this inspection can be effectively used, normany for motors 1000 hp and larger, a 60- to 72-month schedule is recommended. Look for oil leaks and loose end windings.

- **Disassemble/Inspect** - In establishing the interval for disassembly for complete inspection, it should be recognized that this maintenance Guide is structured to minimize the amount of disassembly necessary because of the cost involved. The decision to disassemble for complete inspection should take into account whether or not the trending has produced any negative indications. Other factors could be motor speed category; 3600 rpm motors tend to produce more oil leakage into windings than lower speed motors. Oil saturation can degrade insulation and should be cleaned up before deterioration sets in. Outdoor motors in wet climates can develop moisture related problems that may require disassembly, dry out and retreat the windings. Verticat motors tend to require disassembly more often than horizontal motors to restore clearances and take care of oil leak problems. The Guide recommends disassembly for inspection of motors 1000 hp and larger on a 120- to 180-month interval, but this may be modified by such factors as those cited above. Where lube oil tests indicate the presence of bearing, the bearings can be inspected without complete disassembly of the motor.

- **Regrease - Schedules for regreasing bearings are presented in Appendix B.**

  Surge Comparison - Useful for random-wound motors Some operating company engineers are concerned about test-induced failure It is an excellent test for checking random-wound motors for shorted turns and for deteriorated ground insulation On the other hand, random-wound motors do not have many failures and they are usually backed up with an operating spare

- **Rotate by Hand** - (Applies to layup and storage).

5.2.3 Summaries of Recommended Tests

The recommended tests are presented in tabular form as follows, specifying test frequency in months and indicating whether the tests are made on-line or off-line.

5.3 Non-periodic Tests/Inspections

- **AC Hipot** - This test is not recommended for motors because of its potential to cause failure without warning. If it is to be used the schedule would be the same as for the DC Hipot (step).
- **Power Factor** - Not recommended for plant use because of cost and inability of test to search for localized defects. Step voltage DC Hipot Test provides equivalent trending information.
- **Dissipation Factor** - Not recommended for plant use because of cost and inability of test to search for localized defects. Step voltage DC Hipot Test provides equivalent trending information.
- **Capacitance** - This test has an inability to search for localized defects. Not recommended for use on completed stator windings unless looking for defective coil. Not recommended for plant use because of cost and inability of test to search for localized defects. Step voltage DC Hipot Test provides equivalent trending information.
- **Partial Discharge** - This test has potential to provide trendable information on void development which relates to insulation deterioration. Trial application with 36- to 60-month intervals could be beneficial.

- **EL-CID -** This test detects stator core damage by indicating shorted laminations. Shorts occur between core laminations when insulation coating is damaged. The electromagnetic core imperfection detector (EL-CID) is a low power test compared to the Rated Core Flux Test or "ring test" which uses rated voltage to generate rated flux in the core. Although this test makes use of a low voltage source to power the test, the test requires experience in its application and interpretation. In order to apply this test, motor disassembly must be done. If core damage is detected, core replacement may be considered.

- **Growler -** This test makes use of an electromagnet which is used to detect rotor circuit damage. It is often used to locate broken or damaged rotor bars within the rotor core area. This test would possibly be used after indication of rotor trouble such as high current side-bands or vibration indications. To apply this test, the rotor must be removed from the motor.

- **Ultrasound Inspection -** Evaluation of ultrasonic emissions from bearings can aid in evaluating the condition of antifriction bearings and particle discharges in the insulations of windings. There are several probes used for this activity, one such probe is the TVA probe.

- **Alignment Inspection** - Verification of the alignment of motor and driven equipment shafts is performed when resetting one or both of the components or when investigating the cause of vibration.

- **Driven Device Inspection -** Performed to determine if the driven equipment is having an effect on motor performance. These type of inspections may include such activities as pump impeller and shaft checks for corrosion or erosion effects.

- **Grease Analysis -** Grease analysis is not a suitable test for trending because of the manner in which grease is added to the bearing cavity. Grease is only added in amounts to provide between 25 to 75 % capacity in the cavity and ideally when grease is added to the cavity, there should not be any released from the drain. Grease samples can be evaluated for particle content as well color or acidity; however, obtaining a representative grease sample can be difficult due to the manner in which grease is usually added to the bearings.

- **Brush Inspection -** Brushes should be checked for even wear and for ease of movement in the brush holder. The brush should be able to slide freely up and down in the holder. The spring should be checked to ensure that it is supplying enough pressure to push the brush properly against the commutator. The connecting wire (pigtail) should be secured and each brush should have a counterpart on the opposite side of the commutator in a DC motor.

- **Commutator Inspections -** Commutators should be checked for even wear along the copper conductor. Check for arcing and sparking during operation. If arcing is excessive, the commutator may have rough spots which may need to be smoothed down. Dirt and other foreign matter should be removed from the commutator surface . A properly operating commutator will usually be dark brown in color.

TABLE 5-1
RECOMMENDED TESTS:
SQUIRREL CAGE INDUCTION MOTORS UNDER 200 HP.
RANDOM WOUND STATOR, LESS THAN 600 VOLTS, ANTIFRICTION BEARINGS,
SAFETY RELATED AND BALANCE OF PLANT

Recommended Tests/Inspections	Duty Cycle[1]		
	Continuous	Intermittent	Layup
Trendable			
Supply Voltage	24-48	24-48	
Running Current	6-12	12-24	
Motor Speed	24-48	24-48	
Bearing Temperature	6-9	6-9	
Winding Temperature			
Insulation Resistance	24-36	24-36	24-48
Polarization Index	▨	▨	▨
Current Analysis			
DC Hipot (Step)	▨	▨	▨
Motor Vibration	6-9	6-9	
(Oil Analysis)[3]	C	C	
Winding Resistance	60-72	60-72	▨
Non Trendable			
External Inspection	12-18	12-18	
Borescope Inspection	▨	▨	▨
Disassemble/Inspect	▨	▨	▨
(Regrease)[2]	B	B	B
Surge Comparison	60-72	60-72	▨
Rotate by Hand	▨	▨	6-12

Legend

1. Numbers in charts are in months.
2. B refers to Appendix B, Table B-1 for grease lubricated bearings.
3. C refers to Appendix C, Table C-2 for oil lubricated bearings.
4. Off-line test = ▨

Note: Performance of off-line tests on large critical motors should be scheduled to coincide with plant refueling cycles.

