Drum Level Control

Myths, Facts, and Other Minutiae

Over the years I have seen and heard a great many debates regarding the proper way to set up drum level controls. Each person presenting their argument often has a very convincing reason for their particular claim. But in the end, it is the actual results that matter. So the question I will answer here is, 'What method of drum level control provides the best results?'

The short answer….**'That Depends'**. The control of drum level is much more complex than a simple answer can provide. In order to help you understand which control method is best for you I will first need to expose some of the physics involved with a drum and how it responds to the ever changing conditions of your plant. Don't worry I will keep the math to the absolute minimum so you can put down your calculus refreshers and read on.

Let's start at the beginning with **'Which drum level measurement do I believe anyway?'**

This is one of the biggest and most often asked questions I run into. The Eye-Hi displays one value, the gauge glass shows something else, the transmitters are another value, and the DCS display…. Well those transmitters never agree! Let's take a look at why this confusion happens and what can be done to dispel it.

Figure 1

ASME pressure vessel code requires that two, independent methods of drum level measurement be visible at all times to the operators. Normally one of these measurements is accomplished with the Eye-Hi or similar indicators. The two most common causes of error with this form of measurement are *improper mounting of the measurement column*, and *improper insulation of this column*. The 'Zero' indication of the measurement column *must be mounted level with the boiler OEMS normal operating level point for the drum* and **not** *the center line of the drum*. This simple mistake can result in a large, 6 or more inches, error in the reading.

The insulation of the measurement column must also be properly installed per the OEMs recommendations. Often it is felt that if we keep the column cool, by leaving the insulation off, the probes will last longer and maintenance will be reduced. The OEM of the column understands the environment it will be installed in and has designed the system to work at these higher temperatures.

Why does the insulation being off effect the readings you ask? The water in the drum is at the saturation temperature for the operating pressure. We can use steam tables to look up a couple of numbers and see what happens. When the insulation is removed, the temperature of the water in the column changes rapidly and so does its density. This change in density causes the level in the column to be at a different physical place than the actual water in the drum. Let's take a look at those steam table numbers.

Speaking of water density! Let's use 1800 psi as an example

	Saturation Temperature	Measurement Column Temperature
	621°F	200°F
Density lbm/ft^3	40.47	60.12

As you can see this density change can make a dramatic difference in the measurement you can see. So make sure that the Eye-Hi Column is properly insulated and mounted.

Figure 2 Photo

By the way (or BTW for you texters), the same situation appears with the *magnetic float gauges.* They are often mounted wrong or insulated wrong causing even more confusion.

Level transmitters are a different case. Many units will have 2 or 3 differential pressure transmitters that are used to convey this seemingly confusing information to the DCS screens in the control room. The transmitter is clearly not at the drum temperature yet we want to believe this transmitter above all others. Well you should believe it because the DCS, if it has been properly configured, will determine the present pressure and temperature in the drum (it does this by measuring the drum pressure and calculating the saturation temperature) and applies a compensation factor based on the average transmitter temperature. "Ah Ha!" you say, "another error! As the ambient temperature changes the indicated drum level will change." "True", I confess, "you are right!" From 33°F to 120°F the density will change 1.1%. So from the average temperature of 87°F the density changes +/- 0.55% or about ¼ inch of level.

Figure 3

As with anything else the transmitters must be properly installed in order provide you with an accurate measurement. A condensate pot that is *not insulated*, is **required** on the top measurement tap. This condensate pot provides a proper reference measurement leg for continued reliability.

To see a properly installed drum level measurement transmitter, take a look at the picture on the left.

A nice shiny condensate pot! The guard cage is to…well guard you hands from touching the pot.

Heat tracing on the sensing lines! Nice shade of red!

Notice also that an insulted cover is added to protect the transmitter.

If your unit is shut down often, then you can fill the reference leg with propylene glycol as an anti-freeze.

So What Is Going On In that Drum Anyway?

