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Coal Pulverizer Design Upgrades to Meet the Demands of Low NO_X Burners

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ABSTRACT

Coal pulverizer design and operation is an important element integral to the long term success of Low NO_x combustion systems. The increased use of Low NO_x burners in the past 10 years has instigated a need for further development of coal pulverizer technology in an effort to ensure efficient operation of a power boiler for minimizing gaseous emissions (NO_x, CO, HC) and unburned carbon in fly ash. Riley Power Inc. (RPI), a Babcock Power Inc. company, has been developing improved coal pulverizer technology during the past several years to meet these challenging demands. All three (3) types of coal pulverizer systems supplied by RPI originally designed for low, medium and high-speed pulverization have undergone design upgrades and improvements. These machines include Ball Tube Mills (BTM), MPS mills and Atrita® Pulverizers, respectively. The Atrita® Pulverizer has been upgraded for better coal fineness and longer service life. BTM systems have been upgraded for more reliable operation and MPS mills have been upgraded for increased capacity. This paper discusses the design details behind these upgrades, reviews the impact on Low NO_x burner performance (emissions and UBC) and presents the advantages of these milling system technology upgrades for switching coal types from bituminous to sub-bituminous coal.

INTRODUCTION

As part of the continuing effort to improve combustion performance commensurate with reduced emissions in coal-fired power plants, Riley Power Inc. (RPI), a Babcock Power Inc. (BPI) company has been actively developing mill system technology to achieve better coal fineness, increased capacity, greater reliability, and longer wear life. The effort has improved the design of low, medium, and high speed pulverizers, all three of which are supplied by RPI.

Improved mill system design combined with field proven Low NO_x burner technology enables a utility boiler today to operate with low emissions and minimal degradation in boiler efficiency. This paper discusses the details behind the pulverizer upgrades and the benefits to utility boiler operation under Low NO_x conditions.

MPS MILL

The MPS mill is classified as an air-swept, pressurized, vertical spindle, table/roller mill. It contains an integral classifier, a grinding section, a windbox (plenum), and auxiliary components. (Figure 1)

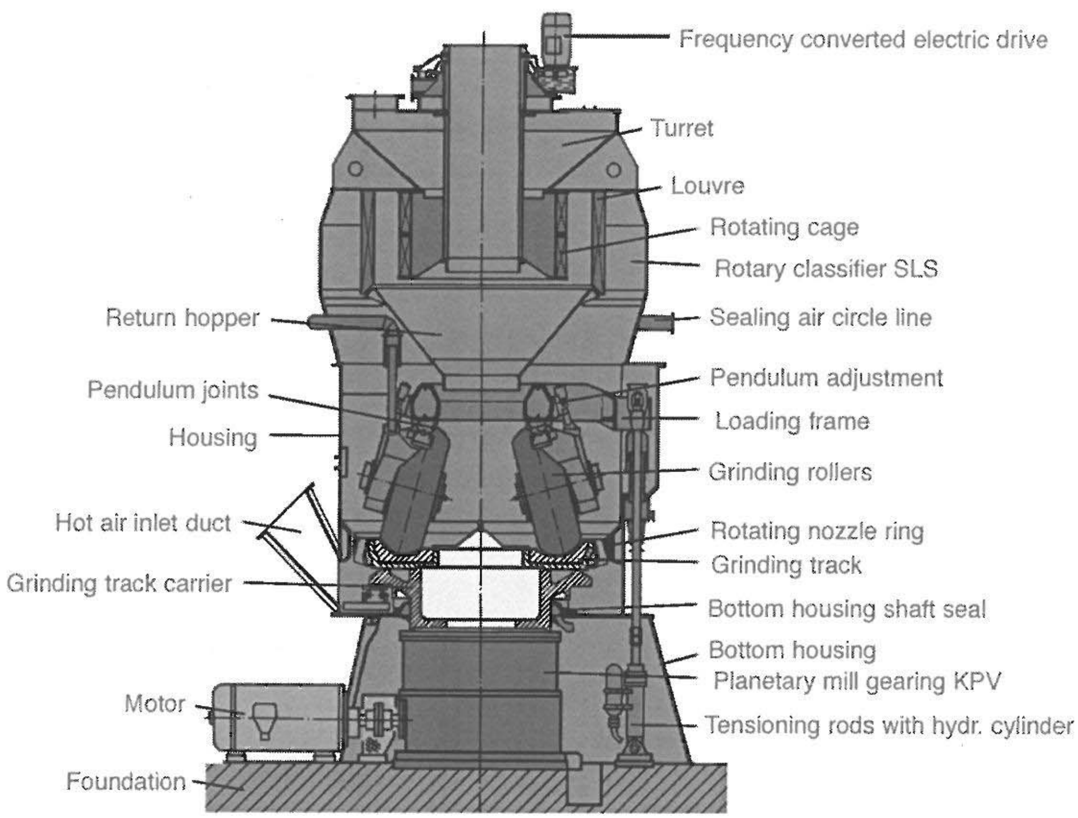

Figure1. MPS Mill with SLS Dynamic Classifier.

Raw coal is gravity-fed through a central feed pipe to the grinding table where it flows outwardly by centrifugal action and is ground between the rollers and table. Hot primary air for drying and coal transport enters the windbox plenum underneath the grinding table and flows upward through a swirl ring having multiple sloped nozzles surrounding the grinding table. The air mixes with and dries coal in the grinding zone and carries pulverized coal particles upward into a classifier. Fine pulverized coal exits the outlet section through multiple discharge coal pipes leading to the burners, while oversized coal particles are rejected and returned to the grinding zone for further grinding. Pyrites and extraneous dense impurity material fall through the nozzle ring and are plowed, by scraper blades attached to the grinding table, into the pyrites chamber to be removed.

