SAMA Symbols White Paper #3 – Drum Level

SAMA Symbols can show the cascade and feedforward aspects of three-element drum level control.

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 that can be included in the boiler operation by the process control engineer. These extra elements are process variables that have an effect the drum level control. They typically involve mass or energy balances or imbalances.

One tool the process control 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 SAMA drawing of Figure 1 shows this single element drum level control loop.

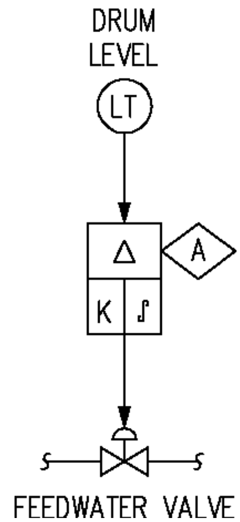

Figure 1

As noted in a previous SAMA article, the circle (LT) is the drum level transmitter. The two mode (proportional and integral) controller is shown as 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 symbol 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 those 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. Swell occurs with drops in steam pressure and shrink occurs with a rise in steam pressure. 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 and water level goes up. 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. However, the drum level transmitter sees a rise in water level and the controller takes action to reduce the feedwater input.

As the firing rate increases, more of 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 and mass balance made up of 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.

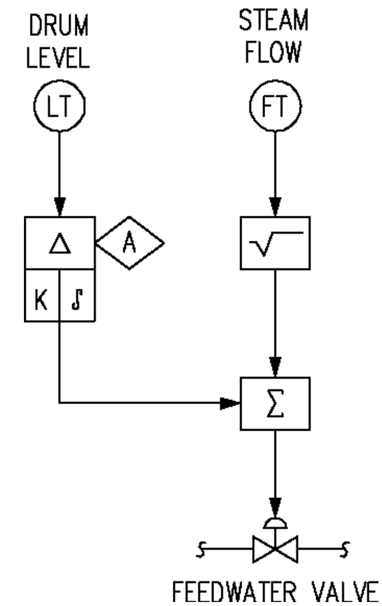

Figure 2

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 SAMA drawings of Figure 2 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.

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. It is an approximate balance because while steam flow is measured feedwater flow is not.

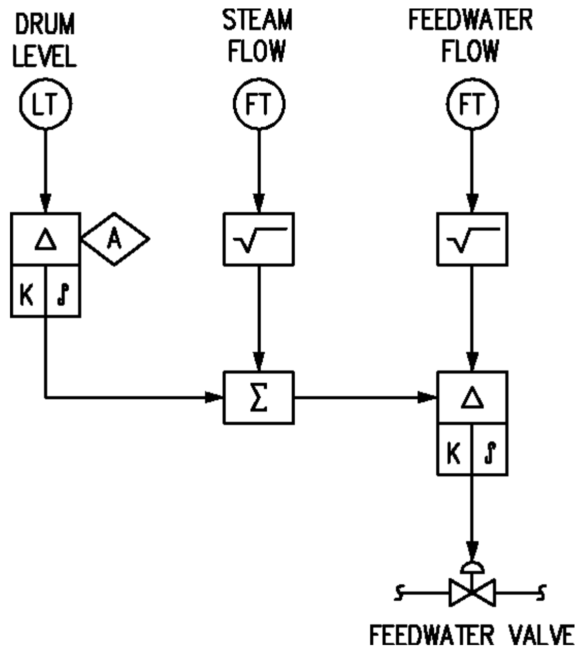

Figure 3

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 drawing in Figure 3 shows the addition of a feedwater flow element and transmitter.

The feedwater flow signal serves as feedback for the feedwater flow controller which is tuned for a fast response. This loop simply measures feedwater and controls feedwater. The steam flow measurement is a feedforward signal for the feedwater flow controller. As the steam flow changes the feedwater flow controller set point is also changed. For say 200,000 pounds per hour of steam you need 200,000 pounds per hour of feedwater flow. Hence steam flow matches feedwater flow. For flow instrument error, blowdown, soot blowing, etc., the drum level controller output is added with the steam flow signal to allow trim action.

