APPLICATION DATA

AD353-132
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Procidia Control Solutions
Boiler Control Overview

This application data sheet provides an overview of boiler control concepts. A basic water-tube boiler is shown in Figure 1. The Siemens 353[1] controller, with its versatile, powerful configuration platform for tight control of boiler control loops, is ideal for boiler control applications. Complex boiler control algorithms can be quickly implemented using the PC-based Siemens i|config™ Graphical Configuration software. The 353 controller and i|config help you to:

- Improve boiler performance
- Reduce flue gas emissions
- Maintain a high level of boiler safety
- Reduce boiler operating costs

Improve Boiler Performance

A boiler operation must maximize boiler uptime and performance. Upgrading the boiler control system is an inexpensive way to improve boiler efficiency and reliability. Modern controls can provide a quick response to the large load swings in everyday process and plant operations as well as to unusual, unplanned events.

Reduce Flue Gas Emissions

While environmental legislation has often improved air quality, these mandates can increase boiler operating costs. Modern controls can be used to fine tune boiler operation for an optimum balance between efficient operation and reduced emissions.

Maintain a High Level of Boiler Safety

A modern control system will provide tight integration with the flame safety or burner management system to improve safety. Having access to field data, diagnostics, and alarms, coupled with modern electronic controls, can achieve the desired level of safety and security. Password security of

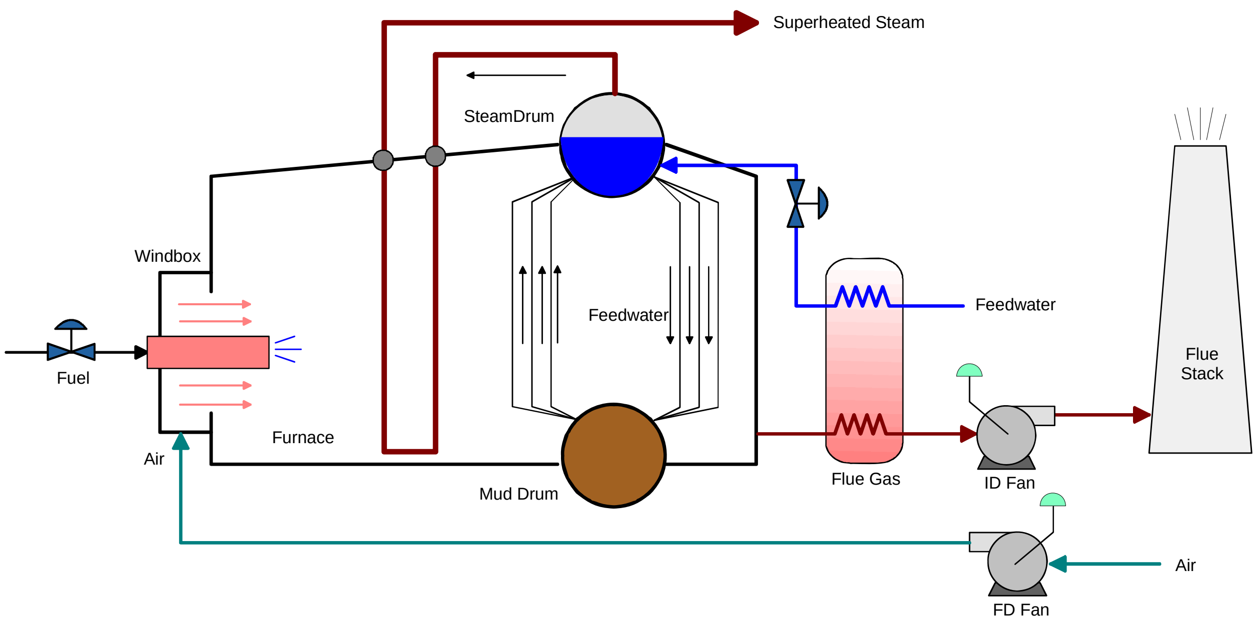

Figure 1 Basic Water Tube Boiler

[1] See Applications Support at the back of this publication for a list of controllers.

configuration software also assures no unintended changes are made which could endanger site personnel and equipment.

