ELECTRIC POWER RESEARCH INSTITUTE

Impact of Pulverizer Performance

Pulverizer Diagnostics for Improved Plant Dynamic Performance and Reliability

2014 TECHNICAL REPORT

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Pulverizer Diagnostics for Improved Plant Dynamic Performance and Reliability

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Abstract

Coal pulverizers play an important role in all aspects of power plant performance, including availability, efficiency, and responsiveness. In relationship to dynamic response, pulverizer response often limits a plant's maximum load rate-of-change. Improved pulverizer control has the potential to increase overall plant responsiveness at many plants, but not all pulverizer response problems are control-related problems. Improved control is becoming more important as flexible operation capabilities, including load following and two-shift operation, are at a premium to better meet the demands of competitive markets and the addition of renewable generation sources. Monitoring and/or testing of pulverizer performance will make it possible to differentiate pulverizer maintenance problems from control hardware and tuning problems. Such determinations will support maintenance planning and tuning of controls for pulverizers, ensuring optimal pulverizer performance and enabling optimum response to load changes. Tools are needed to identify pulverizer response problems and determine if the problems involve pulverizer mechanical issues or are control-related.

The primary objective of the project that is the subject of this report is to identify a mechanism for monitoring pulverizer operation in real time and for testing a pulverizer on-line to determine its responsiveness (or change in responsiveness). Results can be used to determine if the pulverizer needs maintenance or if the control system components need repair or tuning. Diagnostic rules and fault signatures compiled from this study will eventually tie into a fleet-wide prognostic and health management study. The effort concentrates on the use of typical or standard instrumentation. However, the study also considers the value of additional instrumentation that can provide more robust monitoring of the coal pulverizer.

Keywords

Advanced pattern recognition
Asset fault signatures (ASF)
Coal mills
On-line testing
Performance monitoring
Pulverizers

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Section 1: Introduction

The coal pulverizer is a critical piece of equipment for optimal combustion in coal-fired electric utility plants. Pulverizer systems are vital to the availability, efficiency, and responsiveness of coal-fired boilers. Plants use coal pulverizers in a direct-fire system to grind the fuel to an appropriate fineness and dry the material just before it enters the boiler. Coal pulverizers are often the largest cause of forced derates in a plant. While these do not typically result in removal of the unit from service, mill issues do increase maintenance expenditures throughout the year. Mill performance can also directly influence combustion, NOx formation, unburned carbon, and boiler slagging [1].

Most coal pulverizers were designed as a baseload piece of equipment. Generating plants are now required to undergo load following, operate at reduced load for extended periods, or cycle off-line completely at low-demand periods. With the increasing demands of competitive markets, more prominent renewable energy sources, and tighter restrictions on emissions, companies continue to utilize coal pulverizers farther outside of original design criteria.

Not all pulverizer performance issues are control related. Monitoring coal mills via controlled process variables and instrumenting for other measured values is vital to maximizing performance of not only an individual pulverizer, but the boiler as well. Evaluation of the signatures and patterns of mill process data can provide a basis for effective predictive monitoring practices. An overall goal for monitoring a fleet of pulverizers is to diagnose and identify the source of performance problems and differentiate among equipment deterioration, control issues, faulty instrumentation, and fuel changes. This study concentrates on utilizing a plant's historicized data to develop on-line diagnostic methods for use by plant staff, central monitoring centers, and others. This project was initiated to identify fault signatures and develop on-line process anomaly detection methods.

Background

The coal pulverizer is the key processing component of the fuel delivery system, and its performance is instrumental in the availability, efficiency, and responsiveness of the generating facility by providing consistent properly sized fuel for combustion. The coal is crushed to a very fine, powder-like consistency to allow the greatest amount of surface area per volume and higher efficiency during combustion. Coal size is typically reduced through three different means: impact, crushing, and attrition. Different mill types exist that incorporate one or more of these means to crush the coal. This study focuses on Babcock & Wilcox (B&W) MPS-type coal pulverizers, a form of vertical air-swept pulverizer in which coal is fed from above onto the center of a rotating table. Centrifugal force uniformly feeds the coal outward, forcing the coal under spring-loaded rollers or "tires," which reduces the size of the coal. Figure 1-1 shows a cutaway of an MPS-style mill. A description of the host site's generating unit can be found in Appendix A.

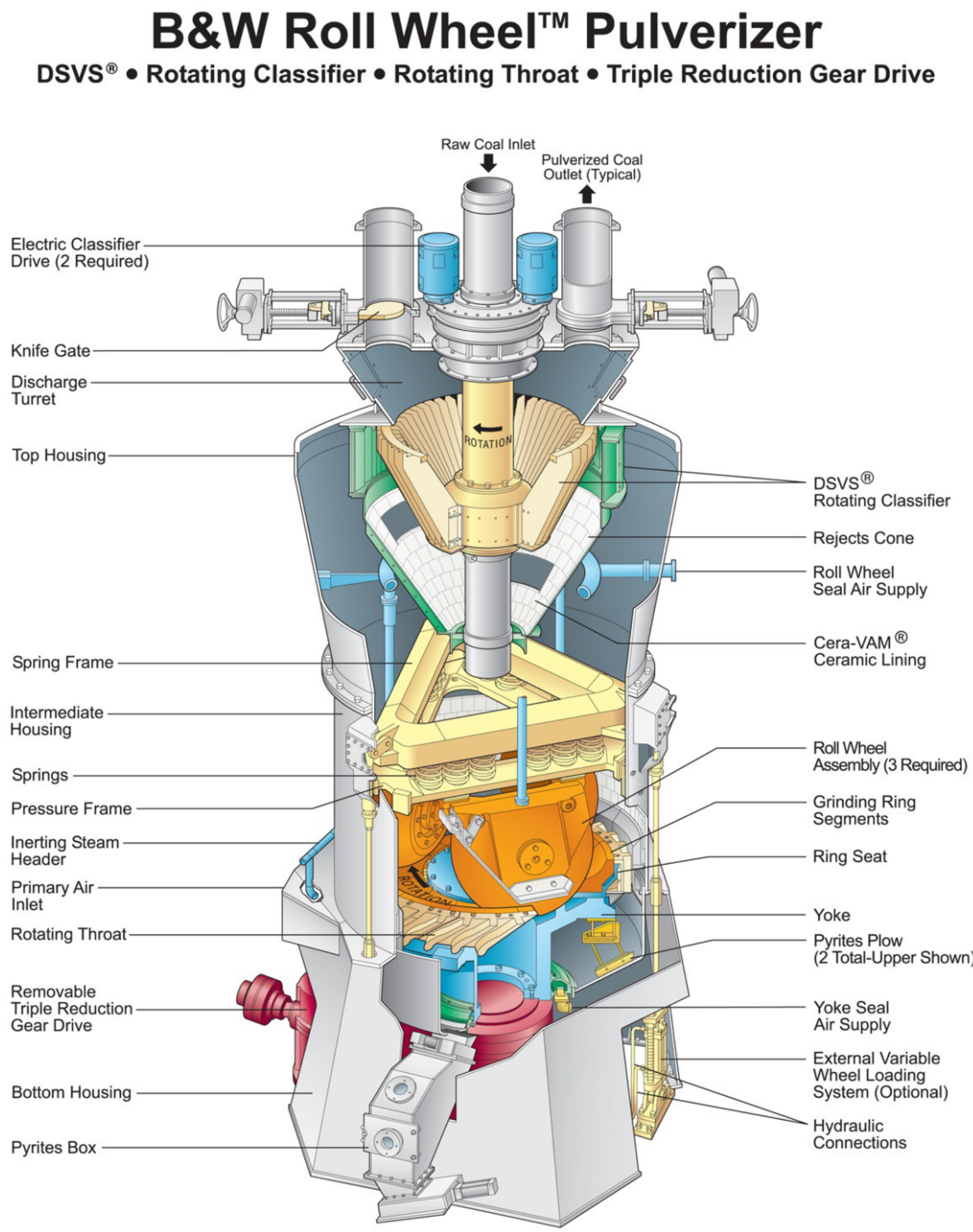

Figure 1-1
MPS pulverizer cutaway diagram
Courtesy of The Babcock & Wilcox Company

In addition to grinding the coal, pulverizers also dry the fuel to improve combustion and to mitigate pluggage in the coal pipes. Hot primary air enters the mill from below the grinding table. As the air enters the grinding zone by flowing through a peripheral annulus at the perimeter of the table, known as the *throat*, it fluidizes the particles that have just passed under the tires. Velocity at the throat is very important because it must lift all the fuel particles, reducing spillage to the hot-air section below the table. As the coal particles are lifted, velocity decreases, allowing larger particles to fall back into circulation. The particles must also pass through a mechanical classifier, either stationary or dynamic, that causes coarse particles to fall back to the grinding zone. The very fine particles contain more surface area, allowing the hot air to quickly vaporize moisture content as they undergo classification.

The temperature of the coal-air mixture exiting the mill is lower than the temperature of the entering hot air because of the thermal energy required to reduce coal moisture. The hot air, evaporated moisture, and pulverized coal then flow directly to the boiler. The fineness of the coal that passes into the burner lines directly affects boiler performance. Fuel particles typically have less than two seconds to complete the combustion process in the boiler. Any unburned carbon (UBC) then carries through the boiler and is collected downstream along with the fly ash. In addition to representing a direct efficiency loss, UBC may also contribute to increased boiler slagging, fouling, poorer steam temperature control, and increased emissions. Particle fineness proves to be of high importance in this process; therefore, optimizing pulverizer performance and limiting maintenance downtime is critical to running an efficient operation.

A fleet of pulverizers is typically used, although the total number of mills per boiler varies based on the size of the unit and throughput of the mills. As little as one mill can be used to feed a boiler, although this greatly limits boiler responsiveness. Typical arrangements may have 6–12 mills per unit, with some units considered "mill-critical," where all mills must be in operation in order to supply full load from the boiler. In the design of a coal-fired unit, it is beneficial to have one more mill than needed so that full load may be attained with a mill down (for maintenance, for example). Figure 1-2 shows typical causes for mill downtime.

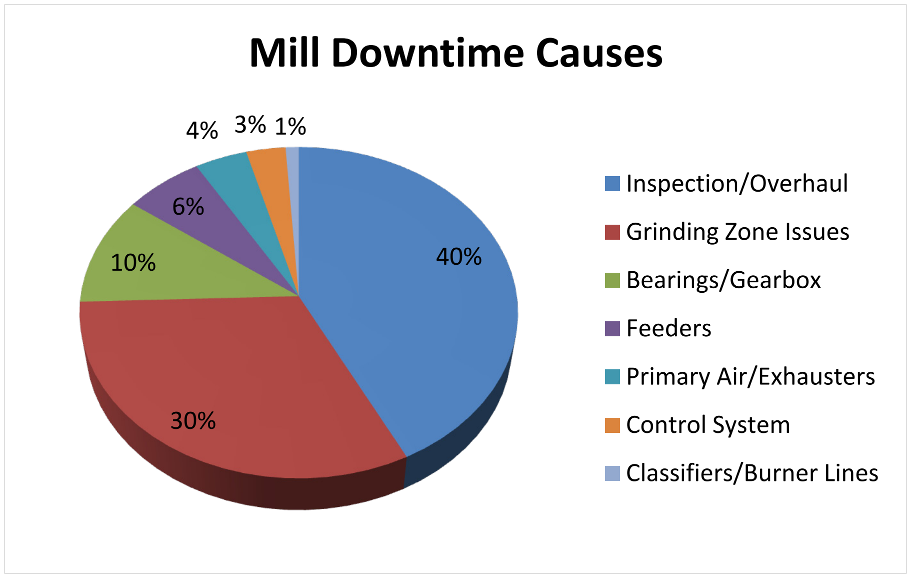

Figure 1-2
Mill downtime causes, averaged from a previous ECG, Inc. study

The Milling Process

The pulverizer operates through several different states including startup, steady state, load shifts, and shutdown. Interactions between various mill conditions and coal quality add to the complexity of this process. Some attempts have been made to quantify these milling stages with mathematical models [2].

The startup state includes any requirements and processes to bring the mill from an off-line state to running at a steady load. The warm-up process begins when hot primary air flow is directed through the mill. In this stage the mill motor remains off. Getting reference readings on instrumentation can be done during the warm-up process, looking at air flow, temperature, and pressure readings with only clean air passing through the mill.

The next step during startup requires powering the mill motor. No-load amps can be indicative of possible issues inside the mill prior to running the mill with coal. Comparing no-load amps from one startup to the next on a single mill, as well as comparing no-load amps of mills across a unit and looking for deviations from each other, can provide early indications of something dragging or rubbing in the mill. Gearbox issues may also be detected during no-load operation.

The final step in the startup process involves powering the mill feeder and introducing coal into the mill. At this point, the differential pressure will increase as coal is crushed and enters the fluidized bed just above the throat. With some additional instrumentation, a considerable amount of information can be gained during this stage regarding the setup and integrity of the grinding elements. Engineering Consultants Group, Inc. has an analytical instrumentation product for use on CE Raymond-style mills. This product monitors the deflection of the three individually loaded journal assemblies called RBC. During the startup, the moment the journal lifts off from the minimum stop bolt should be the same for all three journals. A different liftoff would indicate incorrect ring-to-roll clearance. Looseness in the spring can, as well as unequal spring properties, can also be revealed.

The pulverizer then carries out the steady state process in which the size of coal particles entering the mill is reduced and the fuel is dried and then classified to optimize combustion in the boiler. Again, utilizing ECG's RBC technology on Raymond-style mills, grinding surface information can be gained by looking at the spectral data of the journal displacement data at steady load.

Load shifts and changes in coal properties may affect the mill's performance. Understanding how a mill performs at loads other than maximum capacity and with different types and blends of coal passing through is vital to monitoring the unit as a whole.

Finally, the shutdown process involves removing coal flow and allowing all final pulverized coal particles to flow out from the mill. It is during this state that the pulverizer must be adequately cooled to prevent any fires with remnants of coal settling in the mill as air flow drops.

Section 2: Data Collection

Data was collected for this project to provide the real-time diagnosis of pulverizer performance and reliability with the expected tie-in to advanced pattern recognition (APR) modeling packages and EPRI's Diagnostic Advisor. The data acquisition was to a large degree limited to what is considered available from typical plant instrumentation. An ancillary aspect of this project was to identify any essential additional instrumentation that might be added to the monitoring system to justifiably enhance the troubleshooting and fault detection process (Figure 2-1).