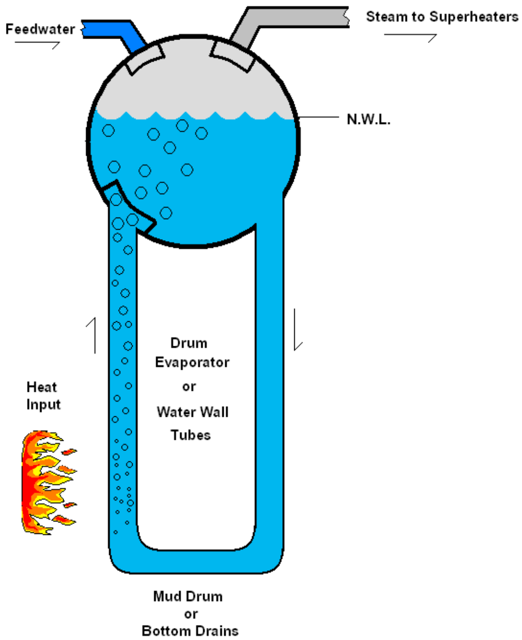

Figure 4

A whole lot more than you might think. The drum is a very dynamic and turbulent area. Understanding what is going here is very important if you are to control the level accurately. We have cold feedwater coming in, hot steam going out, water leaving the drum from one side and water mixed with bubbles rising on the other side. For every pound of steam that leaves the drum we must add a pound of water in order to maintain the desired level.

When everything is balanced, as shown to the left, then the level is relatively constant and stable. I say relatively because the bubbles that are coming back up the evaporator section will cause waves in the drum. On the DCS we will see this as a noisy signal or sometime as an offset or difference between the transmitters. We'll come back to this offset in a little while.

The bubbling, as it increases and decreases, changes the volume of water in the drum but not he mass. The mass of the drum changes with the amount of steam exiting the drum and the amount of feedwater entering the drum.

But All I Did Was Raise the Steam Turbine Megawatts!

How many times have we heard this followed shortly by the drum level control was doing the opposite of what it should have been doing. Let's have a look at how this can possibly happen.

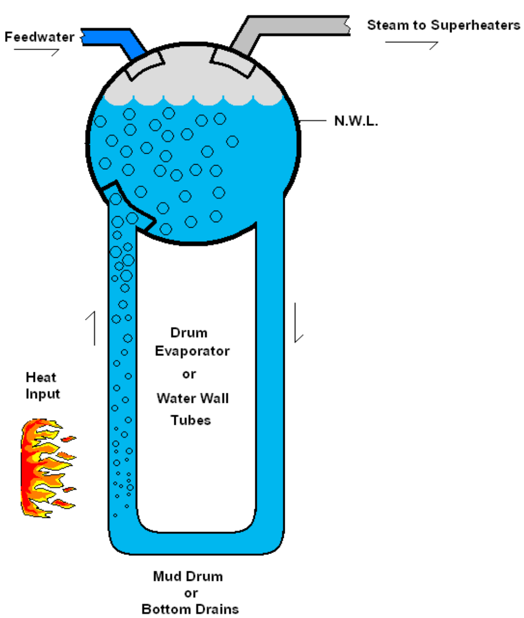

Figure 5

When we open the control valves on the steam turbine the first thing that happens is a sudden pressure drop just upstream of the valves. This pressure drop works its way back up the piping and sometime later (this can range from1 to 10 or more seconds depending on the geometry of the plant) this drop in pressure reaches the drum. When the drum pressure drops, the boiling point of the water in the drum and evaporator also drops, but the heat input to the furnace remains the same so more bubbles form…. a lot more bubbles. So many more bubbles that the water in the drum is actually pushed up by the rising bubbles. At this time however, the water inventory in the drum has not changed. Only the bubbles have increased, the volume has gone up, and the level has gone up. This is why many operators will run with a drum level of -6 or -9 inches. They feel that this gives them more room in case of an upset and thus avoid a high level trip. However, the boiler manufactures do not like this since they have spent a lot of time figuring out the proper level for best operation of the boiler.