Reduce Boiler Operating Costs

A modern boiler control system can:

- Improve combustion efficiency to reduce fuel consumption by reducing excess air
- Reduce engineering , installation, and start-up costs
- Reduce maintenance costs associated with older, less reliable equipment
- Reduce manpower requirements by automatically responding to load changes
- Allow creation of a flexible control strategy to reduce or eliminate process upsets
- Readily make data available for remote monitoring to determine process unit optimization, boiler efficiency, and load allocation

BOILER OPERATION

The drum-type watertube boiler is the fundamental steam generator for many industrial and utility applications. The steam generated by a boiler may be used as a heat transfer fluid for process heating, or it may be expanded in steam turbines to drive rotating machinery such as fans, compressors, or electric generators.

Figure 1 is a schematic representation of a drum-type watertube boiler. Steam and mud drums are mounted within the furnace and are interconnected with watertubes called risers and downcomers. The watertubes serve as the primary heat transfer area. The furnace includes one or more burners for combustion of gaseous or liquid fuels. Combustion energy is transferred to the watertubes via convection of hot flue gases and radiation from the flame. Steam vapor bubbles form in the riser tubes closest to the burner and rise into the steam drum where they separate from the liquid water phase The steam in the risers is replaced by water in the downcomers to provide natural circulation (thermo-siphoning) in the watertubes. A continuous supply of feedwater is necessary to replace the steam leaving the boiler. In most cases, the saturated steam leaving the steam drum is returned to the furnace for superheating.

A forced draft (FD) fan provides combustion air to the windbox from which it is delivered to the burners. An induced draft (ID) fan draws the flue gases from the furnace and drives them up the stack. Hot flue gas is used to preheat either the feedwater in an economizer or the combustion air in a heat exchanger to improve efficiency.

The boiler control system manipulates the firing rate so that the supply of steam remains in balance with the demand for steam over the full load range. In addition, an adequate supply of feedwater must be maintained, as must the correct air/fuel mixture for safe, economical combustion.

In the following sections, boiler control subsystems will be discussed. This publication shows basic boiler control diagrams applicable to most boiler control systems.

PLANT MASTER CONTROL

Steam pressure is the key variable that indicates the state of balance between the supply of steam and the demand for steam. If supply exceeds demand, the pressure will rise. Conversely, if demand exceeds supply, the pressure will fall. Figure 2 shows a single loop control diagram that manipulates the firing rate demand to control steam pressure at the desired setpoint.

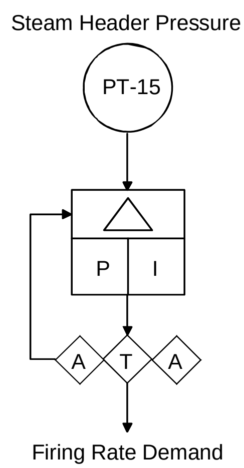

Figure 2 Plant Master Controller

Plants may experience fluctuations in demand due to batch processes or other process changes. In this case, a steam flow feedforward signal is used with steam pressure control. See AD353-129 Feed-forward Control for more information on this topic.

The term *plant master* can be applied when two or more boilers supply steam to a common steam header. Here there are multiple *boiler masters* but only one plant master. The plant master generates the master firing rate demand signal that drives the individual boilers. With multiple boilers, the plant master is typically configured with a variable gain, based on the number of boilers in automatic mode.

BOILER MASTER CONTROL

With several parallel connected boilers supplying a common header, it is generally desirable to provide a way to adjust the load distribution among the boilers. Depending on the load and performance of the individual boilers, the most efficient operation may be achieved with some boilers shut down, some boilers base loaded (constant firing rate), and the remaining boilers allowed to swing with the load (variable firing rate).

Figure 3 shows a boiler master control diagram to provide these adjustments. Each boiler master has a bias adjustment and an auto/manual transfer switch. In manual, the operator can reduce the firing rate to a low fire condition for shutdown, or hold the firing rate at any appropriate base loading condition. In auto, the boiler master follows the master firing rate demand signal except as altered by the bias adjustment. The operator can adjust each boiler master bias up or down to increase or decrease its share of the total load. AD353-123 provides information on the use of the Siemens 353 controller for parallel compressor control. The ideas presented in that publication are also applicable to the operation of multiple parallel connected boilers.

