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SAMA Symbols – Drum Level

SAMA Symbols can show the cascade and feedforward aspects of three-element drum level control. This is the third of a nine part series on SAMA Symbols.

Boiler steam drum water level is one of the most important parameters that must be controlled to ensure safe and efficient boiler operation. The steam drum is a long horizontal pressure vessel at the top of the boiler and contains both water and steam. The drum is typically half full, allowing water to flow up and down the tube banks that surround the fire box. Steam is released from the boiling water surface and passes out through the moisture separating equipment, located in the top half of the steam drum, and then out to the steam header.

This article will explain the differences between one-, two-, and three-element steam drum water level control and also point out extra elements included in the boiler operation by the process control engineer. One tool the engineer uses to illustrate a drum level control loop are SAMA symbols. SAMA stands for Scientific Apparatus Makers Association, the organization that came up with the symbolic language to represent the various pieces of control loop hardware and how they interact together to create a process control scheme.

A single element drum level control loop has one input which is the steam drum water level transmitter. This single process variable is the feedback to the drum level controller. The controller output modulates the feedwater control valve so as to maintain the proper water level or water inventory in the steam drum. The following SAMA drawing shows this single element drum level control loop.

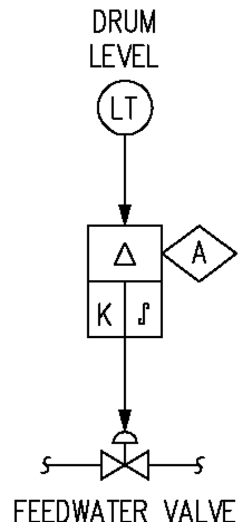

Figure 1

As noted in a previous SAMA article, the circle (LT) is the drum level transmitter. The two mode (proportional and integral) controller is shown in the rectangle. The delta Δ symbol in the top, indicates the difference (or error) between the feedback signal and the set point. The set point is represented as the A in the diamond. Recall that a diamond is used for manual inputs to the control system. The feedwater valve is shown as a control valve. The drawing is laid out top to bottom as the information flows from the transmitter through the controller to the final control element.

The objective of this control scheme is to maintain the water level in the steam drum at approximately the mid line during normal and upset conditions. This ensures that the boiler tubes have adequate water coverage and that the moisture separating equipment in the top of the drum is not flooded. This single element drum level control is good for small boilers or those that do not experience large upsets.

Steam side upsets are introduced into the steam system (steam header) from the many steam customers who represent the process needs. Steam users around the industrial plant are free to open and close their own specific steam valves, taking steam from the main header as needed on their schedule. This on and off steam demand from the independent users changes the steam flow and hence the steam header pressure. Boiler firing rate controls modulate the fuel valve in response to this falling or rising steam header pressure. The firing rate controls also adjust the combustion air damper to meet and match the fuel flow and the fluctuating steam flow and steam pressure (energy) requirement.

Fire side upsets are introduced into the boiler due to changing air conditions like cool moist rain, running fuel changeovers from oil to natural gas, or fuel inconsistency such as experienced with dry or moist biomass.

Water side upsets can come from intermittent blowdown or from multiple parallel boiler operations sharing common feedwater pumps. Chemical additions and possible foaming can also create water side issues.

The most severe upset within the steam drum is called shrink and swell and is the result of steam header pressure changes. Shrink and swell also involves the opposite effect of both common sense and the action of the drum level control loop. When steam users increase their steam usage, the steam header pressure falls and the steam drum pressure falls. With falling pressure, the boiler firing rate control will increase the fuel input to the furnace to boil more water and increase the pressure. The logical reaction is to also add more feedwater to coordinate with the required increased steam production. However, the boiling of water and the formation of steam bubbles increases at this time due to the decreased pressure and increased energy input. Recall that there is a fixed volume or inventory of water in the boiler tubes and drums. The pressure has dropped and the fuel energy has increased. This causes the water inventory in the boiler tubes and drum to swell, due to the expansion of millions of steam bubbles, which raises the steam drum water level above the set point. The bubbles expand because of the decrease in steam pressure. As a result, the single element drum level controller will take action to close down the feedwater control valve which is the opposite of what is desired.

As the firing rate increases, the water inventory is boiled off into steam. The now increased pressure and the decreased inventory of water will cause the drum water level to drop below (shrink) the desired level. With increased pressure the bubbles shrink in size. The single element drum level controller will now open the feedwater valve and "cold" feedwater will now fill the steam drum. This cool water will quench the steam bubbles and actually decrease the drum water level even further. This in turn will cause the drum level controller to call for more feedwater which will quench the steam bubbles even more. This continues until the energy balance or fuel, feedwater and steam flow, along with the large thermal mass of the boiler, are once again in balance. This condition, known as shrink and swell, affects those boilers that experience large pressure swings due to large steam flow changes.

