CHAPTER IV
DRUM BOILER FEEDWATER CONTROLS

The primary function of feedwater controls is to maintain drum water level at the desired setpoint. In its simplest form one can visualize the process of defining drum level as a simple integration of water flow into the boiler less steam flow out of the drum. The gain of integration is readily calculated from the mass of water that is held for each inch of water level around the normal operating level. Fig. 4.1 shows this simple process model.

![Diagram](image)

**FIGURE 4.1**

Since the primary disturbance originates from changes in steam flow, it is logical to structure the controls such as to make feedwater flow follow steam flow, and use the deviation in level as a slow resetting action to bring the required water inventory back to balance.

The use of feedwater, steam flow and level as inputs to the control action gave rise to the term "3 element control".

From a hierarchical point of view, it is convenient to think in terms of a feedwater subloop control, whereby feedwater flow is made to follow a feedwater demand. This demand in turn is derived from steam flow (feedforward primary signal) and a correcting signal from a controller operating on drum level error (Fig. 4.2)

![Diagram](image)

**FIGURE 4.2**
DRUM LEVEL SWELL EFFECTS

The dynamics of drum level response to feedwater, steam flow and heat to the waterwalls are more complicated than conveyed by the simple representation of Fig. 4.1. Drum swell effects accompany a redistribution of water and steam inventories in the waterwalls with changes in steaming rate. This effect is more accentuated in low pressure boilers (600 psi - 1000 psi) because of the greater difference in specific volume between steam and water at these pressures than at the higher pressures (2400 - 2600 psi). The design of drum internals, i.e., the baffling and the manner in which feedwater is introduced into the drum as well as the degree of subcooling of the feedwater have marked effects on level response.

The peculiar dynamic effects that can arise in control of drum level will be illustrated with a few examples.

Take the case of typical low pressure (600 psi) boilers of 300000 to 600000 lbs/hr capacity. Fig. 4.3 shows the boiler drum, downcomers and the risers or waterwalls where steam is generated.

![Diagram of boiler drum, downcomers, risers, and furnace with feedwater pipe and baffle.]
Feedwater is introduced along a feed pipe running along the length of the drum about 5" below normal water level. The feedwater could be considerably subcooled (250°F vs. 486°F saturated liquid at 600 psi). With the internal arrangement and baffling shown in Fig. 4.3, the water entering the downcomers is subcooled and is brought to saturation by the heat added in the furnace.

Another arrangement of drum internals is shown in Fig. 4.4 where the feedwater is free to mix with the steaming mixture exiting from the riser tubes and is brought up to saturation temperature mainly by condensing some of the steam generated in the risers.

The response characteristics of level to feedwater flow rate are radically different for these two types of drum internal configuration.

![Diagram of drum internals](image)

**FIGURE 4.4**

The process can be characterized as in Fig. 4.5; the control variable is feedwater and the controlled variable is level. Other inputs are heat release and valve opening which set the steam flow out of the boiler.

Response characteristics to changes in feedwater flow demand for the boiler types shown in Fig. 4.3 and Fig. 4.4 are shown qualitatively in Fig. 4.6.

It can be noted that in one case level responds with considerable dead time (case where the feedwater does not mix with the steaming mixture in the drum). Evidently the type of drum level control and settings would have to be radically different for the two cases as can be seen in the following analysis. Drum swell effects for changes in steam flow are illustrated in Fig. 4.7.
Figure 4.5

Equations describing boiler dynamics

Figure 4.6 Response to Changes in Feedwater Demand
DRUM LEVEL CONTROLS WITH COMPENSATION FOR SWELL EFFECTS

The block diagram of the feedwater control system, is shown on Fig. 4.8.

\[
\frac{\dot{m}_S}{(1 \text{ lbs/sec})} = \frac{1 - \frac{K_S}{1 + T_{1S}}}{(1 + T_2S)}
\]

Set Point

\[K_{PL} \frac{(1 + T_1S)}{(1 + T_2S)}\]

L (IN)

\[\dot{m}_{fw} \text{ (lbs/sec)}\]

Controller

Valve

FIGURE 4.8

It can be assumed that the feedwater control subloop within the dashed lines could be tuned to give a response of feedwater to a demand for feedwater characterized by a single 10 sec time constant. Hence, the level control system can be viewed as in Fig. 4.9.
The feedforward anticipatory action from steam flow provides an initial demand in the opposite direction to neutralize part of the swell effect. The tuning of the level control system, however, will be determined by the characteristics of the closed loop shown in Fig. 4.9.

![Diagram](image)

**FIGURE 4.9**

The stability of the level control system can be analyzed once the nature of the process transfer function $\Delta L/\Delta m_{FW}$ is known. This process function can be described as an integration with dead time for the configuration of Fig. 4.3, i.e.,

$$\Delta L/\Delta m_{FW} = \frac{e^{-90s}0.0021}{s} \text{ in/lbs/sec}$$

Fig. 4.10 shows the Bode plot of the open loop function that would yield acceptable performance.

Note that a proportional controller with transient gain reduction has been used. Had the response characteristics not exhibited the dead time as is the case for the drum configuration of Fig. 4.4, a much tighter proportional gain setting could be provided, without need for transient gain reduction.