TABLE 5-2

RECOMMENDED TESTS: SQUIRREL CAGE INDUCTION MOTORS ABOVE 200 HP, FORM WOUND STATOR. 4000 VOLTS AND HIGHER, ANTIFRICTION BEARINGS, SAFETY RELATED AND BALANCE OF PLANT

Recommended Tests/Inspections	Duty Cycle[1]		
	Continuous	Intermittent	Layup
Trendable			
Supply Voltage	24-48	24-48	
Running Current	6-12	12-24	
Motor Speed	24-48	24-48	
Bearing Temperature	6-9	6-9	
Winding Temperature	6-12	6-12	
Insulation Resistance	12-18	12-18	12-18
Polarization Index	12-18	12-18	12-18
Current Analysis	36-60	36-60	
DC Hipot (Step)	36-60	36-60	
Motor Vibration	6-9	6-9	
(Oil Analysis)[4]	C	C	
Winding Resistance	12-18	12-18	
Non Trendable			
External Inspection	12-18	12-18	12-18
Borescope Inspection[2]	60-72	60-72	
Disassemble/Inspect	120-180	120-180	
(Regrease)[3]	B	B	B
Surge Comparison	60-72	60-72	
Rotate by Hand			3-9

Legend

1. Numbers in charts are in months.
2. Boroscope Inspection for 1000HP and larger.
3. B refers to Appendix B, Table B-1 for grease lubricated bearings.
4. C refers to Appendix C, Table C-2 for oil lubricated bearings.
5. Off-line test = ▨

Note: Performance of off-line tests on large critical motors should be scheduled to coincide with plant refueling cycles.

TABLE 5-3

RECOMMENDED TESTS: SQUIRREL CAGE INDUCTION MOTORS 200 HP AND ABOVE. FORM WOUND STATOR, 4000 VOLTS AND HIGHER, SLEEVE, PAD OR DISC BEARINGS. SAFETY RELATED AND BALANCE OF PLANT

Recommended Tests/Inspections	Duty Cycle[1]		
	Continuous	Intermittent	Layup
Trendable			
Supply Voltage	24-48	24-48	
Running Current	6-12	12-24	
Motor Speed	24-48	24-48	
Bearing Temperature	6-9	6-9	
Winding Temperature	6-12	6-12	
Insulation Resistance	12-18	12-18	12-18
Polarization Index	12-18	12-18	12-18
Current Analysis	36-60	36-60	
DC Hipot (Step)	36-60	36-60	
Motor Vibration	6-9	6-9	
(Oil Analysis)[3]	C	C	
Winding Resistance	12-18	12-18	
Non Trendable			
External Inspection	12-18	12-18	12-18
Borescope Inspection[2]	60-72	60-72	
Disassemble/Inspect	120-180	120-180	
Surge Comparison	60-72	60-72	
Rotate by Hand			3-9

Legend

1. Numbers in charts are in months.
2. Borescope Inspection for 1000 HP and larger.
3. C refers to Appendix C, Table C-2 for oil lubricated bearings.
4. Off-line test = ▨

Note: Performance of off-line tests on large critical motors should be scheduled to coincide with plant refueling cycles.

TABLE 5-4
RECOMMENDED TESTS: WOUND ROTOR INDUCTION MOTORS UNDER 200 HP, RANDOM WOUND STATOR. LESS THAN 600 VOLTS, ANTIFRICTION BEARINGS, SAFETY RELATED AND BALANCE OF PLANT

Recommended Tests/Inspections	Duty Cycle[1]		
	Continuous	Intermittent	Layup
Trendable			
Supply Voltage	24-48	24-48	
Running Current	6-12	12-24	
Motor Speed	24-48	24-48	
Bearing Temperature	6-9	6-9	
Winding Temperature			
Insulation Resistance	24-36	24-36	24-36
Polarization Index			
Current Analysis			
DC Hipot (Step)			
Motor Vibration	6-9	6-9	
(Oil Analysis)[3]	C	C	
Winding Resistance	60-72	60-72	
Non Trendable			
External Inspection	12-18	12-18	
Borescope Inspection			
Disassemble/Inspect			
(Regrease)[2]	B	B	B
Surge Comparison			
Rotate by Hand			6-12

Legend

1. Numbers in charts are in months.
2. B refers to Appendix B, Table B-1 for grease lubricated bearings
3. C refers to Appendix C, Table C-2 for oil lubricated bearings.
4. Off-line test = ▨

TABLE 5-5
RECOMMENDED TESTS:
SYNCHRONOUS MOTORS 1000 HP AND ABOVE, FORM WOUND STATOR, 4000 VOLTS AND HIGHER, SLEEVE, PAD OR DISC BEARINGS, BALANCE OF PLANT

Recommended Tests/Inspections	Duty Cycle[1]		
	Continuous	Intermittent	Layup
Trendable			
Supply Voltage	24-48	24-48	
Running Current	6-12	12-24	
Motor Speed	24-48	24-48	
Bearing Temperature	6-9	6-9	
Winding Temperature	6-12	6-12	
Insulation Resistance	12-18	12-18	12-18
Polarization Index	12-18	12-18	
Current Analysis	36-60	36-60	
DC Hipot (Step)	36-60	36-60	
Motor Vibration	6-9	6-9	
(Oil Analysis)[2]	C	C	
Winding Resistance	12-18	12-18	
Non Trendable			
External Inspection	12-18	12-18	
Borescope Inspection	60-72	60-72	
Disassemble/Inspect	120-180	120-180	
(Regrease)			
Surge Comparison			
Rotate by Hand			6-9

