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Advanced Milling System Technology Retrofit at New York State Electric and Gas Corp.'s Milliken Station

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ABSTRACT

As U.S. utilities implement low NO_x technologies to achieve compliance under the Clean Air Act Amendments of 1990, demands on boiler fuel and air preparation, delivery and combustion systems have intensified to unprecedented levels. This is particularly true for milling systems used with pulverized coal-fired boilers. Typically, these systems must now handle a considerable diversity of coals and consistently provide high product fineness levels, to permit staged combustion for low NOx generation without an attendant reduction in combustion efficiency.

This paper describes Riley Stoker Corporation's MPS Pulverizer/SLS classifier system retrofit at the Milliken Station of New York State Electric and Gas Corp., as one part of the plant's DOE clean coal technology demonstration project.

Included will be plant background information, scope and description of the new milling system, and operational results therefrom, with emphasis on the effects of milling system performance on boiler combustion efficiency and stack emissions.

INTRODUCTION

New York State Electric & Gas Corp. (NYSE&G) System Particulars

Electric power from six wholly-owned coal-fired generating plants located in central and western New York State, along with that obtained (through partial plant ownership) from one nuclear plant and one other coal-fired plant, constitute the bulk of NYSE&G's system generating capacity of over 2600 MW. This self-generated power, supplemented by purchased power from Independent Power

Producers and others (totaling an additional 800 MW), is distributed to a service area encompassing 35% of New York State.

Milliken Station Background/Description

Located in the Finger Lakes Region of New York State on the eastern shore of Cayuga Lake near Ithaca, NY, Milliken Station has two 150 MW coal-fired units (originally rated at 135 MW) which began commercial operation in the mid-to-late 1950s.

Each unit has a Combustion Engineering (CE) single reheat, natural circulation, balanced draft, tangentially-fired steam generator with a continuous steaming rate of 1,078,000 lbs/hr (originally 900,000) at 1900 psig and 1005°/1005°F, when firing an eastern bituminous coal with a heating value of 13,600 Btu/lb (See Figure 1).

A tandem compound, single reheat, triple flow, condensing turbine-generator was supplied by Westinghouse Electric on Unit 1 and by General Electric on Unit 2.

Each unit's fuel system contained four CE RB613 suction mills with exhausters, riffles, volumetric coal feeders, sixteen 12" O.D. x 7/16" wall coal pipes feeding four elevations of corner-fired burners, and a vacuum pyrite removal system. Mill sizing was such that all four mills were needed to meet the boiler's maximum continuous rating (MCR) fuel requirement.

NYSE&G CORP. - MILLIKEN STATION
FUEL ANALYSIS - EASTERN BITUMINOUS
(Original Coal)

Proximate Analysis (%) - As Received	
Moisture	5
Volatile	35.75
Ash	7.35
Fixed Carbon	51.9
HHV (BTU/lb)	13,600
HGI	57

Figure 1

Department of Energy (D.O.E.) Sponsored Clean Coal Technology (CCT) Demonstration Project

Milliken Station, with its two base-loaded units having the second highest efficiency within NYSE&G's system and with a plant output of 300 MW—equivalent to DOE's 'referenced' plant–was chosen by NYSE&G as their proposed site to demonstrate a combination of innovative pollution control technologies, that will remove sulfur dioxide, nitrogen oxide and trace metal emissions produced by combustion of high sulfur coal.

Accordingly, NYSE&G, in concert with six other investor-owned company participants, applied for and were subsequently awarded a DOE CCT IV cooperative agreement in July 1992.

This demonstration project includes low NO_x combustion technology, an enhanced electrostatic precipitator, and a state- of-the-art scrubber process, having unique materials of construction, while providing 98% SO_2 removal with zero liquid waste. Market grade gypsum will be produced, as well as calcium chloride and cement-grade flyash.

Also included are secondary and primary heat pipe air heaters for Unit 2 to demonstrate their capability to improve unit efficiency and reduce auxiliary power consumption–thus offsetting the scrubber-induced increase in unit power usage.

New Milling System Requirements/Selection

As part of the low NO_x combustion technology included in their demonstration project, NYSE&G specified a replacement milling system with four pressurized vertical spindle mills–three to carry full boiler load, four primary air fans taking suction from the unit's existing hot primary air header, and a new seal air system.

This new milling system must handle future variability in coal supply and meet the boiler's MCR fuel requirements at NYSE&G's specified pulverized coal fineness level of $\geq$ 87% thru 200 mesh and $\geq$ 98% thru 100 mesh. Additional requirements included vendor guarantees on mill turndown, mill system power consumption, and wear life of the mills' grinding parts.

In April 1992, NYSE&G awarded the fuel system contract, for both Milliken Station Units, to Riley Stoker Corporation (RSC), and scheduled a July 1993 start-up for Unit 1.

NEW FUEL SYSTEM DESCRIPTION AND ARRANGEMENT

Unit 1's replacement fuel system consists of four RSC MPS 150 mills, each equipped with planetary gear reducer, hydro-pneumatic roller loading, and hydraulically-driven dynamic classifier (Type SLS); four Stock gravimetric belt feeders (by NYSE&G); four Buffalo Forge centrifugal primary air fans; two Buffalo Forge, 100% capacity, seal air fans; sixteen 14" diameter x 1/2" wall coal pipes, each with two shut off valves and ceramic-lined elbows; tempering and seal air ducting; mill ducting with mass flow meters; control and shut-off dampers; new foundations and platforms. Hot air ducting was retained from the original fuel system (See Figures 2 and 3).

For Unit 2, with its new heat pipe air heaters, the milling system will have two 'cold' primary air fans (by NYSE&G), each taking suction from atmosphere and driven, in tandem with a forced draft fan, by a double shafted electric motor. This cold PA fan and common drive arrangement requires dampered relief lines connecting hot PA ducting to the boiler's secondary air system, and an additional isolation damper in the hot air ducting to each of the four mills.

MPS MILL HISTORICAL SUMMARY

In 1958, this air swept roller/table vertical spindle mill–suitable for pressurized operation–was developed by Gebruder Pfeiffer, AG (GP) of Kaiserslautern, Germany, as a modification to their then-licensed MB mill for non-coal applications.

In 1963, GP granted Deutsche Babcock Energie (DBE) of Oberhausen, Germany an exclusive world-wide license for sale and manufacture of MPS mills for coal grinding applications. Since then, over 1500 MPS mills–many under limited sub-licenses from DBE–have found service in electric power, cement, and other process industries throughout the world.

In 1992, Riley Stoker Corporation, a Deutsche Babcock Technologies Company, received an all-inclusive MPS mill sub-license from DBE. The Milliken Station mills were built and supplied under this license.

MPS 150 MILL SUPPLY

Each of the four MPS 150 mills is equipped with a 300 HP direct-coupled squirrel cage TEFC induction motor; a planetary gear reducer containing a hydrodynamically lubricated tilting pad type thrust bearing; a separate duplex motor/pump/filter lubricating console with cooler and instrumenta-

