Tutorial

Measuring Level With Remote Seal DP Transmitters

Asymmetrical Seal Design Can Help to Compensate Automatically for Errors Introduced by Ambient Temperature Variations.

Ambient temperature changes can introduce significant errors when measuring liquid level with traditional remote seal differential pressure (DP) transmitters. In contrast with traditional design practices, use an asymmetrical transmitter design in which the volumes of the high and low side filled systems and compliances of the seal diaphragms are deliberately unbalanced to compensate for these effects.

Before exploring how to anticipate and correct these errors, a discussion of the general response characteristics of remote seal pressure transmitters is in order. Remote seal pressure transmitters, adaptations of standard pressure and DP transmitters, often are used for level measurement to solve particular application problems and to make it more convenient to mount and service the transmitter.

A traditional remote seal DP transmitter consists of a transmitter body and two diaphragm seal elements connected to the transmitter body by capillary tubes (Figure 1). The transmitter body is located somewhat below the high side seal element. This is the required position if the vessel is to have a high vacuum applied during any part of the processing cycle. Because the low side capillary must be long enough to reach between the transmitter body and the upper vessel connection, and because the manufacturer has made a symmetrical measuring system, there is a coil of excess capillary on the high pressure side.

How seal elements work

It is important to understand the construction and characteristics of the seal elements because these elements are very important in determining the performance of the transmitter and the effect of ambient and process temperature on the stability of the measuring system.

It is straightforward to understand the response of the transmitter to a change in level in a process vessel. The seal diaphragms respond to changes in process pressure as the level changes and as the static pressure over the liquid changes. These pressure changes are carried through the connecting capillary by a suitable hydraulic fluid to the DP sensor, located in the transmitter body. The hydraulic fluid is selected to be compatible with the requirements of the process and entirely fills all cavities of the transmitter in the seal diaphragm assemblies, the capillaries, and the transmitter body.

While there are many designs of seal elements, the seal element shown in Figure 2 is typical. A thin metallic, convoluted diaphragm, protected by a concentric ring, is welded to a heavy flange member. The materials for the diaphragm and the ring are chosen to be compatible with the process fluid. A hole through the flange connects the cavity formed by the diaphragm and the flange to a length of capillary welded to the back of the flange. The other end of the capillary connects to an input pressure port on the transmitter body.

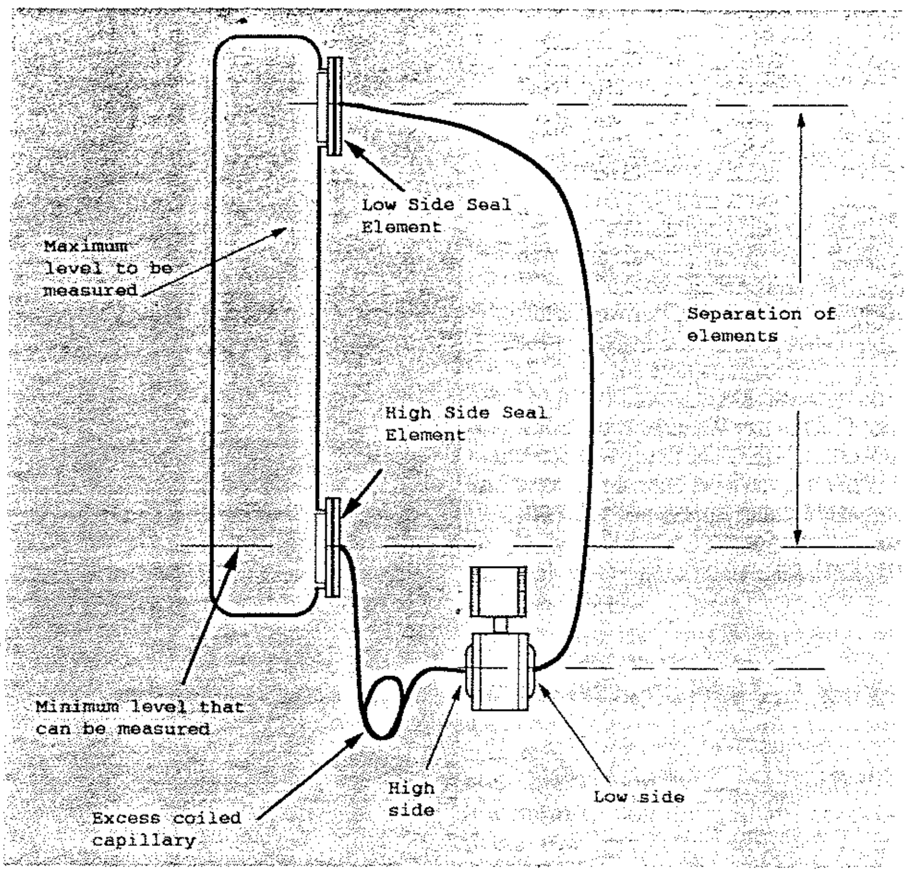

Figure 1. *Traditional remote seal transmitter used to measure level in a closed vessel.*

The effect of temperature changes

It is important to understand the response of the filled, sealed diaphragm system. For example, when an increase in ambient or process temperature occurs, the volume of the liquid contained in the liquid-filled system increases because of thermal expansion. The change in fluid volume exerts pressure against the entire confining system, including the seal diaphragm, the flange, the capillary, the transmitter body, and the sensor. However, the only movable element in the system is the seal diaphragm, so the diaphragm must move outward to accommodate the increased volume of liquid.