Mechanically, the MPS mill is categorized as an applied force mill. There are three grinding roller wheel assemblies in the mill grinding section, which are mounted on a loading frame via pivot point. The fixed-axis roller in each roller wheel assembly rotates on a segmentally-lined grinding table that is supported and driven by a planetary gear reducer direct-coupled to a motor. The grinding force for coal pulverization is applied by a loading frame. This frame is connected by vertical tension rods to three hydraulic cylinders secured to the mill foundation. All forces used in the pulverizing process are transmitted to the foundation via the gear reducer and loading elements. The pendulum movement of the roller wheels provides a freedom for wheels to move in a radial direction, which results in no radial loading against the mill housing during the pulverizing process.

Depending on the required coal fineness, there are two types of classifier that may be selected for an MPS mill. The SLS dynamic classifier, which consists of a stationary angled inlet vane assembly surrounding a rotating vane assembly or cage, is capable of producing micron fine pulverized coal with a narrow particle size distribution. In addition, adjusting the speed of the rotating cage can easily change the intensity of the centrifugal force field in the classification zone to achieve coal fineness control real-time to make immediate accommodation for a change in fuel or boiler load conditions. For the applications where a micron fine pulverized coal is not necessary, the SLK static classifier, which consists of a cone equipped with adjustable vanes, is an option at a lower cost since it contains no moving parts. With adequate mill grinding capacity, the MPS mill equipped with SLK static classifier is capable of producing a coal fineness up to 99.5% or higher <50 mesh and 80% or higher <200 mesh, while the SLS dynamic classifier produces coal fineness levels of 100% <100 mesh and 95% <200 mesh, or better.

NEW MPS MILL DEVELOPMENT

Since the first application using an MPS mill to process pulverized coal in Germany in the mid 1960s, there have been over 2,000 different MPS mill installations operating in coal-fired power plants worldwide. As one of the most popular coal pulverizers in the utility industry, the MPS mill was first introduced into the US in the early 1970s. Most of the first generation design with a mechanical spring grinding force loading system (Figure 2) are still operating today in coal-fired power plants.

With the development of advanced grinding technology, modern MPS mills have improved to its third generation design utilizing a hydropneumatic grinding force loading system with enhanced grinding force. To date, MPS mills have been successfully used for grinding a wide range of coals from bituminous to high moisture sub-bituminous to lignite type coals.

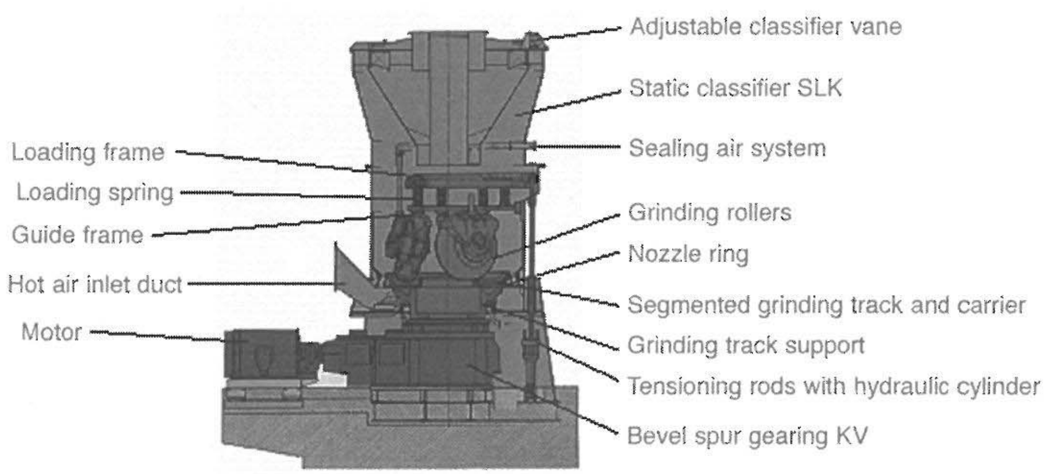

Figure 2. First Generation MPS Mill with spring grinding force loading system.

The standard mill capacity for twenty (20) different mill sizes ranges from 10 tph to 190 tph (Figure 3).