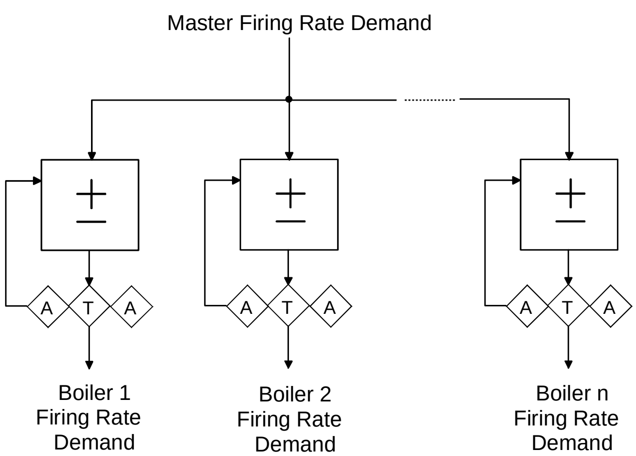

Figure 3 Boiler Master Control

COMBUSTION CONTROL

The primary function of combustion control is to deliver air and fuel to the burner at a rate that satisfies the firing rate demand and with a mixture (air/fuel ratio) that provides safe and efficient combustion. Insufficient air flow wastes fuel due to incomplete combustion, and it can cause an accumulation of combustible gases that can be ignited explosively by hot spots in the furnace. Excess air flow wastes fuel by carrying excess heat up the stack.

Combustion controls are designed to achieve the optimum air/fuel ratio, while guarding against the hazard caused by insufficient air flow. See AD353-130 for more details on the fundamentals of combustion.

Four combustion control methods are discussed in this section: single point positioning control, parallel positioning control, full-metered, cross-limited control, and O_2 trim control.

Single Point Positioning Control

The simplest combustion control strategy that can be applied to boilers is single-point positioning, often referred to as jackshaft control. It is commonly used on firetube and small watertube boilers. Figure 4 shows the feedback control scheme employed.

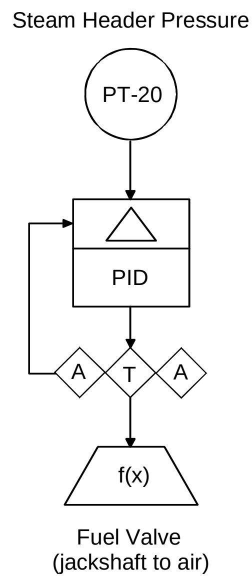

Figure 4 Single-Point Positioning Control

Single-point positioning uses a mechanical linkage to manipulate the fuel control valve and the combustion air flow damper in a fixed relationship. The alignment of the fuel valve and the air damper positioners is critical for this type of control. Because fuel valves and air dampers have different flow characteristics, it is necessary to linearize these flow characteristics. Typically, the air flow characteristic is linearized first, and then the fuel flow characteristic is linearized to match the air flow. When properly aligned, the percentage of fuel and air flow will match the percentage demanded by the single control output.

In a single-point positioning control strategy, only one measurement is used: steam header pressure or hot water outlet temperature, depending on the type of boiler. Both the fuel control valve and the air damper are positioned based on this signal.

Parallel Positioning Control

To regulate the firing rate, parallel positioning control employs a strategy that is similar to single-point positioning. Once again, only one measurement is used and this is either the steam header pressure or the hot water outlet temperature, depending upon the type of boiler. Both the fuel control valve and the air control damper are positioned based on this signal.

Unlike single-point positioning, parallel positioning has two control outputs. One controls the fuel valve, the other controls the air damper position. Since both fuel flow and air flow are non-linear, the fuel flow is mechanically linearized using a cam. Air flow is linearized within a digital electronic controller. Parallel positioning permits the optimum air/fuel ratio to be maintained across the entire firing rate. This control scheme is commonly used on package boilers.