To compensate for shrink and swell, two-element drum level control was developed and involves the addition of a steam flow measuring device like an orifice plate or vortex meter. The following SAMA drawings show the two-element drum level control scheme and it is clear that two process variables, drum level and steam flow, are involved in the feedwater control valve modulation, hence the name two element.

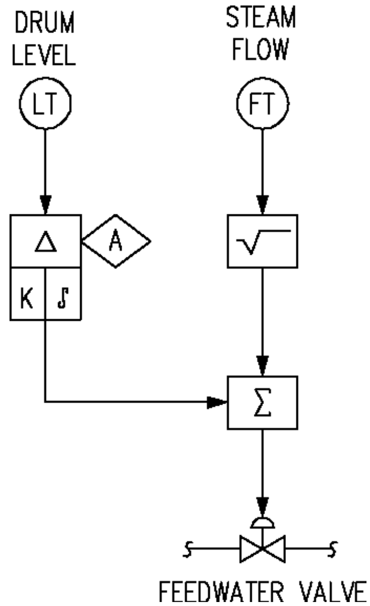

Figure 2

The output of the drum level controller is added with the steam flow signal to regulate the feedwater control valve. The steam flow signal serves as a feedforward signal for the feedwater valve. The drum level controller acts as a trim action to correct for imbalances in the system. The steam flow signal is characterized to match the feedwater control valve opening as close as possible. This allows for a crude mass balance of feedwater into the steam drum and steam flow out of the steam drum.

When a better mass balance is needed or the feedwater system has shared users, such as other boilers, then a three-element drum level control is required. The following drawing shows the addition of a feedwater flow element and transmitter.

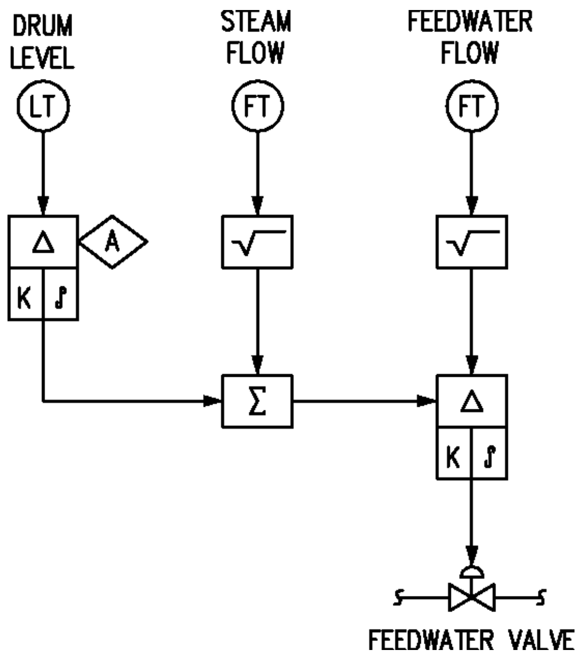

Figure 3

The feedwater flow signal serves as feedback for the feedwater flow controller which is tuned for a fast response. The steam flow measurement is a feedforward signal for the feedwater flow controller. The drum level controller output is added with the steam flow signal to allow trim action.

These control schemes with their respective equations are the result of analysis by the process control engineer. By reviewing the mass and energy balances of the boiler and taking into consideration the instrument calibration and process dynamics, the process control engineer can design effective control system solutions.

For instance, the feedwater control system and/or the firing rate control system, could be improved by considering the following examples of upsets:

- Soot blower operation is frequent and consumes steam that would otherwise pass through the main steam flow meter. Measuring this steam flow would allow the feedwater to better match the overall steam usage.
- Mud drum blowdown and surface blowdown are intermittent and result in feedwater loss that is unmeasured. Is this quantity of water sufficient to warrant measurement and should this signal be used to adjust feedwater flow?
- The steam boiler is used to supply the needs of a large steam turbine generator. The steam turbine throttle valve is opened and closed in response to electrical loads and creates a steam pressure upset condition that the firing rate control system must react to. Should the throttle valve signal be used as a feedforward signal for both the firing rate control and feedwater control?

- The steam boiler is in a pulp mill and provides steam for 20 different batch digesters. The steam flows of each digester are based on schedules that involve unique fill, heat, cook, cool, and empty times. The upsets to the steam header are significant. Could monitoring each digester steam flow be used as a feedforward signal for both the firing rate control and feedwater control? Would this digester feedforward be considered a four-element feedwater control scheme or a 23 element feedwater control scheme?

The next article, the fourth in a series of nine articles on SAMA symbols looks at firing rate control.

This article on SAMA Symbols was written to convey the power, elegance, and ease of designing complex control schemes. This article is not a full, complete, or correct design of any control system. The reader shall retain the services of a licensed professional engineer with extensive process control experience. The professional engineer must first analyze the specific process in question. As my college professor used to say, "You can't design a control system ***until*** you understand the process."

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