<u>Legend</u>

1. Numbers in charts are in months.
2. C refers to Appendix C, Table C-2 for oil lubricated bearings.
3. Off-line test = ▨

TABLE 5-6
RECOMMENDED TESTS: DC MOTORS UNDER 100HP, 115 VOLTS OR 230 VOLTS, ANTIFRICTION BEARINGS, SAFETY RELATED AND BALANCE OF PLANT

Recommended Tests/Inspections	Duty Cycle[1]		
	Continuous	Intermittent	Layup
Trendable			
Supply Voltage	24-48	24-48	
Running Current	6-12	12-24	
Motor Speed	24-48	24-48	
Bearing Temperature	6-9	6-9	
Winding Temperature			
Insulation Resistance	24-36	24-36	24-36
Polarization Index			
Current Analysis			
DC Hipot (Step)			
Motor Vibration	6-9	6-9	
(Oil Analysis)[3]	C	C	
Winding Resistance	60-72	60-72	
Non Trendable			
External Inspection	12-18	12-18	
Brush Inspection	12-18	12-18	
Disassemble/Inspect			
(Regrease)[2]	B	B	B
Surge Comparison			
Rotate by Hand			6-9
Commutor Inspection	12-18	12-18	

Legend

1. Numbers in charts are in months.
2. B refers to Appendix B, Table B-1 for grease lubricated bearings.
3. C refers to Appendix C, Table C-2 for oil lubricated bearing.
4. Off-line test = ▨

Note: Performance of off-line tests on large critical motors should be scheduled to coincide with plant refueling cycles.

Section 6.0

References

6.0 References

6.1 EPRI Power Plant Reference Series, EL-5036 Volume 6, Motors.

6.2 NUREG/CR-4939, "Improving Motor Reliability in Nuclear Power Plants," Vol. 2, November 1987.

6.3 NUREG/CR-4939, "Improving Motor Reliability in Nuclear Power Plants," Vol. 3, November 1987.

6.4 Report of Large Motor Reliability Survey of Industrial and Commercial Installations, Parts I and II, Motor Reliability Working Group, IEEE Transactions on Industry Applications, Vol. IA-21, No. 4, pp 863-872, 1985.

6.5 "Improved Motors for Utility Applications," EPRI EL-4286, Vol. 1 & 2, 1763-1, Final Report, October 1982.

6.6 IEEE Work-in-Progress Report on Maintenance Good Practices for Motors in Nuclear Power Generating Stations - Part I 89TH0248-5PWR.

6.7 Nuclear Plant Reliability Data System (NPRDS), database operated by Institute of Nuclear Plant Operations (INPO).

6.8 NUREG/CR4939, "Improving Motor Reliability in Power Plants," Vol. 1, November 1987.

6.9 EPRI Power Plant Electrical Reference Series, EL-5036 Volume 16 Handbook to Assess the Insulation Condition of Large Rotating Machinery.

6.10 EPRI Power Plant Electrical Reference Series, EL-5036 Volume 1 Electric Generators.

6.11 IEEE Std 43-1974, IEEE Recommended Practice for Testing Insulation resistance of Rotating Machinery.

6.12 IEEE Std 56-1977, IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10,000 kVA and Larger).

6.13 IEEE Std 95-1977, IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.

6.14 IEEE Standard 286-1975, IEEE Recommended Practice for Measurement of Power-Factor-Tip-Up of Rotating Machinery Stator Coil Insulation.

6.15 IEEE Standard 522-1977, IEEE Guide for Testing Turn-to-Turn Insulation on Form wound Stator Coils for Alternating-Current Rotating Electric Machines - For Trial Use.

6.16 IEEE Standard 432-1976, IEEE Guide for Insulation Maintenance for Rotating Electrical Machinery (5 hp to less than 10,000 hp).

6.17 Antifriction Bearing Maintenance Manual, Antifriction Bearing Manufacturers Association .

6.18 Plant Engineering, June 18, 1987. Ultrasonic Testing.

6.19 EPRI Report GS-7352. "Manual of Bearing Failures and Repair in Power Plant Rotating Equipment", July 1991.

6.20 10 CFR Part 50 "Domestic Licensing of Production and Utilization Facilities".

6.21 NEMA-MG-1, 1978 (rev. 1982), "Motors and Generators", National Electrical Manufacturers Association, 1982.

Appendices

Appendix A

Glossary of Terms

Motor Types

Direct Current Motor (DC motor). A motor that operates from direct current power.

Induction motor. An alternating current motor in which the primary winding on the stator is connected to the power source and a squirrel cage secondary winding on the rotor carries induced current.

Wound Rotor Induction motor. This motor is similar to the squirrel cage induction motor, except that the rotor carries a three-phase winding.

Synchronous motor. A motor in which the speed of operation is exactly proportional to the supply frequency. It has field poles excited by direct current.

Motor Components

Antifriction Bearing. A bearing incorporating a peripheral assembly of rotating elements which are used to support and control the shaft of a motor. The rotating element can be ball or roller type.

Armature. The part of the motor containing the winding in which an alternating voltage is generated by relative motion of a magnetic field. It is the stator of induction and synchronous motors and the rotor of a DC motor.

Brush Holder. A structure that supports a carbon brush and enables it to be maintained in contact with the sliding surface (commutator or slip ring).

Commutator. An assembly of conducting members insulated from one another, in the radial-axial plane, against which brushes bear. Used to enable current flow from stationary to rotating parts.

Die Cast Rotor. The rotor of certain induction motor in which rotor bars and short circuiting rings are manufactured as a single casting.

Fabricated Rotor winding. The rotor winding of certain induction motors in which bars and short circuiting rings are made of copper, brass, bronze, or aluminum bars inserted into rotor slots individually and brazed or welded to short circuiting rings.

Field Winding. A winding on the rotating part of a synchronous motor whose sole purpose is the production of the main electromagnetic field of the motor.

