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Design and Integration Engineering

A Distributed Control System Software and Control Strategy for Furnace Stove Combustion

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USS/Kobe Steel Company recently modernized its No. 3 blast furnace to make it a world class competitor. The furnace, which was bought on stream again on May 4, 1992, now is operated using a total furnace control system that permits one operator to monitor the entire furnace complex from a central control room.

This high degree of automation is made possible by a fully integrated and automated control system architecture, a distributed control system (DCS) and a programmable logic controller (PLC). The DCS controls the traditional analog functions. It also acts as the main window to the blast furnace process for the stove, furnace, gas cleaning and water cooling areas. It does this by using the DCS's color graphics features. The PLC, meanwhile, handles the traditional digital or sequential functions.

This control strategy is not an entirely now development. There were past contributions to its success. During the late 1970's and early 1980's, engineers from what was then U.S. Steel Corporation developed a blast furnace stove combustion control strategy at its research laboratories and Gary Works. This strategy was grounded in sophisticated calculations that established operating setpoints for the stove burner flame temperature and the stove heat demand. The calculations were based on the hot blast requirement needed to support the iron production schedules.

The major objectives of the flame temperature/stove heat demand control strategy were to:

-Maximize fuel efficiency.

-Reduce combustion related refractory problems.

-Establish combustion control operating setpoints based on the hot blast requirements that were set to achieve iron production goals.

-Minimize operator interventions.

More recently, Applied Control Systems, Inc. transformed the flame temperature and zone heat demand calculations into customized control algorithms. The algorithms were implemented using Leeds &

Northrup (L&N) Excel Programming language. Excel is an acronym for "extended controller engineering language."

The customized control strategy is now configured in each of the L&N MAX1 DCS controller files at USS/Kobe, residing in the programmed functions section of the file. Each stove has a primary controller file supported by a hot redundant backup file.

The stove on-gas/on-blast cycle times have been established in the DCS and are included in the heat demand calculations. The DCS also monitors stove operating mode cycle times. Automatic stove changing is initiated within the L&N system and is executed through the sequencing logic of a PLC designed by Allen-Bradley Co., Inc. hence, the stoves are maintained in a fully automatic mode without the need for operator intervention. More operators are only needed only if full automatic control is not available because of a mechanical or electrical problem within the stove facility. Included in the overall control system is the capability to provide tagged variables and status conditions over a communications network to a Level 2 system for statistical report generation.

The No. 3 furnace's entire control system has been on-line since May 1992 and has achieved the stated objectives.

PROCESS CONTROL ARCHITECTURE

The No. 3 blast furnace control system architecture is comprised of a fully integrated and automated PLC based controlled system that performs processes as well as batch and sequential functions. And, as already stated, it has a DCS performing process and sequential control.

At the top of the Level 1 control architecture is a pair of Allen-Bradley pyramid integrators and a MicroVAX 3000, functioning primarily as a data concentrator and a local report generator. A pair of L&N MAXport computers mainly serve as a gateway to provide redundant data communications from both the PLC and the DCS systems to a Level 2 terminal server. Figure 1 shows the process control architecture.

Note that the stoves and some of the common control loops on the No. 4 furnace are incorporated into the No. 3 furnace system architecture and are available to the operator stations via fiber optic highway No. 1. Previously, a limited DCS/PLC system was provided on the No. 4 furnace, which came on-line in November 1989.

The No. 3 furnace stove combustion control system is contained in controller files 36, 38 and 40 (Figure 1). Each primary controller is supported by an on-line hot redundant backup file (i.e. 37, 39 and 41). Should the primary file fail, the transfer to the backup file is instantaneous and smooth. No hard-wired manual stations are provided.

STOVES

The three blast furnace stoves on the No. 3 blast furnace were completely replaced with new Martin & Pagenstecher (M&P) engineered stoves. The new stoves have a height of 124 feet 8 inches and a diameter of 25 feet and 6 inches. The checker heating surface area encompasses and area of 390,773 ft2 per stove. The stoves have internal, vertical ceramic burners (Figure 2), and are fired with combustion fans capable of producing 40,000SCFM at a discharge pressure of 45 inches W.C. The fans are driven by 450 horsepower motors.