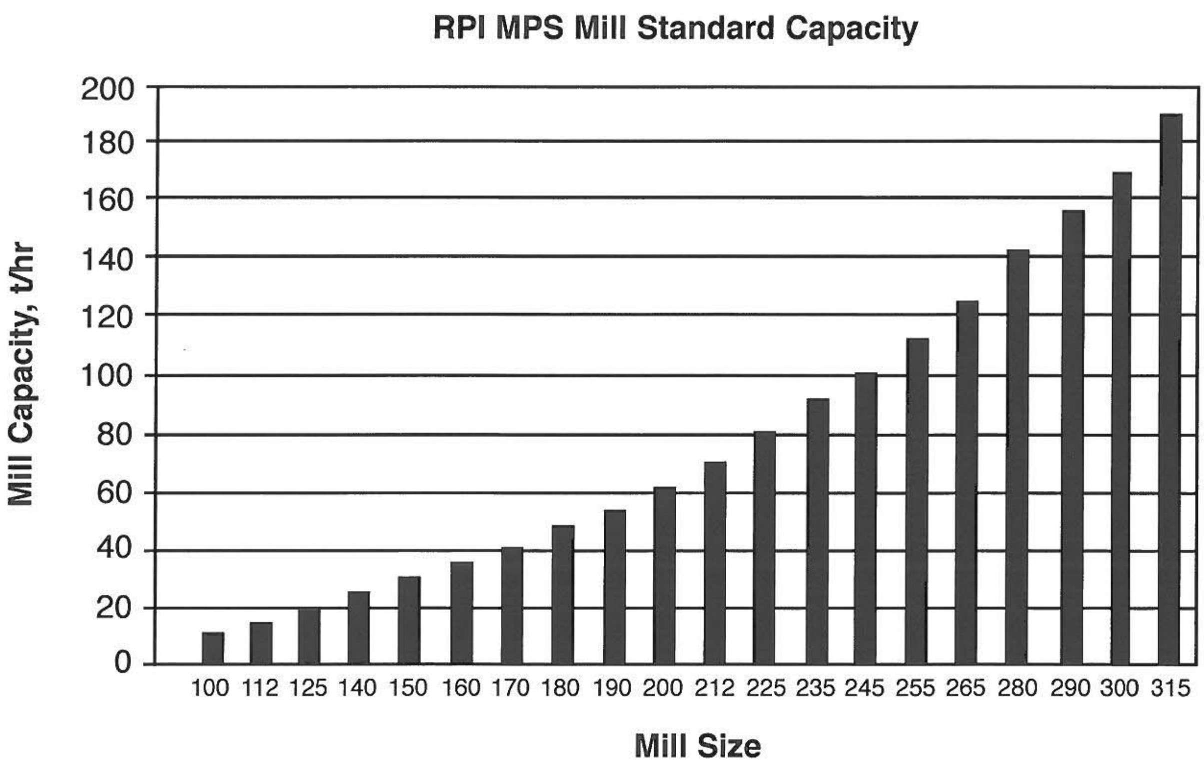

Figure 3. MPS Mill standard capacity.

Today's coal-fired utility boiler operation needs pulverizer designs to supply pulverized coal with required throughput and coal fineness, and also perform with lower specific power consumption, especially at reduced mill load. The designs must be capable of proper mill operation and control with quick response to boiler load demand for a variety of coal switching or coal quality fluctuations. The designs must also have greater mill turndown capability without mill vibration. Obviously, the first generation of MPS mill designs with limited adjustability for a spring-loaded grinding force loading system, in which the grinding force is produced by pretensioned compression springs, are often inadequate to satisfy today's mill operation requirements, since this nonadjustable grinding force concept produces little flexibility of grinding pressure for different mill operating conditions.

A modern MPS mill design is equipped with a hydropneumatic grinding force loading system that consists of three hydraulic cylinders with one tension rod each to pull down a rigid loading frame. The grinding rollers fixed to the loading frame are thus pressed against the coal bed between the rollers and grinding table segments (Figure 4). The applied grinding load is capable of being adjusted in real time with the mill in operation.

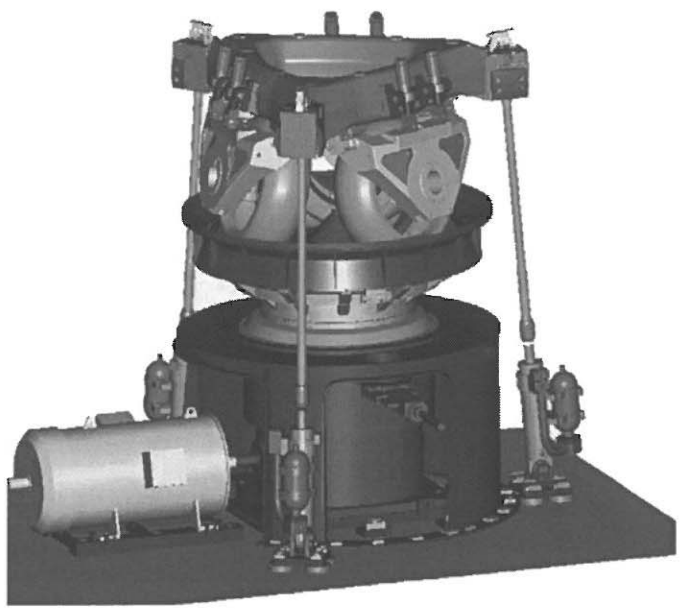

Figure 4. Hydropneumatic grinding force loading system.

The hydraulic cylinder configuration shown in Figure 5 indicates that the applied grinding force is produced by the oil pressure on the piston ring surface (grinding pressure) and reduced by the oil pressure acting on the piston bottom face (counter pressure) of the loading cylinder.

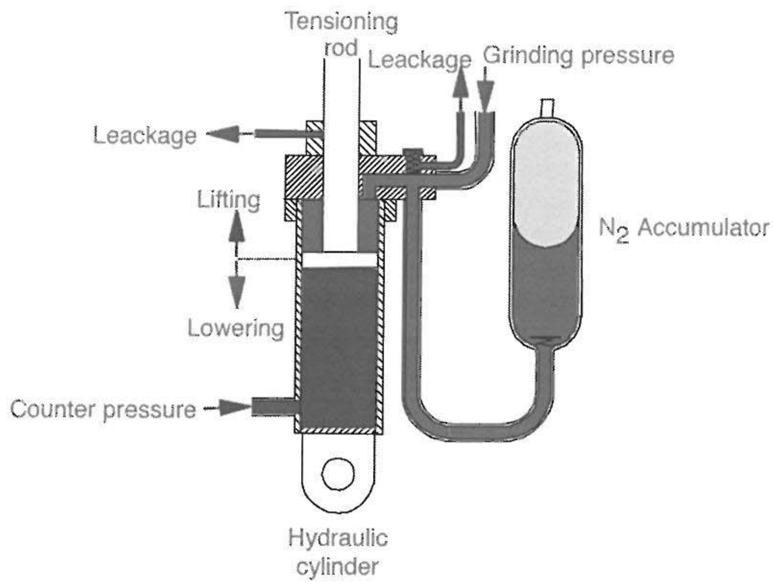

Figure 5. Hydraulic Cylinder Configuration.