Form-Wound Stator Coils. Coils that are wound, shaped, and insulated before insertion into stator slots.

Phase Separator. Insulation sheets placed between phases of random wound stator windings.

Pigtail. A stranded copper wire shunt that connects carbon brush to brush holder.

Random wound. A method of manufacturing stator windings of motors rated 600 volts and below in which round magnet wires are coiled into loops of correct dimensions and installed in stator slot without forming or pre-insulating.

Sleeve bearing. A bearing with a cylindrical inner surface often made of tin, zinc, lead, etc in which the journal of the rotor shaft rotates.

Slip ring (or Collector Ring). A metal ring suitably mounted on an electric machine that through stationary brushes conducts current into or out of the rotor.

Slot Liner. A sheet of insulation used to line a slot before the winding is placed in it.

Thrust bearing. A bearing designed to carry an axial load so as to prevent or to limit axial movement of the shaft or to carry the weight of a vertical rotor system.

Vacuum-Pressure Impregnation (VPI). The filling of voids in a coil or insulation system by withdrawing air or solvent, if any, from the contained voids, by vacuum, admitting a resin or resin solution, pressurizing, and finally curing, usually with the application of heat.

Maintenance

Corrective Maintenance. Activities performed in response to unsatisfactory equipment conditions, including repair and replacement activities.

Preventive Maintenance. Activities performed to prevent unsatisfactory equipment conditions from occurring, or if they occur, to prevent them from accumulating, so that the need for corrective maintenance is reduced.

Predictive Maintenance. A subset of preventive maintenance, referring to activities performed to develop maintenance schedules according to equipment history and/or its present condition, testing or analysis techniques, or a combination of these.

Tests

AC Hipot Test (High Potential Test or Overvoltage, Test). A test that consists of the application of an AC voltage higher than rated voltage for a specified time (usually 1 minute) for the purpose of determining adequacy against breakdown of insulation under normal (rated) conditions.

DC Hipot Test (High Potential Test or Overvoltage Test). A test that consists of the application of a DC voltage higher than rated voltage for a specified time (usually 1 minute) for the purpose of determining adequacy against breakdown of insulation under normal conditions. For equivalency of test, the DC Hipot Test is usually carried out at 1.7 times the AC Hipot Test value.

DC Step Voltage Test (DC Absorption). A controlled overvoltage test in which designated voltage increments are applied at designated times and leakage current recorded. Time increments may be constant or graded.

EL-CID Test. A low power, low core flux level test to search stator cores for hot spots. It uses a Chattock coil to bridge adjacent stator teeth. The coil is used to sweep the entire stator.

Insulation Resistance Test. A test for measuring the resistance of insulation under specified conditions. The quotient of a specified direct voltage maintained on an insulation system divided by the resulting current at a specified time after the application of voltage under designated conditions of temperature, humidity, and previous charge.

Partial Discharge Test. A test, responsive to the high frequency discharge, that only partially bridges the insulation between conductors. Is used to measure the relative discharge intensity.

Polarization Index Test. The ratio of the insulation resistance of a motor winding measured at one minute after voltage has been applied divided into the measurement at 10 minutes

Power Factor Tip-Up Test. The difference in power factors measured at two different designated voltages applied to an insulation system, other conditions being constant. This test is used mainly as a measure of discharges, and hence of voids within the system at the higher voltage.

Resistance Measurement Test. A measurement of the stator winding resistance with a Kelvin Bridge type of measurement device to determine poor connections within the winding or at the winding terminations.

Side-Band Analysis. A technique for analyzing stator current in induction motors with Fast Fourier Transform equipment to determine the presence or absence of broken rotor bars.

Surge Comparison Test. A test for evaluating the integrity of turn insulation in the stator winding by transmitting electrical pulses from twin capacitors into two different phase coils and comparing the damped oscillating current wave shapes on the oscilloscope of the test equipment.

Ultrasound Test. A test which listens for ultrasonic noise produced by antifriction bearings to determine if deterioration may be occurring. Ultrasonic frequencies are selectively monitored. A 10-12dB increase provides warning of bearing failure before changes in temperature or vibration develop. This test equipment can also be used to detect partial discharges in stator windings.

Appendix B

Regreasing Guidelines for Motors with Antifriction Bearings

1.0 Purpose

The purpose of this appendix is to provide recommended guidance on:

- How often motor bearings should be greased.
- How much grease should be added.
- How grease should be added.

2.0 Discussion

This appendix was prepared to minimize the potential of over greasing grease-lubricated antifriction bearings in motors. The only true way to prevent over greasing is to disassemble the motor, clean the bearing and grease cavity, and hand pack the bearing and grease cavity. However, the information contained in this appendix will aid in establishing a motor greasing program that will minimize over greasing. Refer to Section 2.2.2 and 2.2.3 of the Guide for further information on bearing types and lubrication requirements.

3.0 Grease Degradation

Grease degradation is a gradual process; grease does not abruptly cease to be an effective lubricant. Most grease degrading influences are present only while the motor is running. Lubrication practices must therefore take into account the motor's operating cycle.

Grease degradation can occur because of the following:

- Hardening of grease, such that it no longer freely feeds oil to bearing surfaces. This can result from absorption of dirt or moisture, and can occur because of oxidation over a long period of time.
- Chemical breakdown caused by excessive heat. This can occur by overfilling the grease cavity and can be aggravated by high winding temperatures, especially in totally enclosed motors.
- High bearing loads, usually caused by excessive belt tension on side loaded bearings and by misalignment.
- Oil separation from the base material of the grease. This usually occurs when a motor is not rotated for a long period of time and the grease is not mixed in the bearing.

Although rotating a motor periodically will mix the grease in the bearing it does not mix the grease in the bearing grease cavity around the bearing.