Fig. 4.11 shows that with the response of $\Delta L/\Delta m_{FW}$ characterized as $\frac{0.0021}{s}$ with no dead time, a simple proportional gain can be applied yielding considerably better closed loop performance. For the same phase margin of 45°, this gain could be approximately 50, giving an open loop function...
\frac{0.105}{5(1 + 10s)^{0.5}}. \text{ Note that the scale of frequency of } \omega \text{ in Fig. 4.11 is 10 times greater than in Fig. 4.10.}

The impact of this change in process characteristics is that in the first case the crossover frequency of the drum level control loop is about 0.0043 rads/sec, while in the second it is 0.1 rads/sec, i.e. a bandwidth 23 times greater in the second case.

Further, a 10% error between feedwater and steam flow (8 lbs/sec) as might be caused by blow down or inaccuracies in metering, would require a compensating error in drum level of 8/7 inches in the first case versus 8/50 inches in the second.

While on this example it is appropriate to note that the transient gain reduction as in Fig. 4.10 yields a system which is subject to poor damping or even instability during major upsets that exercise the feedwater controls through limits. This so-called conditional stability (drum level hunt in this instance) can be readily explained by describing function analysis methods. The effective gain of feedwater subloop and its effective response is reduced (time lag increased) as the oscillation exercises the valves to limits. These effects interpreted on the Bode plot of Fig. 4.10 shows that crossover would occur in the lower frequency region where the phase angle approaches 180°.

Power plant operators often encounter these conditions and have gotten out of the problem by placing the controls on manual, controlling the process until the oscillations are within the linear range of controls at which time automatic control is restored.

Variations on the basic scheme of Fig. 4.2 can be introduced to account for swell effects, and interactions between firing rate and drum level transients.
Bode Plot of
\[
\frac{-905}{0.0197 (1+286s) s} \frac{1}{S (1+1000s)(1+10s)}
\]

Contributions to phase angle

\[\frac{1}{s} \rightarrow 70^\circ \text{ lag}\]
\[\frac{1}{(1+1000s)} \rightarrow 71^\circ \text{ lag}\]
\[\frac{1}{(1+10s)} \rightarrow 2^\circ \text{ lag}\]
\[e^{-200s} \rightarrow 22^\circ \text{ lag}\]
\[(1+286s) \rightarrow 56^\circ \text{ lead}\]

Phase angle
\[\phi = 125^\circ\]

**Figure 4.10**
Bode Plot of
\[ \frac{0.105}{s(1+10s)} \]

Magnitude

Phase Angle
\[ \approx 135^\circ \]

Figure 4.11
Fig. 4.12 shows one such scheme. Feedwater demand is again formed from steam flow, although a lag on steam flow is provided to avoid augmenting the swell effect. A rate of change from drum pressure was found to be a good anticipator of swell effects.

![Diagram showing the feedwater control system with Level Setpoint, Steam Flow, Level, Drum Press, and F.W. Demand.]

**FIGURE 4.12**

The feedwater demand is corrected by a proportional control with transient gain reduction operating on level error.

The feedwater demand is then acted upon by a subloop which should be reasonably fast since the response characteristics of flow to changes in feedwater valve position, or changes in feed pump speed, should be fast.

**Feedwater Subloop Controls**

One of the serious difficulties in control relates to process nonlinearities which radically change the gain and/or response characteristics of the process. Control settings which are proper for a given operating point may thus cause poorly damped or unstable operation at other operating points.
While nonlinear characteristics of the main process are unavoidable, one often finds that much of the problem belongs in inadequately designed subloops, with nonlinear valve or damper characteristics. It should be a basic axiom of good control practice that subloops should be designed to be uniformly responsive throughout the operating range and should have a bandwidth greater (preferably by one order of magnitude) than the main process controls.

The difficulties with obtaining a linear response from a feedwater subloop where flow changes are accomplished with changes in pump speed are described in Figs. 4.13 to 4.16.

Fig. 4.13 shows the pump head versus flow characteristics for different pump speeds. On the same figure are superposed the boiler feedwater versus pressure characteristics for 100% and 50% loads.

![Figure 4.13](image)

From the intersection of these pump and boiler pressure characteristics, the pump flow versus pump rpm relationships are shown on Fig. 4.14.

![Figure 4.14](image)
This figure shows that the pump rpm has to reach a certain threshold value before any flow will occur—a threshold value which is a function of drum pressure. The characteristic also shows that at low flows there is a high gain between rpm and flow. It has been common practice to attempt to compensate this nonlinearity with a cam at the hydraulic coupling scoop tube positioner.

Figure 4.15 shows how the cam could only compensate correctly for one particular drum pressure. This expedient would be satisfactory if constant drum pressure were held, or even if it were held within a fairly narrow band. Unfortunately, during startup, or even to take advantage of variable pressure operation for efficiency optimization, the boiler pressure may have to go through wide ranges and, therefore, a cam which accomplished linearization between signal to scoop tube and flow at one pressure would be inadequate.
By providing a function generator and signal proportional to drum pressure, as indicated in Fig. 4.16, the feedwater flow loop is linearized and should operate stably throughout the load range and over significant variations of boiler pressure.

Because of the interaction between feedwater flow and drum pressure, the drum pressure signal is lagged or filtered with a time constant.

The feedwater subloop control as described can thus be adjusted to exhibit a response described by a single 15 sec time constant throughout the operating range.

![Diagram of feedwater flow loop](image)

**FIGURE 4.16**