The counter pressure reduces the noise generated by the mill and is adjustable depending on the coal properties and required coal fineness. During operation, both pressures are adjusted proportionately to the feeder speed by means of pressure control valves to achieve an optimized grinding force characteristic throughout the mill load range. During mill startup or shutdown, a higher pressure is applied on the piston bottom face than on the piston ring face to eliminate mill vibration or rumble by reducing the grinding force against the mill table. With sufficient high pressure on the piston bottom face, the rollers can even be lifted off of the grinding table segments, which results in a significant wear reduction between the rollers and grinding segments, as well as minimal mill torque requirement during mill startup.

With the successful application of hydropneumatic loading systems, further adjustments in the design have been implemented in recent years. MPS mills have experienced their "third generation" design by increasing mill grinding force by over 60%. As a result, mill capacity increases of 20%-50%, depending on the coal application, have been experienced since the mill grinding capability is directly proportional to available grinding force. This implies, for example, that only six (6) or seven (7) mills of the same physical size are required today for a boiler that previously needed eight (8) mills to supply the same coal flow. This significantly reduces the initial capital investment for mills and associated burners and coal piping systems.

The adjustable grinding force capability with hydropneumatic loading system designs enables MPS mills to vary the grinding load as mill load demand changes. This optimizes mill grinding force loading characteristics such that the mill grinding force increases as mill load increases. Figure 6 illustrates a typical mill grinding force loading characteristic. The grinding load increasing from 100% to 160% corresponds to mill capacity increasing from 100% to 135%, which reflects mill design upgrade from second generation to third generation by enhancing this grinding force. For comparison purposes, a grinding force loading characteristic of the mill with a spring loading system and the second generation of hydropneumatic loading system design are also shown in Figure 6. For the mill equipped with spring load system, the grinding force is overloaded at reduced mill load. This will result in additional wear on roller and table segments and will produce excessive mill vibration. While at high mill load operation, the grinding force is insufficient to meet the requirement for mill load increase.

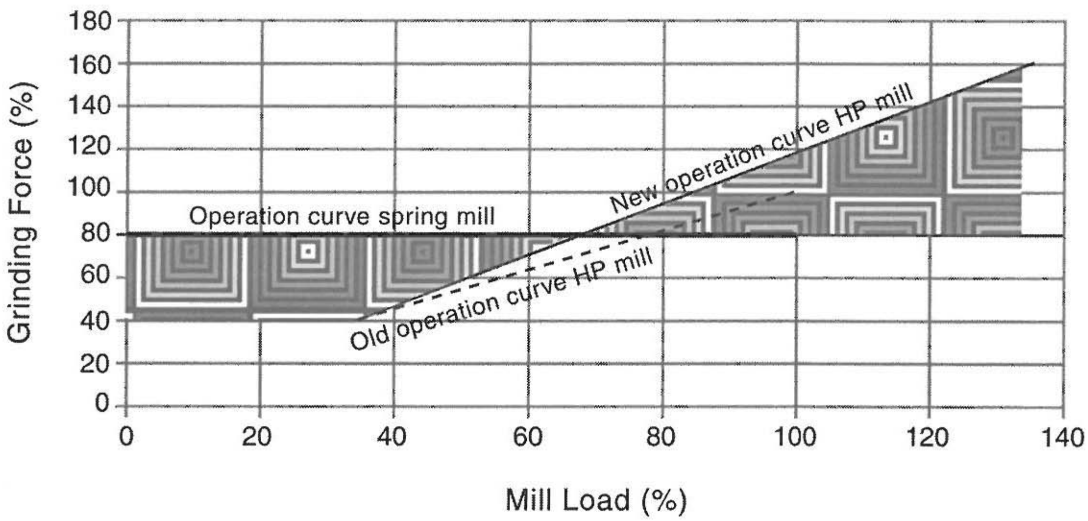

Figure 6. Mill grinding force loading characteristic.

ATRITA® PULVERIZER

The Atrita® Pulverizer is a horizontal type high speed coal mill (Figure 7), which consists primarily of three sections: crusher, grinding and fan section. The coal feed into the mill is first reduced in size in the crushing section for primary size reduction and drying. Screened by the grid segments under the hammers, the reduced-size coal is introduced to the grinding section for pulverization. The conveying air or primary air, developed by an integral fan in the mill's fan section, transports the pulverized coal from the grinding section to the burners.