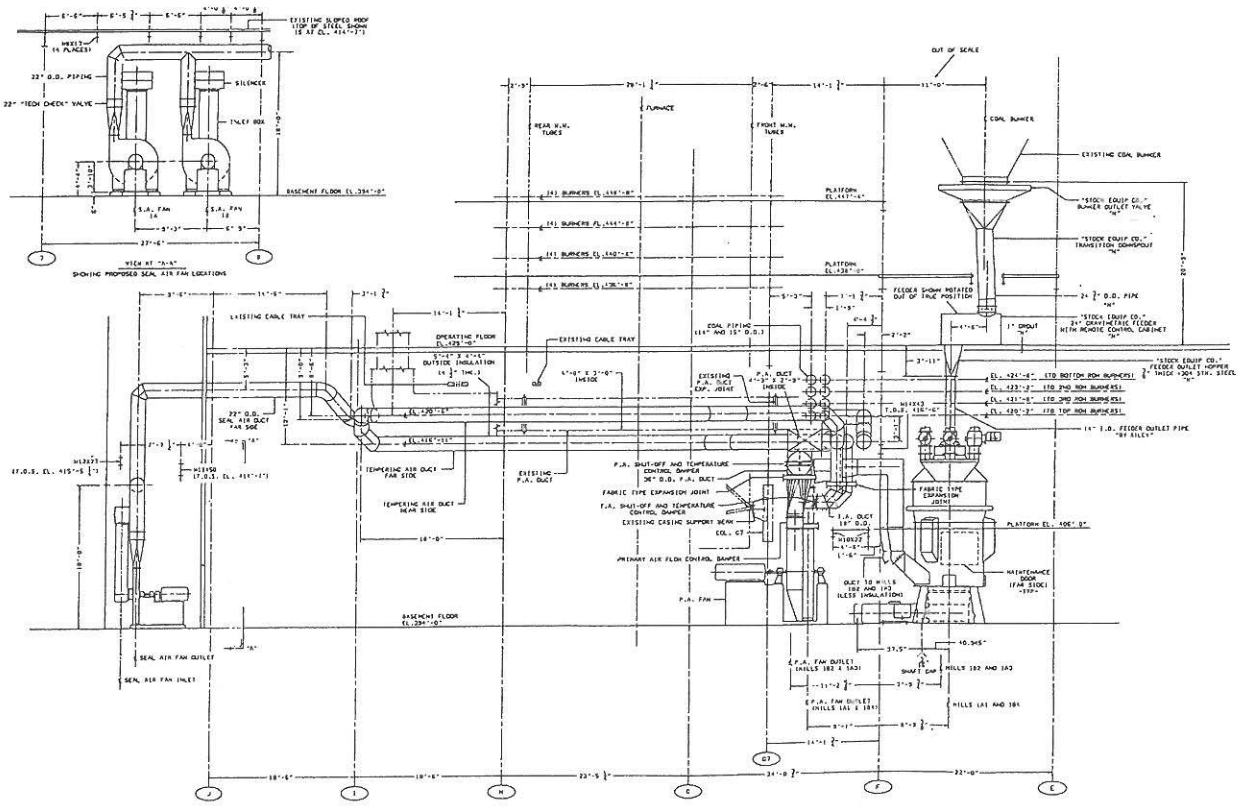

Figure 2 Side Elevation

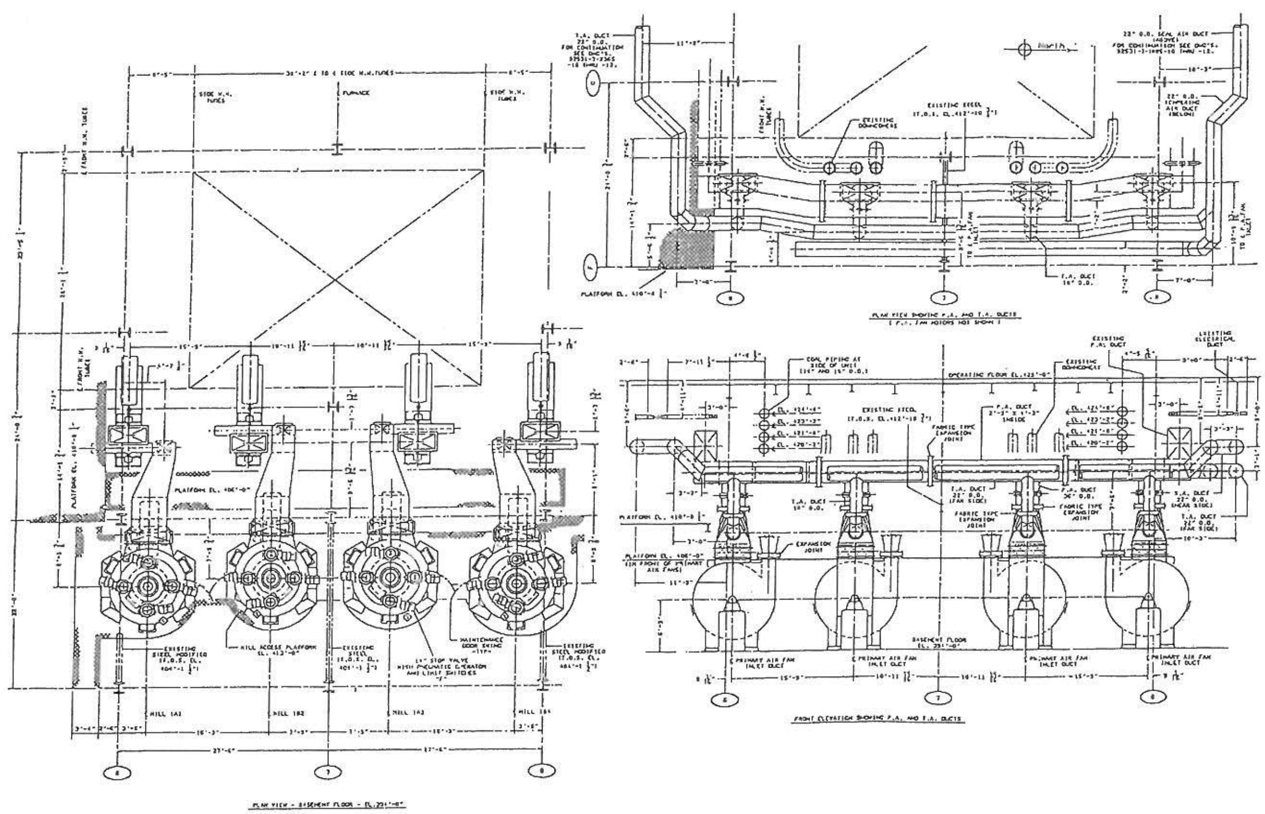

Figure 2 Front Elevation and Plan Views

tion; a separate roller loading and classifier drive hydraulic console with filters, accumulators, directional valving, motors, pumps, reservoir and instrumentation; three hydro-pneumatic roller loading cylinder assemblies; an SLS classifier assembly with variable speed hydraulic motor drive, and an oil-lubricated slewing ring support bearing and drive pinion installed in a sealed housing with seal air provision; mill seals, seal air connections, steam-inerting connections; and numerous hinged and peripherally bolted doors for inspection, access, and maintenance.

The mill supply also included all necessary special tools and fixtures for initial installation and subsequent maintenance, plus a carriage-mounted mill turning gear assembly with electric motor drive and flexible coupling for attachment to the mill motor's opposite drive end shaft.

DESCRIPTION OF OPERATION

The MPS 150 mill is classified as an air-swept, pressurized, applied-force, vertical spindle, table/roller mill. It contains an integral classifier, a grinding section, a base section, and auxiliary components (See Figure 4).

In the grinding section, three fixed-axis rollers rotate on a segmentally-lined grinding table supported and driven by a planetary gear reducer, that is direct-coupled to a squirrel cage induction type drive motor. Equal grinding force is applied to each of the three grinding rollers by a loading frame connected by vertical tension rods to three hydro-pneumatic cylinder loaders secured to the mill foundation.