4.0 Guidelines

4.1 Prerequisites

There are certain prerequisites that must be verified before adding grease to a motor. They are listed below:

- Determine that the bearing is a greasable bearing. Sealed bearings do not accept grease.
- Before grease is added, the fill plug or grease fitting, the drain plug, and the grease gun need to be cleaned with a suitable grease solvent and wiped with lint-free rags.
- Remove the drain plug and by use of a metal rod or equivalent, ensure that the drain path is clear of any hardened grease.
- Immediately before regreasing, ensure that the motor to be regreased is at a stable operating temperature, if possible. This allows the hot grease in the bearing grease cavity to be purged through the bearing and out of the drain hole more efficiently than it would if the grease was at ambient temperature. Greasing the motors while they are hot will provide better grease distribution of the new grease entering the bearing grease cavity.

4.2 Post-Requisites

- After greasing is complete, the motor should run until stable operating temperatures have been reached (typically 1 to 2 hours if motor is greased while hot, 2 to 3 hours if the motor is greased while at ambient temperatures) with the drain plug removed to allow further purging of the excess grease in the bearing grease cavity due to thermal expansion.
- After the excess grease ceases to be pushed out of the drain plug, the drain plug area should be cleaned to remove purged grease and the drain plug installed.
- The grease that is purged from the bearing grease cavity should be visually inspected for signs of oil separation, soapiness, or indications of metallic particles.

4.3 How Often Should Bearings Be Greased?

This interval depends on whether the motor is in layup/standby mode or continuous operation.

4.3.1 Motors in Layup or Standby Mode

Since most degrading influences are present only while the motor is operating, except oil separation, the regreasing intervals will be longer for motors in layup/standby mode than those given for motors in continuous operation (typically 1.6 to 2 times). The intervals are listed in Table B-1 of this guideline and are based on the assumption that the motors are rotated at least semi-annually. However, if the motors are in layup/standby mode for several years, the motor should be disassembled, the old grease removed, and new grease hand packed to a 50 percent fill of the bearing grease cavity before the motor is placed into operation. This recommendation is made because periodic motor rotation only mixes the grease in the bearing and not the grease in the bearing grease cavity.

4.3.2 Motors in Continuous Operation

Several factors determine the greasing intervals for motors in continuous operation. They are:

- Motor rpm
- Motor horse power (direct relationship to bearing size)
- Motor load configuration (direct coupled versus side loaded)
- Bearing operation temperature
- Bearing size
- Motor environment (humid, hot, dirty, etc.)

All manufacturers concur that the higher the speed, the larger the bearing, and the more dirt or moisture is present, the more often a bearing needs regreasing. Also side loaded motors (as those in belt drives) need to be regreased more often than direct coupled motors. Motors in high ambient temperature areas (above 140°F) are also in need of regressing more often than motors in normal environments. However, not all agree on regreasing intervals. Table B-1 is a merger of numerous published regressing intervals with the most commonly suggested intervals listed with a correction factor to support plant operating cycles.

> Note 1: Because of the clean environment in a nuclear plant) a motor located in a dirty environment was not considered as part of the matrix in Table B-1.
>
> Note 2: For intermittent duty cycle motors, the greasing intervals should be the same time frame as continuous duty cycle motors measured by their operation time not calendar days.
>
> For example, if an intermittent duty cycle motor runs 50 percent of the time and meets the same characteristics in Table B-1 as a continuous duty cycle motor which has a 24- to 36-month regressing interval, then the intermittent duty cycle motor's regreasing interval will be 48 to 72 months.

TABLE B-1
REGREASING INTERVALS

RPM			HP		Load Config.		Ambient Temp (F°)		Operation		Regreasing Interval Months
1200	1800	3600(a)	>100(a)	<100	Belt (a)	Direct	>140 (a)	<140	cont(a)	stby/layup	
X				X		X		X	X	(b) For all standby or layup motors	36-54(c)
X				X		X	X		X		24-36(d)
X				X	X			X	X		24-36(d)
X				X	X		X		X		12-18(e)
X			X			X		X	X		24-36(d)
X			X			X	X		X		12-18(e)
X			X		X			X	X		12-18(e)
X			X		X		X		X		6-9(f)
	X			X		X		X	X	(b) For all standby or layup motors	36-54(c)
	X			X		X	X		X		24-36(d)
	X			X	X			X	X		24-36(d)
	X			X	X		X		X		12-18(e)
	X		X			X		X	X		24-36(d)
	X		X			X	X		X		12-18(e)
	X		X		X			X	X		12-18(e)
	X		X		X		X		X		6-9(f)
		X		X		X		X	X	(b) For all standby or layup motors	24-36(d)
		X		X		X	X		X		12-18(e)
		X		X	X			X	X		12-18(e)
		X		X	X		X		X		6-9(f)
		X	X			X		X	X		12-18(e)
		X	X			X	X		X		6-9(f)
		X	X		X			X	X		6-9(f)
		X	X		X		X		X		6-9(f)

(a) Motors with these design characteristics tend to require less time between greasing intervals. The number of characteristics designated by that each motor has a X under (e.g., 1.2.3.4 or 5), was used for determining the greasing interval.

(b) The greasing intervals for motors in the standby or layup mode should be 1.5 times that of motors that are operating continuously.

(c) Once/3 operating cycles not to exceed 58 month

(d) Once/2 operating cycles not to exceed 40 months.

(e) Once/operating cycle not to exceed 22 months.

(f) Twice/operating cycle not to exceed 11 months.