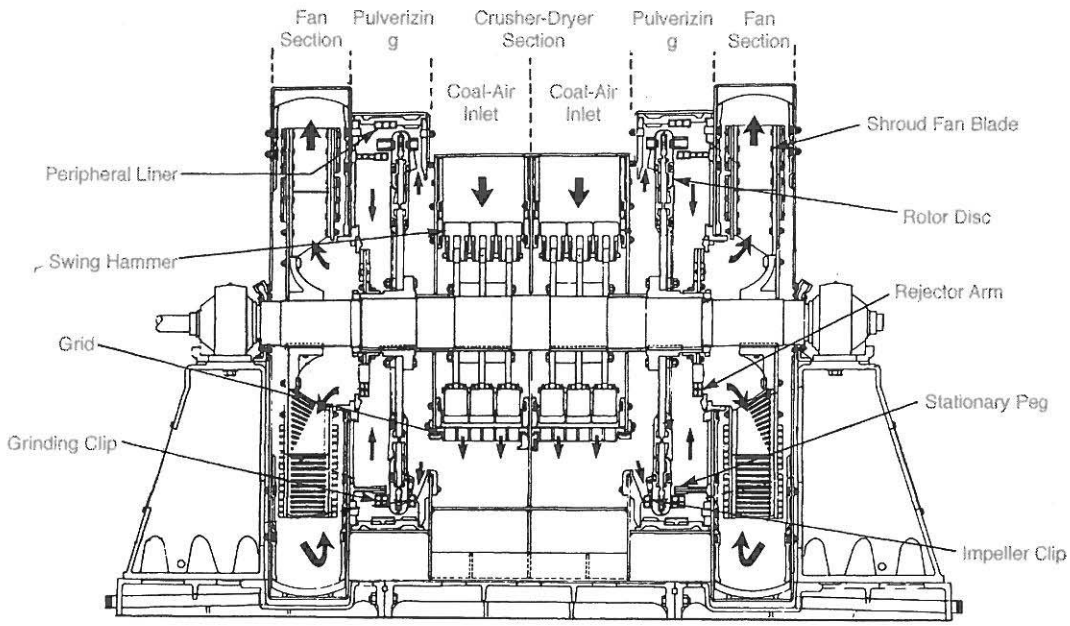

Figure 7. Duplex Atrita® Pulverizer.

In the crusher section, there are hammers and a breaker plate to perform a crushing function. Below the breaker plate, there is a crusher block, which can be adjusted to move forward or backward against the hammers to establish a gap between hammer tips and crusher block. This gap, associated with the grid segments under the hammers, controls the size of crushed coal entering the grinding section. In the grinding section, major grinding components are stationary pegs and moving clips. The clips are attached to the wheel that rotates around the mill axis at a high rate of speed. The turbulent flow and impact momentum on coal particles developed by the high speed movement of the clips create an intensive particle-to-particle attrition or a pulverizing effect to further grind the coal particles in the grinding zone. In order to control pulverized coal fineness, there is a whizzer type classifier or rejector arm assembly between the grinding section and the fan section within the Atrita® Pulverizer. In the grinding process, the V-shaped rejector arms, rotating with the pulverizer rotor, magnified the intensity of centrifugal forces within the grinding section, which retains courser coal particles in the grinding zone for additional pulverization. The finer coal particles, subjected to less centrifugal and drag forces due to reduced mass and sectional area, pass through the rejector arms with primary air into the fan section and are delivered to the burners through coal pipes.

NEW ATRITA® PULVERIZER DEVELOPMENTS

With more than 50 years of operational experience and more than 1600 installations, the Atrita® Pulverizer is faced with the challenge of continually improving pulverized coal fineness and reducing mill down time with design modification and material upgrades.

In the present design, the rejector arm assembly is composed of an axially adjustable hub, several V-shape arms with attached guards, and a stationary rejector ring.

It is essential to set a very small clearance between the side surfaces of the rejector ring and the side end of the rejector arms to achieve acceptable coal fineness. However, this tight clearance requirement is difficult to maintain due to material wear and dimensional variation. This results in the inability to control coal fineness in the pulverizing process by failure to prevent coarse particles from "leaking" through the gap between the rejector arms and rejector ring.

Therefore, a new rejector arm assembly design has been developed with a dynamic seal effect by creating a labyrinth seal gap along with additional beaters. In this new design, referred to as a DynaRing™ Classifier (patent pending), a solid continuous ring made from segments is added in between the rejector ring and rejector arms. This added ring, attached to rejector arms, is rotated by the main shaft through the rejector arms. Thus, the seal gap between the rotating and stationary parts is a continuous clearance formed between the end surfaces of the dynamic ring and the rejector ring seated on the rejector ring support, instead of the rejector arms and the reject ring. To make a more effective seal, the seal gap is made with a labyrinth shape, that is, the end surfaces of the rejector ring and dynamic ring are made with offset steps to form a labyrinth type gap. On the dynamic ring, there are a number of beaters equally spaced and attached on the outer end surface facing the rejector ring. The main shaft rotates these beaters at a high speed through the rejector arms and dynamic ring, which further controls coal fineness by reducing the size of the particles entering into the gap or by preventing the coarse particles from entering the seal gap. The beaters are either mounted to or integral with the dynamic ring. The leading face of the beaters is tiled or coated with a wear resistant alloy for long wear life. In the DynaRing™ Classifier design, the rejector arms have been redesigned with an attachable capability to tailor different coal application and coal fineness requirements.

A field installation test of the DynaRing™ Classifier was conducted on an Atrita® 550D Pulverizer installed at a utility located in the Northeast (Figure 8). The DynaRing™ Classifier improved coal fineness significantly. Table 1 presents the typical test results from the mill tests. The data show that with the DynaRing™ Classifier, the coal fineness improved from the previous 67.6% to 80% passing

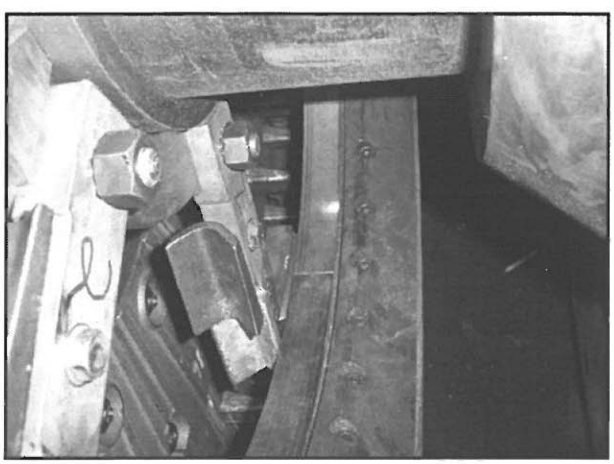

Figure 8. DynaRing™ Classifier.