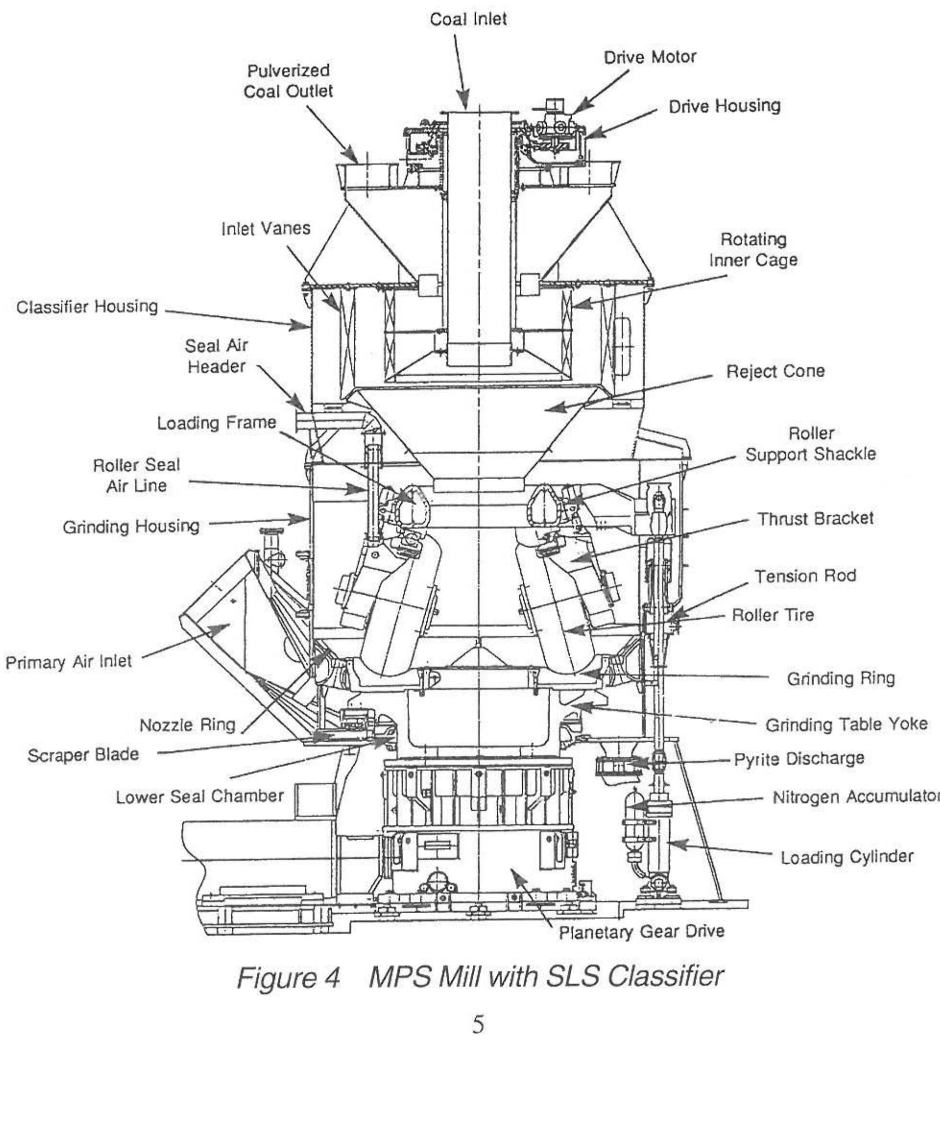

Figure 4 MPS Mill with SLS Classifier

Coal is metered and 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. Metered hot air for drying and coal transport enters the base section and flows upward through a stationary swirl ring having multiple sloped nozzles surrounding the rotating grinding table. The air mixes with and dries coal in the grinding zone and carries pulverized coal particles upward into a dynamic classifier (Type SLS), having angled inlet vanes, an adjustable speed rotating inner cage, outlet section, and reject hopper. Fine pulverized coal exits the outlet section through multiple discharge coal pipes leading to the boiler; oversized coal particles spiral down the classifier reject cone and discharge back into the grinding zone for further grinding.

Pyrites and extraneous dense materials fall through the nozzle ring onto the base section top plate where they are swept, by two scraper blades attached to the grinding table, into the pyrite discharge chute and collection hopper located below.

FUEL SYSTEM DESIGN PARAMETERS AND CONTROLS

For three mill operation at boiler MCR, when grinding contract-specified 'performance' coal (See Figure 5), each mill must deliver 36,800 lbs/hr at a fineness of ≥ 87% through 200 mesh and ≥ 98% through100 mesh.

NYSE&G CORP. - MILLIKEN STATION
FUEL SPECIFICATION
PERFORMANCE COAL

Moisture (%)	5.6
HGI	57
HHV	12,800 Btu/lb

Figure 5

Alternatively, when grinding the 'worst' coal having lower heating value and grindability and higher moisture (See Figure 6), four operating mills must each deliver 30,720 lbs/hr–at the same product fineness.

Such specified mill operating conditions required new larger coal piping to satisfy the diverse goals of minimizing system pressure drop and pipe wear, but maintain adequate transport velocity over the milling system's full load range.

Accordingly, with the air-to-coal (weight basis) characterization established for this system (See Figure 7), transport velocities with the new piping range from 80-74-60 FPS for three mills at boiler MCR, four mills at boiler MCR (worst coal), and minimum mill load, respectively. Corresponding mill air-to-coal ratios are 1.7, 1.9 and 3.7.

Accurate flow measurement, using gravimetric coal feeders and mass air flow meters in conjunction with a three controller load control system (See Figure 8), enables tight regulation of the milling system's prescribed air-to-coal characterization. The control system has separate three-function controllers for coal and air, with an independent auto/manual option on each, and a third controller (mill differential) that provides coal feeder runback whenever mill pressure differential exceeds a preset high value.

Also characterized with mill throughput is grinding roller loading or "grinding force" (See Figure 9). Made possible through the use of a hydro-pneumatic system, variable roller loading provides improved responsiveness to changes in mill demand, and with the ability to change either magnitude or slope of this loading curve, can provide immediate adaptability to fuel changes.

By comparing a function of coal feeder speed to hydraulic system back pressure (See Figure 10), and through proportional plus reset action, the hydraulic system's output control valve is adjusted to satisfy this programmed grinding force/feeder speed relationship. Also, upon deviation of mill grinding zone pressure differential from a preset value established as a function of mill load, grinding force is automatically biased up to ±10% (See Figure 11).

To sustain good combustion efficiency under staged low NO_x firing conditions, precise control of pulverized coal fineness is essential. This is accomplished through the use of dynamic classifiers (Type SLS), which can provide virtually any characterization of product fineness with mill load.

Such product fineness characterization is achieved by varying the SLS classifier's inner cage rotational speed as a function of mill load (See Figure 12).

NYSE&G CORP. - MILLIKEN STATION
FUEL SPECIFICATION
WORST COAL

Moisture (%)	14.0
HGI	50
HHV	11,500 Btu/lb

Figure 6

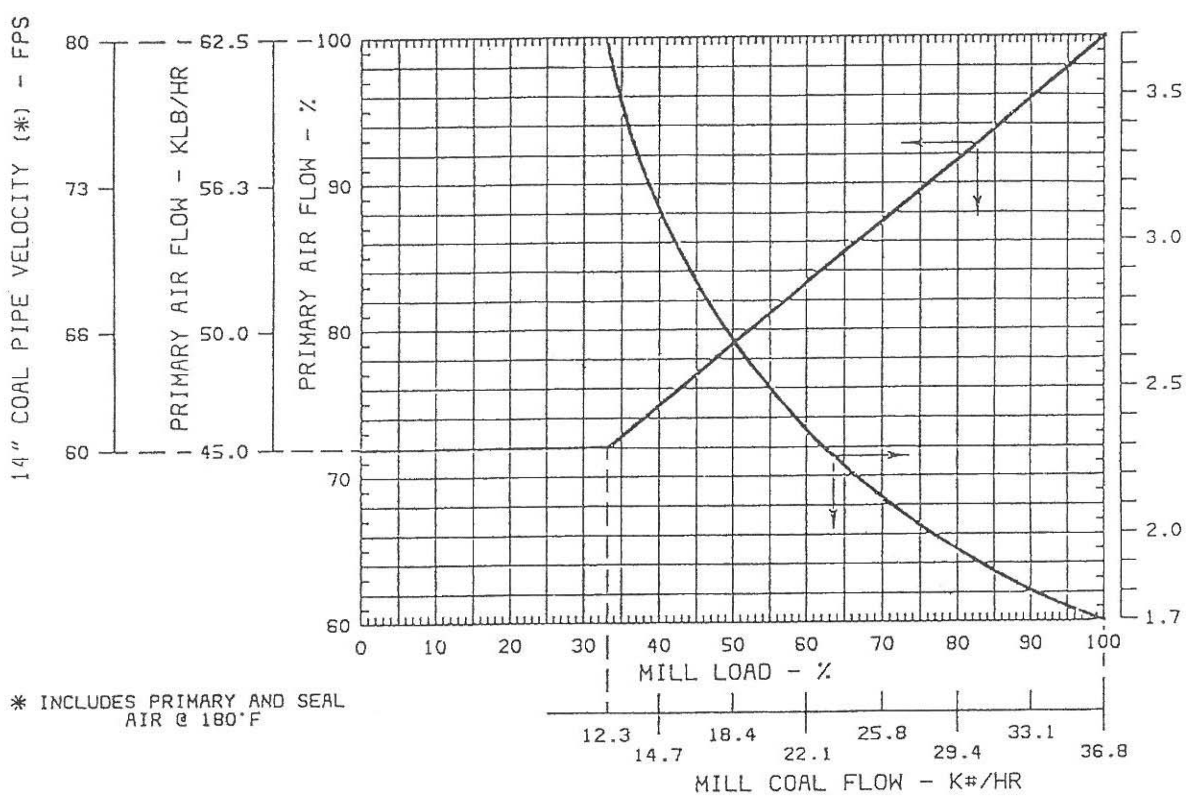

Figure 7 MPS 150 Air/Coal Characterization, NYSE&G Corp., Milliken Station #1 and #2