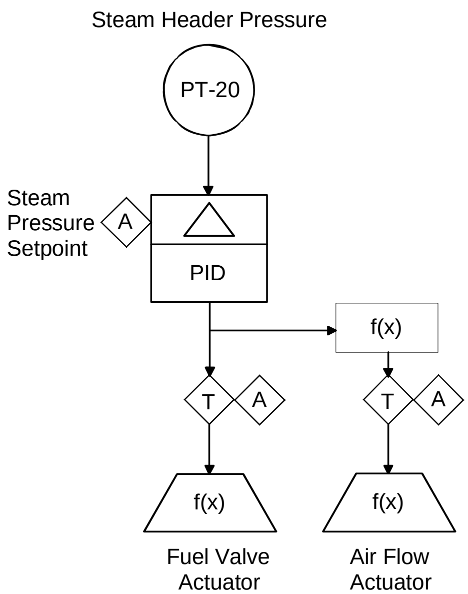

Figure 5 Parallel Positioning Control

Figure 5 shows the parallel positioning control scheme. The two controller outputs go to the fuel valve and the air damper. The jackshaft used in single-point positioning is replaced by a characterizer within the controller.

Full-Metered, Cross-Limited Control

The full-metered, cross-limited control scheme is sometimes referred to as the standard control arrangement. Full metered control measures both the fuel and air flows in order to improve control of the air to fuel ratio. This control scheme:

- Compensates for fuel and combustion air flow variations
- Provides active safety constraints to prevent hazardous conditions

In a metered control system, three measurements are used to balance the air/fuel mixture: steam header pressure, fuel flow, and air flow.

As shown in Figure 6, the combustion controls consist of fuel flow and air flow control loops that are driven by the firing rate demand signal. The characterizer [f(x)] on the air flow measurement scales the air flow signal relative to the fuel flow signal to provide the optimum air/fuel ratio. Characterizer points are determined empirically by testing the boiler at various loads and adjusting the fuel relative to the air at each test load to achieve optimum combustion. This allows the air and fuel setpoints to be driven by the same firing rate demand signal.

The cross-limiting (or lead-lag) circuit assures a dynamic air-rich mixture since the air flow setpoint will always lead the fuel on an increasing load and lag when the load is decreasing, thus preventing an excess fuel situation.

O_2 Trim Control

Automatic air/fuel ratio adjustment is often based on the percentage of excess oxygen (O_2) in the flue gas. If the air and fuel are mixed in chemically correct (stoichiometric) proportions, the theoretical products of combustion are carbon dioxide and water vapor. Under ideal conditions, all of the oxygen supplied with the air would be consumed by the combustion process. Due to the dynamic nature of combustion, it is necessary to provide slightly more air than is theoretically required for the complete combustion of the fuel. This insures complete combustion and minimizes the formation of carbon monoxide. The result is a small percentage of excess oxygen in the flue gas. A flue gas oxygen analyzer supplies feedback on the combustion process and is the basis for trimming the air/fuel ratio to maintain optimum combustion.