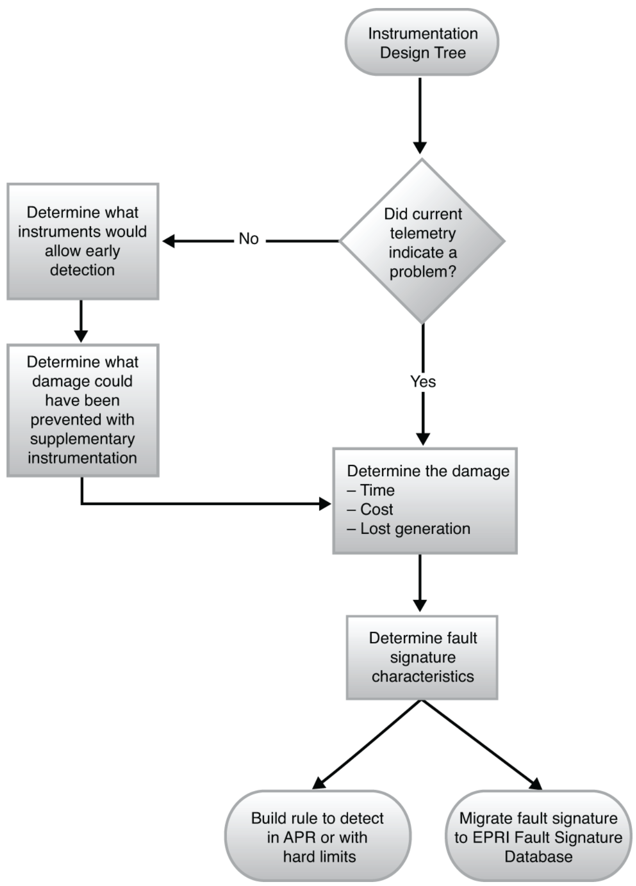

Figure 2-1
Instrumentation decision tree

Pulverizer Process Data

The plant's data historian, Aspen Info Plus21, is being used to collect the large majority of the data undergoing analysis. For the analysis period of approximately six months, approximately 175 points of 10-minute-sample data were retrieved from the historian for further analysis. Points included, but were not limited to, coal and air flows; pulverizer motor current; primary air temperatures; pulverizer discharge temperatures; hot, tempering, and primary damper positions; mill differential pressure; classifier speed; and unit load. The collected data was reviewed for reasonableness prior to use (mainly to discard data or points from further analysis), but no special effort to cleanse or otherwise correct faulty data was made beyond what the plant does as part of its normal practice. As for the data sampling rate, it appears that the 10-minute data rate is sufficiently fast to capture operational or equipment changes that over longer periods (hours/days/years) would manifest themselves in pulverizer system degradation, while minimizing the burden of very large data sets. For features that occur over shorter periods (seconds to minutes), faster sampling would be required, or these features could be mapped to a longer period (most likely in the digital control system [DCS] but potentially in the historian). Possible mappings include moving averages (mean, variance, others) and period determination for oscillatory processes, among others.

In addition to the data collected through the plant historian, a standalone vibration monitoring system was deployed and vibration data collected from each of the three pulverizers. Accelerometers were installed at the pinion drive shaft (inboard axial), the second intermediate shaft (inboard vertical), and the outboard end of the gearbox (outboard axial) (Figure 2-2). Low-cost industrial accelerometers were used; they were attached to the pulverizer using magnet mounts (Figure 2-3). With this configuration, the effective measurement frequency range is 30 to 120,000 cycles per minute (0.5 to 2000 Hz). A National Instruments (NI) CompactRIO system was used to power the accelerometers and perform sampling (Figure 2-4). A data collection event was triggered every 30 minutes, with sampling at 10,240 Hz for 10 seconds. All channels were sampled simultaneously. Waveform datasets were stored locally and periodically uploaded to a server. The datasets, one for each 30-minute period, are stored in NI's TDMS (Technical Data Management Streaming) format, which facilitates importing into other programs for subsequent analysis.

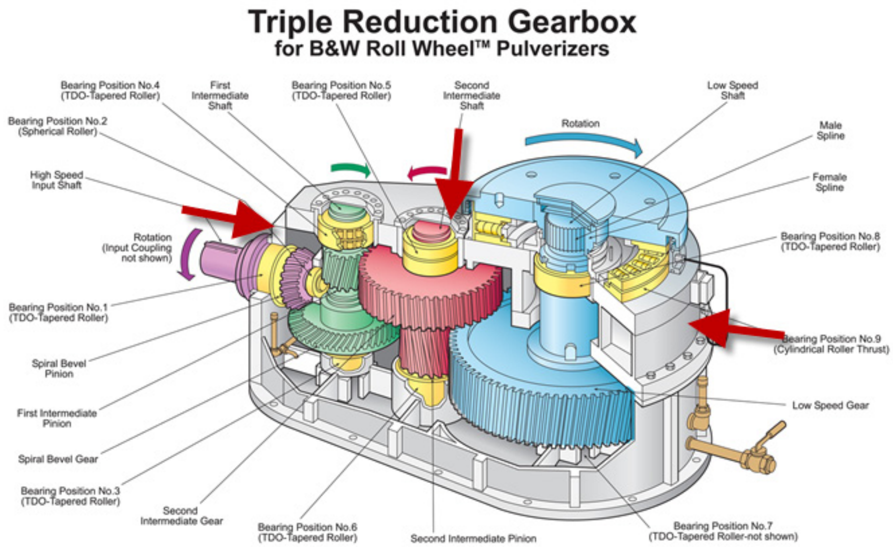

Figure 2-2
Accelerometer locations (see large red arrows)
Courtesy of The Babcock & Wilcox Company

Figure 2-3
Pulverizer gearbox accelerometers

Figure 2-4
Vibration monitoring system

Section 3: Testing Procedures

A series of on-line test procedures have been developed. These on-line test procedures are intended to be used to help determine pulverizer response and identify possible degradations in the pulverized fuel system and its associated instrumentation and controls.

On-line testing provides a more complete view of pulverizer performance and potential degradations than relying only on archived data from a historian. Equipment and operational limitations, constraints, and problems that existed during a disturbance are often difficult to identify on the basis of archived data alone. On-line tests allow this information to accompany the test data, which helps in identifying the reasons for unexpected changes in the results.

On-line testing also allows the use of repeatable test conditions over time, which simplifies the identification of changes in the performance of the pulverized fuel system and its instrumentation and controls. Most of the on-line tests are similar to those conducted for tuning of the control system but only need to be performed once during a test program unless tuning of controls is included in the test program.

The suggested load points and changes are shown in this document as percent referenced to rated pulverizer capacity. This is identified as the *pulverizer output ratio* (POR) to distinguish it from percent of transmitter span, which is typically used in control systems.

In addition to the process data that is associated with a pulverized fuel system, instrumentation and control configuration, tuning, and calibration data should also be collected. Coal characteristics, such as moisture, grindability, and grinding element wear, are significant factors that can affect pulverizer performance, and available data on these characteristics should be collected as well.

While the process data points that need to be collected during on-line testing are the same as needed from archived data, archived data points may have correction factors applied, while the raw data would be preferred for performance evaluation. Although this can make some archived data unusable for dynamic performance analysis, these corrections must be documented as a minimum. As an example, feeder coal rate data that is archived on the host site reflects the coal flow into the pulverizer adjusted through a single-order lag function with a two-minute time constant in an effort to correct for the lag between coal flow to the pulverizer and coal flow to the burners. On-line testing often records data directly from the DCS rather than the historian to avoid the additional data compression associated with the historian. Using data from the DCS may allow access to raw data (without the corrections or undesirable filtering) that is not available through the historian.

For the purpose of identifying pulverizer performance issues, a data point sample rate of every 60 seconds appears to provide usable data, even though a faster sample rate could be used. DCSs often incorporate exception reporting in addition to a fixed sampling rate, which may increase the apparent sample rate.

Data Points

The following data points should be collected as a function of time for each pulverizer being tested, to obtain a diagnostic signature:

- Process Data for Pulverizer Being Tested
- Pulverizer Differential Pressure
- Primary Air Flow Element Differential Pressure
- Primary Air Mass (or Volumetric) Flow
- Pulverizer Primary Air Inlet Temperature
- Pulverizer Coal-Air Temperature
- Feeder Coal Flow
- Pulverizer Motor Amps
- Pulverizer Master Control Station Output
- Feeder Control Station Output
- Primary Air Flow Control Station Output
- Coal-Air Temperature Control Station Output

In addition, the following boiler data points common to each pulverizer should be collected during each pulverizer response test:

- Gross Megawatts Generated
- Hot Primary Air Temperature
- Tempering (or Cold) Primary Air Temperature
- Boiler Demand
- Total Fuel Flow (summation of individual pulverizer coal flows and igniter/auxiliary fuel flows)
- Firing Rate Demand

Any changes in the configuration or tuning of the pulverizer controls made between pulverizer response tests need to be documented. For each pulverizer test, the following need to be documented even if there were no changes since the previous test:

- Primary Air Flow Demand Curve
- Primary Air Flow Bias
- Coal-Air Temperature Set Point

Steady State Testing Methods

Steady state data establishes baseline pulverizer performance signatures rather than dynamic response signatures. Comparison of the performance signatures to current operating data assists in determining that a change has occurred in the pulverized fuel system and in establishing whether the probable cause is a change in coal characteristics, a mechanical equipment problem, or a control problem.

Three key steady state testing methods have been identified to help set a normal operating characteristic of a pulverizer. Table 3-1 lists these testing methods. Details of each procedure can be found in Appendix B.

Table 3-1
Steady state tests

Steady State Testing Method	Purpose
Pulverizer Clean Air Curve	Establish pulverizer clean air curve to identify changes in pulverizer primary air system calibration and to identify pulverizer pressure drop from coal inventory in the pulverizer.
Pulverizer Loading Curve	Determine the existing pulverizer loading curve for the pulverizer to determine the pulverizer fuel-air ratio.
Pulverizer Motor No-Load Amps	Determine the pulverizer motor no-load amps for the pulverizer. It will be used in conjunction with the motor amp data obtained from the pulverizer loading curve tests to establish the baseline pulverizer motor amps curve to identify the amount of coal grinding occurring.

Dynamic Response Testing Methods

Dynamic response testing allows evaluation of pulverizer performance compared to baseline data that was previously established. Step and ramp tests are used to establish baseline signatures to evaluate pulverized fuel system dynamic response. One part of the response signatures is the deviation from the steady state pulverizer loading and pulverizer motor amps curves developed from the steady state test data. While these step and ramp tests are basically the same as typically used for control system tuning, if any tuning changes are made after completion of a test, the response test needs to be repeated to provide the new baseline response signature.

Open loop step tests should start and end on the pulverizer demand curve, while closed loop step tests should automatically follow the pulverizer demand curve, as shown in Figure 3-1. Note that a 5% step increase in primary air flow demand requires a corresponding step of ~10% in feeder demand to maintain operation on the pulverizer demand curve. Also, the primary air flow damper position demand change required will be influenced by how the damper actuator is characterized.

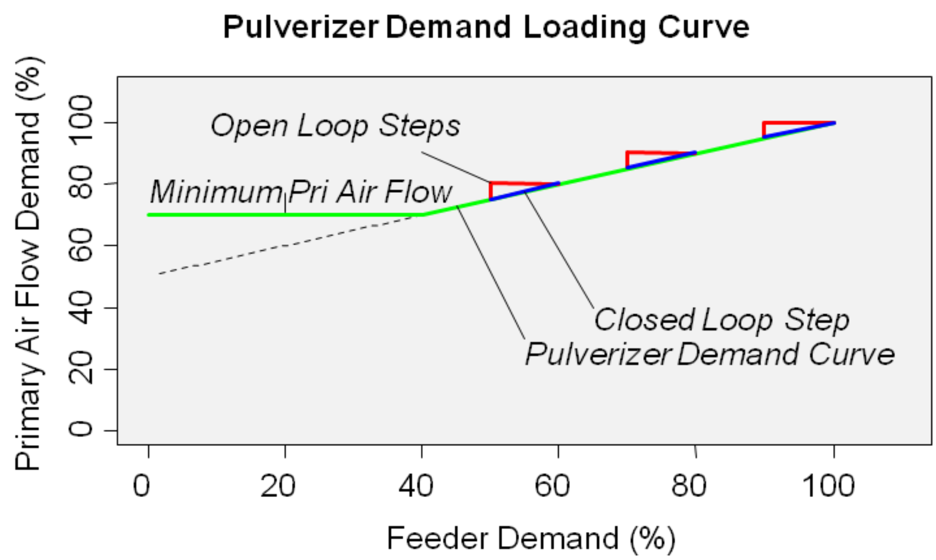

Figure 3-1
Open and closed loop step tests

Three key steady state testing methods have been identified to help test dynamic response of a pulverizer. Table 3-2 lists these testing methods. Details of each procedure can be found in Appendix B.

Table 3-2
Dynamic response tests

Dynamic Response Testing Method	Purpose
Open Loop Step Tests	Determine the pulverized fuel system open loop response to small perturbations in primary air flow and coal feed at several different pulverizer loads. Suggested loads are 50%, 70%, and 90% POR for the pulverizer.
Closed Loop Step Tests	Determine the pulverized fuel system closed loop response to small perturbations in pulverizer demand at several different pulverizer loads. Suggested loads are 50%, 70%, and 90% POR for the pulverizer.
Load Ramp Tests	Determine the pulverized fuel system closed loop response characteristics to a ramp change in pulverizer demand using normal automatic pulverizer control. Load ramp tests are between two pulverizer steady state load points at a constant rate of change.

Analysis of the test data can be used to establish baseline signatures to compare against future test results. The data can also be used to develop simple correlation models that can predict expected response for comparison against actual operation.

Section 4: Pattern Recognition

Advanced pattern recognition software can often be adapted to industrial processes. Utilizing historical data of multiple variables, APR uses correlations from the variables to predict the expected value of variable *A* based on the values of variables such as *B*, *C*, and so on. Comparing the expected value with the actual will identify a data point deviation. These deviations can provide early indication of anomalies caused by various types of changes (Figure 4-1). This leads to preliminary indications of impending faults such as equipment wear or fatigue; process upset conditions such as plugging; and monitoring instrumentation failure or degradation. The pulverizer process lends itself well to pattern recognition since many components of the system are mechanically intertwined.

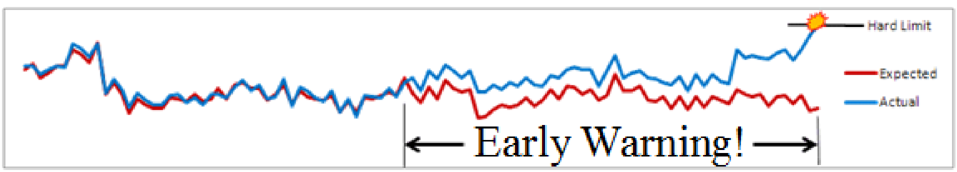

Figure 4-1
Early fault detection compared to hard-limit methods

APR is a statistical, nonparametric regression method in which historical data is used as a training baseline. The relationships between independent variables associated with an asset, called *states*, are learned for each operating condition throughout the load range. For the current operating condition, the method finds a certain number of nearest states and performs a weighted averaged to obtain a predicted value for each variable. A modified regression method is introduced by ECG, Inc. in the APR software employed in this study, which allows for a robust fault detection method by computing a weighted average. In typical regression methods such as linear regression, if a fault is introduced in one variable, the predicted values of the other variables may reflect that erroneous data because the method assumes error-free independent variables. This error-free condition, however, is not common in process monitoring.

