# FEEDWATER VALVE SPEED REQUIREMENTS: Responsive, Consistent Valve Performance Rather Than Fast Stroking Speed is Critical for Control

## Problem Overview:

All boilers require feedwater flow control to make up for the steam that leaves the boiler. Most boiler designs use a steam drum, which is where the feedwater flow enters the boiler and where the steam leaves. The water level in the drum must be maintained to provide responsive and stable control of the steam flow, as well as to prevent equipment damage. To maintain drum level, the feedwater flow into the drum must equal the flow of steam out on a mass flow basis. Therefore, boiler load changes, which change the steam flow demand out of the boiler, require that the feedwater flow be changed to control and maintain the drum level. If the drum level drops too low, the boiler can suffer thermal stress damage. If the level gets too high, steam leaving the drum may carry some water particles along, which can cause damage to turbines or other steam users. Finally, fluctuations in drum level cause interactions with the boiler combustion controls and can create cyclical, or even unstable boiler control resulting in inefficient and dangerous operation.

Drum level control is critical to the operation of a boiler. Consequently, the feedwater flow valve is also critical and often receives attention. As is often the case with a critical control application subject to load changes, users sometimes feel drum level control requires a very fast feedwater valve. Every control loop has its own unique set of dynamics and physical constraints, and in some applications a relatively fast control valve may be warranted; however, this is usually not the case, and the feedwater control valve is no exception. Typically, a feedwater control valve does not need to be faster than most other control valves, but it does need to be responsive, repeatable, and capable of making consistently small adjustments. The confusion between responsiveness and fast stroking speed is common regardless of the application.

## Drum Level Control is Complex and Demanding:

Generally, level is one of the simpler processes to control. Level measurements are usually easy to make. Level dynamics are normally linear, predictable and not overly fast compared to the dynamics of the feed or exit flows. These factors normally make good control possible using just a simple level controller and level measurement. Unfortunately, boiler drum level control is far less simple to control, and in nearly all cases, a simple level control loop alone will not provide acceptable performance.

High operating temperatures and pressures coupled with combustion control interactions and steam load swings can make controlling drum level very difficult. Except for the simplest of boilers, modern control systems use at least three elements, or measurements, to control the drum level. These measurements include the drum level, steam flow out of the drum, and feedwater flow into the drum; and they are used in a combination cascade-feedforward control strategy (see **Fig. 1**).