Now remember opening those pesky control valves? Well so does the drum. Now that the pressure wave is complete the steam flow will start picking up. This increase in steam flow will start to reduce the mass inventory of water in the drum. Sadly at about the same time, the pressure in the drum has re-stabilized and the bubbling rate has returned to its previous value which means. The bubbles are not pushing the water up so the volume of water goes down and so does the level. At the same time the steam leaving the drum is making the mass water level go down. But there is one more whammy that can add insult to injury here.

My drum level was going down so I opened the feedwater valve and the unit tripped on low level!

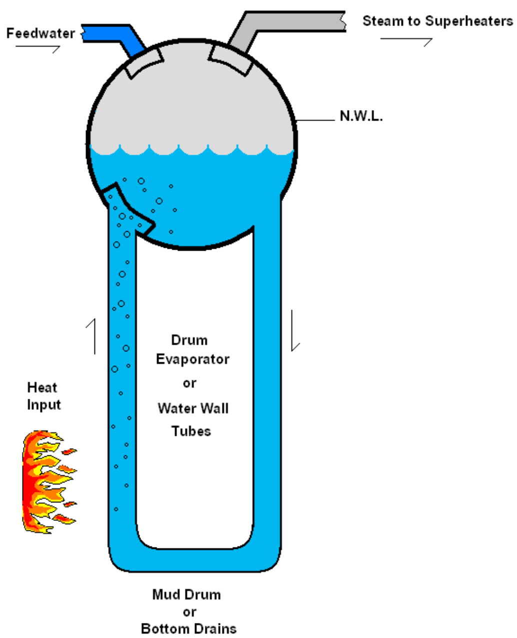

Figure 6

If you were adding more water why did the level go down? Back to the bubble maker.

So here we are with a nice hot drum that has just lost a bunch of bubbles and the volume has to go down **and** the steam flow has increased which makes the drum mass level go down even more. So the natural reaction is to open the feedwater valve and pour in nice fresh ***cool*** water. When you add cool water to boiling water the boiling stops for a few moments until the temperature can re-stabilize.

So opening the feedwater valve really can make the level go lower for a few seconds. This few seconds of lower level is because of two reasons. First the quenching of the boiling rate causes a temporary ***decrease in the bubbles that are lifting the water and increasing the volume*** which will recover. And second, if the feedwater flow entering the drum is greater than the steam flow leaving the drum, the mass inventory in the drum must be increasing regardless of the change in bubbling rate.

And Yet Another Dynamic in the Drum…..

Well it's not really in the drum, but it does directly affect the drum water level. This additional dynamic is the heat input to the boiler. One of the many myths I have heard is that the heat input into a coal plant is different than the heat input to an HRSG. Really? I think not. Heat is heat weather it is coming from geo-thermal, solar, gas, oil, coal, nuclear, or something else, it is still heat. Yes the method of transformation of the fuel into heat varies and yes there are subtle differences between boiler design types; however, a water wall boiler operates pretty much the same as an HRSG drum evaporator.

Changing the Firing Rate Changes the Boiling Rate.

When the firing rate increases the boiler tubes start creating more bubbles. As we have seen above, more bubbles means a higher level because of the increased volume. The mass inventory of water in the drum however, remains the same for a period of time. The increased firing rate causes an increase in drum pressure which decreases the size of the bubbles and increases the steam flow. The result is an increase in ***volume*** causing the water level to rise for a few seconds followed by a further drop in level due to the steam flow.

When we start unloading a unit everything reverses. We decrease the firing rate so there are fewer bubbles and so, less level due to less volume so the level goes down for a few seconds, less drum pressure, and less steam flow which means, higher water level in the drum.

Lesson to be learned…. Things are not always as they appear!

So How Do I Control The Drum Level and Not Trip the Plant?

Before we can answer that question we need to talk about the elements! Not Earth, Wind, Fire, and Water, well okay we do need to talk about water, and fire, hmmm and wind, arggg and in the case of a coal plant, earth.

An element is just something that we measure and with a DCS we measure a lot of elements. Some of the ones we are interested in are Feedwater Flow, Steam Flow, Drum Level, Drum Pressure, Firing Rate or CTG Megawatts. Each one of these elements has an effect on the primary element we are trying to control, the ***Drum Level.***

We Use Single Element Only Because…..

