Boiler Drum Level Transmitter Calibration

KEY POINTS

- Fluctuating water level or changing rate of water inflow and steam outflow can cause measurement errors.
- Thermodynamics of pressure and temperature, geometry of the steam drum, and equation of continuity define transmitter calibration.
- Check the zero elevation and span against transmitter specifications to ensure selected transmitter can be calibrated to required values.

APPLICATION OVERVIEW

Steam Drum Level is both a critical and difficult measurement to make. Control of the water level in the drum must be precise. A water level that is too high can result in water carryover into the steam piping. A level that is too low can expose the generating tubes (down comers), preventing the water in the drum from cooling the furnace tubes, possibly damaging them.

Several factors make this measurement difficult to obtain. The steam drum itself may not be perfectly level, and even at steady state conditions, considerable turbulence in the drum can cause the level to fluctuate. In addition, a changing rate of water inflow and steam outflow adds to the potential for measurement error.

Measurement of boiler steam drum level using a differential pressure transmitter must take into account certain physical properties of the fluid.

- The Steam drum contains a two-phase mixture of water and steam at saturation conditions.
- The densities of water and steam vary with saturation temperature or pressure.
- The density of saturated steam above water must be considered, as well as the density of saturated water in the drum.

This technical note offers a method for calibrating transmitters that takes into account these factors.
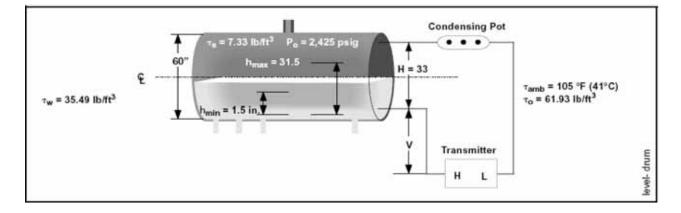
PROCESS

Figure 1 on page 2 shows a simplified sketch of the process. Note that level, as we define it, is measured in units of length—in this case, inches. Differential pressure, on the other hand, is measured in inches of water column differential pressure. The two are sometimes confused, but do not refer to the same thing.

A column of water one inch high under one set of operating conditions does not exert the same hydrostatic head pressure as a column of water of the same height under another set of conditions. The objective is to measure differential pressure and "read" it as a unit of length.

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Figure 1. Boiler Steam Drum

The steps necessary to define the transmitter calibration use the thermodynamic operating conditions of pressure and temperature, the geometry of the steam drum, and the equation of continuity. Note that this calibration assumes only one set of operating conditions. In real practice, operating parameters change with boiler load and other factors, such as ambient temperature. For that reason, three element feedwater control systems often require that the drum level measurement be compensated for deviations from design operating drum pressure. It is also convenient to know the drum level during startup of the plant—that is, from 0 psig to full operating pressure. This dynamic pressure and temperature compensation requires a separate computational device.

The first step in the calibration is to define the process variables (shown in Figure 1):

P_o = Static pressure in the steam drum at the top tap

P_h = Static pressure at the high side of the transmitter

P_l = Static pressure at the low side of the transmitter

τ_s = Density of saturated steam at operating conditions

τ_w = Density of saturated water at operating conditions

τ_o = Density of water in the "wet" or reference leg

H = Distance between the high and low drum taps

h = Drum water level (measured from the bottom tap)

h_{max} = Maximum water level allowed (measured from the bottom tap)

h_{min} = Minimum water level allowed (measured from the bottom tap)

$\mathcal{L}$ = Center line of the steam drum

V = Vertical distance from the bottom tap to the transmitter

SOLUTION

From the equation of continuity:

$$P_h = P_O + (H - h)(\tau_s) + h(\tau_w) + V(\tau_o)$$

$$P_l = P_O + H(\tau_o) + V(\tau_o)$$

Thus, $\Delta P = H(\tau_s - \tau_o) + h(\tau_w - \tau_s)$

This equation calculates the differential pressure on the transmitter. The differential pressure is highest when the drum water level is lowest, and the differential pressure is lowest when the level is highest. Therefore, the transmitter zero must be elevated so that an increasing level results in an increasing output signal.