Detailed operating specifications were included with stove specifications provided by M&P. Table 1 shows an excerpt of some of the M&P specifications and the operating status of the No. 3 stoves as set by USS/Kobe.

During the early construction stages of the Furnace No. 3 rebuild, the decision was made to use the existing top gas analyzer and gas sampling system that was in service on the No. 4 blast furnace. This decision was made because the stoves on both furnaces receive their top gas from a common blast furnace gas main. The stoves on the No. 4 furnace had been controlled from an L&N DCS since November 1989. These stoves use the same stove heat demand/flame temperature combustion control program now in use on the No. 3 furnace stoves.

The top gas sampling system has proven to be very reliable. The sampling system was specified by Perkin Elmer and was furnished by JNM Corporation. It provides a clean sample to the analyzer and includes an automatic Blow Back regulated by a built-in cycle timer.

The top gas analyzer is a Perkin Elmer MGA1200 magnetic sector mass spectrometer. It is equipped with a special feature that provides individual 4-20 mA signals to the DCS, rather than the typical RS232 or 422 communications links. This feature permits continuous inputs for each top gas constituent (CO, CO2, and H2) needed for flame temperature calculations.

The blast furnace gas is sampled in the gas main after the gas from the No. 3 furnace is cleaned by a Davy cone scrubber system and the gas from the No. 4 furnace passes through the Venturi scrubber. The sampling point is common to both stove control systems (i.e., the top gas sample is a combination of the gas contributed from each furnace).

STOVE COMBUSTION CONTROL

Each stove on the No. 3 blast furnace, as well as on the No. 4 furnace, has its own separate combustion control program that is initiated when the initial stove is selected for its on-gas period.

Figure 3 shows the combustion control flow diagram and the sequence of events contained in the calculations for setting the stove heat demand in Btu/minute and the flame temperature in degrees Fahrenheit.

The calculations and algorithms presently in use at USS/Kobe have been modified to some extent from the original version prepared for Gary Works' No. 7 furnace. The control flow has six steps:

1. Calculate the stove heat demand.

2. Correct the dry top gas analysis from the gas analyzer for the wet gas analysis to provide the true Btu/ft3 value of the blast furnace top gas.

3. Calculate the stove burner operating flame temperature setpoint.

4. Calculate the required enrichment Btu/ft3 provided from natural gas.

5. Calculate the air flow setpoint for stoichiometric combustion.

6. Calculate the actual burner flame temperature.

Calculate the stove heat demand -

The stove heat demand is calculated in Btu/minute as a function of wind rate, hot blast moisture and temperature content, stove cycle times and stove efficiencies. Stove heat demand limits then are established based on stove utilities and capacities. If the limits are reached, alarm is posted and the system assumes a safe stove heat demand setpoint. The result of this calculation is established as the numerator in a later calculation.

Correct the dry top gas analysis from the gas analyzer for the wet gas analysis to provide the true Btu/ft3 value of the blast furnace top gas -

The individual top gas constituents, (i.e., CO, CO2 and H2) are subjected to a five minute rolling average by the MAX 1 DCS processor. The average analysis is error checked and used. In the event that the average analysis is not acceptable, or if the top gas analyzer is out of service, the system reverts to preselected stored values and an appropriate alarm is sounded. The Btu/ft3 of the wet top gas is calculated.

Calculate the stove burner operating flame temperature setpoint -

The stove burner operating flame temperature setpoint is calculated based on the required heating value of the mixed gas and is stated in Btu/ft3. This result is provided to the mixed gas flow setpoint as the denominator. Btu/minute (heat demand) divided by Btu/ft3 (flame temperature) provides ft3/minute, which serves as the mixed gas flow setpoint.