through 200 mesh at approximately the same fuel flow (Test 1 vs. Test 3). After the retrofit, the mill also enhanced the top size control capability significantly; the coarse residue on 50 mesh averaged 0.5% or less! Even at a higher mill throughput (16% higher capacity) the mill retrofitted with the DynaRing™ Classifier still produced much finer coal than that of the pre-retrofitted mill (Test 2 vs. Test 3). This coal fineness improvement was also demonstrated by the comparison between Mill C and Mill D that is equipped with the standard rejector arm assembly (Test 1 vs. Test 4). The improvement of coal fineness between the DynaRing™ Classifier and original or standard rejector arm designs is also illustrated in Figure 9.

Table 1

Test Results of DynaRing™ Classifier

Test #	1	2	3
Test Mill Mill rejector arm setup	Mill C New Design	Mill C New Design	Mill C Std Design
Coal Fineness			
%<50 mesh	99.55	99.5	97.93
%<100 mesh	95.95	94.3	89.2
%<200 mesh	80	78.25	67.6
Coal Throughput @ test, tph	14.9	17.7	15.2
Required standard mill capacity, tph*	30.1	29.8	16.9

* Based on Atrita® Mill Engineering Standards; these mill standard capacities are required for the achieved fineness with the tested throughput.

Note: Specific power consumption increased 7 to 15% with the new DynaRing™ Classifier, reflecting the significantly improved coal fineness levels produced.

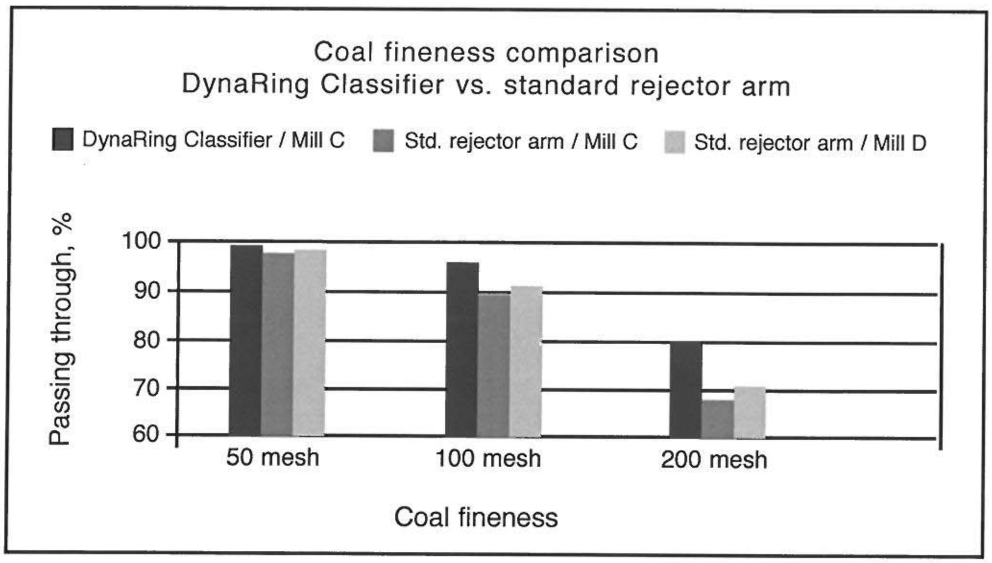

Figure 9. Test Results of DynaRing™ vs. Rejector Arm Classifier.

With the DynaRing™ Classifier, derating the mill capacity is significantly minimized when it is desired to produce a high level of coal fineness product and for the pulverizer to handle high moisture PRB coal. In addition, the DynaRing™ Classifier allows much more latitude when setting the seal gap clearance. This greatly simplifies the setup of the DynaRing™ Classifier during the initial installation and should help to prevent the coal fineness from deteriorating as the relevant components wear in service. As coal fineness increases, the DynaRing™ Classifier needs more power input into the mill for additional grinding work. Preliminary data indicated that the corresponding increase in power consumption is approximately 12%.

In addition to improving coal fineness with the DynaRing™ Classifier, the Atrita® Pulverizer grinding elements, such as hammers, crusher block, pegs and clips, have also experienced material upgrades and/or a redesign of the components. This reduces mill down time and enables the Atrita® Pulverizer to operate at design conditions for a longer period of time. With lab testing of coupon samples to screen newly developed abrasive resistant materials, followed by proper field testing, Atrita® Pulverizers will be continually upgraded with better materials and improved service life to respond to the challenge for today's utility needs.

BALL TUBE MILL

The RPI Ball Tube Mill (BTM) is a cylindrical low-speed grinding mill. As one of the most robust mills, it consists of a steel barrel, lined with cast abrasion resistant liners, and partially filled with hardened steel balls. Coal mixed with preheated primary air enters both ends of the mill from a crusher/dryer or feeder. As the mill rotates, the balls cascade and pulverize the coal by impact and attrition. The pulverized coal is then conveyed by primary air to external centrifugal classifiers. Fine coal particles exit the classifier into coal piping for transport to the furnace, while oversized coal particles return to the mill, by classification, for further pulverizing.