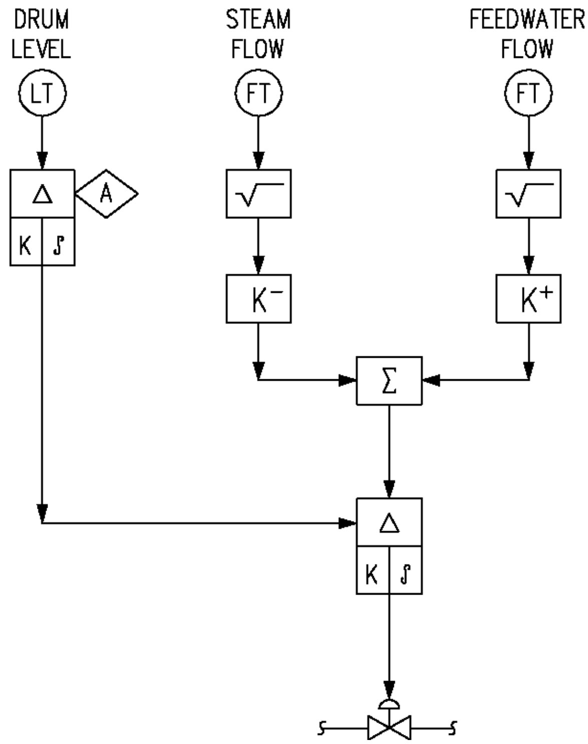

Figure 4

Three-element drum level control can also be done as a mass balance as shown in Figure 4. This mass balance approach allows the feedwater flow to closely track the steam flow with correction from the drum level controller. The K- and K+ allow the designer to match the ranges of the two different flow meters. The square root function is typical of orifice plates and would not be needed if vortex meters or turbine meters were used.

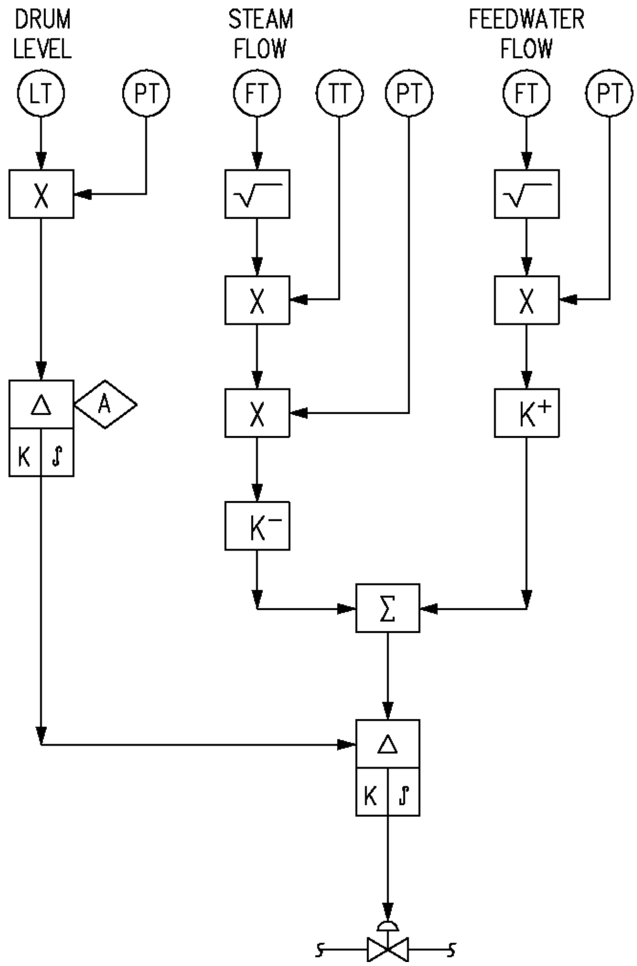

Figure 5

Three-element drum level control can also be enhanced with pressure compensated drum level, pressure compensated feedwater flow, and pressure and temperature compensated steam flow as shown in Figure 5

This temperature and pressure compensated control scheme is very easy to understand because we can see the three main transmitters and the associated compensation transmitters. The process control engineer and / or the instrument designer can easily set up the required equations and program them into the correct control blocks.

