MOORE®

APPLICATION DATA

AD352-113
Issue: 1
May 1994

PRESSURE AND TEMPERATURE COMPENSATION OF AN ORIFICE METER USING THE MODEL 352 SINGLE-LOOP CONTROLLER

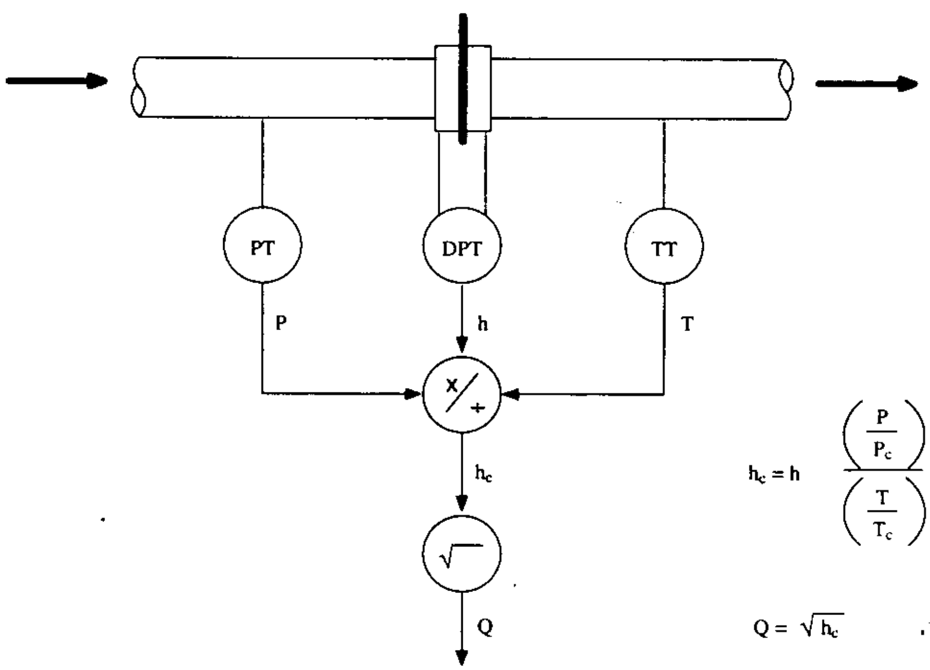
PURPOSE

Orifice meters require compensation whenever they are used to measure gas flow in lines that have variable operating pressure and temperature. Variations in pressure and temperature have a significant effect on gas density, which, in turn, affects the calibration of the orifice meter. Without compensation, changes in pressure and temperature can cause large errors in the flow measurement.

Figure 1 shows an orifice flange union with transmitters for measuring the differential pressure (ΔP) across the orifice plate and the pressure and temperature in the line. The ΔP generated by the plate is proportional to the density of the gas and the square of the volumetric flowrate. Pressure and temperature measurements are used to infer gas density and to compensate the ΔP so that it only responds to changes in flow.

Pressure and temperature compensation is a mathematical operation that corrects the measured differential pressure at actual operating conditions to an equivalent differential pressure at calibration conditions. Calibration conditions are the specific operating pressure and temperature that were used to size the orifice plate. The correction is based on equivalent mass flow at the two sets of operating conditions.

The compensated flow measurement is proportional to the square root of the corrected differential pressure. Therefore, the pressure and temperature corrections must take place upstream of the square root extractor as shown in Figure 1.



$$h_c = h \frac{\left(\frac{P}{P_c}\right)}{\left(\frac{T}{T_c}\right)}$$

$$Q = \sqrt{h_c}$$

FIGURE 1 Pressure & Temperature Compensation of Orifice Meter

HIGHLIGHTS

- Math blocks provide the means for calculating pressure and temperature corrections
- Square root extractor linearizes the corrected differential pressure signal
- Math blocks can be configured for pressure-only or temperature-only compensation
- Math blocks can be configured to calculate standard volume (mass) flow or actual volume flow

DESIGN

The vast majority of gas flowmeters are calibrated to provide a signal that represents standard volume flow. Standard volume flow is proportional to mass flow and is based on the density of the gas at standard reference conditions (usually 14.7 PSIA and 60°F). Although most flowmeters operate at pressures and temperatures that are considerably different from standard reference conditions, it is customary to convert the actual volume flow to an equivalent mass flow in standard volume units.