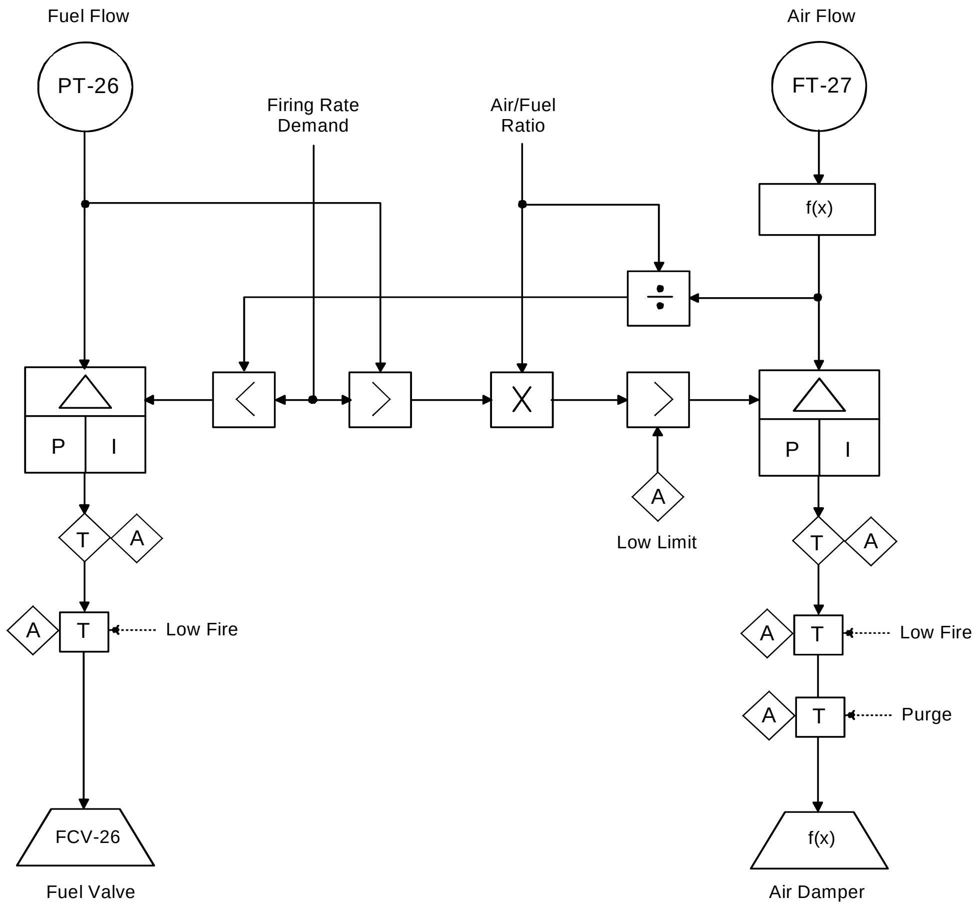

Figure 6 Full-Metered, Cross-Limited Combustion Control

Figure 7 shows one method of trimming the air/fuel ratio based on O_2 control. The optimum percentage of O_2 in the flue gas depends on the type of fuel and varies with load. Therefore, the O_2 setpoint is characterized as a function of steam flow, which provides an index of the boiler load.

Figure 8 shows a plot of excess O_2 as a function of steam flow for a particular application. Controller output is restricted by high and low limiters to prevent driving the air/fuel ratio beyond safe and efficient operating points.

FURNACE PRESSURE CONTROL

A basic boiler has a steam water system and a fuel-air-flue gas system. In the fuel-air-flue gas system, the air and fuel are mixed and ignited in the furnace. Air and fuel flow into the furnace and flue gas flows out.

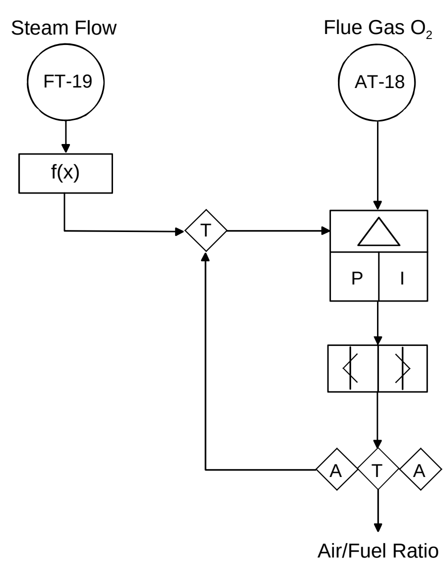

Figure 7 O_2 Trim Control

The force driving this flow is the differential pressure between the gases inside the furnace and those outside the furnace. Furnace pressure is commonly referred to as draft or draft pressure. The draft is maintained slightly negative to prevent the combustion products and ash from being discharged from the furnace into surrounding areas through inspection ports, doors, feeders, etc. For greatest efficiency, the controlled pressure should be as close as possible to atmosphere thereby minimizing the ingestion of “tramp air” or excess air drawn through the openings in the furnace duct work that cool combustion gases.

Furnaces are classified by the method for moving air and other gases through the system.