The immediate benefit of the APR software is realized from the model building process. Utilizing graphical techniques, rather than simply observing historical trends of data, allows patterns and correlations to be more easily recognized and understood. Separating variables and looking at their correlations with respect to an entire model, especially if there are several variables, allows the analyst to grasp the concept of relationships.

The data selected for training APR models must be obtained under normal operations and good mechanical conditions and must represent known fuel characteristics. In reviewing the data and utilizing major driving variables to determine a standard, the end user selects what data to keep for training the APR software. If bad data or an undesirable operating condition are accepted for training the model, that condition, if seen again, will not raise any alarms since the model has been builtto expect it. If the constraints on deviation are set too tight, the end user may be plagued with false alarms.

As an example, historical data was uploaded into a local data historian for application to the APR software. Models were built to determine correlations among the variables. Major variables for a coal pulverizer include the coal feed rate, mill differential pressure, inlet and outlet temperatures, motor amps, air flow, and fuel characteristics. These parameters should typically correlate well within a single system. An example can be seen below showing the correlations among these variables for Mill A (Figure 4-2). Three distinct air flow vs. coal feed rate curves can be seen for Mill A. Typically, a single correlative curve would be produced. These additional curves can be the result of a bias on the mill or changes to the air-fuel curve.

The correlations for Mills B and C are also shown, to display unique characteristics each mill can present (Figures 4-3 and 4-4). It is the mill-specific correlations among these major variables that are used for this project to detect operational anomalies and to determine the cause of the deviations from expected. If the characteristic correlations differ between mills, it can be indicative of a problem with a particular mill.

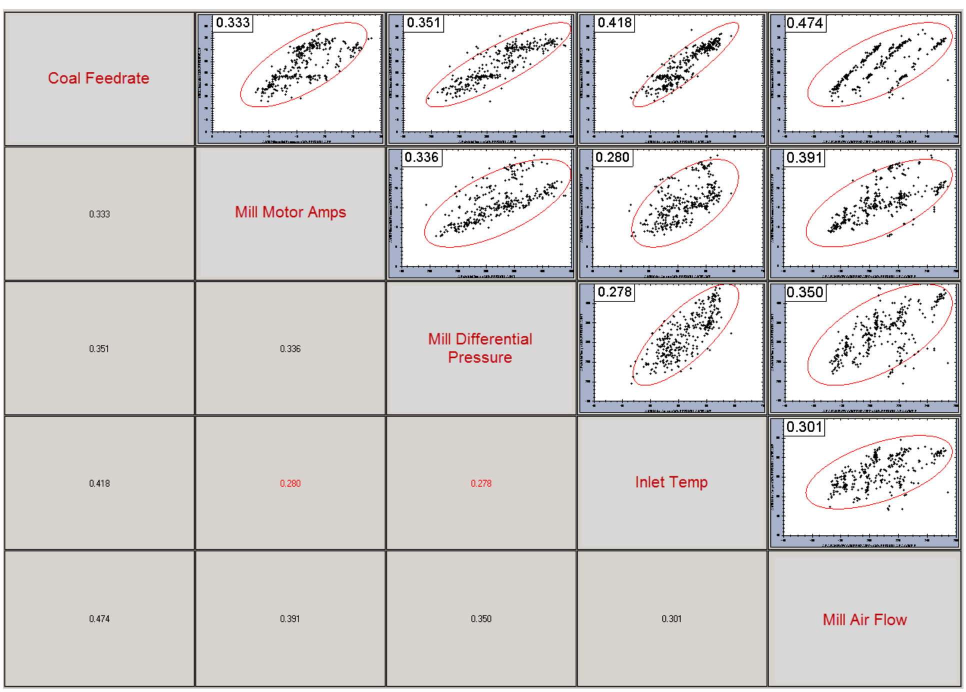

Figure 4-2
Mill A major variables

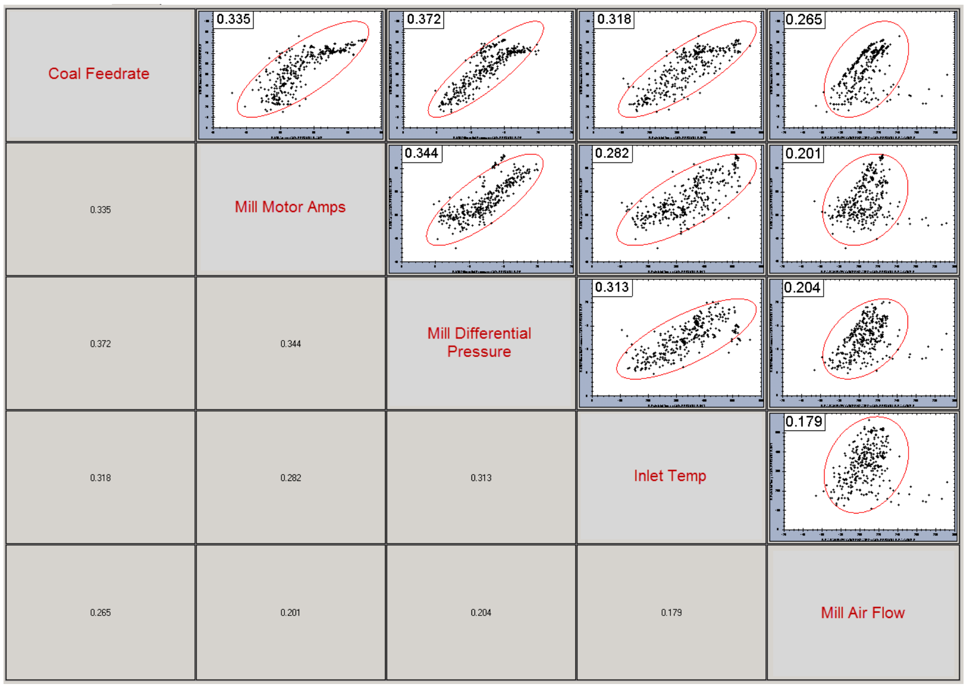

Figure 4-3
Mill B major variables

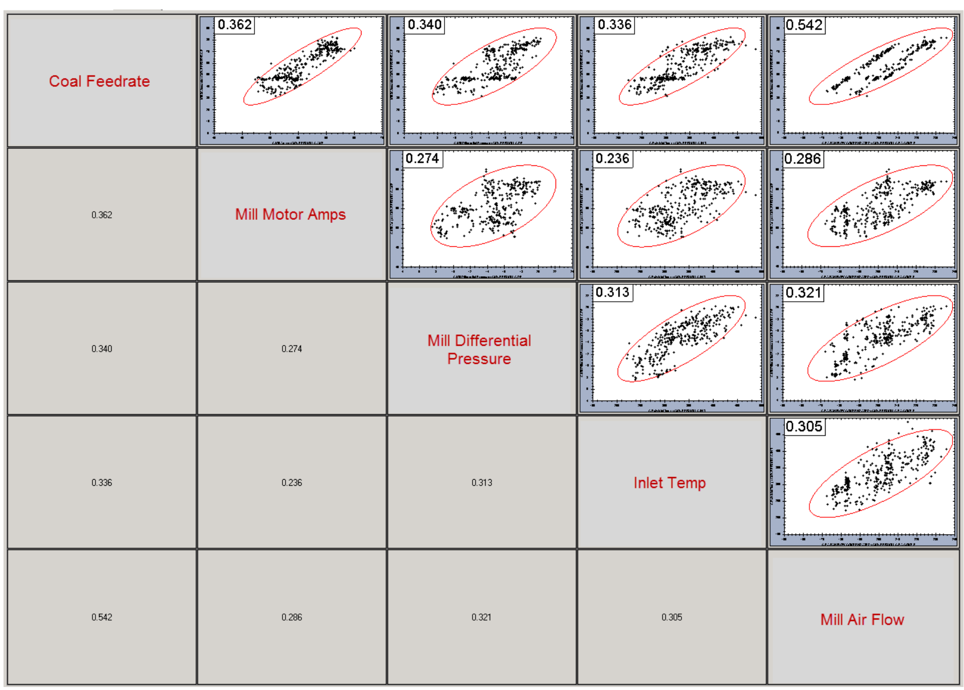

Figure 4-4
Mill C major variables

All process variables relating to the mills as well as boiler demand were included in building models for each mill. These models include 25 variables, increasing the complexity but providing greater insight into potential problems. Some additional variables were included but were essentially duplicate tags. Consideration must be given to the quality of the variables included in the model along with avoiding unnecessary addition of complexity to the APR model. Variables not associated with the mill or only very indirectly associated should not be included in the model. Also, depending on the APR modeling package, it may be useful to include some variables in the training as information only and not include them in the predictive model itself. An example would be Unit Gross MW, since individual mill loading is only loosely dependent on unit load due to varying mill loading patterns. Inclusion of this type of variable in the input/output model could obscure the interpretation of the model predictions. For this example, the training data available for these models varied due to individual mill operation, but was gathered from November 19, 2013, to January 29, 2014, for each mill. The mills were verified to be in satisfactory mechanical condition during this timeframe. The different fuel types used during this timeframe are documented. The data points used in these models can be seen in Table 4-1.

Table 4-1
Mill operation variables

Unit Data Points	Mill-Specific Data Points	
Unit Boiler Master	Mill Feed Rate	Classifier Speed
Unit Gross MW	Mill Motor Amps	PA Fan Flow Compensated
	Mill Differential Pressure	PA Fan Flow Differential
	Mill Inlet Temperature	Primary Air Flow Control
	Primary Air (PA) Flow	Primary Air Flow Set Point
	Primary Air Damper Position	Primary Air Temperature
	Primary Air Damper Demand	PA Motor Temperature
	Tempering Air Damper Position	Mill Temperature Control
	Tempering Air Damper Demand	Wheel Loading Pressure
	Hot Air Damper Position	Wheel Pressure Control
	Hot Air Damper Demand	Wheel Pressure Set Point
	Mill Temperature	

Typical plant data includes several demand and feedback variables. Figure 4-5 demonstrates the expected linear correlations for tempering air damper demand vs. position (upper left trend) and hot air damper demand vs. position (bottom right trend). The remaining four boxes show the inverse relation the tempering and hot air dampers have with each other. Variables with such a high correlation should be grouped together within the models with tight tolerances.

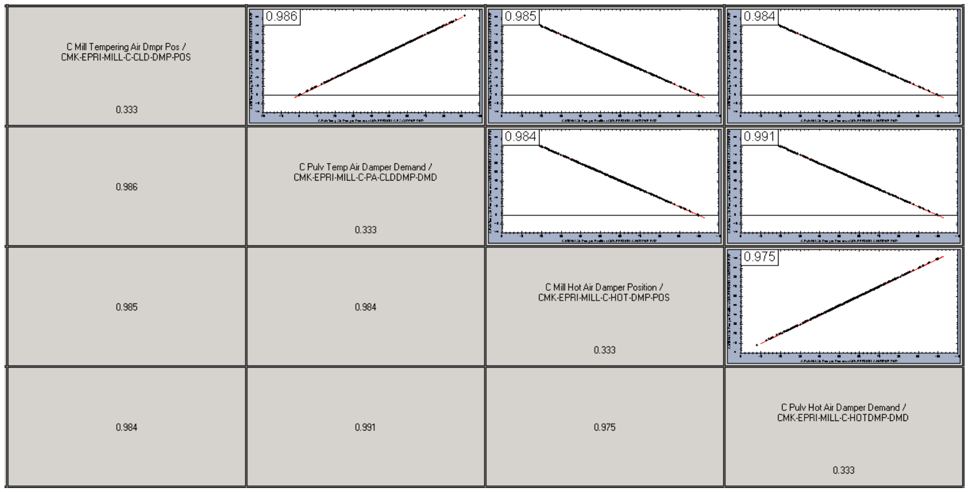

Figure 4-5
Tempering and hot air demand vs. position correlations

It was mentioned that Mill A had multiple air-fuel curves in the training data. The different curves may stem from biasing mill air flow due to different fuel types. Seeing a graphical representation of the correlation in these x-y plots makes it easy to build models for different operational modes and to remove erroneous data. For example, the end user may be interested only in the first air-fuel curve. Using the Feed Rate vs. Air Flow plot, the other curves can be selected for removal from training. This removes all data points associated with those curves. Figure 4-6 shows in red the data points that would be removed from training. The correlation for feed rate to air flow is much tighter, as expected. This removes several outliers from the model and increases the correlation of most of the other variables as well.

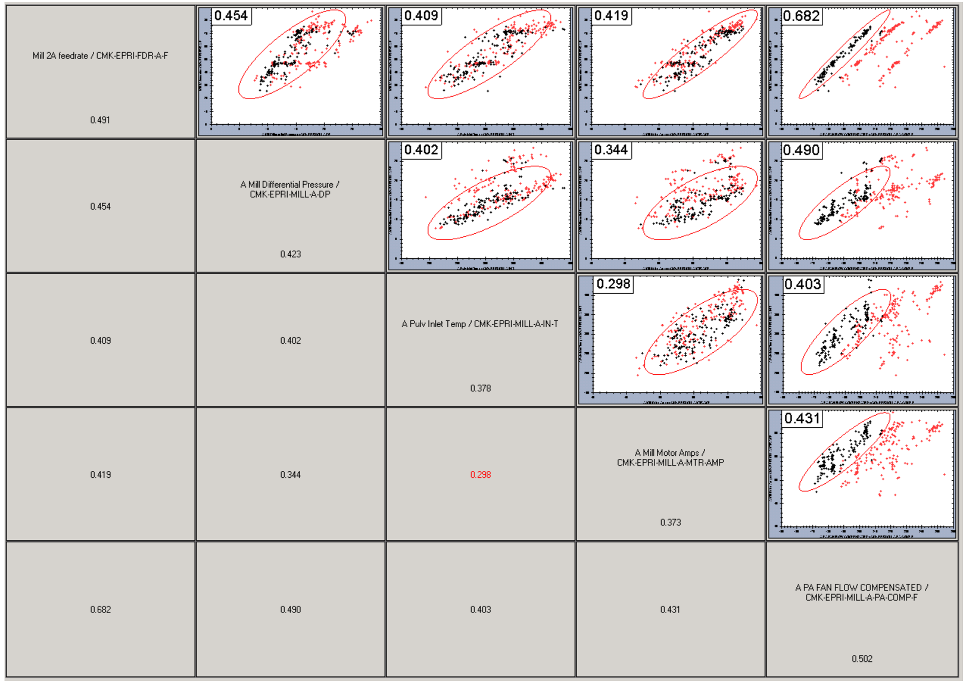

Figure 4-6
Narrowing training data

Other metrics may also be used to identify patterns. The mean value of a variable may be traced across a unit of pulverizers to identify outliers. When measuring the deflection of each journal, the mean value of each journal within a single mill should be roughly the same. The mean values can also be compared across sister mills, assuming the coal characteristics are known and accounted for.