For standard volume flow, the following engineering equation is used to correct the differential pressure from actual conditions to calibration conditions.

Standard Volume Flow:

$$h_c = h \frac{\left(\frac{P}{P_c}\right)}{\left(\frac{T}{T_c}\right)}$$

where: h = differential pressure
P = line pressure (absolute)
T = line temperature (absolute)
c = calibration conditions subscript

To implement this equation in the Model 352 single-loop controller, it is necessary to convert the engineering equation to an equivalent signal equation based on the calibration ranges of the individual signal variables. This is accomplished by writing simple transformation equations for each variable and then substituting the transforms into the engineering equation. The following example illustrates the procedure.

Orifice Calibration Conditions:

Full scale flow:	15,000 SCFM
Full scale ΔP:	100 "H_2O
Line pressure:	125 PSIG (139.7 PSIA)
Line temperature:	110°F (570°R)
Barometer:	14.7 PSIA

Transmitter Ranges:

DPT: 0 to 100"H_2O
PT: 0 to 200 PSIG (14.7 to 214.7 PSIA)
TT: 0 to 150°F (460 to 610°R)

For each variable in the engineering equation, there is a normalized signal (S) that varies from 0 to 1 as the process variable varies from 0 to 100% of the transmitted range. The zero and span of the calibrated range are used to write the following transformation equations.

Transformation Equations:

$$h_c = 100\,S_{hc}$$
$$h = 100\,S_h$$
$$P = 200\,S_p + 14.7$$
$$T = 150\,S_t + 460$$
$$P_c = 139.7$$
$$T_c = 570$$

The following signal equation is derived by substituting the transformation equations into the engineering equation:

$$100\,S_{hc} = \frac{100\,S_h \left[\frac{200\,S_P + 14.7}{139.7}\right]}{\left[\frac{150\,S_T + 460}{570}\right]}$$

$$S_{hc} = \frac{S_h\,[1.432\,S_P + 0.105]}{[0.263\,S_T + 0.807]}$$

The coefficients of the equation derived above are the scaling coefficients that weight the signals to match the engineering variables they represent. The math blocks in the 352 provide gains and biases to configure these scaling coefficients.

The configuration for the example problem is shown in Figure 2. This configuration requires a Model 352E expanded single-loop controller. This control strategy can also be implemented in the APACS™ control system by using Figure 1 as a guide and applying the concepts of Figure 2 within the APACS controller's function block language.

Three analog input blocks (FB01, FB02, FB25) provide the ΔP, pressure, and temperature inputs. As shown in the derivation of the signal equation, it is not generally necessary to calibrate the pressure and temperature transmitters in absolute units. The conversion to absolute units is accomplished by the scaling coefficients. However, an absolute pressure transmitter is recommended if the calibration range has a span less than 50 PSI. The scaling factors for the pressure signal are based on a fixed value of barometric pressure. For narrow spans, the normal variation in barometric pressure can become a significant percentage of the signal range. In that case, an absolute pressure transmitter eliminates the error that results when the barometer varies.