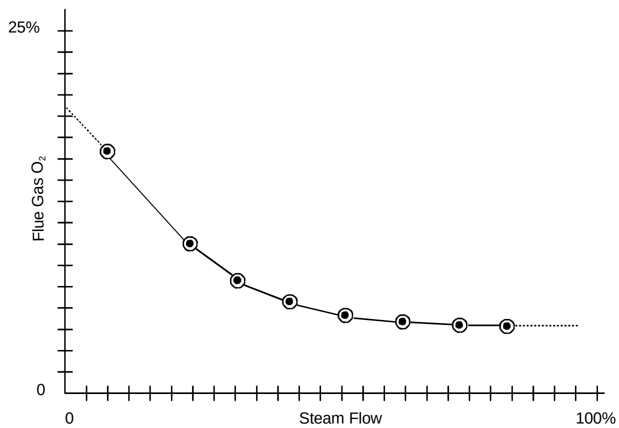

Figure 8 O_2 Characterizer

Natural Draft

A natural draft furnace uses the stack (chimney) effect. Hot gases inside the stack are less dense than those outside the chimney and will rise, creating a vacuum (suction) which will draw combustion air into the furnace. Natural draft furnaces naturally operate below atmospheric pressure.

Induced Draft

An induced draft (ID) fan, see Figure 1, draws combustion by-products and flue gases from the furnace and fresh combustion air into the furnace. An induced draft fan makes high stacks unnecessary. Control is accomplished by regulating either fan speed or damper operation. An induced draft furnace is operated slightly below atmospheric pressure.

Forced Draft

A forced draft (FD) furnace uses a fan or blower, see Figure 1, to force combustion air through the system. Control is accomplished by regulating either fan speed or damper operation. This type of furnace is operated slightly above atmospheric pressure.

Balanced Draft

Furnaces equipped with both FD and ID fans are called balanced draft systems. To control furnace pressure, it is necessary to maintain a balance between the flow in and the flow out of the furnace. Balanced draft furnaces operate at slightly negative pressures to prevent flue gas leakage into the surroundings. However, too low a pressure must also be avoided to minimize air leakage into the furnace and, in the extreme, to prevent furnace implosion.

As shown in Figure 9, the FD fan is generally manipulated by the air flow controller, and the ID fan damper is manipulated by the furnace pressure controller. When the air flow controller manipulates the flow into the furnace, pressure will be disturbed unless there is a corresponding change to the flow out of the furnace. An impulse feedforward connection couples the two dampers to minimize the furnace pressure disturbance on a change in air flow. As the impulse decays, external reset feedback to the furnace pressure controller drives the integral component to maintain the new steady state ID damper position. The furnace pressure controller trims the feedforward compensation as required to control the pressure at setpoint. (See AD353-129 for more on the use of impulse type feedforward control.)

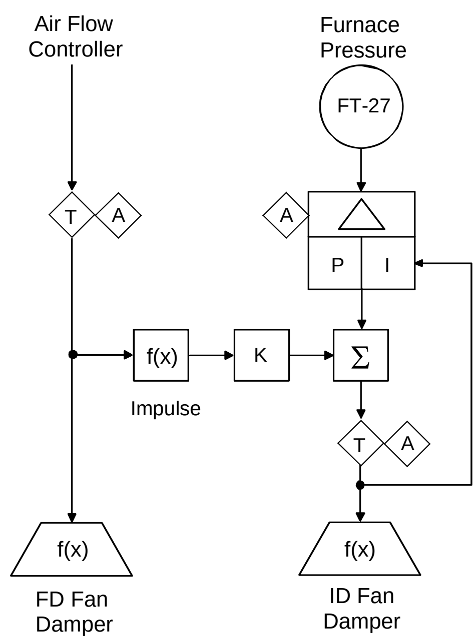

Figure 9 Furnace Pressure Control

BOILER DRUM LEVEL (FEEDWATER) CONTROL

Boiler drum level control provides two benefits. It maximizes steam quality and it maintains proper drum level to prevent damage to the boiler.

The cylindrical vessel where the water-steam interface occurs is called the boiler drum or steam drum. Boiler drum level is a critical variable in the safe operation of a boiler. A low drum level risks uncovering the watertubes and exposing them to heat stress and damage. High drum level risks water carry over into the steam header and exposing steam turbines or other equipment to corrosion and damage. The level problem is complicated by inverse response transients known as shrink and swell.

Simply put, shrink and swell refer to a decreased or an increased drum level signal due to the formation of fewer or more vapor bubbles in the water without a change in the amount of water in the drum. This condition produces level changes during boiler load changes in the opposite direction of what is expected with a particular load change. Although only temporary, these changes can cause severe control system overshoot or undershoot.