The standard deviation or peak-to-peak deviation can represent the dynamic motion of a variable. The journals have a cyclic motion as the coal bed is forced under each roller. The maximum and minimum values can be determined, and the range and standard deviation between them can indicate spring properties, coal characteristics, and roller/table geometry. Figure 4-7 displays the standard deviation values for three mills in a single unit. The scale of the three trends is the same, and the three journals are denoted by the blue, red, and green traces. Mill A exhibits expected standard deviation, with all three journals having the same range of motion.

The journals in Mill B show different deviations, as the deflection for the red trace has more movement than the green, which has more movement than the blue. This can indicate uneven wear and/or eccentric geometry for the red trace. Mill C has a high standard deviation for all three journals, even though they are equal within the mill. If standard deviation is calculated on a running basis for other variables in the mill, the values may be used to build APR models as well. Changes in the standard deviation values can indicate dynamic issues within the mill.

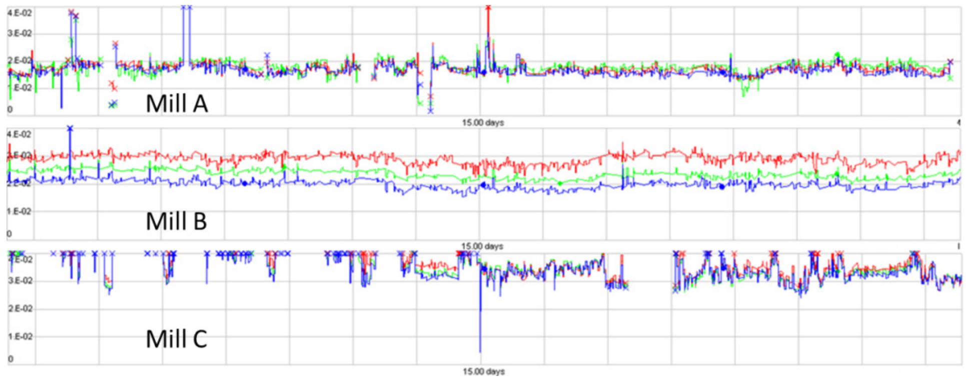

Figure 4-7
Standard deviation values of journal deflection, 15 days of data

Section 5: Performance Anomaly Detection

Examples of pulverizer anomaly detection are provided in the following paragraphs. Mill operations data was obtained for the host unit during January through February 2012, January through February 2013, and August 2013 through March 17, 2014. The APR models were run against all applicable data in the system and show a time period prior to the training data where mill differential pressure (DP) and inlet temperature in particular were different than the training data—that is, higher than expected (Figure 5-1). This time period of November 1–24, 2013, was a time when the plant was testing Powder River Basin (PRB) coal. PRB coal typically leads to thicker bed levels and lower DP compared to lower-quality fuels such as bituminous or lignite coal. PRB is also inherently higher in moisture content, requiring higher inlet temps to properly dry the coal. PRB moisture for this period averaged 27.7% compared to the month of December 2013, which averaged 7.7% moisture burning a different coal. Figure 5-2 shows another example of the differences in operation with two different fuel types. Although the data is not from the host site, it shows differences in PRB coal vs. lignite coal.

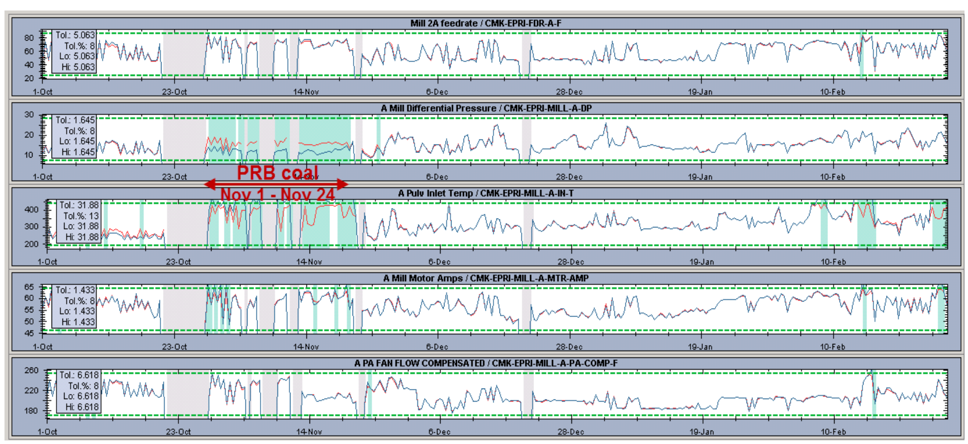

Figure 5-1
Mill 2A data, October 1, 2013, through March 1, 2014; note PRB test burn November 1–24

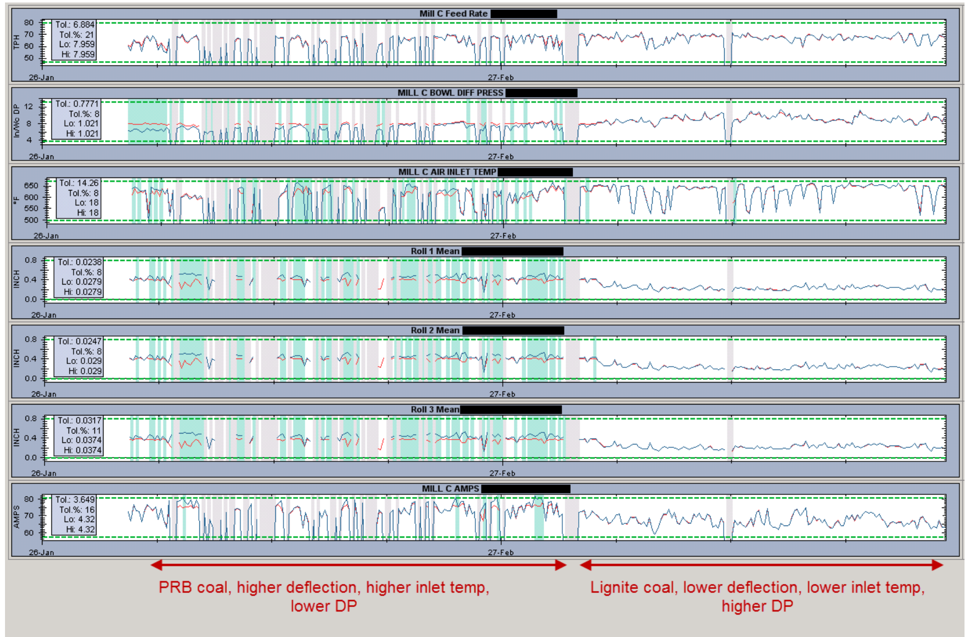

Figure 5-2
Example mill PRB coal vs. lignite coal

The host plant had modified the primary air set point curves for the PRB test burn. The set point curves can be seen in Figure 5-3 with all November data for Mill A. One set of data lies on the old set point, while the other was biased high, but relates to the new set point.

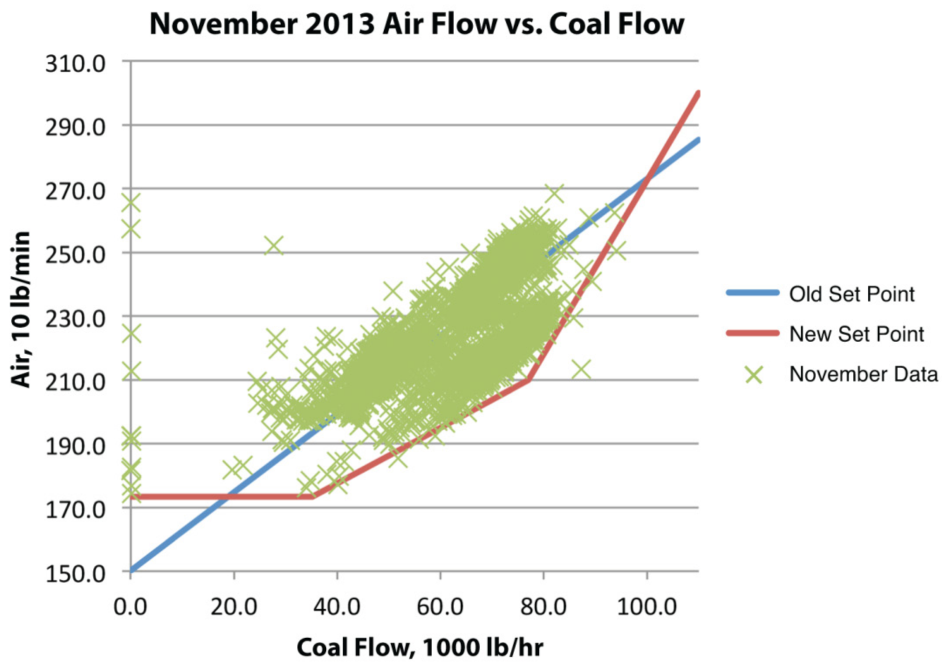

Figure 5-3
Air flow set point for PRB test burn

Monitoring these process control variables in real time allows plant personnel to see changes as they take place. When a change in the operation of the mills is detected with APR, control parameters may need adjustment or maintenance on one or more mills to return the system to optimal conditions. At the very least, this change in fuel can be tracked and the operators can see in real time the effect that different fuels may have on the unit.

Vibration Analysis

Vibration analysis is one of the most popular additional techniques used to monitor rotating machinery. Nearly all machines will produce vibrations, although the levels of vibration should be very low and/or constant if operating as expected. As a fault develops, interactions of the components within the machine will produce higher levels of vibration, typically at specific frequencies associated with the failing component. Three accelerometers were installed on each mill in the study to monitor the gearboxes. Readings are taken at the pinion drive shaft (inboard axial), the second intermediate shaft (inboard vertical) and the outboard end of the gearbox (outboard axial). Major gear drive frequencies are shown in Table 5-1.

Table 5-1
Major gear drive frequencies for the MPS-75G mill

Shaft or Gear Mesh	Cycles per Minute
Motor, input shaft	900
First intermediate shaft	565
Second intermediate shaft	136.8
Main vertical shaft	27.63
High-speed gear mesh	24,300
First helical gear mesh	12,996
Second helical gear mesh	2,601

The overall vibration value (ips Pk) can be trended over time to monitor changes in vibration levels for a particular piece of equipment. These changes can be due to wear, increased clearances, misalignment, or imbalance in rotating machinery. This is typically an adequate method for monitoring the equipment, but it cannot narrow down specific components or faults. An example of the overall vibration trend for Mill 2A IBA is shown in Figure 5-4. No specific gearbox or motor faults have occurred since the implementation of the added accelerometers. But monitoring the overall trend for step changes or gradual increases in overall vibration can be an early indicator of an impending problem.

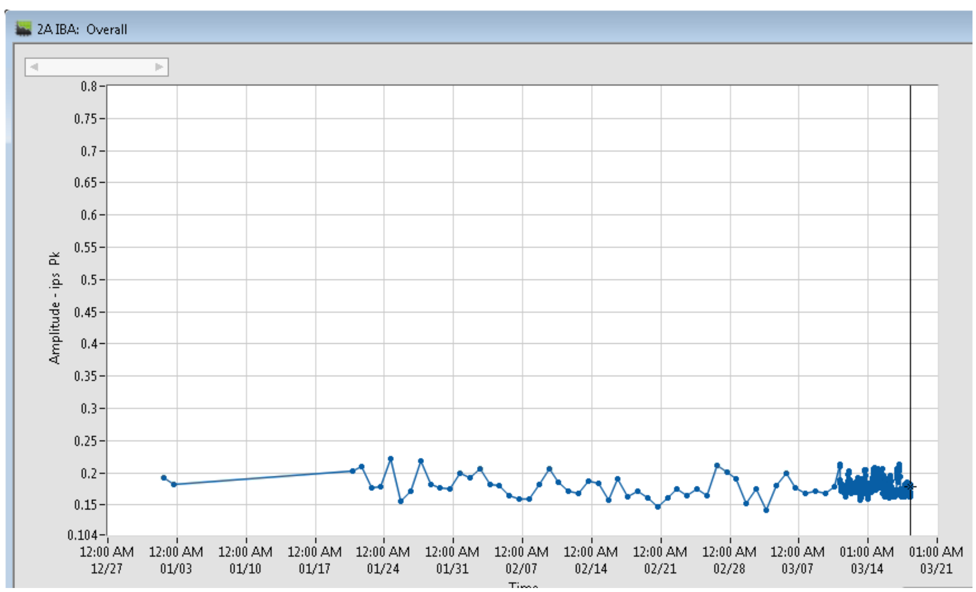

Figure 5-4
Overall vibration trend for Mill 2A IBA (inboard axial)

Analyzing the frequency data can help differentiate components inside the gearbox. Example frequency data can be seen in Figure 5-5. Monitoring the energy or amplitude of known frequencies allows plant personnel to see if a specific component within the gearbox is deteriorating. This vibration information may also be used in the APR analysis.

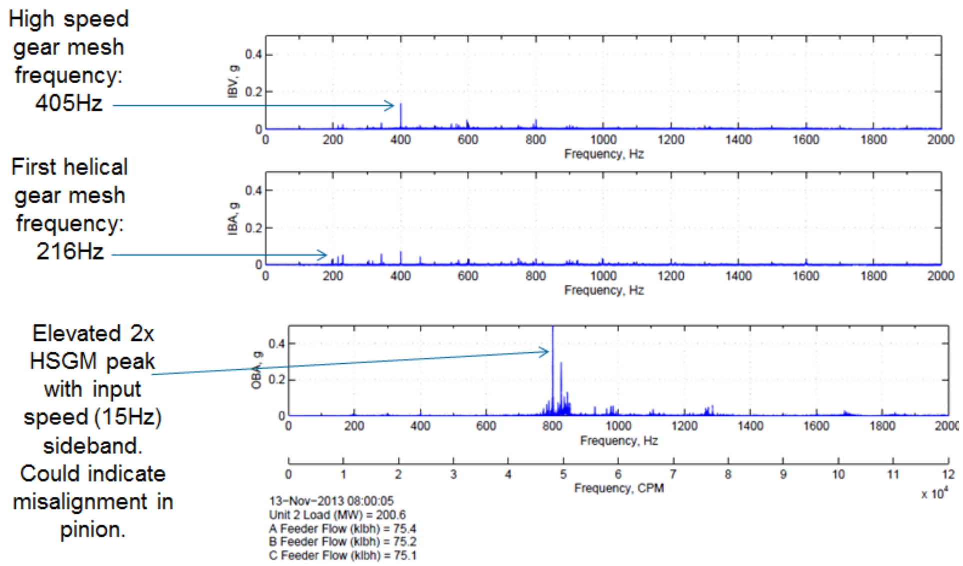

Figure 5-5
Example spectral data from mill gearbox

Section 6: Fault Matrix

The fault matrix presented in Table 6-1 was compiled with the intent of using it in association with the Fleet-Wide Prognostic and Health Management (FW-PHM) Suite software developed by EPRI. The FW-PHM Diagnostic Advisor identifies fault and impending failure conditions of plant assets by cross-referencing the database of known asset fault signatures with operating data, technology examination, and expert entry information from power plant personnel. An example of the Fault Signature Specification and Fault Feature Specification forms can be found in Appendix C. These forms are used to input the fault data to the Diagnostic Advisor software. The fault signatures are listed in table form in Appendix D.