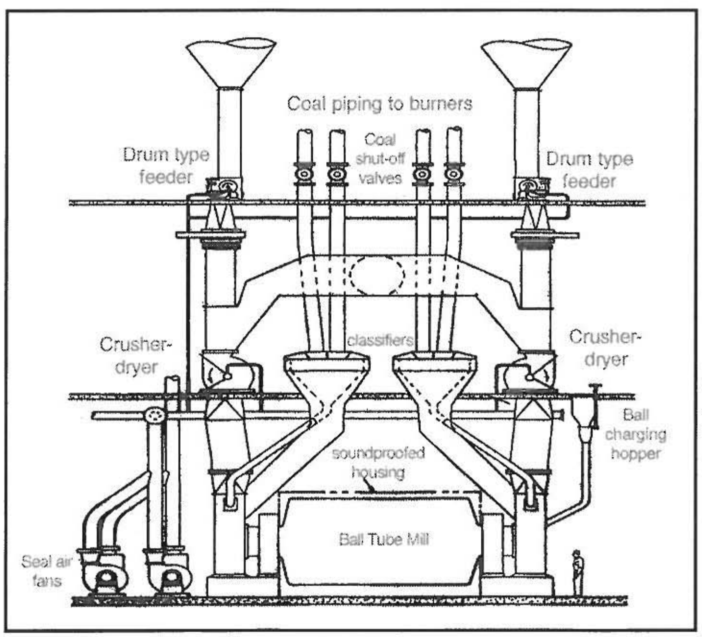

Figure 10. Ball Tube Mill

Figure 10 shows a typical BTM system. The crusher dryer ahead of the BTM performs the primary crushing process. Not only does it reduce feed size into the BTM resulting in lower overall mill system power consumption, but it also significantly increases mill system drying capacity by enhancing the drying process. This is particularly beneficial in applications firing sub-bituminous coals with high moisture content. The RPI Model 80 Centrifugal Static Classifier, which contains no moving parts and is almost maintenance free, is integrated into the BTM system design to establish a complete pulverizer system. The classifiers enhance mill capacity by reducing over-grinding in the pulverizing process and control the coal fineness. With sufficient mill grinding capacity, BTM systems equipped with Model 80 Centrifugal Classifiers are capable of producing a coal fineness of 99% or higher through 50 mesh and 80% through 200 mesh.

NEW BTM SYSTEM DEVELOPMENT

1. Trickle valve

It is critical, for proper operation and performance of a Ball Tube Mill system, to maintain smooth uninterrupted rejects flow of the coarse return particles and to prevent primary air from flowing backwards through the reject pipe. Typically, a trickle valve, similar to a conventional check valve, is designed and installed to perform this function. The driving force to open and close the valve is determined by a balance of the forces exerted on the valve plate. Under normal operating conditions, there are three main forces acting on the valve plate: rejected coal pressure, primary air system pressure, and gravitational force on the plate. When the rejected coal pressures are greater than the summation of the primary air pressure and the normal gravitational force on the valve plate, the valve will open to discharge rejects from the rejects pipe. Since it is a function of the accumulation of the coal rejects above the valve, the rejected coal pressure will decline as the coal accumulation level above the valve decreases. This, in turn, results in the valve moving to a more closed position. The valve will open again when the coal inventory above the valve plate accumulates to a certain level. In general, the valve moves continuously back and forth during normal operation.

The mill recirculation load or rejects flow rate is dependant on mill and classifier operating conditions rather than operation of the trickle valve. However, it is necessary to maintain a certain level of rejects dynamically above the valve for proper sealing to prevent primary air backflow through the rejects pipe. The actual rejects amount accumulated above the valve will vary from application to application as coal properties and primary air pressures change due to mill system operation. A new design trickle valve with an adjustable counterweight is capable of controlling the rejects level above the valve for various applications and operating conditions to achieve the best performance. This new trickle valve design consists primarily of the valve housing with flanged connections to the rejects pipe, valve plate, valve shaft with external indicator, shaft support (bearings), and adjustable counterweight, as shown in Figure 11.

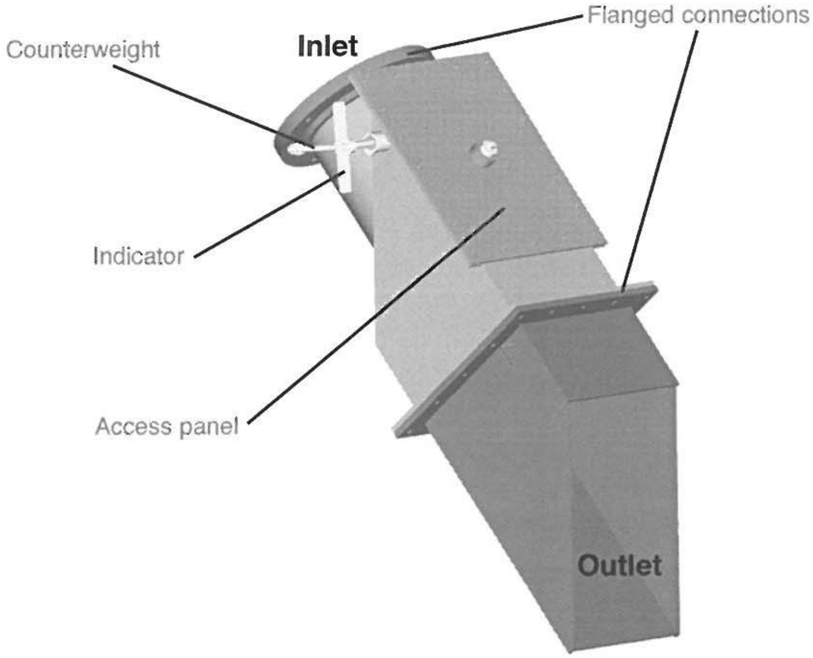

Figure 11. New Trickle Valve Design for BTM.