4.4 How Much Grease Should Be Added?

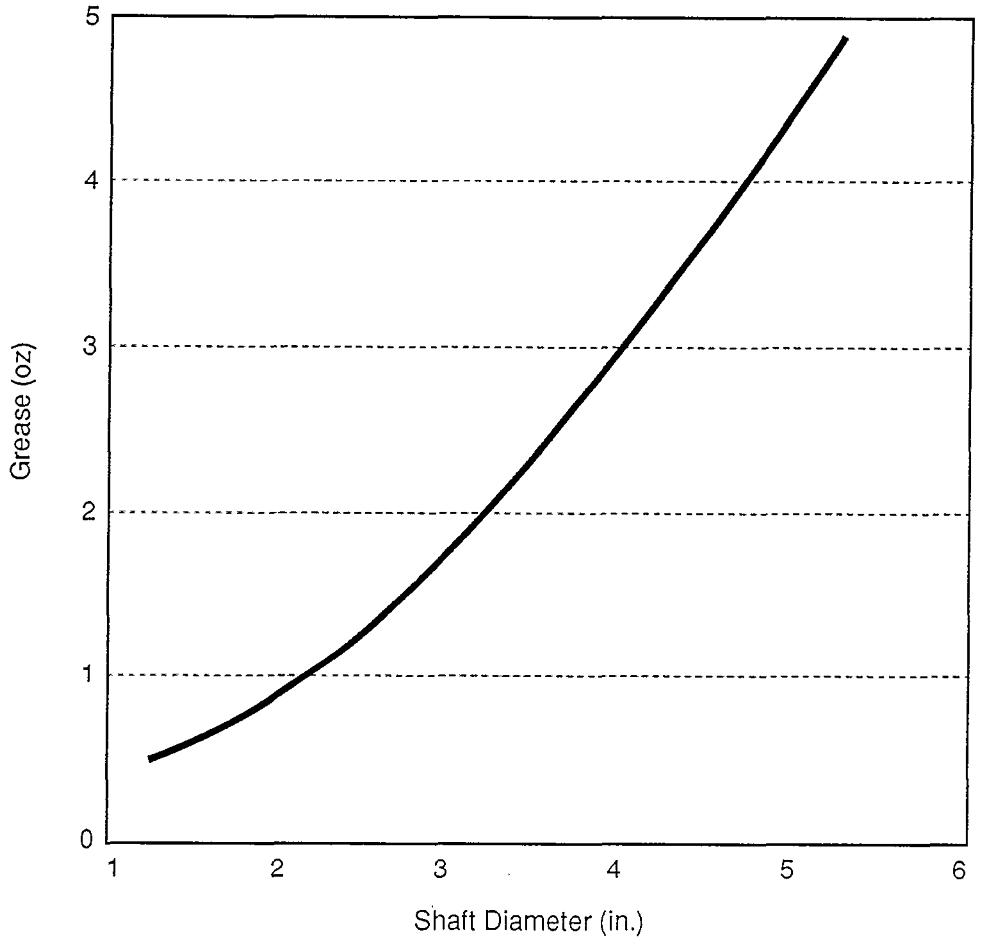
This is another area in which different manufacturers give various recommendations. However, to provide guidance on the amount of grease to be added for different size motors, a grease weight versus shaft diameter curve was determined to provide the most useful information. See Figure Bat.

For ease of plant implementation, the number of ounces of grease should be converted into strokes for each different type grease gun that is used.

4.5 How Should the Grease Be Added?

Unfortunately, it is better to grease some motors while running and others while de-energized depending on how the bearing pumps the grease, the bearing cap clearance, grease Viscosity, bearing grease cavity design, and other factors. There is no universal method that will work for all motors. Only experience can dictate which is best for each motor. It is recommended that a motor be greased while in operation unless experience or operating conditions dictate otherwise. The reason for this is that bearing balls act as tiny viscosity pumps and will aid in purging the old grease out and pulling the new grease in if the motor is running. This action does not take place when the motor is stopped.

If grease cannot be added while the motor is operating or while the bearings are near operating temperatures, then the possibility of overgreasing the bearing grease cavity is greater and some consideration should be given to reducing the amount of grease added to possibly the same amount as recommended for the motors in standby.



Note: For motors in the standby or layup mode, the ounces of grease identified by the above curve for any given motor should be divided by 2 and that value should be used for the amount added.

FIGURE B-1
GREASE AMOUNT CURVE

5.0 References

1. EPRI, Power Plant Electrical Reference Series, Volume 6, Motors.
2. SKF Bearing Maintenance Institute Manual. (This manual is only obtainable by attending SKF bearing maintenance seminar.)
3. Anti-Friction Bearing Manufacturers Association (AFBMA) Standards Nos. 1, 1984 and 9, 1978.
4. AFBMA — Anti-Friction Bearing Maintenance Manual.
5. General Electric's Guide for Relubrication and Relubrication Intervals for Grease-Lubricated Ball and Roller Bearing Motors. (B-19).
6. FAFNIR, TEXTRON, Inc. Manual, "How to Prevent Ball Bearing Failures."
7. EPRI, NMAC — Lube Notes written by Bob Bolt.
8. NRC Information Notice No. 88-12, "Overgreasing of Electric Motor Bearings," NER 880492.

APPENDIX C

Oil Monitoring for Electric Motor

1.0 Purpose

This appendix will discuss the use of oil as a lubricant in electric motor bearings and provides recommendations on its testing methods and intervals to aid in predicting possible motor bearing failures.

2.0 Discussion

Oil is the primary lubricant for motors which use plain type bearings. These motors range in sizes from fractional-horsepower motors with wick-oiled sleeve bearings to heavily loaded sleeve or plate bearings in motors typically above 500 hp.

Oils used in most electric motors will be petroleum based derivatives which vary in mixture dependent on motor application and environment. These derivatives are usually turbine grade oils because of the stability and load carrying characteristics of these types of oils. Synthetic oils have gained popularity in high temperature applications and for motors with long running intervals between oil changes. When considering use of synthetic oils, possible effect on other motor parts should be considered. Some synthetic oils may attack paint, rubber, and electrical insulation and may not provide suitable heat transfer characteristics.

Oils used for lubricating also have other chemical additives which are used to enhance some of the natural properties of lube oil. These additives fall into several categories such as:

Antiwear Additives: Aids the oil's load carrying capabilities and coats moving parts for scuff prevention

Inhibitor Additives: Slows oxidation, rust, and corrosion

Special Additives: Used to enhance certain characteristics in the oil such as pour, bacteria resistance, viscosity adjusters, thermal conductivity, etc.