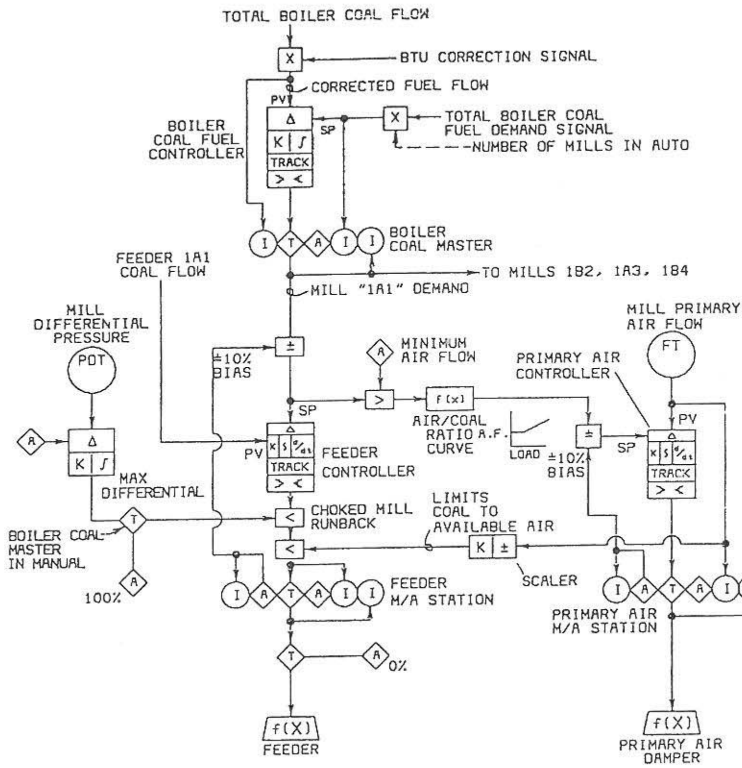

Figure 8 Mill Load Control

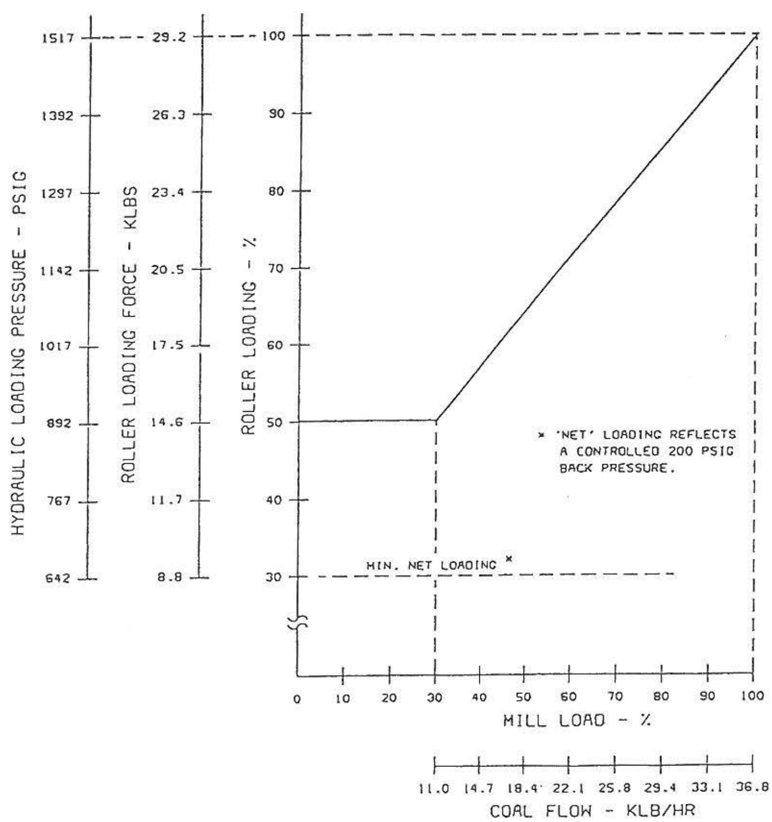

Figure 9 Grinding Roller Loading vs Mill Load Characterization

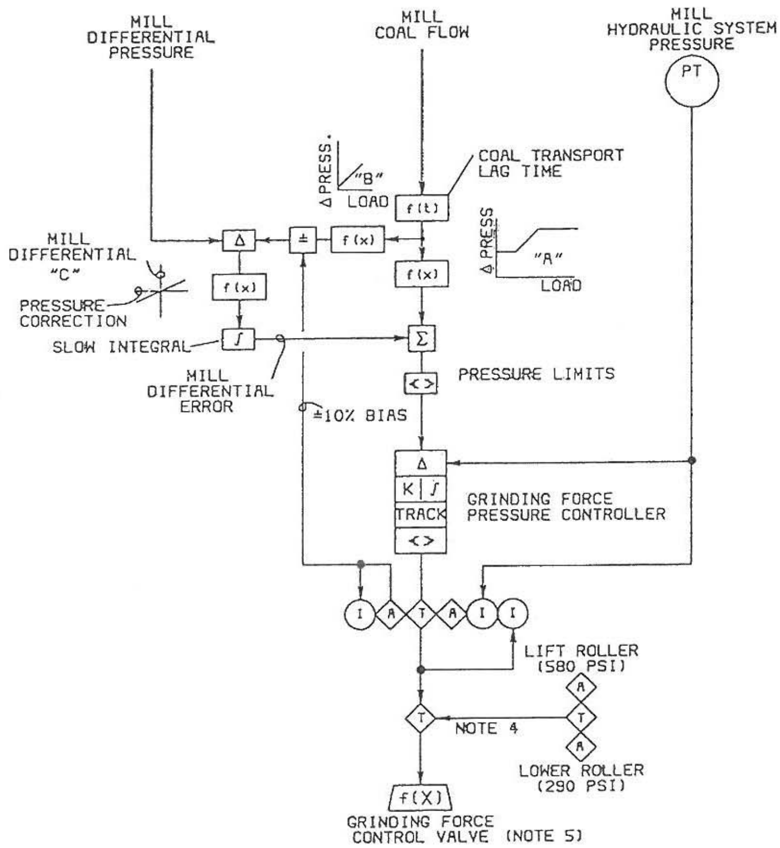

Figure 10 Mill Grinding Pressure Control

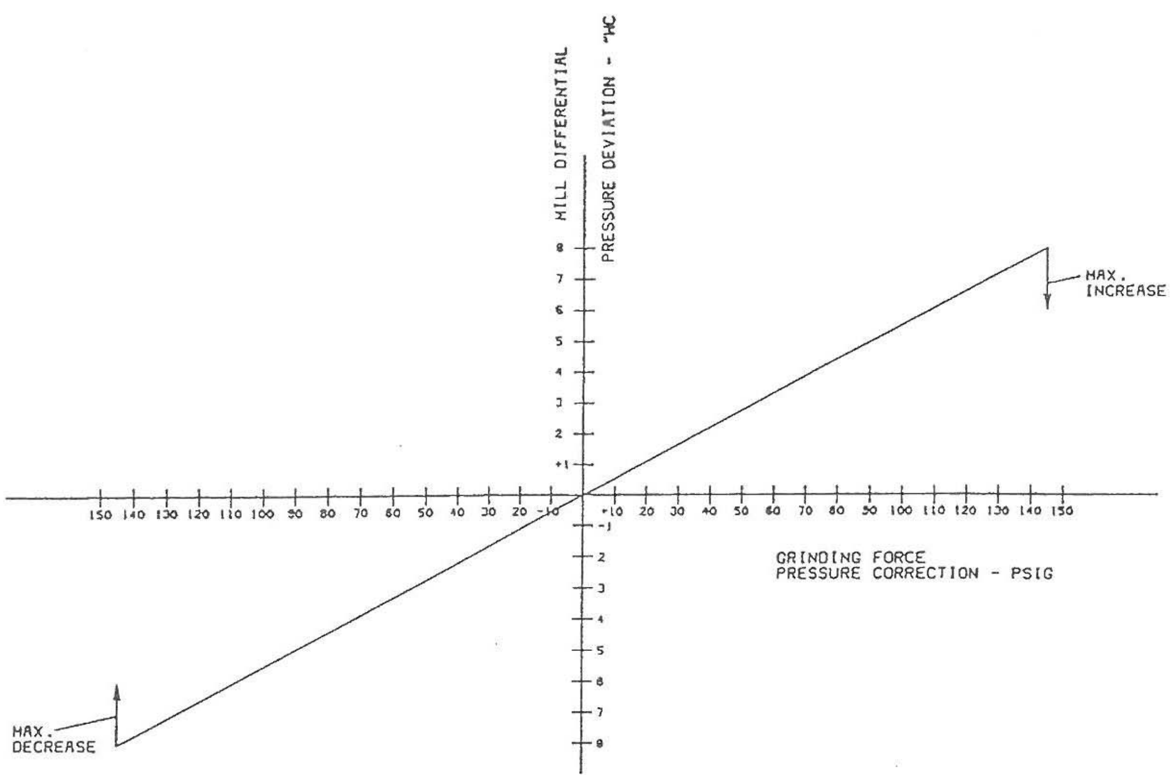

Figure 11 Boiler Grinding Force Correction vs Mill Pressure Differential Deviation