In this section, the following types of drum level control are discussed: single-element, two-element, and three-element; see Figure 10. Single/Three-Element drum level control is discussed later.

Single-Element Drum Level Control

The single-element system is the simplest type used for controlling packaged firetube and watertube boilers. In this strategy, control is based on the boiler drum level measurement only. This does not allow for compensation of shrink or swell and, therefore, is an acceptable control strategy only for small boilers with slow load changes.

Two-Element Drum Level Control

In two-element control, steam flow and boiler drum level are measured. The steam flow signal is used in a feedforward control loop to anticipate the need for an increase in feedwater to maintain a constant drum level. This strategy requires that the open loop relationship between the steam flow transmitter signal and the feedwater flow remain constant. Boilers with moderate load changes can usually be controlled with this strategy.

Three-Element Drum Level Control

Three-element drum level control adds a feedwater flow signal to the steam flow and boiler drum level signals used in two-element drum level control. The drum level controller manipulates the feedwater flow setpoint in conjunction with feedforward from the steam flow measurement. The feedforward component keeps the feedwater supply in balance with the steam demand. The drum level controller

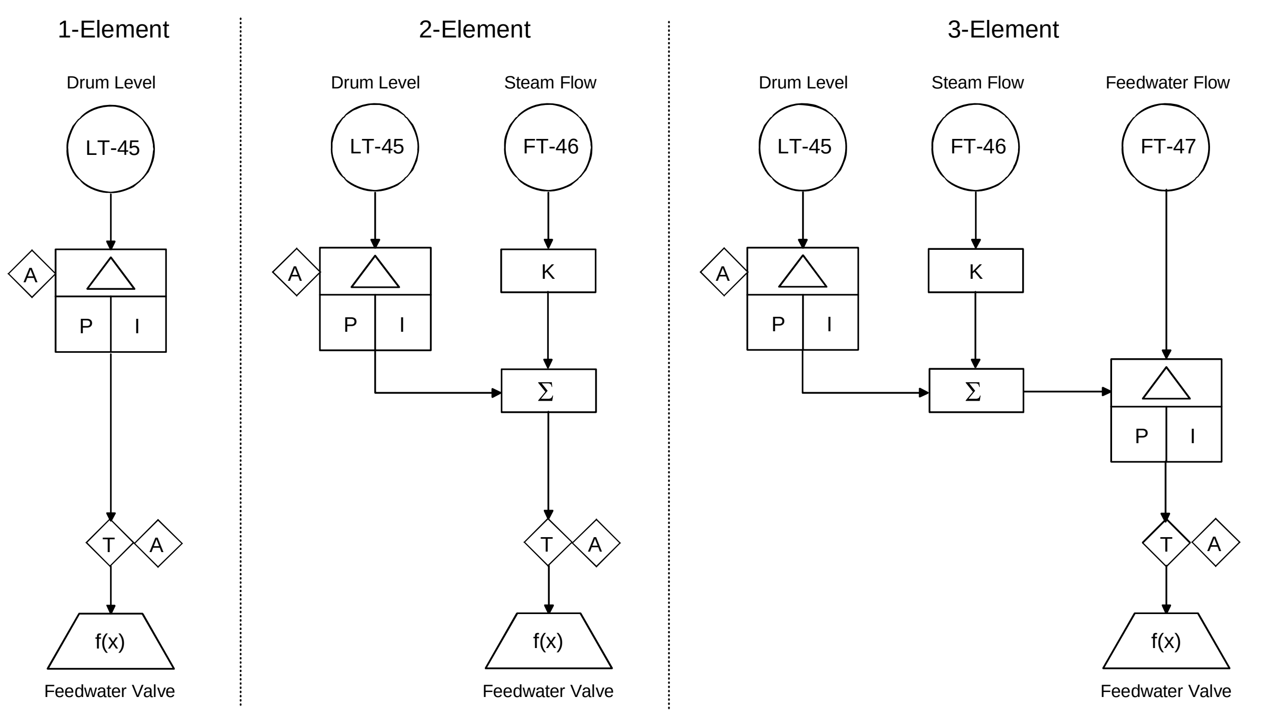

Figure 10 Drum Level Control Schemes

trims the feedwater flow setpoint to compensate for errors in the flow measurements or any other unmeasured load disturbances (e.g. blowdown) that may affect the drum level. Three-element control is used in boilers that experience wide, fast load changes, and is the most widely used control strategy.