Oil not only functions as a lubricant, but also provides cooling for bearings. The oil flows through the bearing to remove heat away from the bearing and shaft area. In some larger loads or continuous duty applications, motors will be designed with oil coolers to assist in keeping the oil cool and extend its useful life.

3.0 Oil Degradation

Oil degradation is caused by two general mechanisms - contamination and chemical breakdown.

Contamination is the primary cause for oil "breakdown" The sources of contamination are both external and internal. Dirt, water, air entrapment and other materials can enter the machine from faulty seals or gaskets, condensation, and improper maintenance. Contamination can also occur from internal sources such as metal wear from moving parts of the motor (i.e. bearings).

Chemical breakdown can have many causes, but the usual source is excessive heat. Heat usually promotes chemical changes in the oil, such as additive separation and oxidation. These changes deplete the lubricating properties of oil. Changes in oil properties are useful in trending oil quality or indicating signs of bearing degradation.

4.0 Guidelines

Understanding how oil degrades is part art and part science. There are some very definable conditions, but the symptoms can have many sources.

Oil sampling can be a very useful tool in the effort to diagnose the condition of a machine. Oil can be sampled for the following reasons:

- To ensure correct oil is used
- To ensure equipment is clean and in good operating condition
- To provide trending data that can indicate lubricant breakdown
- To provide trending data that can indicate bearing wear
- To detect cooler leaks (if applicable)

In an effort to prevent or predict bearing failures, it is important to establish a baseline condition for the motor parts and the lubricant condition.

Once a machine has been in service, periodic samples can be taken to establish the oil's condition. The oil condition should be monitored and trended over a period of time to determine if any deviations in measured properties are occurring or have occurred since the last sample. These sampling routines would allow for planning machine service intervals. Typical warning limits for changes in oil properties can be found in NMAC publication NP4916R1, Lubrication Guide.

Sampling is an art within itself. Before the approximate condition of any medium can be detected, a proper sample must be taken. Oil should be sampled when the system is stable, ahead of any filters in the system, and before any make-up oil is added to the motor. Also the sample line should be opened and a small amount of oil allowed to flow through the line to flush any suspended particles which may have been left in the line. Samples should be drawn into a clean container. The American Society of Testing Methods (ASTM) provide standards and instructions for sampling such as ASTM D4057, "Practice for Manual Sampling of Petroleum Products" and ASTM D4177, "Method for Automatic Sampling of Petroleum and Petroleum Products".

Testing should begin with the simple methods that can be performed by sight and smell. This type of testing can be done readily and could prove to be most valuable when trying to determine equipment condition or whether to consider running more in depth test. If the oil has a sudden change in clarity, color, or odor, this should signal the need to have a laboratory test performed to determine what condition(s) could possibly cause the change(s).

Sight and smell can be done at any convenient interval to detect lubricant degradation. It is more difficult to sample those machines that are in constant service or are only accessible during outages. The information that is available from the readily accessible motors can be used for comparison to the motors that are not, if approximately the same operating parameters (hp. speed, operating temperature) are used. It may be prudent to establish a battery of tests that would possibly reveal the condition of the lubricant and apply those tests during every outage or every other outage depending on baseline information and trended data.

Motors which are in storage and have oil reservoirs, should be filled to the high level and the shaft rotated by hand on at least a semi-annual basis. The oil in these machines will probably be more susceptible to condensation; however, the oil should not experience any significant chemical changes due to the controlled environment in which the motor should be stored.

Figure C-1 below taken from June 1991 issue of NMAC Lube Notes discussed the failure modes associated with size and concentration of particles found in lubricating oil. Monitoring the size and concentration of particles in lube oil samples can be a very good trending tool for predicting bearing wear. By tracking these values over a period of time, a bearing replacement plan can be worked out.

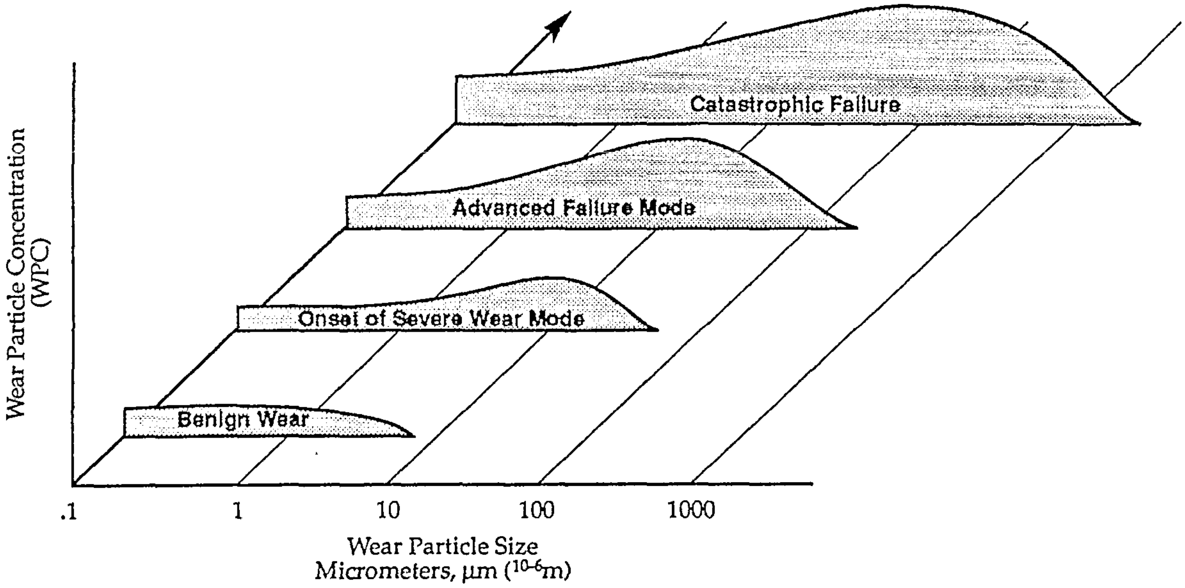


FIGURE C-1
FAILURE MODES ASSOCIATED WITH SIZE AND CONCENTRATION OF PARTICLES

There are several tests which can provide this information for a motor owner. However the choice of test is dependent type of material and suspected particle size. The chart in Fire C-2 compares the ability of several common tests which are used to detect particles.