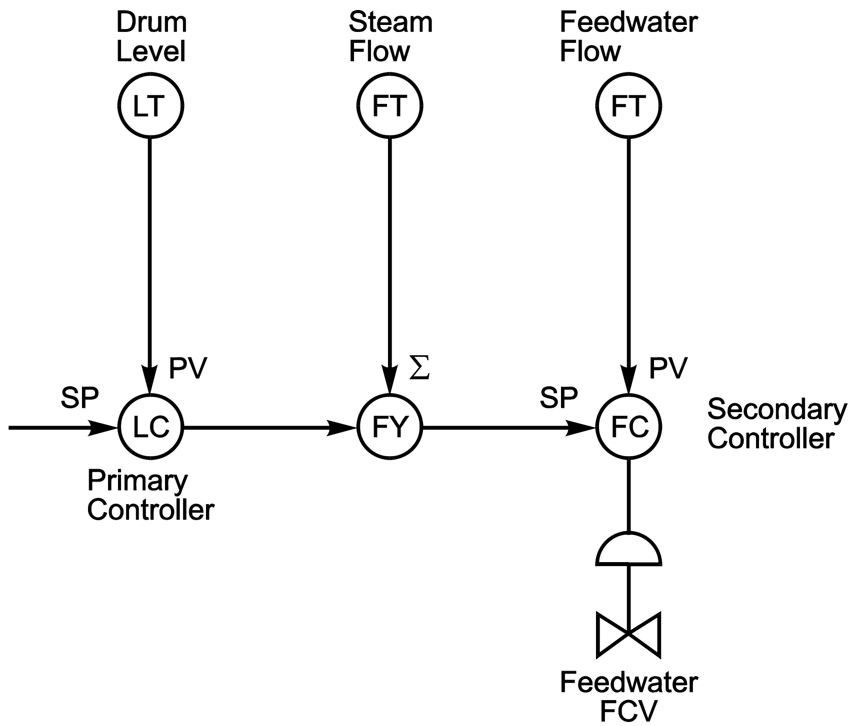


**Figure 1 3-Element Drum Level Control**

In the 3-element strategy, the "inner", or "secondary" controller uses the feedwater flow signal as a process variable and modulates the feedwater control valve to maintain setpoint. The setpoint is a combination of the drum level controller ("primary" controller) output and the steam flow feedforward signal. The steam flow signal tells the feedwater controller how much steam is leaving the boiler and, consequently, how much feedwater needs to be added to make up for the steam loss before the level actually changes. Since the drum level is ultimately the process variable of concern, and feedforward control is not usually very effective without feedback from the process, the drum level controller provides the feedback to the 3-element control strategy. Therefore, as drum pressure, temperature, and density change, or as any other nonlinearity occurs that cannot be compensated for by feedforward control alone, the drum level controller provides the additional feedwater control action required to maintain drum level at setpoint.

Drum level control becomes even more complex with increasing boiler size and drum pressure. As many as seven measurements (seven element) may be required to perform additional control functions like pressure, temperature and density compensations; however, the added complexity does not change the fundamental three element control strategy, nor does it change the basic dynamics of the feedwater flow and drum level processes. Drum level control is clearly a critical and demanding application that requires a responsive, repeatable feedwater valve, but adding complexity does not dictate that a fast feedwater control valve speed is necessary.

Since every boiler has its own requirements for drum level control and feedwater valve performance, it is not possible to specify a single valve stroking speed that meets the needs of every is feedwater flow control valve.  Each loop has unique requirements based on many factors.  Some of the factors that effect the valve speed requirements include the drum volume-to-boiler rating ratio, the drum level measurement range, and load swing severity.  For example, a large boiler, with a relatively small drum and a narrow drum level measurement range, that is subject to large, sudden load swings will require larger and faster feedwater corrections than a boiler with a relatively large drum, wide level measurement range and less severe load swings.  In either case, however, it is not necessary that the feedwater control valve be capable of extraordinarily fast full-stroke speed.  In fact, good boiler drum level control normally requires a smooth, ramping response of the valve, even when a large load swing occurs.  The remainder of this paper summarizes why it is the nature of drum level control that makes fast valve stroking speed unnecessary.

**Swell and Shrink:**

When a boiler's steam flow rate changes, an energy and mass imbalance is introduced to the system.  The energy imbalance causes the combustion controls to change the firing rate in response to an change in steam demand.  The mass imbalance between steam leaving the drum and feedwater entering the drum causes the drum level controls to adjust feedwater flow to re-achieve balance and maintain level in the drum. Clearly, when the steam flow is increased the feedwater flow must be equally increased, and when the steam flow is decreased the feedwater flow must be equally decreased. Intuitively, it seems that the faster the feedwater flow is changed to match a change in steam flow, the better the control, but this is not the case.

The initial response of boiler drum level to a load change is called inverse response.  This means that drum level does the opposite of what would be expected when the steam load changes.  For example, if the steam flow from the boiler is increased, the drum level initially begins to rise even though the drum will eventually run dry if feedwater is not increased.  Likewise, if the steam flow is reduced, the drum level initially begins to fall.  The initial level rise upon increasing load is called "swell", while the initial drop in level upon a decreasing load is called "shrink

Swell and shrink can be easily understood by example.  Consider a boiler firing at steady-state.  At any given load, the water within the drum, boiler tubes and mud drum coexists with the bubbles of steam that are being generated.  If the demand for steam suddenly increases, the resultant increase in steam flow from the drum causes a drop in drum pressure.  Since steam generation rate is a function of drum pressure, the drop in pressure instantly causes more steam to be produced.  This means that more steam bubbles are coexisting within the water "inventory" of the boiler and the steam-to-water ratio below the water surface increases.  Because steam has a greater specific volume than water, the drum level rises or "swells" until the new steam generation rate stabilizes. Once the new steaming rate does stabilize, the mass flow imbalance between the feedwater and steam flows will cause the drum level to quickly drop unless the feedwater flow is increased.  This makes controlling the drum level difficult.

If the demand for steam suddenly decreases, a similar but opposite effect occurs. In this scenario, drum press instantly increases thus reducing the steam generation rate and steam-to-water ratio. This means that the drum level initially falls or "shrinks" until the new steam generating rate stabilizes. Once stabilized, the drum level will quickly begin to rise unless the feedwater flow is reduced to balance with the new steam flow rate.