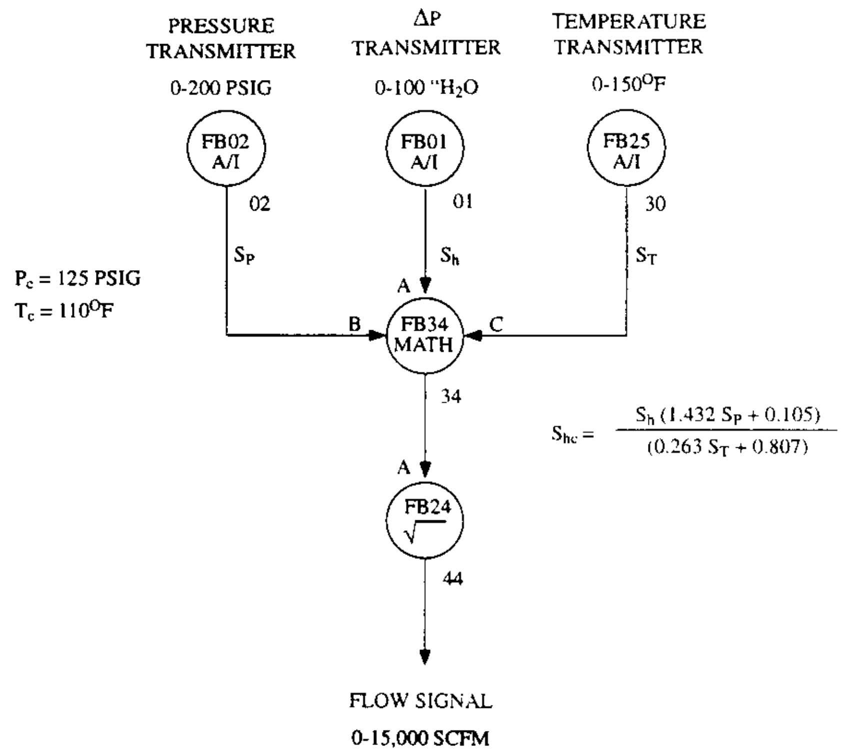


FIGURE 2 Configuration Example

The math block (FB34) implements the signal equation derived above. The general equation of the math block for this application is:

$$S_O = \frac{G_O\,[G_A S_A + B_A]\,[G_B S_B + B_B]}{[G_C S_C + B_C]} + B_O$$

For signal scaling, the gains (**G**) are adjustable from 0.030 to 3.000, and the biases (**B**) are adjustable from –3.000 to +3.000. Although these ranges accommodate most applications, it is sometimes necessary to factor the signal equation to get the coefficients to fall within these constraints. For this example, the gains and biases are configured as follows:

$G_O = 1.000$
$G_A = 1.000$
$G_B = 1.432$
$G_C = 0.263$
$B_O = 0.000$
$B_A = 0.000$
$B_B = 0.105$
$B_C = 0.807$

The square root extractor (FB24) converts the corrected ΔP signal ($\mathbf{h_c}$) to a standard volume flow signal. It should be noted that the square root extractor must be downstream of the pressure and temperature compensation. If the square root function is included in the differential pressure transmitter, the transmitted signal represents $\sqrt{\mathbf{h}}$ instead of **h** as required by the engineering equation. In that case, a math block must be used to square the $\sqrt{\mathbf{h}}$ signal before performing the compensation calculations.

No scaling is required in the square root extractor. Since the corrected differential pressure at fullscale (100 "H_2O) corresponds to fullscale flow (15,000 SCFM), the conversion from ΔP to flow is accomplished by assigning the appropriate scale range (0 to 15,000) to the resultant signal. It is not even necessary to know the flow range or the ΔP range to derive the signal equation for pressure and temperature compensation. The flow range is assigned to the end result, and the ΔP range cancels out since it appears on both sides of the equation.

APPLICATIONS

For applications requiring pressure compensation only, the temperature is assumed to be constant at the value used for calibration (**T_c**). The signal equation is derived using a value of **1** for the ratio **T/T_c**. Likewise, for applications requiring temperature compensation only, the signal equation is derived using a value of **1** for the ratio of **P/P_c**.

Although most applications require standard volume (mass) flow, some applications require actual volume flow. For example, the performance of centrifugal and axial compressors is related to the actual volume flow at the compressor inlet. The compensation procedure for actual volume flow is identical to the procedure for standard volume flow except that the pressure and temperature corrections are inverted as follows:

Actual Volume Flow:

$$h_c = h \frac{\left(\frac{T}{T_c}\right)}{\left(\frac{P}{P_c}\right)}$$

Pressure and temperature compensation for other head type flowmeters (flow nozzles, venturis, etc.) is identical to the procedure shown here for orifice meters. These compensation calculations are also applicable to other types of volumetric gas flow meters (vortex shedding meters, turbine meters, etc.). However, the square root extractor is only required for head type flowmeters.