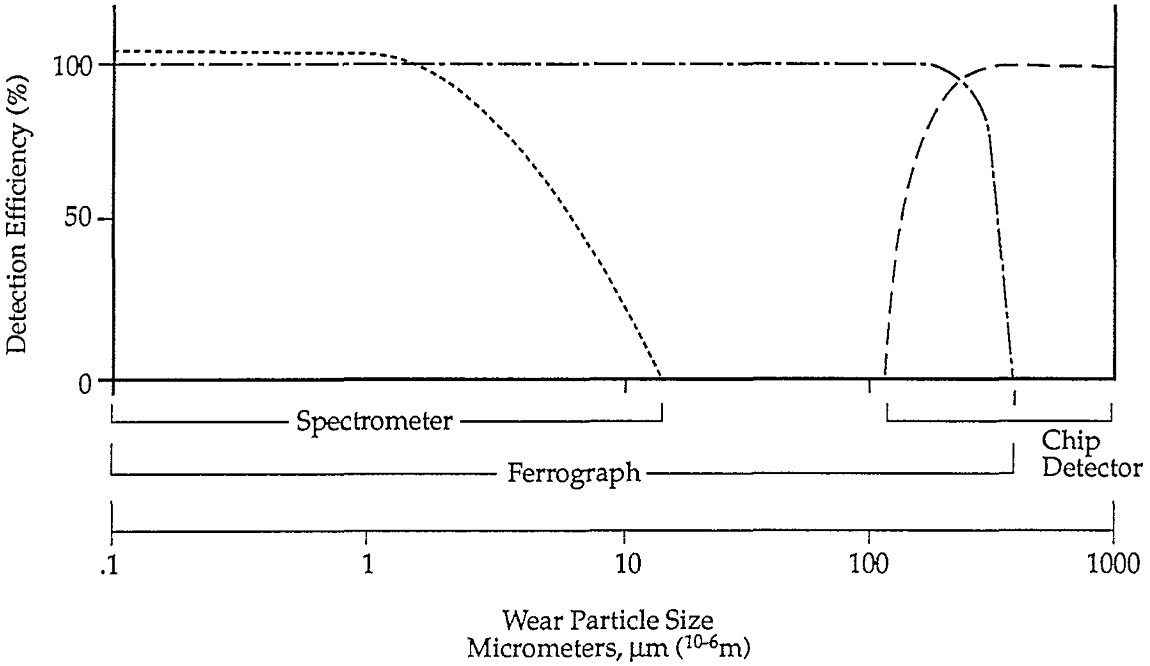


FIGURE C-2
TESTS USED TO DETECT PARTICLES

We can see from the chart that Ferrography has a very broad range for particle detection. However, it is limited in that it is most effective in detecting magnetic materials, whereas, emission spectroscopy can detect various common metals and inorganic compounds. Particle Count Analysis may also be performed to determine total number of all particles in various micron ranges. A combination of these two tests would provide a good program for particle detection in oil.

A list of laboratory tests is included at the end of this section (Table C-1) and also there are several EPRI documents, GS-7352, "Manual on Bearing Failures and Repair", and NP-4916R1, "Lubrication Guide", which discuss the merits of several tests.

Whichever methods are chosen, it is important to track oil quality in a time vs condition manner in order to form a predictive maintenance scheme.

The purpose of oil in an electric motor is two-fold as mentioned previously. Oil provides cooling to the bearing, but it also must provide load carry ability by preventing metal to metal contact. The ability of oil to provide this function is a measure of its viscosity.

Viscosity is the measure of the oil's resistance to flow, otherwise stated as the thickness or thinness of the oil. Viscosity change is an important measure of used oil condition. An increase in viscosity can indicate oxidation has taken place or oil has been contaminated with dirt or water. An oil's viscosity will decrease if contaminated with a solvent or another grade of oil.

Most often the first physical indicator of oil trouble will be color. Color changes often signal oxidation has taken or is taking place. Oxidation of an oil occurs when oxygen chemically combines with oil molecules. As the oil is exposed to heat and air, the greater the oxidation. Oxidation in itself is not harmful, but as oxidation increases, acids are formed which attack and corrode metals. Oils are often blended with oxidation inhibitors, but these only retard the oxidation process. Oil has a limited operation life and oxidation is a good indicator of end of useful life for oil.

We have described several tests which are relatively cheap and simple to apply in an effort to detect oil condition. Bearing condition can be a useful by-product of this testing. Table C-2 makes several recommendations to assist in establishing a skeletal oil analysis program.

TABLE C-1
OIL ANALYSIS TESTS

Symptom	Possible Cause	Test	Cost
Viscosity change	Water or High Temperature	Water content	Low
		ASTM 445 Viscosity	Low
Viscosity Change, Color change	Oxidation	ASTM 974, Neutralization number	Low
		ASTM 664, Neutralization number	Moderate
		ASTM 2296, Alkalinity.	Moderate
Particles	Bearing deterioration or foreign matter	Spectroscopy	Low
		Particle Count	Moderate
		Direct Reading Ferrography	Moderate
		Analytical Ferrography	High

Testing of oil properties must take into account the operating cycles of each motor and the availability of the sample points. These periods have been chosen to provide a baseline for monitoring oil quality and to build a foundation for bearing condition monitoring.

TABLE C-2
TEST PERIOD

Test	Period
Water Content	3-18 months
Viscosity	3-18 months
Oxidation	3-18 months
Spectroscopy	3-18 months
Ferrography, Direct Reading or Particle Count	3-18 months
Ferrography, Analytical	12-24 months (or as needed for problem determination)

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