If I got paid every time I heard a sentence starting this way I would not need to write this paper. The most common statements are,

Single Element is our company standard.
Three Element was never commissioned
Three element does not work on this type of boiler (strange I hear that about all types of boilers)
Three Element just does not work and should **Never** be used
Three Element control does not provide any advantage over single element
I have been at XX number of plants and we never used Three Element control

All of these answers, except the last one, are **myths**. I may be proven wrong but I have yet to find a company that has made single element their standard for boiler drum level control. As to the last statement, I cannot speak to others experience but, if the attitude of the first 5 statements prevail it is no wonder someone has never seen three element control used.

I have had plant personnel at a coal plant operating in single element tell me that three element is only for combined cycle plants because of the type of heat used. (Hopefully this makes you scratch you head in wonder). I have also heard from personnel at combined cycle plants that three element control is only for coal plants because of the type of heat used.

What all of these statements tell me is that if you do not understand the fundamentals of a boiler and a boiler drum, three element control will not work and you will make sure it doesn't. This, in combination with poor tuning practices, leads to this 'standard of single element' control.

So what is Single Element and Three Element Control anyway?

Single Element control looks only at the drum level transmitters. It has no information about the rest of the plant.

Three Element control looks at Drum Level, Feedwater Flow, and Steam Flow. With this additional information, if the controllers are properly set up, the controllers have more information about the what is happening in the plant.

4, 5, 6, & 7 Element control? Yes it is used depending on the conditions in the plant. This will normally be transparent to the operators who will only see 1 – Element or 3 – Element control options.

Well we have been using Single Element since the Plant Started and it Works Fine!

Does it? Are you sure? Let's take a look at some trends of plants with different types of boiler upsets and see what the differences are. In addition to the trends I am going to use a number called IAE or Integrated Absolute Error. IAE gives you a qualitative number that describes how well a process is being controlled. The lower the IAE number, the better the control of the process.

First let's look at a 5% change in drum level.

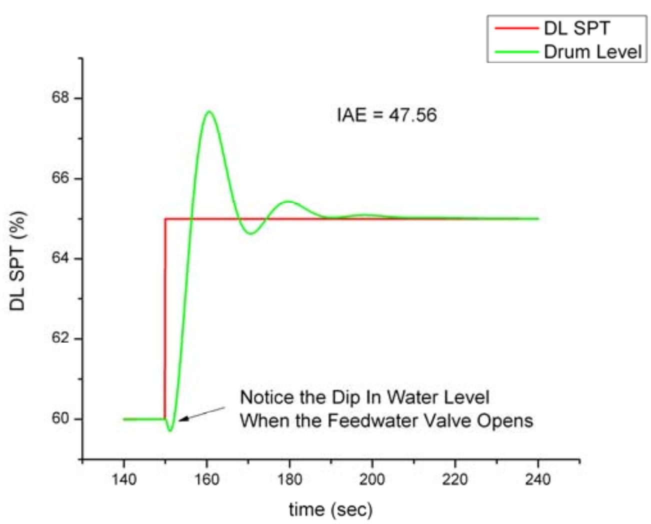

Figure 7 Drum Level Response to Set Point Change in Single Element Control

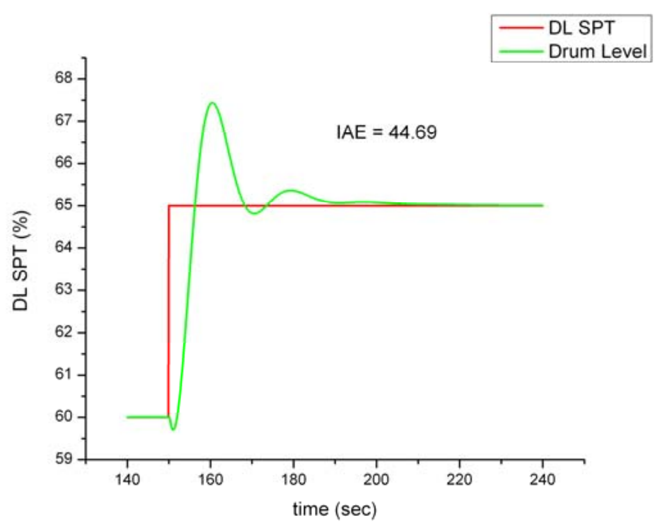

Figure 8 Drum Level Response to Set Point Change in Three Element Control

Now Wait Just a Minute! Both of the plots are the same! Why did I read all of this if there is no difference between single element and three element?