For the most part, standard pulverizer variables available to most power plants were assumed in developing these fault signatures. Basic instrumentation includes the coal feed rate, air flow, inlet air temperature, outlet coal/air temperature, mill differential pressure, and mill amps. The damper positions are typically monitored as well. Additional instrumentation can provide several benefits to the overall monitoring effort. Some instrumentation that has been implemented on coal pulverizers includes, but is not limited to, thermocouples, accelerometers, displacement transmitters, CO detectors, oil particle counters, pressure transducers, and ultrasonic sensors. Testing for coal fineness exiting the pulverizer or oil analysis can also be used in determining component health.

Accelerometers can be installed on the pulverizer, gearbox, and motor to aid in diagnosing problems. Displacement transmitters can be used to measure the movement of the grinding elements within the mill. In MPS mills, the three tires are attached to a single spring plate. Raymond-style mills have three rollers as well, but they are individually spring-loaded. Understanding the amount of deflection from each of the grinding tires or rolls leads to better knowledge of the resultant forces exerted on the table/main shaft by the spring system(s).

CO detectors are sometimes installed on pulverizers as a fire detection system. Typically, if a fire is detected, the mill will trip and the tempering air damper swings open to pull colder air through the mill to extinguish the fire. Oil particle counters are a good on-line method for monitoring the lubricating oil in the gearbox and other components of the mill. While these do not diagnose exactly what elements are in the oil like an oil analysis would, monitoring the size and amount of particles can lend to early fault indications. Pressure transducers and thermocouples are common instruments used on the pulverizer. However, additional locations may be monitored to form a more complete picture of the pulverizer health.

Table 6-1
Pulverizer fault matrix

Mill Component Fault	Detection Method	Additional Instrumentation
Hole in classifier cone	Low DP, normal demand – severe case	
	Poor fineness	
Plugged coal flow – classifier cone	Poor fineness, low DP, low amps, normal demand	
	Low deflection, increased demand	Displacement transmitters
Tire or roller wear	MPS mills: increased inventory, high DP, high amps, lateral movement of tire assembly	Displacement transmitters
	CE mills: reduced DP, low amps, less overall deflection from journal assemblies	Displacement transmitters
	Poor fineness, i.e., high +50 mesh, low -200 mesh readings	
Table wear	Displacement spectral data	Displacement transmitters
	Poor fineness, i.e., high +50 mesh, low -200 mesh readings	
High primary air flow – sensor issue high side blockage or leak	High DP, normal to low amps, high outlet pressure, high inlet pressure,	
	High DP, normal to low mill amps, high fan amps (if dedicated fan)	
	Poor fineness	
Low primary air flow – sensor issue low side blockage or leak	Low DP, low outlet pressure, low inlet pressure	
	High DP, high amps, high deflection (due to recirculation)	Displacement transmitters
	Excess coal spillage into pyrites area	
Missing/damaged classifier blades	Normal feed, low DP, low amps (due to less circulation)	
	Poor fineness, pipe-to-pipe poor distribution	

Table 6-1 (Continued)
Pulverizer fault matrix

Mill Component Fault	Detection Method	Additional Instrumentation
Excessive fuel moisture	High inlet temp, damper swings	
	High hot air damper demand, low outlet temp (can't make set point)	
Plugged classifier discharge	High inlet pressure, high outlet pressure (upstream of obstruction)	
	High inlet pressure, low outlet pressure (downstream of obstruction)	
Classifier setting – too open	Poor fineness readings, low -200 mesh fineness	
	Low amps, low DP	
Classifier setting – restricted	High 200 mesh fineness, higher amps, high DP, capacity limited	
Mill overloaded	High amps, high DP	
Mill underloaded	Swings in amps, DP	
	Minimal deflection, contact on minimum stops	Displacement transmitters
Plugging/unplugging of coal feed chute	Swings in amps, DP, mill inlet and outlet temps, boiler swing	
Partially plugged feeder	Increasing feeder demand, low amps, low DP, low deflection	Displacement transmitters
Feeder adjustments/calibrations needed	Swings in amps, DP	
	High demand on feeder – pluggage prior to coal feeder or worn	
	Normal demand, high amps – leveling bar wear	
	Normal demand, low DP, low amps	
Skidding tires or rolls	Deflection levels (usually flat line)	Displacement transmitters
	Elevated amps	
Coal contamination/tramp material	Amp spikes	
	Noise	Ultrasonic
Excessive internal circulation	High DP, high amps, coal spillage	
	High deflection level	Displacement transmitters

Table 6-1 (Continued)
Pulverizer fault matrix

Mill Component Fault	Detection Method	Additional Instrumentation
Pulverizer springs loose/broken	CE: deflection level	Displacement transmitters
	MPS: lower amps, deflection	Displacement transmitters
Missing/damaged pyrites plow	Little to no pyrites in reject chute	
	Mill fire	
Mill fire	CO detection	CO detector
	High outlet temp – tempering air damper swings open, hot air damper swings closed	
Collapsed spring due to localized mill fire	CE: low amps, roll deflection increase	Displacement transmitters
	CE: standard deviation of affected journal may increase due to lack of spring tension	Displacement transmitters
Excessive throat clearance, wear	Low DP, inlet pressure low	
Control damper malfunction	Frozen/swinging damper, swinging pressures in mill	
	Increased damper demand for normal coal flow	
Outlet temperature thermocouple failure	Tempering damper drives open or closed, outlet temperature reading bad	
Tempering air damper control malfunction	MPS: tempering damper demand vs. sister mills	
	Swing in outlet temperature, can't hold set point	
	No change in temperature for change in damper demand	
Hot air damper malfunction	Swing in mill air flow	
	Air flow demand to coal flow change, demand changes relative to same coal flow	
Air heater plugged	Hot air damper 100%, can't hold outlet temperature set point	
	Can't reach airflow set point	
Oil viscosity high	Oil temperature high	Thermocouple
	Particulate measure	Particle counter
Oil viscosity low	Oil temperature high	Thermocouple

Table 6-1 (Continued)
Pulverizer fault matrix

Mill Component Fault	Detection Method	Additional Instrumentation
Oil cooler plugged	High differential pressure across filter, high gearbox temperature	Pressure transducer for oil filter
	Particulate measure	Particle counter
Gearbox vibrations – bearings, gear mesh, alignment	Bearing fault frequency amplitude increase	Accelerometer
	Gear mesh frequency amplitude increase	Accelerometer
	Waveform data impacting – overall vibration value	Accelerometer
	Suspended solids in oil	Particle counter
	Temperature increase with associated vibration changes	Thermocouple (combined with accelerometer)
CE roll bearing failure	Bearing fault frequency amplitude increase	Accelerometer
CE mill lost motion in spring assembly	Journal liftoff traces show unimpeded liftoff prior to overcoming spring preload	Displacement transmitters
	High amplitude deflection at low load	Displacement transmitters
CE mill excessive clearance for roll	Staggered journal liftoff	Displacement transmitters
	Poor fineness, high +50 mesh	
Resultant force – main shaft fatigue	Unequal deflection from rollers/tires	Displacement transmitters
Spalled weld overlay – roll or table	Spectral data of journal deflections – activity at roll or table speeds	Displacement transmitters
Tapper fit problem – bowl hub to main shaft	Spectral data – bowl harmonics	Displacement transmitters
Excessive preload	Delayed liftoff, low overall deflection levels, compare to other rolls	Displacement transmitters
Insufficient preload	High deflection, compare liftoff traces to other rolls in same mill	Displacement transmitters
	Poor fineness results	
Spring stiffness or tension	Compare liftoff traces to rolls in same mill, differences in overall deflection levels	Displacement transmitters
Squeaking in journal assembly	Noise levels	Ultrasonic

Section 7: Summary

Because of the importance of the coal pulverizer, good monitoring and maintenance practices are fundamental in reducing maintenance costs while sustaining unit efficiency and improving reliability. The demands placed on today's fossil-fuel power plants may require load following, significantly reduced loads, or cycling off-line completely at times, and optimum pulverizer performance has the potential to increase overall plant responsiveness. Distinguishing specific pulverizer faults or control issues can streamline maintenance planning.

Standard process variables associated with the mills may vary slightly from plant to plant, but additional telemetry has been identified in this report to expand the pulverizer-specific features used for monitoring the equipment. A continuous monitoring process such as advanced pattern recognition (APR) can be utilized to ensure that pulverizer internal conditions do not change or deviate during operation. APR models were built with major variables such as coal feeder demand, pulverizer differential pressure, and motor amps to observe deviations under abnormal operating conditions. The models were eventually expanded to include several different pulverizer data points. These on-line diagnostic methods can be used in real time to determine pulverizer responsiveness and degradation.

Fault signatures were derived from APR models by observing a variable's deviation from an expected value when a fault was present. Additional instrumentation was discussed, including displacement transducers to measure roll/tire deflection levels; accelerometers to measure vibration levels and monitor fault frequencies in gears and bearings; CO detectors; oil particle counters; and thermocouples for additional temperature readings. The fault signatures will present operators and engineers with early indications of pending faults in the pulverizer.

The Fleet-Wide Prognostic and Health Management (FW-PHM) Suite is a diagnostic advisor software system developed by EPRI that helps identify component faults and impending failures of specific assets in a power plant. The Fault Signature Forms found in Appendix C can be used to enter the fault signatures into the database for the FW-PHM Suite software. Adding pulverizer fault signature data to the FW-PHM software will facilitate pulverizer diagnostic practices for plant staff, central monitoring centers, and others.

Section 8: References

References Called Out in the Report

1. C. M. Kleineke and M. T. Santucci, "Health Management of Utility Coal Pulverizers," MFPT Proceedings 2013.
2. J. Wang, J. Wei, and S. Guo, "Condition Monitoring of Power Plant Milling Process using Intelligent Optimisation and Model Based Techniques," *Fault Detection,* Wei Zhang (Ed.) ISBN: 978-953-307-037-7, InTech, Available from: http://www.intechopen.com/

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Pulverizer Maintenance Guide, Volume 3: Ball/Tube Mills. EPRI, Palo Alto, CA: 2006. 1010443.

Appendix A: Host Site: Unit Description

Greene County Generating Station is a coal-fired plant located on the Warrior River about 10 miles north of Demopolis, Alabama, and is operated by Alabama Power. The plant is jointly owned: Alabama Power owns 60% and Mississippi Power owns 40% (of the steam units). Construction of the steam units began in 1962, Unit 1 began commercial operation in 1965, and Unit 2 began commercial operation in 1966. In 1993, construction began on nine GE combustion turbines. Five CTs began commercial operation in May 1995, and the other four followed in May 1996. Units 1 and 2 use coal as the primary fuel. The combustion turbines use gas as the primary fuel and oil as the secondary fuel. Unit 2 is the host site for the current demonstration of this study's subject technology.

Unit 2 is a 250 MWe (nameplate) unit. A list of the major components is presented in Table A-1. The unit incorporates a Riley Stoker[1] radiant, natural-circulation boiler rated at 1,750,000 lb/hr (793,787 kg/hr) of steam at an operating pressure of 2500 psig (17,237 kPa) with superheat and reheat temperatures of 1000°F (538°C) and 1000°F (538°C), respectively. At these design conditions, the heat release rate in the furnace is 18,200 Btu/ft^3/hr, and the total thermal output is 2.9x10^9 Btu/hr. This unit was designed to use eastern bituminous coal as a fuel but often uses other coal types as well, including Powder River Basin (PRB) fuel. Originally designed as a pressurized boiler, it was converted to balanced draft in the late 1970s. Eighteen low-NOx burners (B&W XCL) were installed on the unit during the late 1990s. Three retrofitted B&W MPS 75G pulverizers supply pulverized coal to six burners each (Figure A-1). The unit is equipped with a Metso Max distributed control system. The current version is a mixture of Max1000plus+ and MaxDNA2 hardware and software.

[1] Riley is now a division of Babcock Power.

Table A-1
Major component list for the host site demonstration unit

Equipment	Vendor	Description
Boiler	Riley Stoker	Rated capacity 1,750,000 lb/hr at 2,500 psig and 1000°F superheat and 1000°F reheat; 18 burners total (9 front wall and 9 rear wall)
Burners	B&W (low-NOx)	XCL (Modified by Riley)
Pulverizers	B&W	Three MPS 75G pulverizers Capacity ~ 40 tons/hour (36,287 kg/hour) Each pulverizer supplies six burners Dynamic classifiers
Feeders	Merrick	Model 496-G gravimetric feeders
Control System	Metso	Max1000plus+ / MaxDNA2 distributed controls

The B&W MPS pulverizer is a roller race mill operating at slow speed (approximately 27 rpm) driven by a constant-speed (885 rpm) motor that drives the grinding table through a triple-reduction gearbox. Grinding elements consist of three fixed-position roll wheel assemblies that fan in a rotating segmental grinding ring. Rolls are spring loaded to obtain the pressure required for grinding. Spring tension on Unit 2 pulverizers is adjustable with an automatic wheel loading system that varies spring tension with various feeder flows. Dynamic (rotating) motor-driven classifiers are used on these pulverizers. Operators can adjust the speed of these classifiers on-line to maintain mill loading.

Figure A-1
Pulverizers at the host site

An overview of the air system is shown in Figure A-2. Two motor-driven forced-draft (FD) fans supply air to the primary and secondary air systems. Ljungstrom rotating air heaters (2) supply the combustion air to these systems. A three-damper arrangement (per pulverizer) is used to regulate the flow and temperature of the air entering the pulverizers.