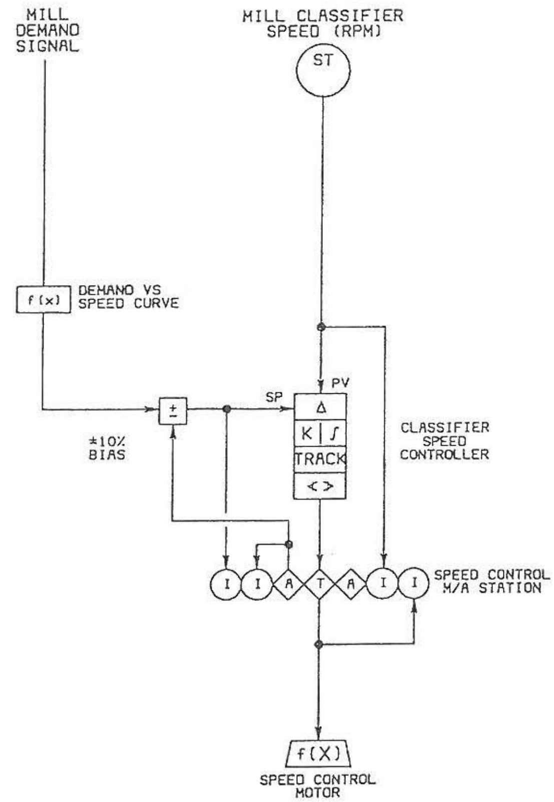

Figure 12 Mill Classifer Speed Control

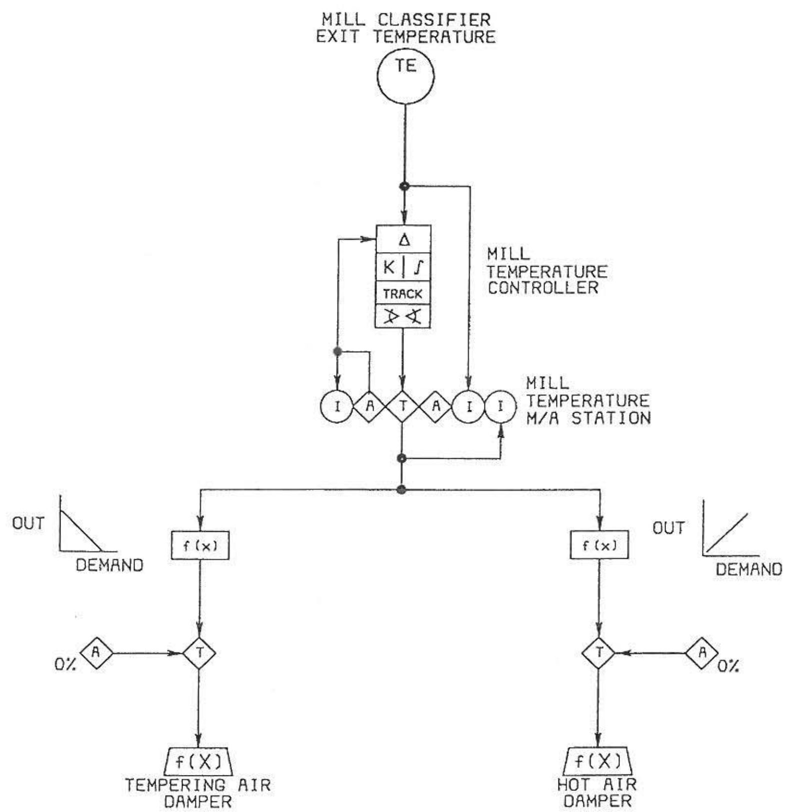

Figure 13 Mill Outlet Temperature Control

Mill outlet air/coal temperature is measured at each mill's classifier exit, and through proportional and reset action, is controlled to a pre-determined set point by adjusting positions of both the hot and tempering air dampers (See Figure 13).

For seal air admittance and control to each mill and associated equipment, a control valve in each mill's seal air supply line maintains a fixed differential pressure between the mill's seal air ring header and primary air duct at the entrance to the mill.

Predicted milling system operating data for three and four mill operation, at boiler MCR when grinding performance coal, are shown in Figures 14 and 15.

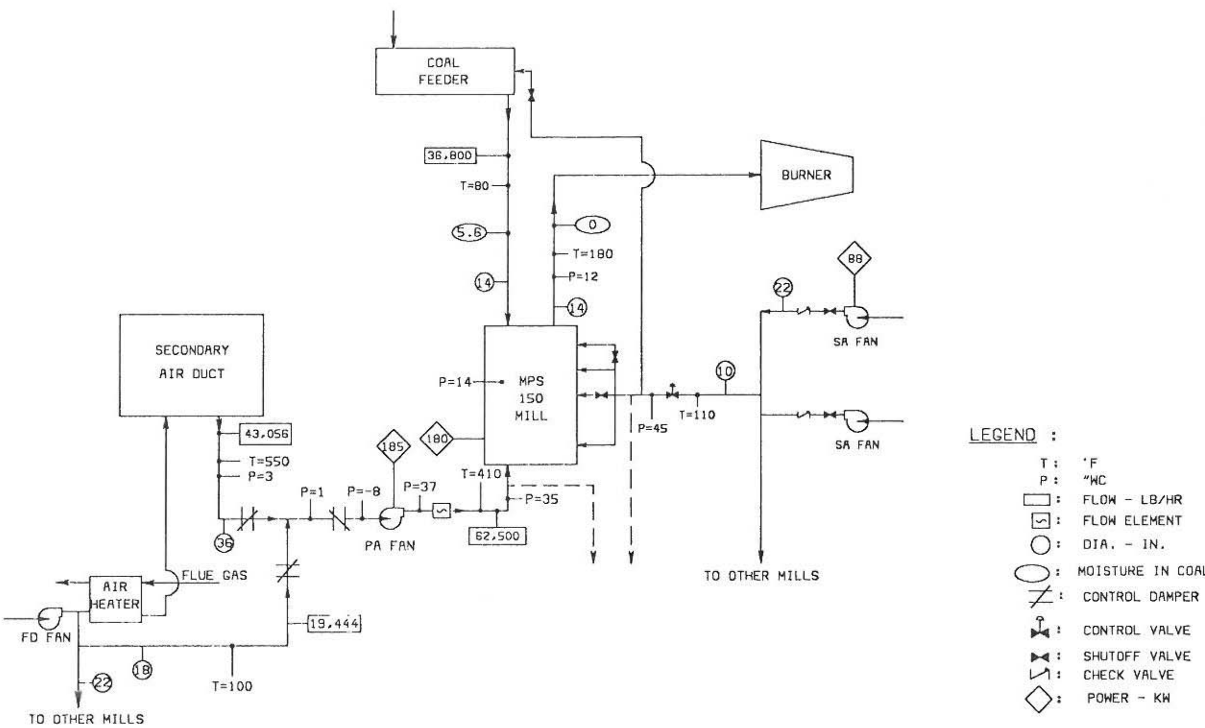

Figure 14 Fuel System Process Flow Schematic
Predicted Values for Full Boiler Load
Three Mills in Service
NYSE&G Corp., Milliken Station #1

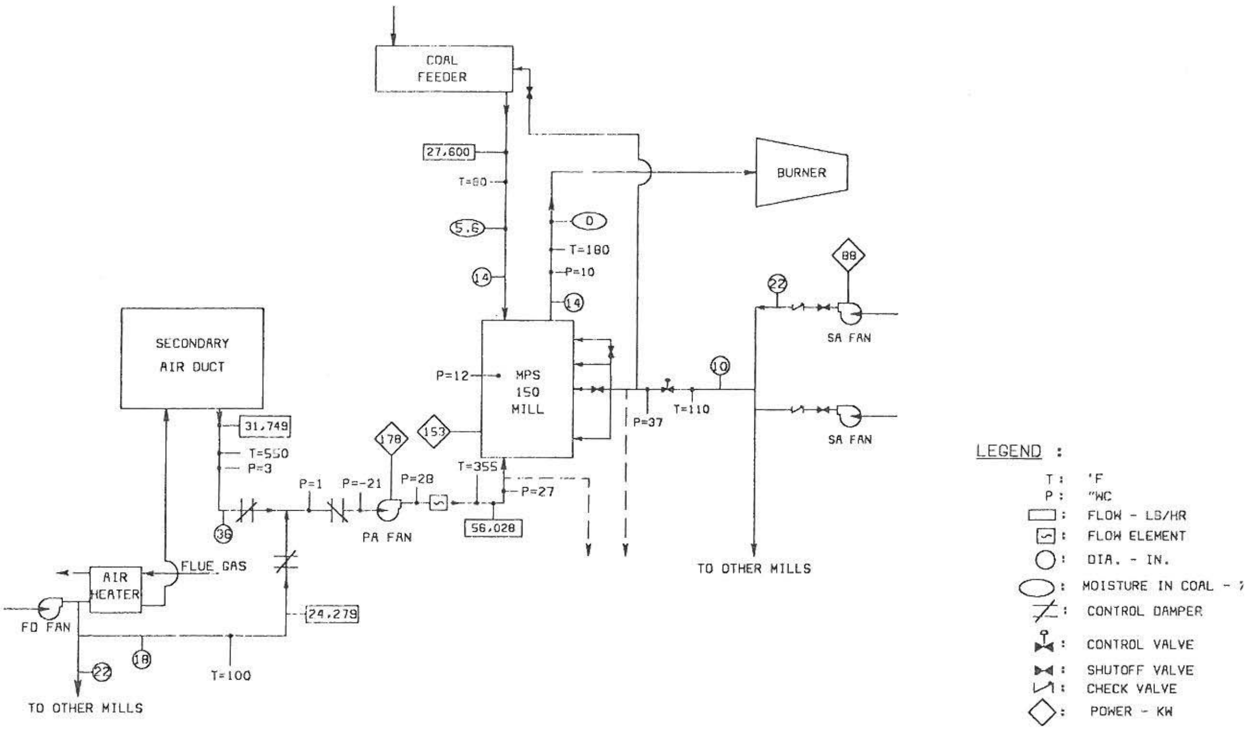

Figure 15 Fuel System Process Flow Schematic
Predicted Values for Full Boiler Load
Four Mills in Service
NYSE&G Corp., Milliken Station #1

OPERATING RESULTS

Upon completion of fuel system modifications, Unit 1 resumed operation in July 1993.