Keep reading and the advantages of three element will become apparent. But first, you are correct that there is no difference between single element and three element ***when the boiler is in steady state and there are no disturbances to the process.*** As long as everything is quiet then single element is all you need.

You can see the dip in the drum level, caused by the decreased volume, when the feedwater valve is first increased illustrating the effect that quenching the bubbles has on the drum level.

The tuning for this loop was set for the minimum IAE or the least amount of time that the level is in error.

Your level responses may have less over shoot. But the trade off is that you spend more time with an error and your controller is less able to respond to changes in your plant as we will see next.

Next we will have a look at what happens when something in the feedwater system changes. In this case the drum level is initially balanced then something happens in the feedwater system. Maybe a heater valve is opened or a leak developed.

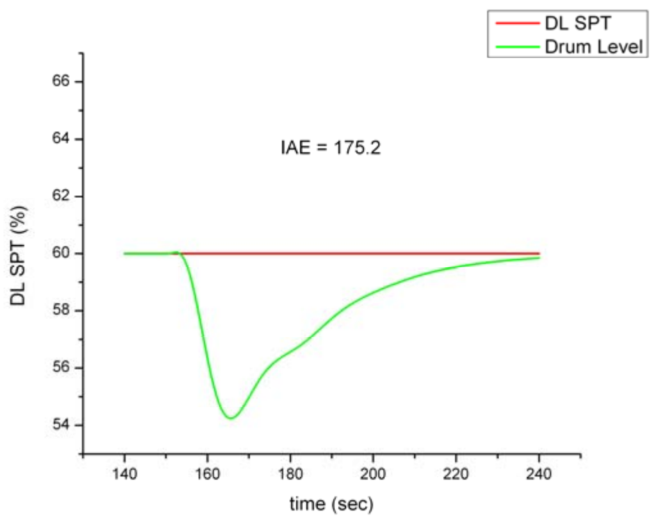

Figure 9 Drum Level Response to a Feedwater Upset Single Element Control

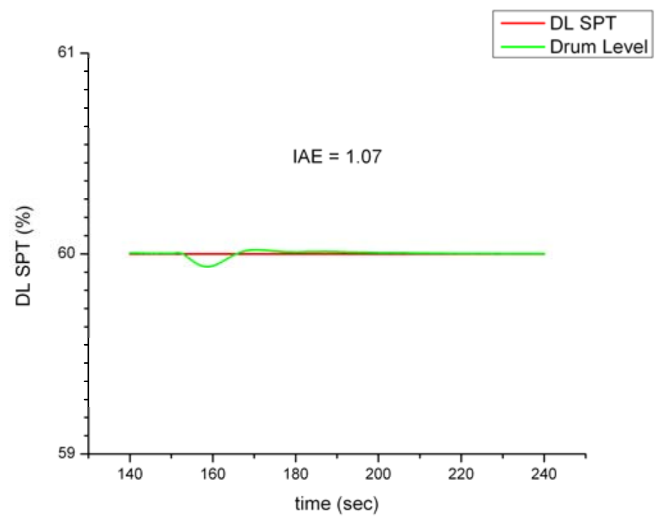

Figure 10 Drum Level Response to Feedwater Upset Three Element Control

First notice the difference in the vertical scale. The single element graph is +/-6% while the three element graph is +/-1%

Because the feedwater is being diverted from the drum level control the level sages about 6% in this case. The single element controller will eventually make up the level but the IAE is much higher. This indicates you are in error for a much longer period of time and are unable to respond to changes in the system rapidly.

Feedwater upsets occur for various reasons. Some are controlled such as manually opening a valve. Others are uncontrolled and cause you real difficulties on the unit. Valve failures, sudden leaks in the feedwater system, attemperators, and others can happen at any time.

