Boiler safety improvement for safety controls utilizing flow measurement for input

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Abstract

This paper describes a very interesting industrial safety problem and its solutions. Currently, boiler safety controls utilize pressure drop across various boiler elements in an attempt to guarantee adequate combustion air flow, purge air flow, and atomizing media flow. This paper describes various practical situations where these flow measurements are inadequate. Various alternative measures are described to mitigate the problems presented. The paper should serve as a basis for complete re-thinking on these safety controls on both power, industrial, and commercial boilers.
Keywords: boiler, safety control, flow measurement.

1 Introduction

A typical industrial or steam boiler utilizes approximately 50 different alarms and interlocks to satisfy safety for automatic operation. Some of these interlocks require that flow rate be measured and compared to a minimum requirement. There are two kinds of interlocks that are used in the boiler safety control system: 1. pre-ignition or start-up interlocks and 2. running interlocks.

The start-up interlock monitors the pertinent parameter only during start-up and once that parameter is satisfied it allows the boiler to continue in the start-up sequence. Running interlocks are active once the boiler begins firing. These interlocks use a continuously measured signal to shut the boiler down if the pertinent measured parameter does not meet its requirement. A running interlock interrupts boiler operation by causing the closure of two automatic fuel shut off valves. A pre-ignition interlock causes the safety control system to return the boiler to its initial start-up position. Three of these controls are considered in this paper. For each of these controls, the system is described, the problems are

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presented, and solutions are discussed. A much more detailed discussion of boiler safety controls is given in references Dyer [1] and ASME [2] although neither references discusses the problems considered in this paper.

2 Combustion air flow interlock

2.1 Typical system requirements, design, and operation

There is an interlock control which continually monitors flow of combustion air while the boiler is firing. (In other words this is a running interlock as opposed to a start-up interlock). The purpose of this interlock is to guarantee as much as possible that adequate air flow is present at all firing rates for the boiler. The flow rate through the boiler varies dramatically with load-typically the flow rate at minimum firing rate would be 20% of that at maximum firing rate. To guarantee adequate flow rate one would want the signal coming to the interlock to be approximately the same at all firing rates. Another desirable characteristic is that the signal be as large as possible to make the control sensitive and accurate. This interlock typically works by measuring the pressure rise across the combustion air supply fan because the head/flow characteristic for centrifugal fans used is usually fairly "flat" over the operating range of flow rates typically used. A schematic diagram of a boiler showing the flow circuits and safety controls considered in this paper are shown in Figure 1.

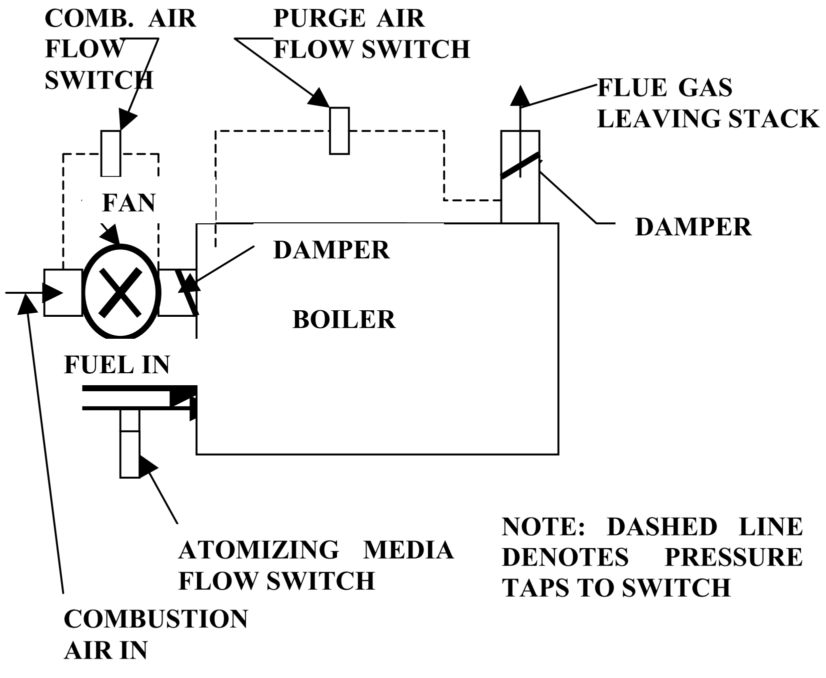

Figure 1: Schematic of boiler and safety system.

2.2 Problems with combustion air interlock arising in applications

Because of rising fuel prices, increasing emphasis is being placed on reducing energy use in boilers. Savings can be obtained by using "O_2 control" by adjusting automatically the relationship between the fuel and air supply rates. This is done by biasing the ratio between the air and fuel supplied to the boiler by continually measuring the $\%O_2$ in stack gases and using this signal in a feedback control system. Probably the best way to accomplish the required bias is to use variable speed control of the combustion fan. Variable speed control produces a linear relationship between speed and flow as opposed to a highly non-linear relationship when dampers or valves are used. In addition, considerable energy savings result from variable speed control. Use of variable speed control introduces a new problem for the combustion air switch because the pressure falls off as the square of the flow rather than remaining essentially linear.

A second problem that occurs is that for some boilers the pressure drop across the boiler system is very low. Hence, the pressure signal generated across the combustion air supply fan is low. This results in a low sensitivity for the control that in turn limits its effectiveness.