Within the first few weeks of operation, the essential mill system performance requirement was demonstrated: namely, ability of three mills to continuously carry full boiler load at a product fineness of ≥ 87% through 200 mesh and ≥ 98% through 100 mesh. Actual mill system operating data at boiler MCR for three and four mill operation are shown in Figures 16 and 17.

For the next several months, however, mill system/combustion testing and optimization was delayed due to sporadic overheating of burner nozzles, which required continual switching and loading/unloading of operating mills, as well as abnormal biasing of primary air flows. In February, 1994, after installation of new (modified) burner nozzles, this problem was corrected and mill system testing began.

Initial tests established a SLS classifier speed characterization with fineness and mill load on all four mills (See Figure 18). This was followed by a contract mill performance test on one mill. Results are shown in Figure 19.

For constant mill 200 mesh product fineness at all mill loads, a classifier cage speed/mill load characterization was developed as shown in Figure 20. Also, for a constant product fineness of 90-92% through 200 mesh with varying mill load, the mill's specific power consumption was found to range from 7.65 kw/ton at 100% mill load to 9.84 kw/ton at 33% mill load (See Figure 21).

Reducing 200 mesh product fineness (by lowering classifier cage speed) from > 94% to 82+% at full mill load reduced the mill's specific power consumption from 8.16 to 6.10 kw/ton (See Figure 22).

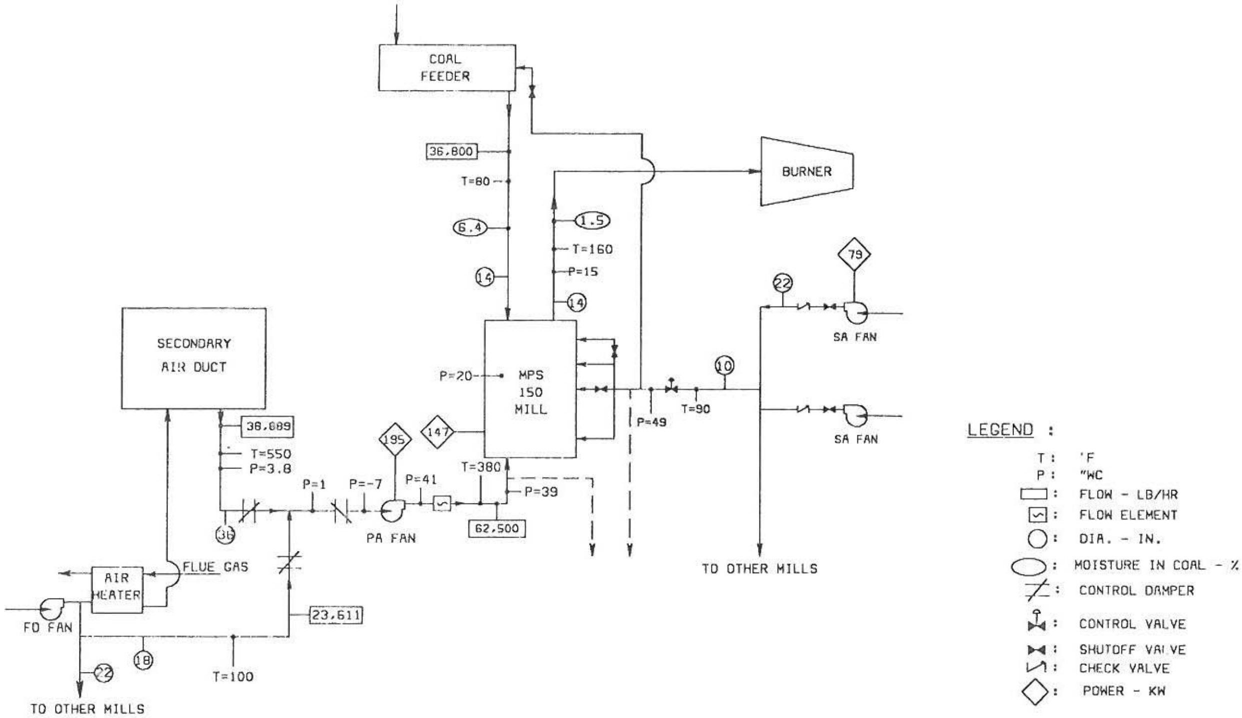

Figure 16 Fuel System Process Flow Schematic
Actual Values for Full Boiler Load
Three Mills in Service
NYSE&G Corp., Milliken Station #1

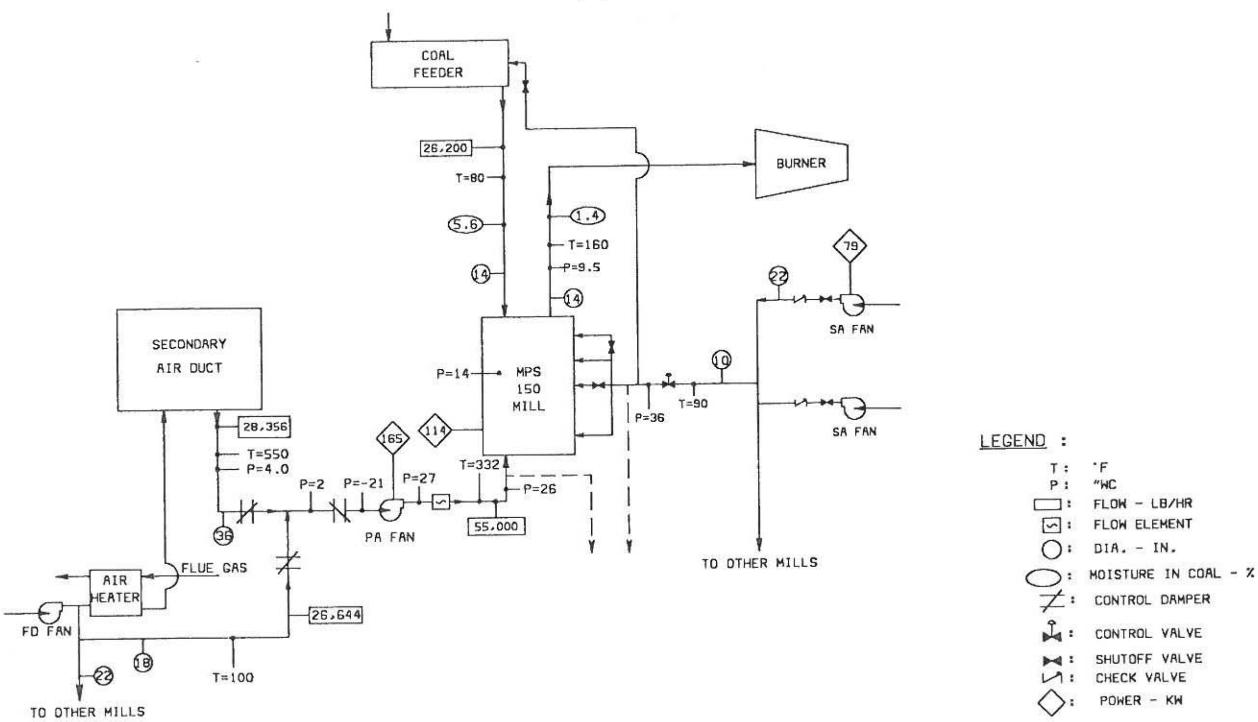

Figure 17 Fuel System Process Flow Schematic
Actual Values for Full Boiler Load
Four Mills in Service
NYSE&G Corp., Milliken Station #1