In single element control your drum is going to go for a ride and if you are lucky your unit will not trip. But why take the chance? Three element control can help eliminate these types of upsets and maintain unit reliability.

The next disturbance I will illustrate is a change in steam flow. This can be changing load on the steam turbine, changing load by the host, tube leaks, or sootblowing to name a few. Let's compare the two systems ability to handle steam flow upsets.

Again notice the different vertical scales for each graph.

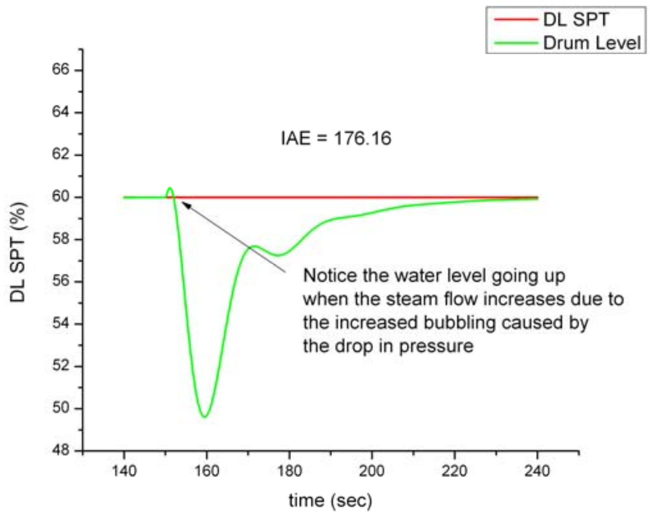

Figure 11 Drum Level Response to a Steam Flow Change in Single Element Control

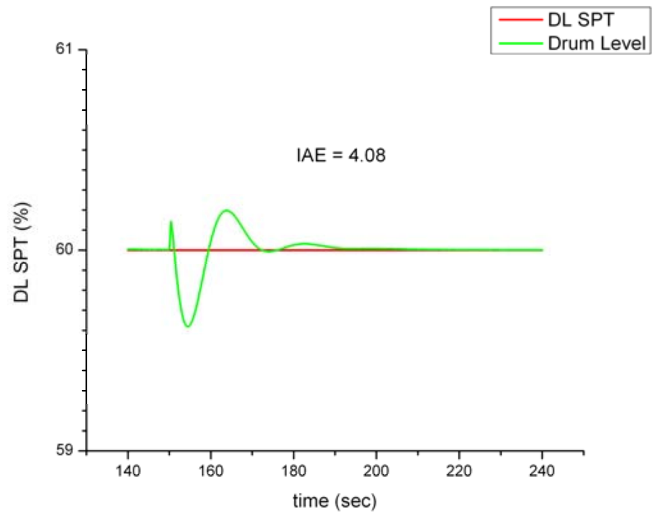

Figure 12 Drum Level Response to a Steam Flow Change in Three Element Control

Initially when the steam flow increases the pressure in the drum is reduced and the amount of bubbles increases. These extra bubbles cause an increase in volume and lift the water level in the drum and the level does rise. Shortly after this happens the steam flow increases and the mass inventory in the drum starts to drop.

When that first initial swell occurs and the level appears to go up the single element controller will start closing the feedwater valve. This puts the drum level control behind right from the get go. Now when the inventory does start dropping, the feedwater is already behind and has to play catch up. This makes the shrink larger than is reasonable and can lead to tripping of the unit.

The last comparison I will make will be during the ramping of the load of the unit. This particular disturbance is often over looked when tuning the drum level controllers. As a result the operators will limit the ramping rate because the drum levels get 'out of hand'. As you can see this is not the case in three element control.