The swell and shrink phenomena pose a control problem to standard level controllers because a steam load change causes the controller to initially change feedwater flow in the wrong direction. This causes greater variability and larger excursions in the drum level, and it also causes interactions with the combustion controls, thus reducing the ability of the boiler to respond to load swings. A more complex 3-element control strategy, as already discussed, includes control action based on both level and steam flow changes to help eliminate these problems. When properly adjusted, this control strategy balances the influence of level with the influence of steam flow thus eliminating incorrect response to swell and shrink and allowing time for the boiler water inventory to re-adjust gradually. Ultimately, this results in optimum drum level control with a minimum of level variation and combustion control interaction. What this means with respect to the feedwater control valve is that 3-element drum level control, by design, will not change the valve position quickly, but rather, smoothly ramp it in the proper direction allowing the water inventory to gradually change. **Figures 2A, 2B & 2C** show the response of properly and improperly adjusted 3-element drum level control strategies.

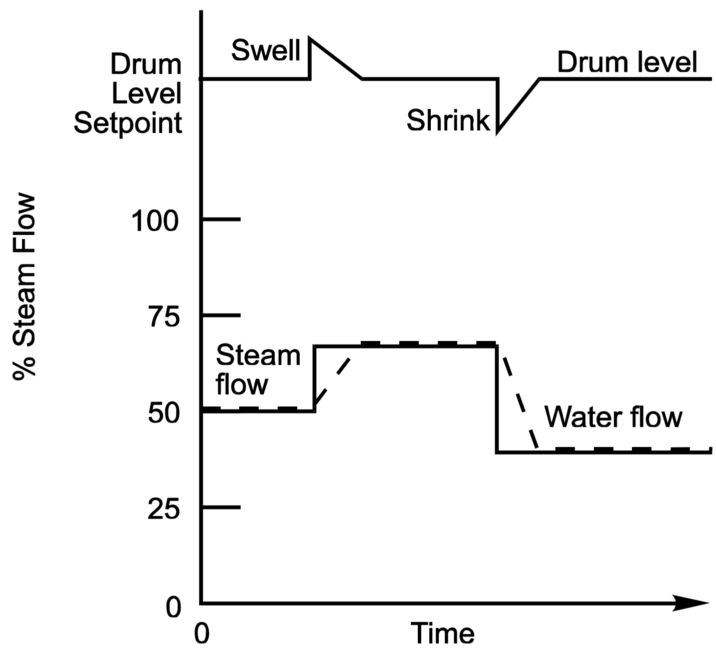


**Figure 2A Proper Balance of Feedwater Control Influences**

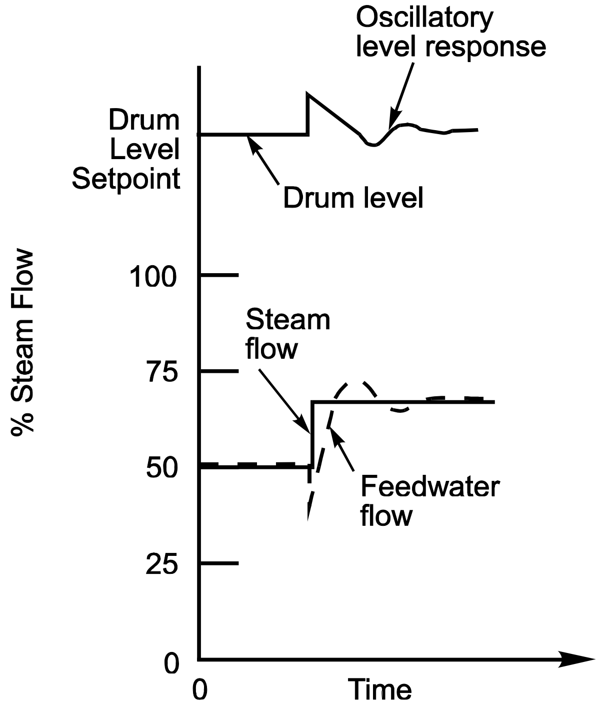


**Figure 2B  Drum Level Influence Too Great**

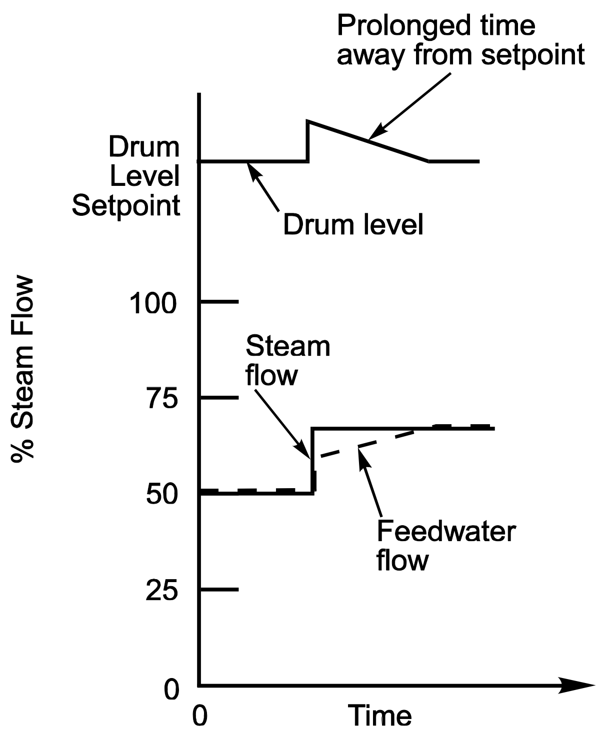


**Figure 2C  Steam Flow Influence Too Great**

**Combustion Control Interactions:**

Boiler Controls are tricky because of loop interactions, and boiler drum level controls interact with the combustion controls that adjust the boiler firing rate. Therefore, in addition to the problems associated with swell, shrink and changing water inventory, a drum level control strategy must consider the effect on the firing rate and combustion controls. The objective of drum level control is to maintain level at setpoint while minimizing level variability, excursion size and recovery time; however, control action taken to achieve this objective does have an effect on the rest of the system.

The rate at which steam is generated is a function of both drum pressure and the firing rate (heat input) of the boiler. The boiler master controller determines the boiler firing rate based on the steam header pressure; therefore, if the steam pressure changes the boiler master will adjust the firing rate such that the steam pressure returns to normal. Since large, sudden additions of feedwater, which is considerably cooler than the water already in the drum, causes the steam pressure to drop, firing rate may be increased if a slug of feedwater enters the drum. Thus, a cycle between firing rate and feedwater flow can be perpetuated without any change in steam demand or steam flow. Minimizing the interaction can only be accomplished if the control system is properly designed and adjusted. Under these conditions, the feedwater control valve must be modulated in a smooth, gradual fashion to eliminate sudden bursts of feedwater into the drum.