Single/Three-Element Drum Level Control

During startup or low load operation, the flow measurements used in the three-element control strategy may fall well below the rangeability limits of these flowmeters. In this situation, three-element drum level control becomes erratic, and adding a single loop (one-element) control strategy to control the drum level will improve stability.

As shown in Figure 11, drum level control automatically switches from three-element to one-element when the steam flow falls below an adjustable low limit. Separate level controllers are used to allow separate controller tuning for one-element control and three-element control and to provide appropriate tracking strategies for bumpless transfer between these two control modes.

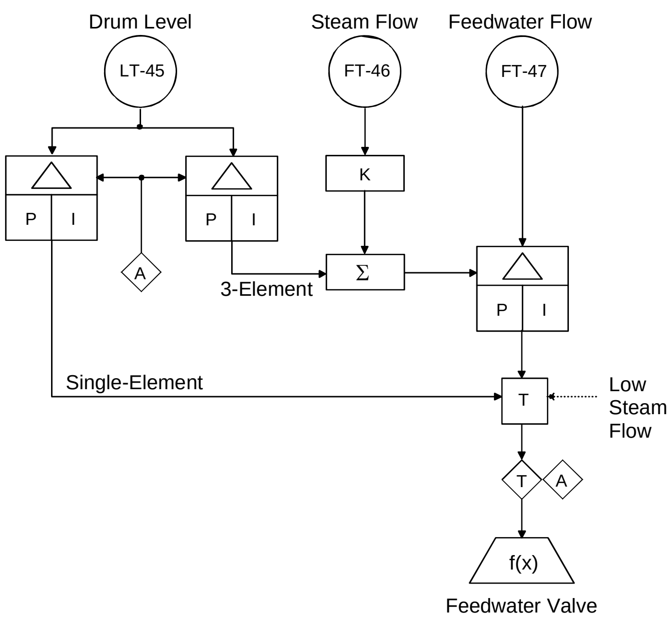

Figure 11 Single/Three-Element Drum Level Control

DRUM PRESSURE COMPENSATION

When the design steam pressure exceeds 400 psig, pressure compensation of the drum level signal is recommended. Drum level measurement is a hydrostatic differential pressure measurement between the top and bottom taps in the drum. Drum level measurement is typically in 'inWC' (inches water column) and it is calculated based on the densities of both the liquid and vapor phases. However, both densities change with steam drum pressure affecting the conversion calculation. The result is an increasing error in drum level with increasing steam drum pressure. In pressure compensated drum level, the measured differential pressure signal is corrected for the operating liquid and vapor densities.

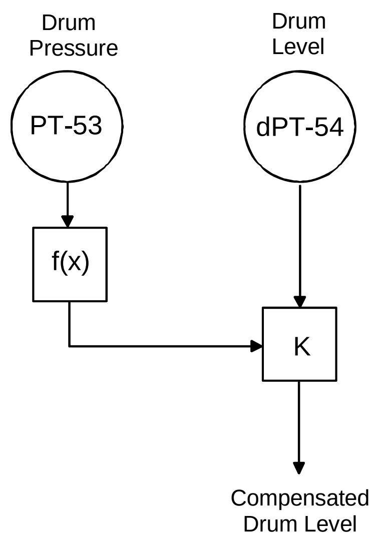

Figure 12 Drum Level Pressure Compensation

APPLICATION SUPPORT

User manuals for controllers and transmitters, addresses of Siemens sales representatives, and more application data sheets can be found at www.usa.siemens.com/ia. To reach the process controller page, click **Process Instrumentation** and then **Process Controllers and Recorders**. To select the type of assistance desired, click **Support** (in the right-hand column). See AD353-138 for a list of Application Data sheets.

The control concepts in this publication can be implemented in any of the following controllers:

- Model 353 Process Automation Controller
- Model 353R Rack Mount Process Automation Controller*
- i|pac™ Internet Control System*
- Model 352*Plus*™ Single-Loop Digital Controller*

  * Discontinued model