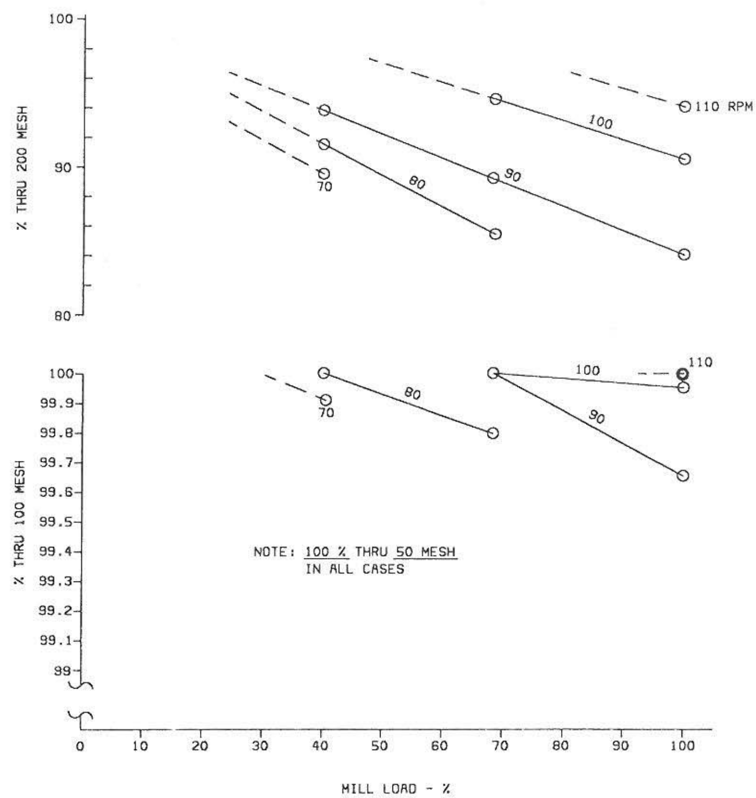

Figure 18 MPS 150 Mill With SLS Classifier
Typical Product Fineness vs. Mill Load for Different Cage Speeds
(Adjustable Speed Range 0-150 RPM
NYSE&G Corp., Milliken Station #1

Item	Guarantee	Test Results[1] (Mar. 16, 1994)
Coal Flow, lbs/hr	36,800	36,800
Mill Motor Power, HP	271	196
Mill System Power, HP	551	518
Coal Grindability, HGI	57	55.8
Coal Moisture, %	5.6	5.0
Mill Turndown	4:1	*
Product Fineness USS Mesh Size	% Through USS Mesh	
50	–	100
100	98.0	100
200	87.0	94.1
325	–	76.0

* Demonstrated but not formally tested due to NYSE&G's decision to limit turndown to about 2.5 to 1.

[1] Mill 1A3 with classifier cage speed at 110 RPM

Figure 19 MPS 150 Mill Performance vs. Contract Guarantees
NYSE&G Corp., Milliken Station #1

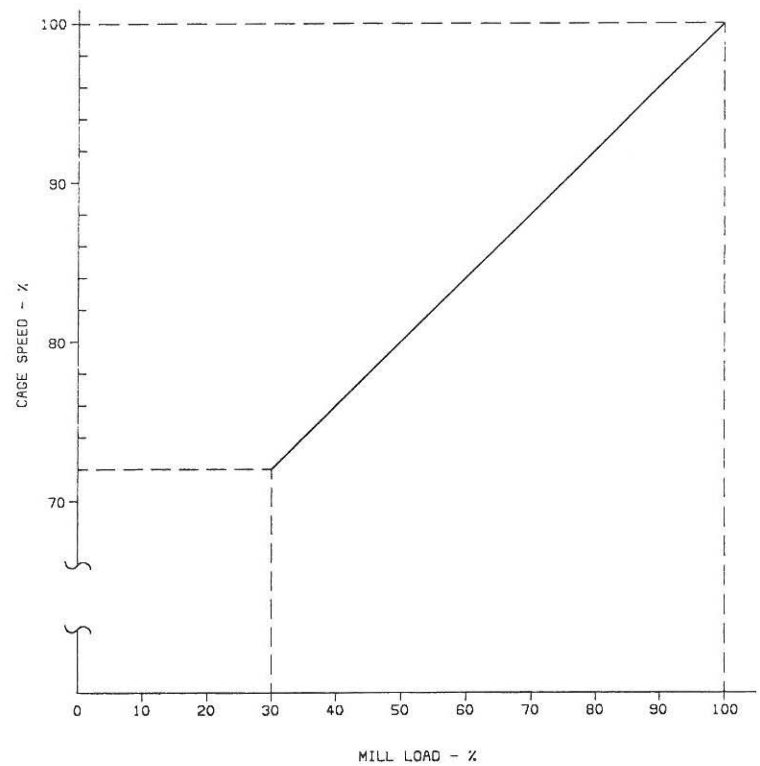

Figure 20 SLS Classifier Cage Speed vs. Mill Load for Constant USS 200 Mesh Fineness NYSE&G Corp., Milliken Station #1

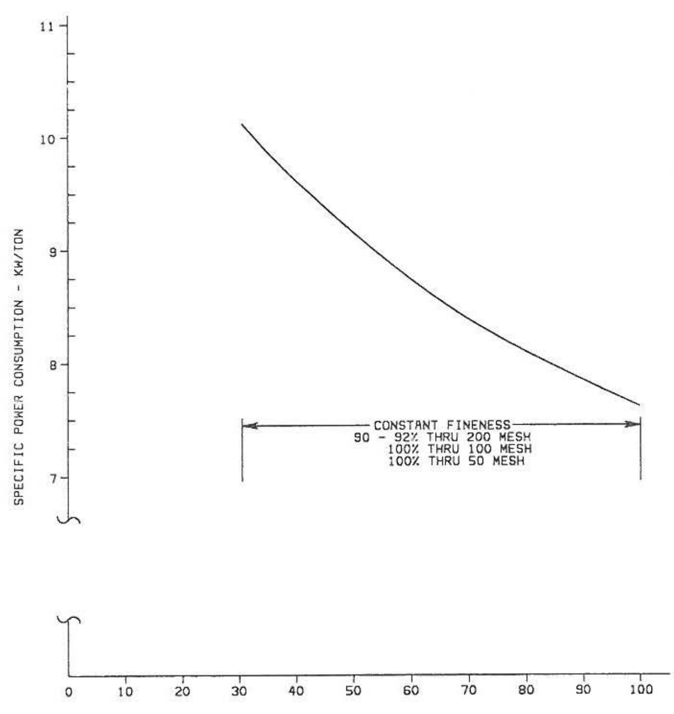

Figure 21 Specific Power Consumption vs. Mill Load at Constant Product Fineness MPS 150 Mill with SLS Classifier NYSE&G Corp., Milliken Station #1

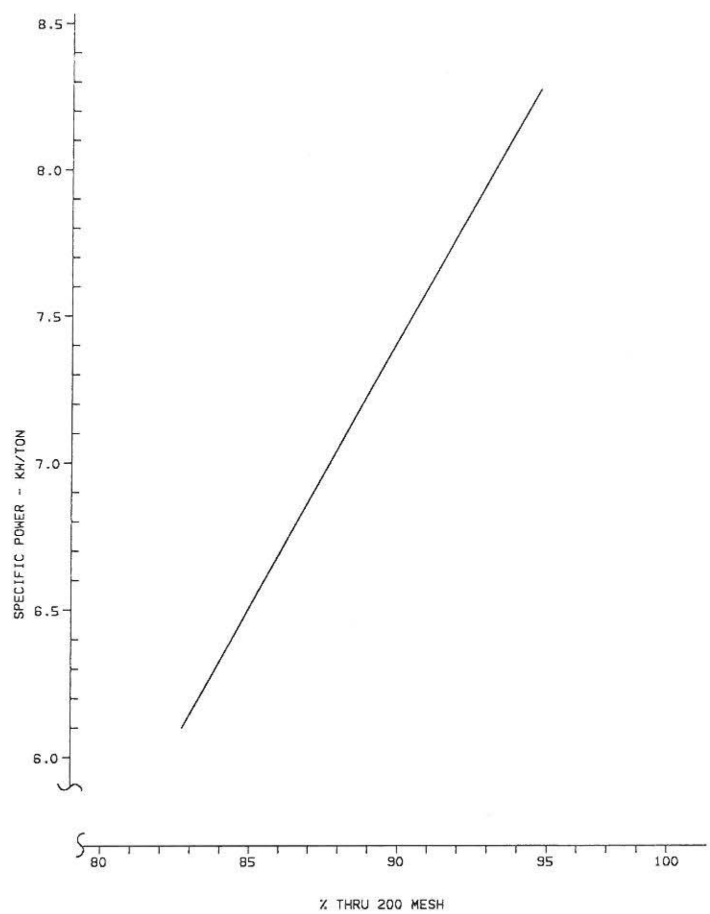

Figure 22 Mill Motor Specific Power Consumption vs USS 200 Mesh Product
Full Mill Load (18.4 TPH)
NYSE&G Corp., Milliken Station #1

A Rosin-Rammler plot (Figure 23) of product fineness distribution, at full mill load and different classifier speeds, shows steep slopes and a non-linear relationship for the coarser particle sizes (≥ 110 - 140 micron - μM).

Figure 24 shows the relationship of average classifier pressure drop to mill load.