2. Trunnion Seal

The mill heads in a BTM are cast integral with trunnions that are supported in special heavy duty water-cooled bearings. It is necessary for pressurized BTMs to utilize pressurized air seals between the rotating mill and mill inlet/outlet boxes (Figure 12). This prevents leakage of coal dust or air from the mill. The new seal design applies a self-tightening pad type seal arrangement by eliminating previous lip seal arrangements, and improves seal air distribution with an enlarged air chamber. This new seal design has been proven to have a longer service life and is capable of tolerating higher radial run-out of the mill head extension.

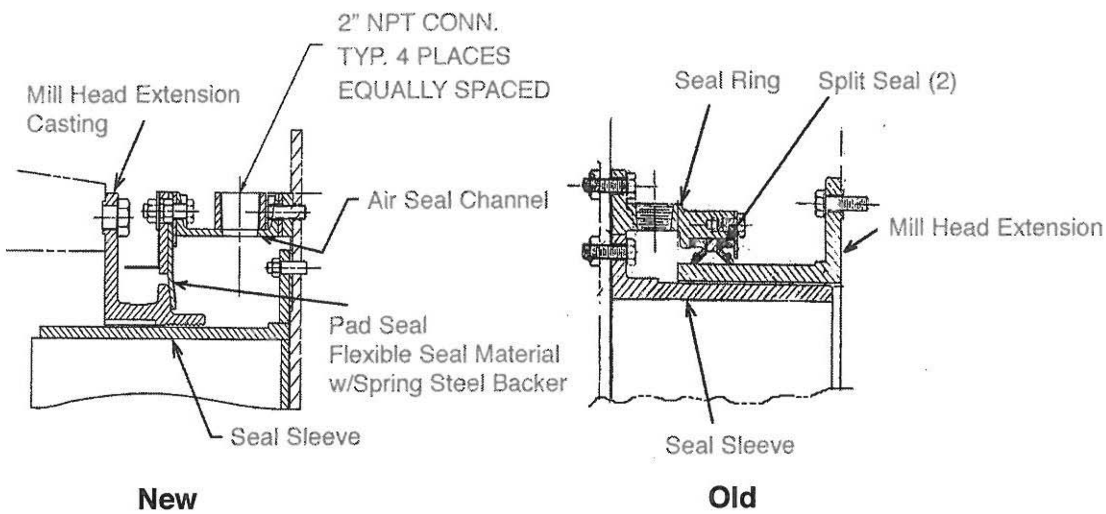

Figure 12. BTM Trunnion Seal Design: New vs. Old.

3. Power-Sonic® II Mill Conditioning System

Coal charge inventory in a BTM directly influences the pulverizing efficiency and power consumption for a BTM system operation. An RPI Power-Sonic® Mill Conditioning System was developed in the 1970's to control the total coal inventory in the mill by using measurements of two mill variables. One variable is obtained by comparing the coal inventory to the mill power required for the mill motor to rotate the mill barrel (kW input). The second variable is the sound or sonic level of the steel balls colliding with each other and with the mill liners. This sonic level is also related to the amount of coal inventory in the mill. RPI recently upgraded its Power-Sonic® Mill Conditioning System design, incorporating an Allen-Bradley PLC Based System with control setup display as shown in Figure 13, which allows the operator to easily adjust parameters and setpoints for various applications. The response for the new design to mill system operating requirement becomes more quickly and reliably. The new design is DCS compatible, if required, and is capable of peak display/recording.

Figure 13. Power-Sonic® II Design with User-Friendly Interface Feature.

IMPACT OF MILL PERFORMANCE IMPROVEMENT ON LOW NO_x BURNER OPERATION

The most significant mill performance enhancement for Low NO_x burner operation is improved coal fineness. The development of dynamic classifiers for both MPS and Atrita® Pulverizer technology enables Low NO_x burners to operate at reduced emissions with minimal impact on flyash unburned carbon. As discussed earlier, the new DynaRing™ Classifier applied to only one of four Atrita® 550D Pulverizers at a 150 MW utility boiler improved coal fineness from the retrofitted mill significantly. The remaining mills will be retrofitted shortly with the same upgraded hardware. With the DynaRing™ Classifier retrofit, Atrita® Pulverizers will improve coal fineness over 1% to 2% points on 50 mesh and 10% point on 200 mesh. Experience indicates this coal fineness improvement will reduce LOI by 5% to 10% points, which accordingly increases boiler efficiency up to 1%, and improves fly ash quality as well.

Better wear resistant materials have been applied to RPI pulverizers so that proper coal fineness and other operating conditions can be maintained for a long period of time. This ensures that Low NO_x burners will continue to operate at peak performance for extended periods of operation. Typical operating life of critical wear components as a result of utilizing better materials in medium speed machines has increased by 20% while high speed machines has increased 30-40%.

CONCLUSION

Continual enhancement in the design of RPI's coal pulverizer designs has effectively met the demands of modern Low NO_x combustion systems. The need to maintain Low NO_x emissions over extended periods of time with minimal impact on unburned carbon has instigated a need to improve coal pulverizer design. The development and use of dynamic classifier for better fineness, along with the increased usage of wear resistant alloys in the design of coal pulverizers for longer life, are a few of the more pronounced design changes in pulverizer design and application benefiting Low NO_x systems. Future efforts will continue to focus on further pulverizer improvements to meet the demands of Low NO_x combustion systems as NO_x emissions levels are further reduced.