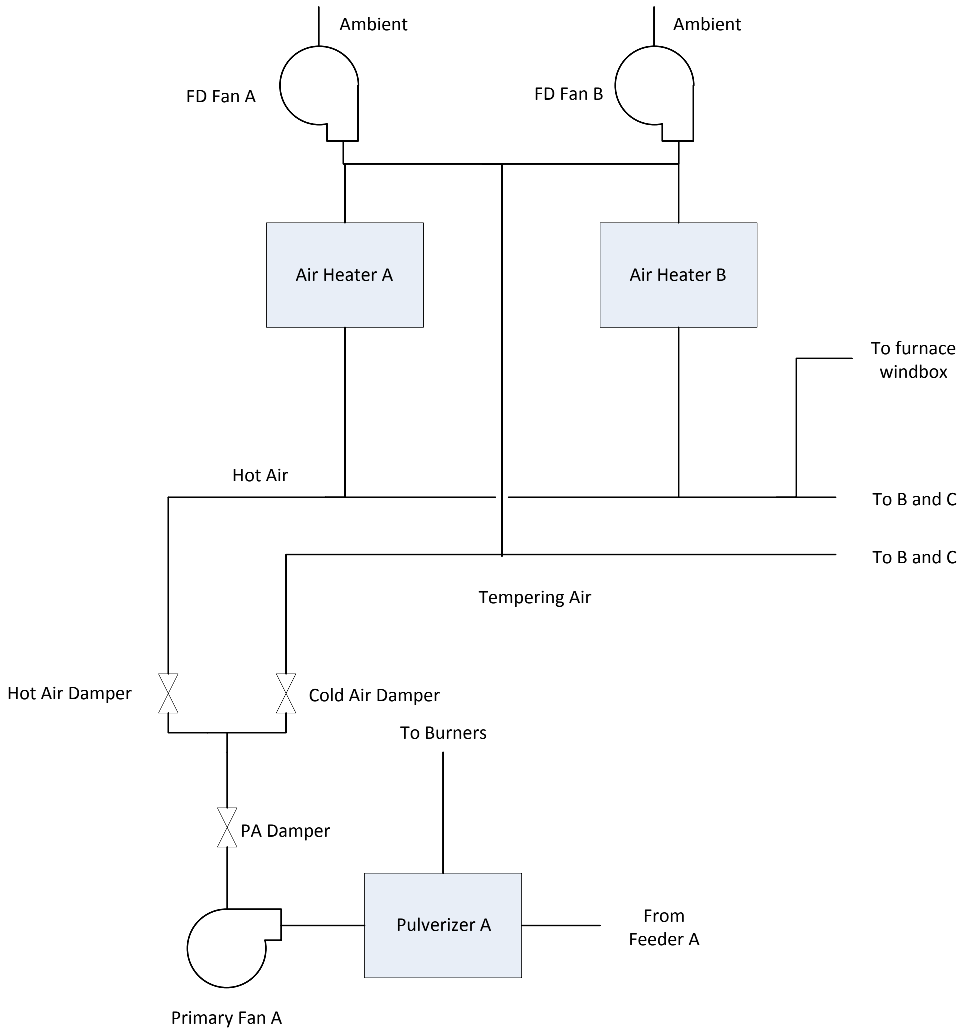

Figure A-2
Air system overview

Appendix B: Testing Methods

A number of testing methods have been identified to help determine the steady state performance and dynamic performance of a pulverizer. In combination, these tests can be used to identify potential issues with performance as well as degradation over time. These tests are outlined in this appendix.

Each test procedure contains the following sections:

- Purpose
- Performance Frequency
- Initial Conditions
- Process Data
- Calibration Data
- Procedure
- Data Processing

Initial Conditions

During these individual pulverizer tests, the Coal Fuel Master should be in Automatic mode, with the Pulverizer Master stations on the other operating pulverizers in Automatic mode and able to respond to changes in coal flow on the pulverizer being tested.

Pulverizer Clean Air Curve

Purpose

To establish the Pulverizer Clean Air Curve in order to identify changes in pulverizer primary air system calibration and to identify pulverizer pressure drop from coal inventory in the pulverizer.

Performance Frequency

This periodic test will normally take advantage of an out-of-service pulverizer being returned to service. This test should be performed annually, or more frequently when required.

<table>
<tr><th>Initial Conditions</th><th>Procedure</th></tr>
<tr><td>Out-of-service clean pulverizer ready to return to service. Igniters in service with burner line swing valves closed.</td><td rowspan="5">Note: Sufficient primary air flow must be maintained at all times burner line shutoff valves are open, to prevent recirculating flow of hot furnace gases through any burner line into the pulverizer.
Steady state data parameters:
• No primary air flow through pulverizer with burner line shutoff valves closed. Open burner line shutoff valves and establish minimum primary air flow through pulverizer (65–70% of POR). Primary air flow through pulverizer at ~80% POR. Primary air flow through pulverizer at ~90% POR.</td></tr>
<tr><th>Process Data</th></tr>
<tr><td>• Pulverizer Differential Pressure
• Primary Air Flow Element Differential Pressure
• Primary Air Mass (or Volumetric) Flow
• Pulverizer Primary Air Inlet Temperature</td></tr>
<tr><th>Calibration Data</th></tr>
<tr><td>• Primary Air Flow Differential Pressure Transmitter Calibration
• Primary Air Temperature Compensation Curve</td></tr>
</table>

Data Processing

Note: If Primary Air Flow Element Differential Pressure measurement is not available, effective primary air flow differential pressure can be calculated from primary air flow measurement by reverse calculation of the temperature compensation and square root using the control system configuration data.

Calculate curve fit, typically linear (y = ax + b), for Pulverizer Differential Pressure as a function of Primary Air Flow Differential Pressure to produce the Pulverizer Clean Air Curve. A typical clean air curve is shown in Figure B-1.

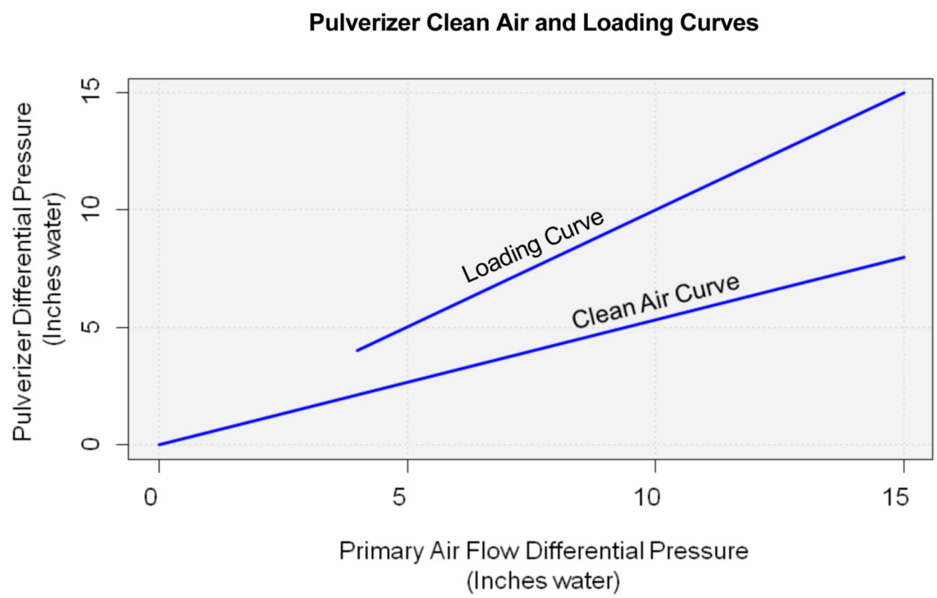

Figure B-1
Pulverizer Clean Air Curve and Pulverizer Loading Curve

Pulverizer Loading Curve

Purpose

To determine the existing Pulverizer Loading Curve for the pulverizer.

Performance Frequency

This periodic test will normally take advantage of an out-of-service pulverizer being returned to service. This test should be performed annually, or more frequently when required.

Initial Conditions	*Calibration Data*
Pulverizer in service with • Pulverizer Master in Manual Mode • Primary Air Flow in Automatic Mode • Feeder in Automatic Mode • Coal-Air Temperature in Automatic Mode	• Primary Air Flow Demand Curve • Primary Air Flow Bias • Coal Air Temperature Set Point
Process Data	***Procedure***
• Pulverizer Differential Pressure • Primary Air Flow Element Differential Pressure • Primary Air Mass (or Volumetric) Flow • Pulverizer Primary Air Inlet Temperature • Pulverizer Coal-Air Temperature • Feeder Coal Flow • Pulverizer Motor Amps • Pulverizer Master Control Station Output • Feeder Control Station Output • Primary Air Flow Control Station Output • Coal-Air Temperature Control Station Output	Establish steady state operation at the following load conditions and record data once steady state conditions are reached: • Minimum Pulverizer Demand ~40% • Pulverizer Demand ~ 70% • Pulverizer Demand ~90% **Note:** *Igniters in service if required.* Data at additional loads may be collected as needed.

Data Processing

Calculate curve fit, typically linear (y = ax + b), for pulverizer differential pressure as a function of primary air flow differential pressure to produce the Pulverizer Loading Curve. A typical pulverizer loading curve is shown in Figure B-1.

Pulverizer Motor No-Load Amps

Purpose

To determine the Pulverizer Motor No-Load Amps for the pulverizer. This will be used in conjunction with the motor amp data obtained from the pulverizer loading curve tests to establish the baseline Pulverizer Motor Amps curve.

Performance Frequency

This periodic test will normally take advantage of an out-of-service pulverizer being returned to service. This test should be performed annually, or more frequently when required.

Initial Conditions	Calibration Data
Primary air flow established through a clean pulverizer with the pulverizer motor running and the feeder stopped. This test is typically conducted as part of the sequence of placing a pulverizer in service after completion of the pulverizer clean air test.	None
Process Data	**Procedure**
• Pulverizer Motor Amps • Pulverizer Demand	Steady state data set with the pulverizer motor running and no coal flow to the pulverizer.

Data Processing

Calculate curve fit for Pulverizer Motor Amps as a function of Pulverizer Demand using the Pulverizer Motor Amp data from the Pulverizer Loading Curve test with the no-load amps as the y intercept, as shown in Figure B-2.

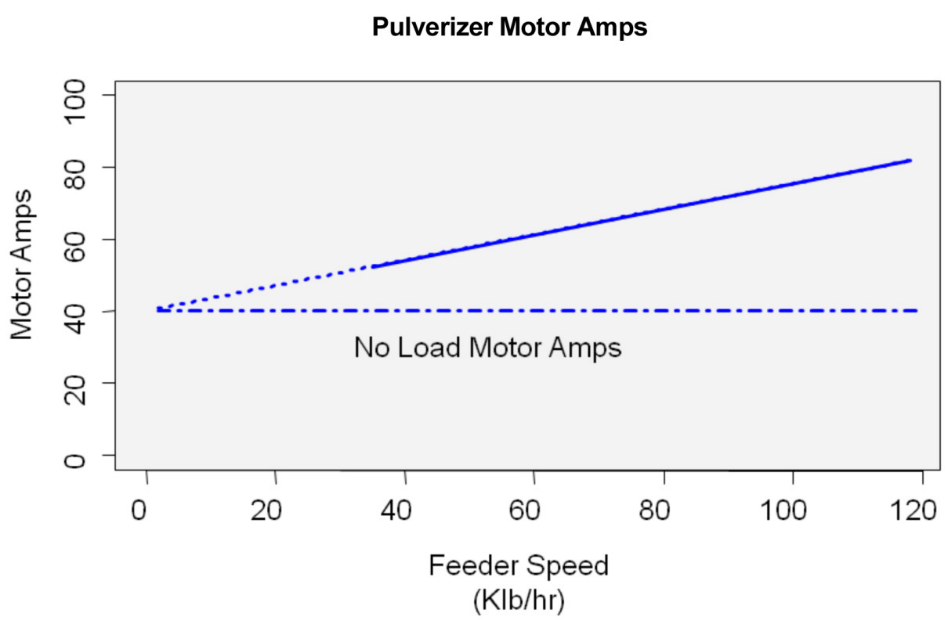

Figure B-2
Pulverizer Motor Amps

Open Loop Step Tests

Purpose

To determine the pulverized fuel system open loop response to small perturbations in primary air flow and coal feed at several different pulverizer loads. Suggested loads are 50%, 70%, and 90% POR for the pulverizer.

Performance Frequency

This periodic test will normally take advantage of an out-of-service pulverizer being returned to service. This test should be performed annually, or more frequently when required.

<table>
<tr><th>Initial Conditions</th><th>Procedure</th></tr>
<tr><td>Pulverizer in service with steady state pulverizer operation at selected load conditions with
• Pulverizer Master in Manual Mode
• Primary Air Flow in Automatic Mode
• Coal Feeder in Automatic Mode
• Coal-Air Temperature in Automatic Mode</td><td rowspan="5">Once steady state operation at the selected load is established:
1. Place the Primary Air Flow, Coal Feeder, and Coal-Air Temperature control stations in Manual mode.
2. Step increase Primary Air Flow control station output by ~5% of range and allow pulverizer to reach steady state conditions.
3. Step increase Coal Feeder control output by ~10% of range and allow pulverizer to reach steady state conditions.
4. Step decrease Coal Feeder control output by ~10% of range and allow pulverizer to reach steady state conditions.
5. Step decrease Primary Air Flow control station output by ~5% of range and allow pulverizer to reach steady state conditions.
6. Place the Primary Air Flow, Coal Feeder, and Coal-Air Temperature control stations in Automatic mode.
7. Using the Pulverizer Master, change pulverizer load to the other selected loads. After steady state conditions are achieved at the new load, repeat Steps 1–6.</td></tr>
<tr><th>Process Data</th></tr>
<tr><td>• Pulverizer Differential Pressure
• Primary Air Flow Element Differential Pressure
• Primary Air Mass (or Volumetric) Flow
• Pulverizer Primary Air Inlet Temperature
• Pulverizer Coal-Air Temperature
• Feeder Coal Flow
• Pulverizer Motor Amps
• Pulverizer Master Control Station Output
• Feeder Control Station Output
• Primary Air Flow Control Station Output
• Coal-Air Temperature Control Station Output</td></tr>
<tr><th>Calibration Data</th></tr>
<tr><td>• Primary Air Flow Demand Curve
• Primary Air Flow Bias
• Coal-Air Temperature Set Point</td></tr>
</table>

Closed Loop Step Tests

Purpose

To determine the pulverized fuel system closed loop response to small perturbations in pulverizer demand at several different pulverizer loads. Suggested loads are 50%, 70%, and 90% POR for the pulverizer.

Performance Frequency

This periodic test will normally take advantage of an out-of-service pulverizer being returned to service. This test should be performed annually, or more frequently when required.

Initial Conditions	*Calibration Data*
Pulverizer in service with steady state pulverizer operation at selected load conditions with • Pulverizer Master in Manual Mode • Primary Air Flow in Automatic Mode • Coal Feeder in Automatic Mode • Coal-Air Temperature in Automatic Mode	• Primary Air Flow Demand Curve • Primary Air Flow Bias • Coal-Air Temperature Set Point
Process Data	***Procedure***
• Pulverizer Differential Pressure • Primary Air Flow Element Differential Pressure • Primary Air Mass (or Volumetric) Flow • Pulverizer Primary Air Inlet Temperature • Pulverizer Coal-Air Temperature • Feeder Coal Flow • Pulverizer Motor Amps • Pulverizer Master Control Station Output • Feeder Control Station Output • Primary Air Flow Control Station Output • Coal-Air Temperature Control Station Output	Once steady state operation at the selected load is established: 1. Step increase Pulverizer Master control station output by ~10% of range and allow pulverizer to reach steady state conditions. 2. Step decrease Pulverizer Master control station output by ~10% of range and allow pulverizer to reach steady state conditions. 3. Using the Pulverizer Master, manually change pulverizer load to the other selected loads. After steady state conditions are achieved at the new load, repeat Steps 1–2.