To perform the calibration, use a table of thermodynamic properties of steam and the following steps:

1. Determine hmin and hmax. These are the minimum and maximum water levels allowed for safe operation of the boiler. They are measured from the bottom tap of the steam drum.

2. Using the saturated steam tables, find the values of and at the drum operating pressure. Use the value for compressed water in the reference (wet) leg at the expected ambient temperature and the drum operating pressure. If the compressed water table is not available, use the reciprocal of the specific volume of saturated water at the ambient temperature. Since water is nearly incompressible, this provides reasonable accuracy for the drum measurement.

3. For this example assume:
   - The inside diameter of the steam drum is 60 in.
   - H = 33 in. (83.82 cm)
   - P_o = 2,425 psig (design operating pressure)
   - Tambient = 105 °F (41 °C)
   - h_{min} = 1.5 in. (3.81 cm)
   - h_{max} = 31.5 in. (80.01 cm)
   - The desired level readout is −15 to 15 in. (a standard indicator faceplate range)

4. Solve the equation:

The specific volume of the saturated water at 2,425 psig is 0.02817 ft³/lb, ➡ τ_w = 35.49 lb/ft³.

The specific volume of the saturated steam at 2,425 psig is 0.1364 ft³/lb, ➡ τ_s = 7.33 lb/ft³.

The specific volume of the saturated water at 105 °F is 0.01615, ➡ τ_o = 61.93 lb/ft³.

To convert all units to consistent inches of water column, correct the above formula to reference conditions. To do this, divide by τ_o.

At h_{min} the transmitter output will be 4mA dc.

$$\Delta P = (H[\tau_s - \tau_o] + h_{min}[\tau_w - \tau_s]) \div \tau_o$$

$= [33(7.33 - 61.93) + 1.5(35.49 - 7.33)] \div 61.93$

$\Delta P = \underline{-28.41}$ inH$_2$O

This is the required zero elevation of the transmitter. At h_{max}: (Transmitter output will be 20 mA dc)

$$\Delta P = [33(7.33 - 61.93) + 31.5(35.49 - 7.33)] \div 61.93$$

$\Delta P = \underline{-14.77}$ inH$_2$O

Therefore, the span of the transmitter:

$28.41 - 14.77 = \underline{13.64}$ inH$_2$O Differential Pressure

Finally, check the zero elevation and span against the transmitter specifications to ensure the selected transmitter can be calibrated to the required values.

SUMMARY

With the drum level transmitter properly calibrated, the midpoint of the actual readout range, typically −15 to 15 in., is zero, or mid-scale. This generally corresponds to the desired setpoint for the drum level controller. However, in some applications the setpoint may be less than zero and depends on your experience with a particular boiler.

If you have any questions about selecting transmitters for drum level or other applications, please contact your Rosemount representative.

Drum Level Workshop

Drum Pressure (P_o) _____

Distance between taps (H) _____

Ambient Temperature _____

Minimum water level (h_{min}) _____

Maximum water level (h_{max}) _____

Density of water in drum (τ_w) _____ (Reciprocal of specific volume of saturated water at drum pressure)

Density of steam in drum (τ_s) _____ (Reciprocal of specific volume of saturated steam at drum pressure)

Density of water in reference leg (τ_o) _____ (At ambient temperature)

$$\Delta P_{min} = [H(\tau_s - \tau_o) + h_{min}(\tau_w - \tau_s)] \div \tau_o$$

[_____ (_____ - _____) + _____ (_____ - _____)] ÷ _____

ΔP_{min} = _____ This is the zero elevation. (Transmitter output will be 4 mA.)

$$\Delta P_{max} = [H(\tau_s - \tau_o) + h_{max}(\tau_w - \tau_s)] \div \tau_o$$

[_____ (_____ - _____) + _____ (_____ - _____)] ÷ _____

ΔP_{max} = _____ (Transmitter output will be 20 mA.)

Span = $\Delta P_{max} - \Delta P_{min}$ = _____

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