Also, in February 1994, testing began with different combinations of mills in service and varying amounts of overfire air to establish boiler/mill system operating parameters that will consistently yield compliance levels of NO_x emissions and optimize combustion efficiency. Limiting levels of NO_x emission and fly ash loss-on-ignition (LOI) are 0.42 lbs/106 Btu and 4%, respectively. The latter value represents the maximum allowable for fly ash salability.

Since February, these goals have been achieved on Unit 1 and remain continuously in effect for three or four mill operation, at all boiler loads, and with all coals currently in use. Optimum unit performance, however, is achieved with three of the four mills in operation, serving the lower three burner elevations.

Ongoing overfire air adjustments are needed to accommodate boiler load and fuel changes, and boiler excess air is varied with load for steam temperature control (20% at boiler MCR, raised to 23% at 60% MCR). Mill classifier cage speed is kept greater than 100 RPM for continuous high product fineness (> 90% through 200 mesh; 100% through 50 and 100 mesh) at all mill loads.

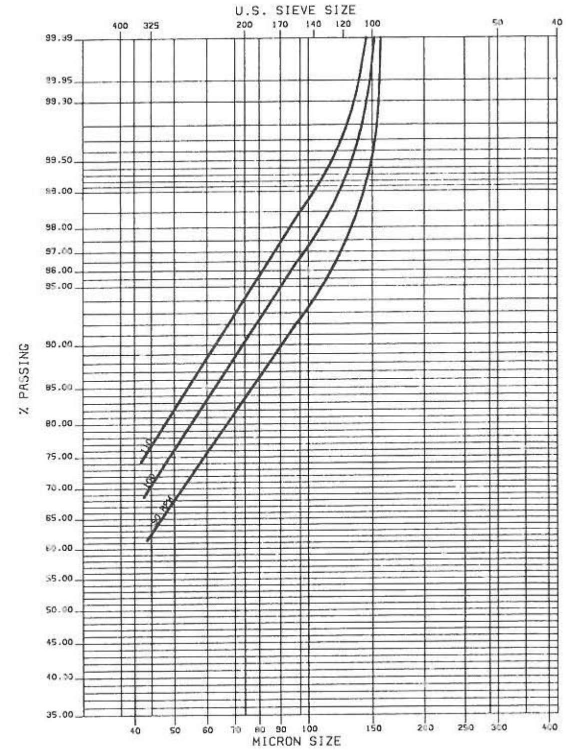

Figure 23 Rosin-Rammler Particle Size Distribution
MPS 150 Mill with SLS Classifier Product Fineness at Full Mill Load (18.4 TPH)
NYSE&G Corp., Milliken Station #1

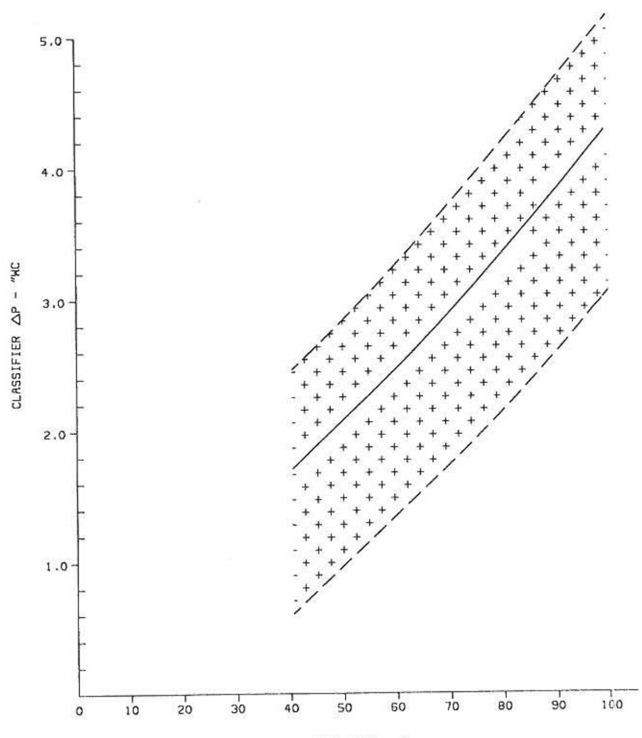

Figure 24 SLS Classifier Pressure Drop vs. Mill Load
NYSE&G Corp., Milliken Station #1

DISCUSSION OF RESULTS

At full boiler load, a comparison of actual three mill and four mill system data with that predicted (Figure 14 vs Figure 16 and Figure 15 vs Figure 17) generally shows good conformity. Exceptions to this, for both operating modes, are the following:

- Mill motor power: 20-25% low
- Seal air fan motor power: 10% low
- Moisture in pulverized fuel: 1.5% (zero predicted)
- Mill air inlet temperature: 7-8% low

The large overstatement in predicted mill power consumption represents a conscious unaccountability of the SLS classifier's high particle selection efficiency (or 'sharpness of classification') that reduces overgrinding of acceptably-sized coal particles and thus improves the mill's grinding efficiency. In brief, this lower mill power was expected but conservatively not predicted.

Conversely, the lower seal air fan power consumption probably reflects relatively tight seals on these new mills and will likely increase with mill age.

Moisture remaining in the pulverized coal along with low mill inlet air temperature can be attributed to controlling mill exit temperatures at 160°F rather than the expected value of 180°F.

The pattern illustrated in Figure 18 of product fineness with classifier cage speed and mill load is consistent with expectations. Of interest, however, are the absolute levels of cage speed that produced these results. At cage speeds less than 110 rpm (73% of design capability), full mill load product fineness exceeded contract-specified values. This indicates higher throughput capability for this particular SLS classifier size.

Performance test data in Figure 19 clearly meets the mill and mill system operating contract guarantees shown here.

In Figure 20, a classifier cage speed characterization with mill load–or constant product fineness–matches that obtained previously on DBE installations in Europe and can be considered typical for the SLS classifier.

The range in mill specific power consumption (7.65 to 9.84 kw/ton) shown in Figure 21, for a three-to-one mill turndown at high constant fineness (90-92% through 200 mesh and 100% through 50 and 100 mesh), is about 30% lower than anticipated. As noted previously, this better-than-expected grinding efficiency is probably due to the dynamic classifier's excellent sharpness of classification.

Alternatively - as seen in Figure 22 - for a constant full mill loading, reducing product fineness from > 94% to 82+% through 200 mesh lowers mill specific power consumption from 8.16 to 6.10 kw/ton - a reduction of 25%. Of interest here is the linear relationship of mill power to product fineness with a rate of specific power change to that in 200 mesh fineness of 0.17 kw/ton/% thru 200 mesh. For some lower fineness level, however, this curve should become non-linear and converge to some minimum power level. SLS classifier tests at lower 200 mesh fineness values will be needed to confirm this.

The Rosin-Rammler product fineness distribution plots in Figure 23 show a gradual increase in line slope with increasing classifier speed, an expected feature of dynamic classification. But unexpected is the asymptotic increase in particle rejection of the coarser (> 100 μM) sizes. A definitive particle size cut-off point seems to exist for each cage speed. Because of this phenomenon, Riley's test lab will perform additional screening on pulverized coal samples taken from mills with SLS classifiers. Specifically, screen sizes 120, 140, and 170 mesh will be used along with the standard 50, 100, 200, and 325 sizes. These added screens will enable better mapping of particle sizing between 75 and 150 μM. Also, the 170 mesh (90 μM) screen will provide a direct correlation with mill test results from Europe where this mesh size is the standard reference for fineness.

In Figure 24, the plotted solid line represents average SLS classifier pressure drop vs mill load for various mill and classifier settings. Due to inaccuracies of local manometer readings, there is much data scattering, even under seemingly identical mill conditions. Nevertheless, the curve shown provides a reasonable approximation of actual ΔP values over a 2 1/2-to-1 (MPS 150) mill turndown.

Although in-compliance boiler emissions and desired combustion efficiency are obtainable with either three or four mills in operation, three mill operation provides the following benefits:

- Higher boiler efficiency due to lower exit gas temperatures (less mill system tempering and seal air)
- Lower auxiliary power
- Better burner turn-down
- Ultimately, lower milling system maintenance costs
- Better control of NO_x emissions and boiler steam temperature with adjustment of over-fire air and boiler excess air

Overfire air manipulation, made necessary with boiler load changes to keep NO_x emissions within compliance, has in some cases adversely affected combustion efficiency (L.O.I. in flyash). To counter this effect, mill system product fineness has been kept at inordinately high levels. Accordingly, some combustion system refinements may be needed to allow more reasonable and efficient mill operation (i.e., operating at a somewhat lower product fineness over the mill's full load range).

CONCLUSIONS

As part of the overall Milliken Station demonstration project, Unit One's fuel system replacement has proven a resounding success with respect to equipment performance, boiler emissions, and combustion efficiency.

Further explorative testing at Milliken Station is indicated to fully exploit the fuel system's extensive adjustability while handling a wide diversity of coals.

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