Load Ramp Tests

Purpose

To determine the pulverized fuel system closed loop response characteristics to a ramp change in pulverizer demand using normal automatic pulverizer control. Ramp load tests are between two pulverizer steady state load points at a constant rate of change, as shown in Figure B-3.

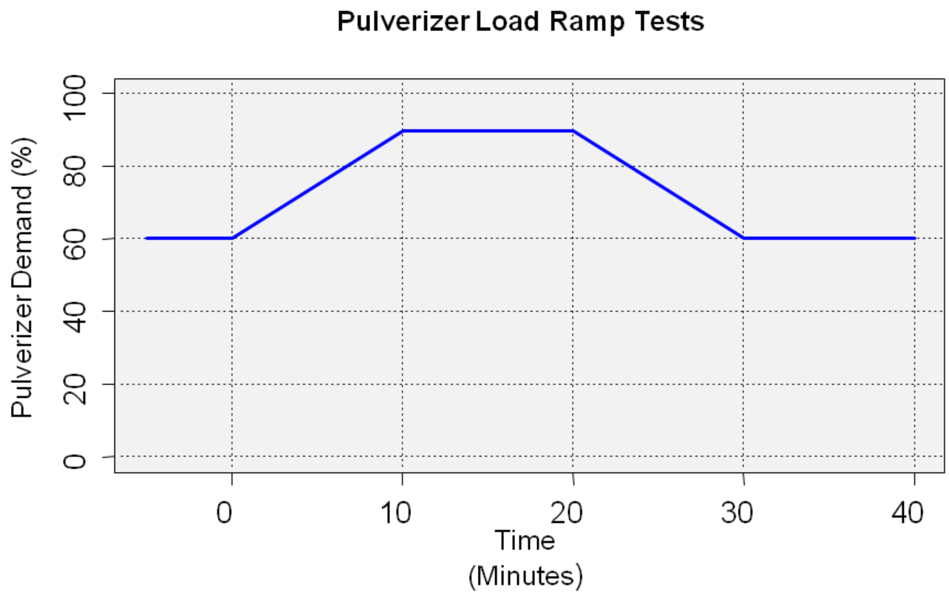

Figure B-3
Typical pulverizer demand load ramp at 3%/min

Note: During individual pulverizer tests, the Coal Fuel Master should be in Automatic mode with the Pulverizer Master stations on the other operating pulverizers in Automatic mode and able to respond to changes in coal flow on the pulverizer being tested.

Performance Frequency

This periodic test will normally take advantage of an out-of-service pulverizer being returned to service. This test should be performed annually, or more frequently when required.

Initial Conditions	***Calibration Data***
Pulverizer being tested in service with steady state pulverizer operation at selected load conditions with • Pulverizer Master in Manual Mode • Primary Air Flow in Automatic Mode • Coal Feeder in Automatic Mode • Coal-Air Temperature in Automatic Mode	• Primary Air Flow Demand Curve • Primary Air Flow Bias • Coal Air Temperature Set Point
Process Data	***Procedure***
• Pulverizer Differential Pressure • Primary Air Flow Element Differential Pressure • Primary Air Mass (or Volumetric) Flow • Pulverizer Primary Air Inlet Temperature • Pulverizer Coal-Air Temperature • Feeder Coal Flow • Pulverizer Motor Amps • Pulverizer Master Control Station Output • Feeder Control Station Output • Primary Air Flow Control Station Output • Coal-Air Temperature Control Station Output	Once steady state operation at the initial load of 60% Pulverizer Demand is established: 1. Ramp Pulverizer Master control station output up at 3%/min to 90% Pulverizer Demand of range and allow pulverizer to reach steady state conditions. 2. Ramp Pulverizer Master control station output down at 3%/min to 60% Pulverizer Demand of range and allow pulverizer to reach steady state conditions.

Pulverizer Startup/Shutdown

Purpose

To determine the pulverized fuel system closed loop response characteristics to a step change in pulverizer demand using normal automatic pulverizer control. Pulverizer Startup/Shutdown tests are step tests between a clean pulverizer state with no pulverizer inventory and a ~ 40–50% load point.

Performance Frequency

This periodic test will normally take advantage of an out-of-service pulverizer being returned to service or an operating pulverizer being taken to an out-of-service state. This test should be performed annually, or more frequently when required.

Initial Conditions	*Calibration Data*
Pulverizer in service with steady state pulverizer operation at selected load conditions with • Pulverizer Master in Manual Mode • Primary Air Flow in Automatic Mode • Coal Feeder in Automatic Mode • Coal-Air Temperature in Automatic Mode	• Primary Air Flow Demand Curve • Primary Air Flow Bias • Coal-Air Temperature Set Point
Process Data	***Procedure***
• Pulverizer Differential Pressure • Primary Air Flow Element Differential Pressure • Primary Air Mass (or Volumetric) Flow • Pulverizer Primary Air Inlet Temperature • Pulverizer Coal-Air Temperature • Feeder Coal Flow • Pulverizer Motor Amps • Pulverizer Master Control Station Output • Feeder Control Station Output • Primary Air Flow Control Station Output • Coal-Air Temperature Control Station Output	Place the Pulverizer Master in Manual mode and reduce pulverizer load to minimum and wait until steady state operation is achieved. Igniters may be placed in service as required. Shut down the pulverizer using either the Automatic or Manual shutdown mode in accordance with the plant's documented operating procedure. Record any deviations from the standard procedure and the reason for the deviation. If any maintenance or inspections are done on the pulverizer while it is out of service, record the condition of the pulverizer as found and as returned to service. When the pulverizer is returned to service, start the pulverizer using either the Automatic or Manual startup mode in accordance with written operating procedures. Document any deviations from the written procedures. At the completion of the startup procedure, allow the pulverizer to reach steady state conditions at minimum loading prior to releasing the pulverizer to normal control.

Appendix C: Fault Signature Specification Forms

The Fault Signature Specification Form

Complete the following form to specify a new asset fault signature. Attach a separate Fault Feature Specification form for each applicable fault feature. Itemized instructions are found later in this appendix.

Describe in detail the asset type for which this fault signature is applicable.
Describe the sources of the information used to specify this fault signature.
Name or briefly describe the fault type for this fault signature.
Describe the condition and/or mechanism of the fault and provide reference information.
Describe any limitations on the applicability or relevance of this fault signature.
List the fault features indicating for the fault and attach a Fault Feature Specification form for each.
Describe other faults that can cause this fault to occur.
Describe other faults that can be caused by this fault.
Describe the corrective actions that might remedy this fault.
Provide contact information for the persons who prepared this fault signature.

The Fault Feature Specification Form

Complete the following form to specify a new fault feature. Attach one or more of these forms to a Fault Signature Specification Form.

Describe the application of the fault feature for detecting the fault condition.
Describe the asset location where the data for assessing the fault feature is acquired initially.
Describe the technology used to acquire the data for assessing the fault feature.
Describe the examination of the data that indicates whether or not the fault is present.
List all possible outcomes of the examination of the data (outcomes should be mutually exclusive).
List in order of increasing confidence the outcomes of the examination that indicate for this fault.
Describe the effectiveness of this fault feature for detecting the fault condition. ☐ Very High; ☐ High; ☐ Medium; ☐ Low; ☐ Very Low
Provide reference information and examples for this fault feature.

Preparing a Fault Signature Specification

The instructions below provide an illustration of how to prepare for an entry of fault signature content into the Signature Database of the FW-PHM Suite software. The information necessary to create a fault signature must be gathered and verified before the fault signature data entry process is performed. The process used to gather and verify the fault signature data into the database is essential for the development of fault signatures that—when used as a collection—provide accurate and useful diagnostic advice.

Worksheets are provided earlier in this appendix to assist a user in collecting the information needed to specify a new fault signature. Not all of the information is mandatory. However, it is highly recommended that the user collect as much of the information requested as possible. This will lead to the best fault signatures when the data is entered into the database.

Two different forms are provided. The Fault Signature Specification form includes all information with the exception of the detailed fault features. The fault features should be identified on the Fault Signature Specification form, and then each individual fault feature should be detailed on a separate Fault Feature Specification form. The requested data fields in each of these forms are described in the sections below.

Fault Signature Specification Form Instructions

One copy of the following form can be used to gather the detailed information for an individual fault signature. For each applicable fault feature, a Fault Feature Specification form should be attached.

Describe in detail the asset type for which this fault signature is applicable. Describe the specific asset type for which this fault signature applies. This could include the specification of multiple asset types, provided that the intent is to enter the equivalent fault signature into the AFS Database for each of the multiple asset types. If possible, the asset type information should include the complete specification of the plant type, unit type, system type, equipment type and component type, since this lineage detail will be needed to enter the fault signature into the database.
Describe the sources of the information used to specify this fault signature. Describe the various sources of information used in creating the fault signature specification. This should allow a later user to identify and reference this source material. If possible, provide contact information for the person who prepared the fault signature, or for a knowledgeable expert who can be contacted for answering questions when the fault signature is entered or when it is later used.
Name or briefly describe the fault type for this fault signature. Provide a descriptive name or short summary statement that describes the fault condition.
Describe the condition and/or mechanism of the fault and provide reference information. Provide a detailed description of the fault condition and the mechanism by which it can lead to a failure condition if not corrected. If examples of this fault have occurred in service, provide references to the historical data for these examples.
Describe any limitations on the applicability or relevance of this fault signature. State whether the fault signature is generally applicable to assets of this type. If there are limitations on the applicability, describe them here. For example, the fault type might occur only in a certain design or model of a component or item of equipment.
List the fault features indicating for the fault and attach a Fault Feature Specification form for each. List the technology type and the examination type for each fault feature that indicates for this fault. Attach a separate detailed description of each listed fault feature using the Fault Feature Specification form.
Describe other faults that can cause this fault to occur. Faults might not happen independently—one fault can cause another to occur. This means that multiple faults can be present simultaneously. List the other faults that can cause this fault to occur. Consider the fault features for the listed causes and determine if any of these features are effective indicators for this fault.
Describe other faults that can be caused by this fault. As described above, this fault can also be the cause for other faults. List the other faults that this fault might cause if it occurs or is left uncorrected.
Describe the corrective actions that might remedy this fault. Provide guidance for correcting the fault should it occur. List reference materials that are relevant for correcting the fault.
Provide contact information for the persons who prepared this fault signature. Provide a name and e-mail address and/or phone number for the person(s) who created this fault signature specification.

Fault Feature Specification Form Instructions

One Fault Feature Specification form should be prepared for each fault feature that applies to a fault. A fault feature might be a condition or symptom in plan data, such as a high temperature reading from an instrument or the results from a visual inspection. A fault feature might also be some other precursor for the fault, such as a recent assembly or disassembly during a maintenance action that would be indicated by the plant's maintenance history record.

Describe the application of the fault feature for detecting the fault condition. Describe the characteristics of the fault feature that enable its use to detect the fault.
Describe the asset location where the data for assessing the fault feature is acquired initially. It is important to clearly specify the actual location where the fault feature is measured or acquired. This is often not the location of the fault itself unless the feature is a measured or observed characteristic acquired at the fault location. A commonly made mistake is to assign the fault feature to the fault location rather than to the asset location where the feature is actually acquired or observed.
Describe the technology used to acquire the data for assessing the fault feature. Specify the technology used to acquire the fault feature information. The term *technology* is expanded here to include the typical use—for example, oil analysis—as well as other means, such as a temperature measurement or a plant maintenance history.
Describe the examination of the data that indicates whether or not the fault is present. Specify the particular examination of the plant information or asset condition that must be performed to determine if the fault feature indication is present or not. For an oil analysis technology, the particle count in the oil might be determined, for example, with reference to the ASTM standard that specifies methods and recommends limiting values for various sizes and types of particles in lubricating oils.
List all possible outcomes of the examination of the data (outcomes should be mutually exclusive). List the mutually exclusive possible outcomes expected from the performance of the examination of the plant information or asset condition. The Normal outcome is always available by default, so the list must include all outcomes other than Normal. The nature of the list will depend on the technology employed and the examination performed. Once again, the list should specify mutually exclusive outcomes so that the result will always be only one of the listed possible results.
List in order of increasing confidence the outcomes of the examination that indicate for this fault. Often, any abnormal result will indicate for the fault. However, the possibility exists that a certain threshold of abnormal behavior must be crossed before an abnormal examination result is reliable as a fault feature. One example is an alert result from an advanced pattern recognition tool that can be Normal, Watch List, Marginal, or Unacceptable. The Marginal result might be specified as the minimum value for which the feature will have full effect as an indicator for the fault. In this example, the Watch List result would receive a lesser weighting, while the Marginal and Unacceptable results would receive a full weighting. Any special instructions for weighting the examination results should be detailed in this section.
Describe the effectiveness of this fault feature for detecting the fault condition. **☐ Very High; ☐ High; ☐ Medium; ☐ Low; ☐ Very Low** Fault features will not be equally effective as indicators for a fault. An expert will give some evidence substantially more weight than other evidence in diagnosing a fault. This weighting is expressed here by selecting a level of fault feature effectiveness from the choices listed above. Only one choice is permitted.

Provide reference information and examples for this fault feature.

Identify reference information that might assist a user in performing the evaluation. The reference information will often include standards or other often-applied procedures for the methods and threshold limits used in performing the evaluation. References to examples might also be provided.

Although the fault feature does not mandate the limit or threshold values that will be applied to determine an examination result, this information is ultimately needed for the fault feature to be evaluated. Typical or industry-standard limit or threshold values should be referenced here to the extent that they are applicable.

Appendix D: Fault Signature Tables

Classifier Setting – Restricted

Feature	Units	Case 1
Differential Pressure	InWC	+
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	+
Fineness	-200 Mesh	+
Journal/Tire Deflection	Inches	+

Notes: Deflection readings require additional displacement transmitters; high deflection may occur due to coal recirculation.

Classifier Setting – Too Open

Feature	Units	Case 1
Differential Pressure	InWC	-
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	-
Fineness	-200 Mesh	-
Fineness	+50 Mesh	+
Journal/Tire Deflection	Inches	-

Notes: Deflection readings require additional displacement transmitters; low deflection may occur due to low coal recirculation.

Coal Contamination/Tramp Material

Feature	Units	Case 1
Differential Pressure	InWC	Expected
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	+/Spikes
Noise		+

Notes: Ultrasonic sensors may be used to quantify noise levels at the mill. Noises may be audible to the human ear as well and noted by an operator.

Collapsed Spring Due to Localized Mill Fire

Feature	Units	Case 1
Differential Pressure	InWC	
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	-
Journal/Tire Deflection	Inches	+
Journal/Tire Deflection St. Dev.	Inches	+

Notes: Deflection readings require additional displacement transmitters. Standard deviation of affected journal may increase due to lack of spring tension. This failure is more common in CE style mills with independent spring/journal assemblies.