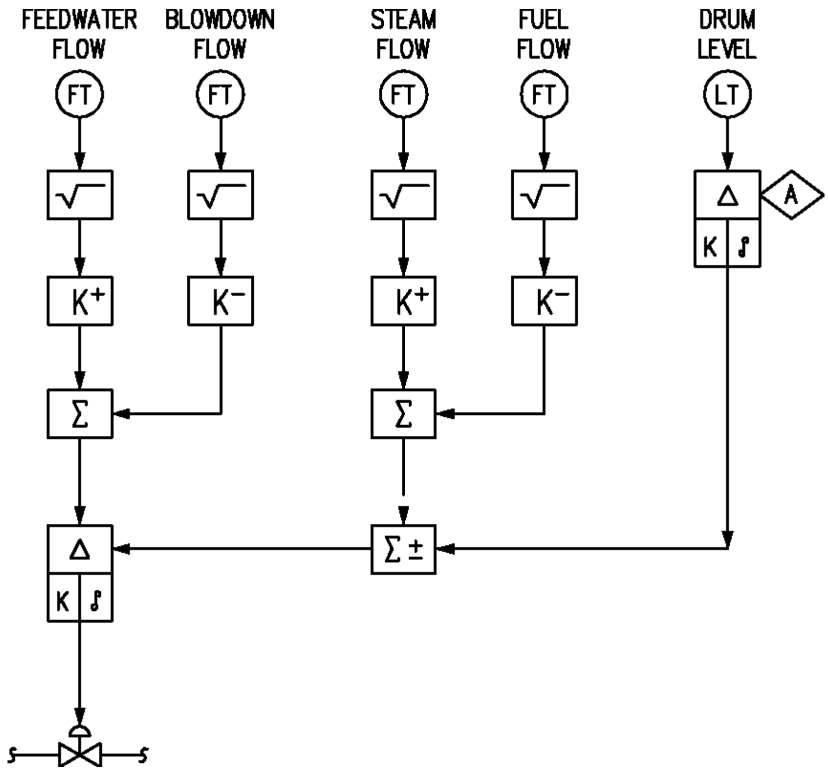

Figure 6

The SAMA symbol drawing in Figure 6 is a five-element drum level control. Once again it is clear that the blowdown signal is subtracted from the feedwater signal to compensate for the lost water. The fuel flow is yet another feedforward signal alerting the feedwater controller of a load increase or load decrease.

These drum level 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.

Larry Klein is a Senior Engineer-Sulfuric Acid and Power Generation with Mosaic Fertilizer Company in Mulberry, Florida. He has depended on SAMA symbols to track the multiple systems in use at the busy phosphate plant.

"Back over 30 years ago when this New Wales Facility was constructed, the engineers used SAMA symbols for the original boiler controls. We have undergone significant expansion and SAMA symbols still help me keep track of the steam system interactions. We now have five sulfuric acid plant boilers, one heat recovery steam generator, three steam turbine generators, and

14 evaporators. All that steam production and steam usage equipment are connected together with four major steam headers operating at various pressures that circle the plant. SAMA symbols help me understand all the interactions and allow me to stay on top of the operation."

This confirms that the engineer needs to keep his mind focused on the process and efficient production of product. Of course, the process is supervised by the control system and interactions or interruptions can be detrimental to production and profitability. Using SAMA symbols to document the control system is a great tool to understand those interactions.

Now that we have discussed the concepts of mass balance and energy balance and how they can be represented with SAMA symbols, think about the following process interactions. Could the boiler feedwater control system and/or the firing rate control system be improved? Consider 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 soot blower steam flow would allow the feedwater to better match the overall steam usage. Sketch out a steam drum and show the in and out flows. Add flow meters and develop a mass balance. Now sketch out a SAMA symbol diagram that compensates for those flows.

- Mud drum blowdown and surface blowdown are intermittent and result in feedwater loss that is unmeasured. Draw a steam drum with flow meters for these blowdown flows and think about the cost of flow meters. 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 in the steam header. The steam header pressure and steam flow swings must be corrected by the boiler firing rate control system. The steam flow and feed water flow are also upset. Should the throttle valve signal be used as a feedforward signal for both the firing rate control and feedwater control? Sketch out the steam turbine generator, steam header and boiler. Think through the mass balance and energy balance between the producer and consumer. Notice that the steam header is simply a big capacitor in the circuit. How would you design the control system to minimize the steam header upsets?

- 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?

It should be clear from these examples that SAMA symbols allow the process control engineer to view the process from an energy balance or material balance viewpoint. I am sure that each of the readers can now think about how to use the above mentioned transmitter signals to enhance their own boiler control schemes.

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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He has a Bachelor's degree in Mechanical Engineering with an emphasis on Thermal Processes, Process Control, and Fluid Flow.

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