Calculate the required enrichment Btu/ft3 provided from natural gas -

The required enrichment Btu/ft3 provided from natural gas is calculated based on the additions necessary to the Btu/ft3 of the wet top gas. Then, the ration setpoint for enrichment is developed based on the Btu/ft3 of the natural gas. Once the enrichment ration is calculated, the natural gas flow controller setpoint is determined based on the mixed gas flow control setpoint.

Calculate the air flow setpoint for stoichiometric combustion -

The air flow setpoint for stoichiometric combustion is calculated based on the mixed gas flow setpoint and mixed gas Btu/ft3. A factor for excess air then is added and the air flow control setpoint is calculated in SCFM.

Oxygen analyzers are provided on each of the two stacks on every stove. The analysis either is automatically or manually selected by the MAX 1 DCS. A flue stack oxygen setpoint is entered to an oxygen controller. The controller is configure d to provide its weighted output to establish a positive or negative oxygen bias to the air flow controller setpoint in and increasing or decreasing direction. The bias is reset to zero when the stove is not in the on-gas period. The final operating air flow setpoint is the calculated value, including the excess air factor, plus or minus the bias factor from the selected stack oxygen analysis.

As a further check on combustion control accuracy, each stove stack on the No. 3 furnace is equipped with a combustibles analyzer. Historical trend screens comparing the oxygen and combustibles analysis are available on the MAX 1 Multi-Operator Stations.

Calculate the actual burner flame temperature -

When the stove is in the on-gas period, the actual burner flame temperature is calculated based on the wet blast furnace gas and the natural gas flow. Should the actual burner flame temperature exceed the aim flame temperature setpoint, the limit setpoint is assumed and an alarm is posted. Before passing the calculated flow setpoints on the controllers, the calculated heat demand is compared with a limit setpoint. If the calculated setpoint reaches or exceeds the limit, the limited setpoint is assumed and an alarm is sounded.

On-Gas Period

The stove on-gas period is established in three phases that are determined by the actual stove dome temperature control setpoint. The three phases are defined as:

1. Stove is on gas and the stove dome temperature is greater that 15 F below the setpoint.

2. Stove is on gas and the stove dome temperature is within 15 F of the setpoint, and enrichment natural gas is available

3. Stove is on gas and the stove dome temperature is within 15 F of the setpoint, and enrichment natural gas is equal to zero.

Figure 3 outlines the three phases

A ramp program is configured in the microprocessor and applied to the stove dome temperature setpoint. It provides an accurate approach to the setpoint without the setpoint overshoot. When the stove dome temperature reaches a preset temperature below the operating setpoint, the approach ramp program is initiated. The operating setpoint assumes the preset value and is increased to the operating setpoint at a specific ramp rate in degrees Fahrenheit per minute.

During the phase II of the on-gas period, the dome temperature control provides bias to the operating Btu/ft3 setpoint calculation. This ultimately results in a recalculation of the mixed gas flow setpoint. Air flow still is calculated as before, and stack oxygen analysis and bias control of the air flow setpoint remain active during phase II.

Phase III of the on-gas period seldom is reached when natural gas enrichment is required. Phase III begins when the stove dome temperature controller has removed all of the natural gas enrichment or if enrichment is not required. During phase III,, the oxygen bias controller is inactive.

The system is configured to permit reentry of any phase as a function of stove temperature deviation temperature from the setpoint.

Special attention is given to the M&P stove design with consideration for the maximum allowable temperature of the ring wall that supports the checker refractory. A maximum limit temperature is configured and an alarm is posted if this limit is reached. A control ramp program is initiated and the mixed gas flow setpoint is reduced at a present rate.

Table II represents one of many reports generated for the blast furnace complex. Data is provided to the VAX system for these reports from the MicroVAX and L&N MAXports.

Summary

A blast furnace stove combustion control strategy that utilizes the sophisticated capabilities of a state of the art microprocessor based DCS has been installed on the No. 3 blast furnace of USS/Kobe Steel Company. Since the May 4, 1992 blow in of the furnace, the reliability of the entire DCS has been proven. The stove operating performance has been met and is within the M&P specified guidelines. The objective of a one person control room operation has been achieved.

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