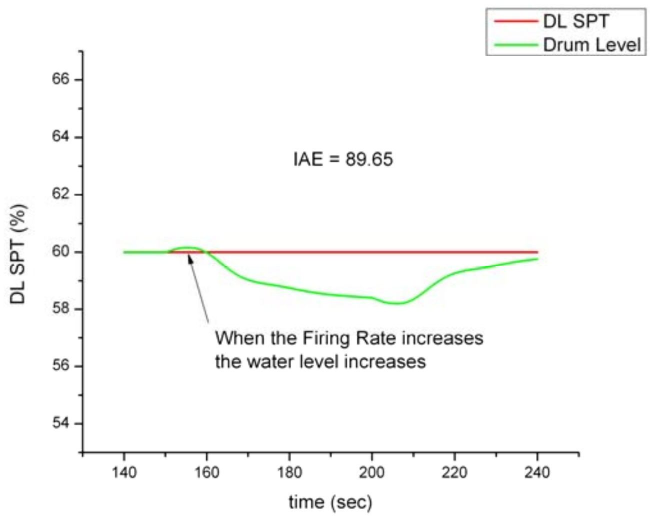

Figure 13 Drum Level Response to a 5 MW/min load increase in Single Element Control

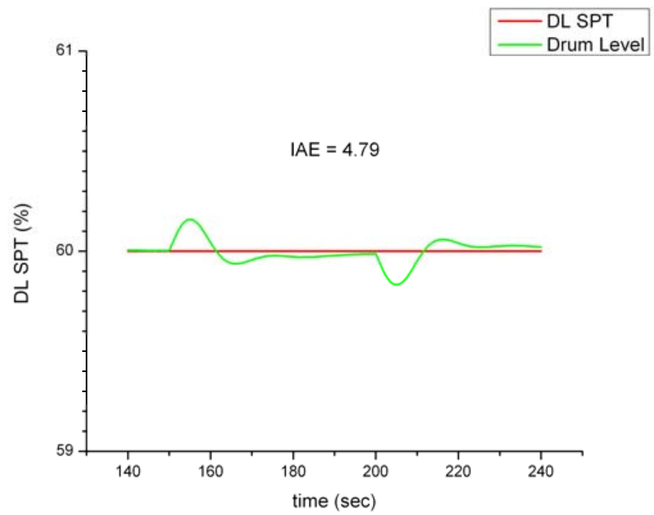

Figure 12 Drum Level Response to a 5 MW/min load increase in Three Element Control

Once again notice the vertical scale on each graph.

Whenever the unit load is changed the firing rate is changed first. This is followed by a change in temperature in the boiler. If the temperature has increased, as illustrated above, then the bubbling increases the drum volume and the level will first go up, then as the steam flow increases the level starts going down. Vice Versa for a load decrease.

Once the single element drum level controller starts moving in the wrong direction the process stays behind until the load ramp is completed.

Shrink and Swell…Not so Swell

All of these dynamics are summed up by calling this shrink and swell in the boiler drum. Shrink is the decrease in water volume due to an increase in pressure or decrease in temperature. In smaller drums, such as an IP drum on and HRSG, shrink becomes a real problem since the amount of water volume is so small. This can lead to overheating of the drum and tripping of the unit on low level.

Swell is the increase in water volume caused by a decrease in pressure or an increase in heat input. On almost any drum that is being operated at the designed level swell is a bad thing. High water levels can cause carryover of moisture and chemicals to the steam turbine. Damage to the moisture separators can occur. And with a large enough swell a high level trip will occur.

Conclusions

Shrink and swell are real phenomena in a drum and cause a great deal of confusion for tuners and operators. If shrink and swell are not properly controlled damage and tripping of the unit can occur.

Operating in single element increases your risk of a component failure or unit trip when an upset in the plant occurs. The plant will also not be able to ramp at the designed rates as the single element controller is, by nature, slow to respond.

Three Element Control provides a dramatic improvement over single element control. This is true if, and only if, the person setting up the controls truly understands the dynamics of the process ***and*** knows how to properly tune a cascaded three element control system.

The decrease in risk to the operation of your plant, especially if you have a steam host, is obvious. Better drum stability will allow you to ramp the unit at a faster rate which, in an Ancillary Services Market, will increase revenue. Decreased work load for the operators means they are able to respond to the real issue at hand rather than the symptoms that result from the disturbance.

If you have any questions regarding this paper please feel free to contact Controller Tuning & Design, LLC