**Summary**

Although level is typically an easy process to control, boiler drum level control does not fit into this category. The high pressures and temperatures, coupled with the coexistence of both steam and water within the drum, lead to control difficulties like level swell and shrink. In addition, boiler controls are very interactive, further complicating the control of drum level.

These difficulties make standard level controls insufficient for most drum level applications; therefore, more complex, 3-element controls strategies are typically used. An appropriately adjusted 3-element strategy is able to balance the conflicting influences of inverse response (swell & shrink) and changing steam flow. Therefore, when steam demand changes, the control strategy, by design, does not make a sudden change in the feedwater flow, but rather, it gradually adjusts the feedwater valve. This avoids accentuating swell or shrink and provides time for the water inventory to re-adjust to the new equilibrium. Ultimately, the smooth control action provides optimum level control, thus minimizing level excursions and variability. Although the feedwater valve does not make large sudden changes, it must be responsive and repeatable.

Boiler drum level control is very interactive with the combustion controls, and it is another issue that drum level control strategies must consider. Minimizing interactions is imperative to efficient, reliable and safe boiler operation. Doing so requires both good control equipment and strategy design, but it also requires appropriate tuning of the controllers. In drum level control, rapid changes in the feedwater valve cannot be dictated by the controller, even under fairly severe load changes, or firing rate interactions could result in cycling. However, the feedwater valve must be very responsive and consistent if drum level control is to work as designed.

This does not mean that feedwater valves should be slow. The capability to move fast can be an advantage if it can be done consistently; however, full-stroke speeds faster than the required changes normally dictated by the controller offer no control advantage. The real issue of the feedwater flow valve performance, as with most critical and complex control valve applications, is not stroking speed, but rather, responsiveness and repeatability. A consistent valve response of 3-5 % per second, including response dead time, is fast enough to meet the control needs of almost any feedwater valve used in a 3-element drum level control strategy. The key word above, however, is “consistent”. The performance of the valve must be repeatable and accurate with changing valve position, conditions and age. The response must also be instantaneous, meaning that response dead time must be very small and repeatable. Stroking speed has little or nothing to do with achieving the required valve performance. More importantly, potential susceptibility to stiction problems and inconsistent performance should be eliminated. Special considerations should always be closely evaluated to determine specific speed requirements if any do exist.

**References:**

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