2.3 Solutions to problems with combustion air flow interlock

Inadequate flow of combustion air can be sensed by a decrease in $\%O_2$ and increase in combustibles in the stack gas. Reliable, self-checking sensors are now available for continually monitoring these two parameters. The use of one or both of these signals to replace the combustion air flow switch would eliminate the deficiencies of the flow switch. However, the relative costs would be dramatically different. A typical flow switch costs approximately one hundred US dollars while sensors to measure the two stack gas parameters and their inclusion into a control system would cost fifty times that much.

An alternative solution for solving the problem introduced by variable speed control would be to use fan speed to set the limit on pressure at which the safety control shuts down the boiler rather than use a fixed limit. However, at low fan speed the pressure rise produced will be low resulting in low sensitivity. If that is the case one would best resort to the use of $\%O_2$ and combustibles in the stack gas as described above.

3 Purge air flow interlock

3.1 Typical system requirements, design, and operation

The purge air flow interlock system functions as a pre-ignition control to guarantee that adequate purge air has been supplied to the boiler to eliminate combustible gases that would cause a boiler explosion if present at light off of the boiler. Actually, there are several elements in the safety control system to guarantee adequate purge air including a position switch(s) to guarantee that the damper(s) (see Figure 1) are open and an electrical switch to guarantee that power is being supplied to the combustion fan. However, the purge air flow switch is the most important of this system of interlocks because if it is properly satisfied adequate purge air is being provided. The purge air switch normally utilizes the pressure drop across the "boiler bank" which is the pressure drop from furnace inlet to boiler outlet stack (see Figure 1). To be an effective control the pressure difference employed must be small when the boiler controls are at low fire condition and large at high fire (purge) condition. The interlock functions by requiring the purge air flow switch be "made" in the start up cycle by sensing a pressure that exceeds the required set point.

3.2 Problems with purge air flow interlock arising from applications

The biggest problem encountered in using pressure drop to operate the purge air flow control is that some boilers exhibit almost no pressure drop resulting in a lack of sensitivity for the control. Thus, flow control is not a viable means for guaranteeing that purge air flow requirements are met.

3.3 Solutions to problems with purge air flow interlock

In cases where the purge air flow interlock can not be effective, it is doubly important that the position switch(s) for dampers be in place and operable and that power going to the combustion air fan be monitored. Hence, both of these interlocks should be operable and functioning continuously during the pre-ignition phase (typically they are operable only during the running phase). In addition several different means are used to monitor power to the combustion air fan that includes an auxiliary contact, phase monitors, and current relays. The auxiliary contact and phase monitors do not guarantee that power is being supplied to the fan and, hence, should not be used (over 90% of the systems currently use an auxiliary contact). Current relays measure current in each of the phases feeding power to the fan motor. If no power is being supplied to the motor, no current will be sensed and the safety control system will shut down the boiler.

An alternative approach to the problem would be to use a combustible sensor in the stack to indicate the presence of combustibles and to prevent firing of the boiler. The same sensor that could be used in the running sequence as described in section 2.3 could be used for this purpose.

4 Atomizing media flow interlock

4.1 Typical system requirements, design, and operation

For oil fired boilers, a secondary fluid (atomizing media) is supplied to the burner to atomize (break up) the oil into droplets and distribute it into the combustion air stream. The fluids used are either steam or compressed air. If inadequate flow of the atomizing fluid is delivered to the burner, unstable, incomplete combustion will result. This condition could lead to flame out and potential combustion explosions as well as poor efficiency. The usual setup to eliminate this problem is to use a differential pressure switch to monitor the pressure difference between the atomizing media and oil. On some boilers there is a "crossover" of pressure with the atomizing media pressure being greater than the oil pressure at low firing condition and lower at high firing condition. A differential switch will not work under this condition because there is no minimum pressure set point that can be used (the pressure difference goes negative at high fire). In this case, a flow switch has been proposed that would measure the flow of atomizing media.

4.2 Problems with an atomizing media flow interlock arising from applications

Although this switch has been proposed and used it provides little protection for the simple fact that the atomizing media flow requirement varies tremendously from the low to high firing condition. Thus, the switch can provide some protection at low fire but virtually no protection at higher firing rates.

4.3 Solutions to problems with atomizing media flow interlock

Since a flow switch can not work, the alternative solutions require a different approach. Probably the best protection is the use of an interlock based on measuring $\%O_2$ in the stack gas as described in section 2.3. The reason why this type interlock will work is interesting. If the atomizing flow decreases, less pressure will exist at the burner nozzle. This reduced pressure will decrease the flow resistance seen by the oil stream. Hence, the oil flow rate will increase which, in turn, will decrease the $\%O_2$ in the stack gas. Obviously, the combustible sensor will also be important in this situation because a high fuel to air ratio will produce combustibles. Therefore, the combustible sensor could become an important part of the solution.

A second solution to the problem, when compressed air is being used, is to use current relays on the power supply to the compressor motor to insure that the compressor is running (see section 3.3). While this is not as fail safe as using combustibles or $\%O_2$ in the stack gas, it does provide a considerable measure of safety.

5 Conclusions

Three safety controls for boilers based on flow measurement are described. Problems in applying these controls in certain situations are discussed. Alternative means to satisfy safety requirements are presented. These solutions are new and are not generally practiced in industry today. The results presented serve as a basis for upgrading existing safety controls to a much higher standard.

There is an urgent need world wide to improve these safety controls and to implement programs to actually test all safety controls on boilers on a regular basis. The authors have found that more than one third of the safety controls on industrial and commercial boilers do not operate properly.

References

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[2] CSD-1 - 2006 Controls and Safety Devices for Automatically Fired Boilers, 2006, American Society of Mechanical Engineers.