Control Damper Malfunction

Feature	Units	Case 1
Differential Pressure	InWC	Swings
Mill Feed Rate	TPH	Expected
Inlet Pressure	InWC	Swings
Outlet Pressure	InWC	Swings
PA Damper Position	Pct	Frozen/Swings
Hot Air Damper Position	Pct	Frozen/Swings
Tempering Air Damper Position	Pct	Frozen/Swings

Notes: Damper demand may increase under an expected or normal coal flow. Swings in data can be measured by trending standard deviation values of the given features.

Excessive Clearance for Roll (CE Mill)

Feature	Units	Case 1
Journal Liftoff Traces	Inches	Staggered
Mill Feed Rate	TPH	Expected
Fineness	-200 Mesh	Expected
Fineness	+50 Mesh	+
Journal/Tire Deflection	Inches	Uneven

Notes: Rolls may lift off from minimum stop bolt at different times. This can result in uneven deflection levels from the journals. Excessive amounts of coal may be left on the 50 Mesh sieve (+50 Mesh) although coal passing 200 Mesh would remain in the expected range. Deflection readings require additional displacement transmitters.

Excessive Fuel Moisture

Feature	Units	Case 1	Case 2
Differential Pressure	InWC	+	+
Mill Feed Rate	TPH	Expected	Expected
Mill Inlet Temperature	DegF	+	
Mill Outlet Temperature	DegF		-
PA Damper Position	Pct	Swings	
Hot Air Damper Position	Pct	Swings	+
Tempering Air Damper Position	Pct	Swings	

Notes: Damper positions may swing in a continuous attempt to correct exit temperatures due to moisture in coal. Case 2 results when hot air damper opens 100% but exit temperature set point cannot be maintained or reached.

Excessive Internal Circulation

Feature	Units	Case 1
Differential Pressure	InWC	+
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	+
Journal/Tire Deflection	Inches	+
Coal Spillage in Pyrites Collection		+

Notes: Deflection readings require additional displacement transmitters. Coal spillage would have to be manually observed.

Excessive Preload

Feature	Units	Case 1
Mill Feed Rate	TPH	Expected
Journal/Tire Deflection	Inches	-
Roll Liftoff		Delayed

Notes: Deflection readings require additional displacement transmitters. A roll with excessive preload would take more coal bed thickness to overcome the preload and lift the roll.

Excessive Throat Clearance

Feature	Units	Case 1
Differential Pressure	InWC	-
Mill Feed Rate	TPH	Expected
Inlet Pressure	InWC	-

Notes: The excessive clearance may affect inlet pressure and air flow, also causing coal spillage.

Feeder Adjustments/Calibration

Feature	Units	Case 1	Case 2
Differential Pressure	InWC	+/Swings	-
Mill Feed Rate	TPH	Expected	Expected
Mill Motor Current	Amps	Swings	-

Notes: Motor current and DP may swing or have trouble making set point if feeder requires calibration.

Gearbox Vibrations – Bearings, Gear Mesh, Alignment

Feature	Units	Case 1	Case 2
Bearing Fault Frequency Peak	ips	+	
Bearing Temperature	DegF	+	+

Notes: Bearing degradation may be monitored by trending values of fault frequency peaks over time and alarming on significant peak magnitude changes. Spectral data may be divided into ranges, and the RMS of each range trended over time can also lend to early fault detection. Temperature increases typically accompany bearing faults.

High Primary Air Flow – Sensor Issue High Side Blockage or Leak

Feature	Units	Case 1
Differential Pressure	InWC	+
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	Expected/-
Fineness	-200 Mesh	-
Fineness	+50 Mesh	+
Inlet Pressure	InWC	+
Outlet Pressure	InWC	+
Fan Current (if dedicated mill fan)	Amps	+

High Resultant Force Exerted on Main Vertical Shaft, Shaft Fatigue

Feature	Units	Case 1
Journal/Tire Deflection	Inches	Uneven

Notes: Deflection readings require additional displacement transmitters. Rolls or tires should have the same overall deflection in a balanced pulverizer. Any variation in deflection levels leads to a bending force exerted on the main shaft.

Hole in Classifier Cone

Feature	Units	Case 1
Differential Pressure	InWC	-
Mill Feed Rate	TPH	Expected
Fineness	-200 Mesh	-
Fineness	+50 Mesh	+

Notes: A hole in the classifier cone will affect air flow and reduce the resulting particle fineness from the milling process.

Hot Air Damper Malfunction

Feature	Units	Case 1
Mill Feed Rate	TPH	Expected
Mill Outlet Temperature	DegF	Swings
Primary Air Flow	lbs/min	Swings
Primary Air Flow Demand	Pct	+/-
Hot Air Damper Position	Pct	+/-

Notes: Air flow demand may change relative to same coal flow. Mill outlet temperature and air flow swings may be monitored by trending the standard deviation of those tags.

Insufficient Preload

Feature	Units	Case 1
Mill Feed Rate	TPH	Expected
Journal/Tire Deflection	Inches	+
Roll Liftoff		Delayed
Mill Motor Current	Amps	-
Fineness	-200 Mesh	-
Fineness	+50 Mesh	+

Notes: Deflection readings require additional displacement transmitters.

Lost Motion in Spring Assembly (CE Mill)

Feature	Units	Case 1
Journal Liftoff Traces	Inches	+
Mill Feed Rate	TPH	Expected
Journal/Tire Deflection	Inches	+

Notes: Journal liftoff traces will show unimpeded liftoff prior to overcoming spring preload on improperly adjusted journal springs. High-amplitude deflection traces would be seen at low load. Deflection readings require additional displacement transmitters.

Low Primary Air Flow – Sensor Issue Low Side Blockage or Leak

Feature	Units	Case 1	Case 2
Differential Pressure	InWC	-	+
Mill Feed Rate	TPH	Expected	Expected
Mill Motor Current	Amps		+
Journal/Tire Deflection	Inches		+
Inlet Pressure	InWC	-	
Outlet Pressure	InWC	-	
Coal Spillage in Pyrites Collection		+	+

Notes: High deflection levels due to recirculation. Deflection levels require additional displacement transmitters.

Missing or Damaged Classifier Blades

Feature	Units	Case 1
Differential Pressure	InWC	-
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	-
Fineness	-200 Mesh	-
Fineness	+50 Mesh	+

Notes: Low mill amps due to less circulation. Fineness results may yield poor pipe-to-pipe distribution as well.

Missing or Damaged Pyrites Plow

Feature	Units	Case 1
Differential Pressure	InWC	Expected
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	+/-
Coal Spillage in Pyrites Collection		-

Notes: There may be little to no pyrites in reject chute. A mill fire can result from damaged pyrite plows.

Oil Viscosity High

Feature	Units	Case 1
Oil Temperature	Deg F	+
Oil Particle Count		+

Notes: Oil particle counters detects and counts particles within the lubrication oil. The concentration of wear particles in the lubrication oil may indicate potential issues within the gearbox.

Oil Viscosity Low

Feature	Units	Case 1
Oil Temperature	Deg F	+

Notes: Oil particle counters detect and count particles within the lubrication oil. The concentration of wear particles in the lubrication oil may indicate potential issues within the gearbox.

Outlet Temperature Thermocouple Failure

Feature	Units	Case 1	Case 2
Differential Pressure	InWC	Expected	
Mill Feed Rate	TPH	Expected	+
Mill Outlet Temperature	DegF	Bad	
Primary Air Flow	lbs/min	Expected	
Tempering Air Damper Position	Pct	+/-	

Notes: Tempering damper may be driven open or closed, but the outlet temp reading is unaffected or bad/unexpected.

Partially Plugged Feeder

Feature	Units	Case 1
Differential Pressure	InWC	-
Mill Feed Rate	TPH	+
Mill Motor Current	Amps	-
Journal/Tire Deflection	Inches	-

Notes: Deflection readings require additional displacement transmitters.

Plugged Air Heater

Feature	Units	Case 1
Mill Feed Rate	TPH	Expected
Mill Outlet Temperature	DegF	+/-
Primary Air Flow	lbs/min	-
Hot Air Damper Position	Pct	+/100%

Notes: The pulverizer may be unable to hold outlet temperature set point and reach air flow set point.

Plugged Classifier Discharge

Feature	Units	Case 1
Differential Pressure	InWC	
Mill Feed Rate	TPH	Expected
Inlet Pressure	InWC	+
Outlet Pressure	InWC	+/-

Notes: Outlet pressure may be higher or lower than expected depending on locations of obstruction and pressure sensors.

Plugged Coal Flow – Classifier Cone

Feature	Units	Case 1	Case 2
Differential Pressure	InWC	-	
Mill Feed Rate	TPH	Expected	+
Mill Motor Current	Amps	-	
Fineness	-200 Mesh	-	
Journal/Tire Deflection	Inches		-

Notes: Displacement transmitters required as additional instrumentation to quantify deflection levels.

Plugged Oil Cooler

Feature	Units	Case 1
Oil Filter Differential Pressure		+
Gearbox Temperature	Deg F	+
Oil Particle Count		+

Plugging/Unplugging of Coal Feed Chute

Feature	Units	Case 1
Differential Pressure	InWC	Swings
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	Swings
Mill Inlet Temperature	DegF	Swings
Mill Outlet Temperature	DegF	Swings
PA Damper Position	Pct	Swings
Hot Air Damper Position	Pct	Swings

Notes: Features may react similarly if feeder calibrations are needed. As coal flow purges, features may swing to accommodate changes in coal entering pulverizer.

Pulverizer Fire

Feature	Units	Case 1
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	-
Mill Inlet Temperature	DegF	-
Mill Outlet Temperature	DegF	+
Hot Air Damper Position	Pct	-
Tempering Air Damper Position	Pct	+
CO Levels	Pct	+

Notes: Due to high exit temperature from fire, the tempering air damper will swing open and the hot air damper may swing shut to compensate for exit temperature. A CO detection system is required to quantify CO levels within the pulverizer.

Pulverizer Overloaded

Feature	Units	Case 1
Differential Pressure	InWC	+
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	+
Journal/Tire Deflection	Inches	-
Coal Spillage in Pyrites Collection		+

Notes: Deflection readings require additional displacement transmitters.

Pulverizer Underloaded

Feature	Units	Case 1
Differential Pressure	InWC	Swings
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	Swings
Journal/Tire Deflection	Inches	-

Notes: Deflection readings require additional displacement transmitters.

Roll Bearing Failure (CE Mill)

Feature	Units	Case 1
Bearing Fault Frequency Peak	ips	+

Notes: Bearing degradation may be monitored by trending values of fault frequency peaks over time and alarming on significant peak magnitude changes. Roll may take longer to "break free" and begin rolling.

Skidding Tires or Rolls

Feature	Units	Case 1
Mill Feed Rate	TPH	Expected
Mill Motor Current	Amps	+
Journal/Tire Deflection St. Dev.	Inches	-
Coal Spillage in Pyrites Collection		+

Notes: Skidding rolls or tires may be an early indication of bearing failure. It will take longer for the rolls to "break free" and begin to roll. Skidding tires will plow the coal bed, leading to lower deflection levels and coal spillage.

Spalled Weld Overlay – Roll or Table

Feature	Units	Case 1
Spectral Data of Journal Deflection	mils	+
Mill Feed Rate	TPH	Expected
Fineness	-200 Mesh	-
Fineness	+50 Mesh	+
Journal/Tire Deflection St. Dev.	Inches	+

Notes: High peaks at the roll or bowl speeds in the deflection spectral data may indicate geometric deformations—that is, a spalled area of weld overlay. Standard deviation for the affected roll(s) may increase, or all three would increase if it is an issue with the bowl. Fineness results are typically affected by worn or spalled rolls/table. Deflection readings require additional displacement transmitters.

Spring Issues Leading to Squeaking in Journal Assembly

Feature	Units	Case 1
Noise		+

Notes: Ultrasonic sensors may be used to quantify noise levels at the mill. Noises may be audible to the human ear as well and noted by an operator.

Spring Stiffness or Tension Off-Spec

Feature	Units	Case 1
Mill Feed Rate	TPH	Expected
Journal/Tire Deflection	Inches	Uneven
Roll liftoff		Delayed

Notes: Deflection readings require additional displacement transmitters.

Spring(s) Loose or Broken

Feature	Units	Case 1 (MPS Mills)	Case 2 (CE Mills)
Mill Feed Rate	TPH	Expected	+
Mill Motor Current	Amps	Expected	-
Fineness	-200 Mesh	-	-
Fineness	+50 Mesh	+	+
Journal/Tire Deflection	Inches	+	+

Notes: Deflection readings require additional displacement transmitters. Affected journal spring will show higher relative deflection.

Table Wear

Feature	Units	Case 1
Fineness	-200 Mesh	-
Fineness	+50 Mesh	+
Journal/Tire Deflection	Inches	Spectral

Notes: Additional displacement telemetry required for deflection data. Spectral data will indicate peak data at table frequency/speed and harmonics.

Tapper Fit Problem – Bowl Hub to Main Shaft

Feature	Units	Case 1
Spectral Data of Journal Deflection	mils	+
Mill Feed Rate	TPH	Expected
Journal/Tire Deflection St. Dev.	Inches	+

Notes: Peaks at harmonics of the bowl speed may indicate a taper fit problem. Deflection readings require additional displacement transmitters.

Tempering Air Damper Control Malfunction

Feature	Units	Case 1
Mill Outlet Temperature	DegF	Swings
Tempering Air Damper Position	Pct	+/-
Primary Air Flow	lbs/min	Swings

Notes: Tempering air damper demand should be compared to sister pulverizers on same unit. Outlet temperature set point may be hard to hold. There may be no change in temperature for a change in damper demand.

Tire or Roller Wear

Feature	Units	Case 1 (MPS Mills)	Case 2 (CE Mills)
Differential Pressure	InWC	+	-
Mill Feed Rate	TPH	Expected	Expected
Mill Motor Current	Amps	+	-
Fineness	-200 Mesh	-	-
Fineness	+50 Mesh	+	+
Journal/Tire Deflection	Inches		-
Pulverizer Inventory	Inches	+	

Notes: Lateral movement of tire assembly may be observed in MPS style mills. All deflection readings require additional displacement telemetry. Deflection spectral data may also be used to determine wear based on activity at roll/tire frequencies/speeds.

Notes and abbreviations:

InWC	=	Inches of water column
TPH	=	Tons per hour
Amps	=	Amperes
Pct	=	Percent
DegF	=	Degrees Fahrenheit
ips	=	Inches per second
lbs/min	=	Pounds per minute
mils	=	Thousandths of an inch (0.001”)

-200 Mesh = Amount of pulverized coal passing through a 200 mesh screen (0.0029” openings). Typical range for expected value is 70–80% passing.

+50 Mesh = Amount of pulverized coal remaining on a 50 mesh screen (0.0117” openings). Typical range for expected value is 99–99.5%.

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