But moving the diaphragm outward requires that some internal pressure be developed. For a given fluid volume change, the amount of pressure change depends on the stiffness or compliance of the seal diaphragm. For a given amount of volume expansion, the pressure within the seal system will rise an amount which is proportional to the compliance of the diaphragm. If the temperature decreases, the internal pressure decreases by a corresponding amount. The amount of pressure change in the filled system is given by:

$$\Delta P = Ve\Delta T/C$$

Where: ΔP = pressure change, inches water column (in. w.c) gauge;

V = volume of liquid subject to the temperature change, $in.^3$;

e = coefficient of volumetric thermal expansion of the liquid, $in.^3/in.^3 {}^\circ F$;

ΔT = temperature change applied to the liquid, °F; and,

C = compliance of the seal diaphragm, $in.^3/in.$ w.c.

Because the transmitter acts upon pressure, any change in the internal pressure of the system applied to the sensor is a potential source of error. Therefore, transmitter manufacturers attempt to keep the total volume in the filled liquid system as small as is practical—this minimizes the internal pressure change caused by a temperature change. The manufacturer also will use a diaphragm that is as soft (highly compliant) as is practical. However, the fluids used to fill the transmitter typically have high thermal coefficients of expansion so that the effects of temperature change can still be significant.

These significant errors are reduced, but not eliminated entirely, because the transmitter sensor is a differential sensor and responds to pressure applied to either side of the sensor. Hence, manufacturers traditionally have provided a symmetrical design of the remote seal system in order to minimize the effect of temperature on the accuracy of the measurement. Manufacturers typically use the same type of diaphragm and flange assembly for the high and for the low side seal elements: each of the capillary systems is the same length, with capillary of the same nominal diameter. Transmitter body cavities are made to contain equal volumes of fill liquid on the high and low sides.

This makes the total volumes of fill liquid contained in the high side of the transmitter approximately equal to the volume of liquid in the low side. With this arrangement, the pressure effects induced by volumetric changes in the fill liquid volumes on the high and low sides offset each other to a large degree and compensate for the effects of ambient temperature and process temperature on the filled systems.

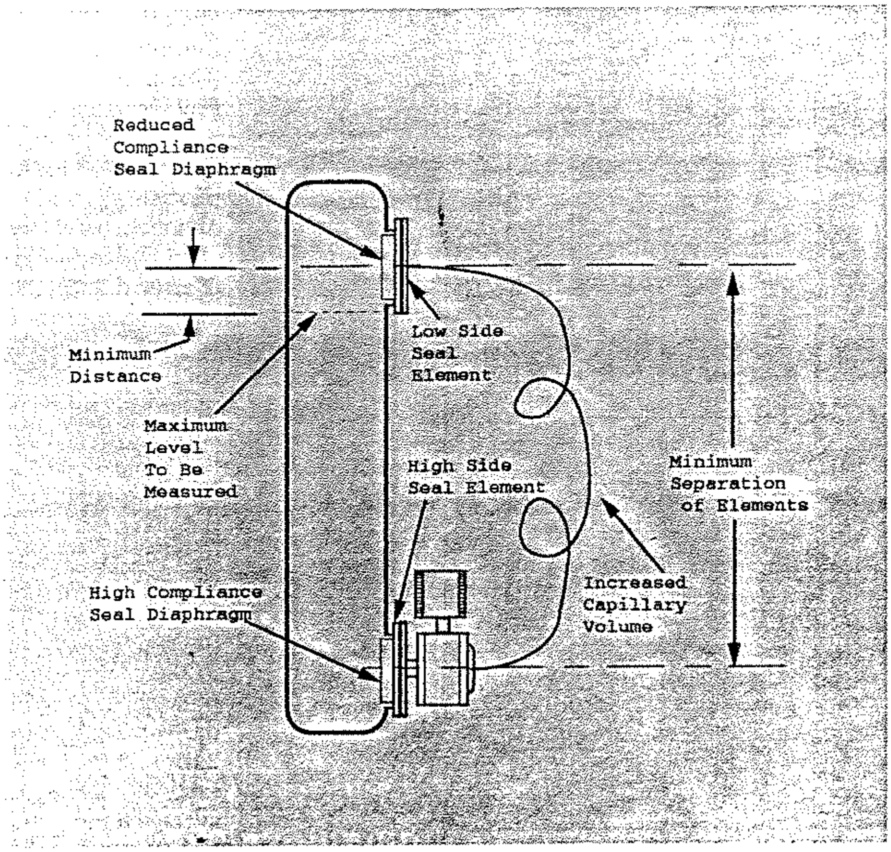

Figure 2. *Cut-away view of a typical remote seal element.*

Elevation difference introduces error

Balancing the volumes of liquid works well when the remote seal systems are installed at the same elevation, as when measuring flow in a horizontal pipe. However, for level measurement applications, the seal elements are necessarily at quite different elevations. This introduces an additional source of temperature error which the manufacturers largely have ignored.

Referring again to Figure 1, because the low side seal is elevated relative to the high side seal, a differential pressure is applied to the sensor. That differential pressure is equal to the vertical distance between the two seal elements multiplied by the specific gravity of the fill liquid at the effective temperature of the connecting capillaries. Of course, the initial effect of the differential pressure is zeroed out in the calibration and commissioning of the transmitter. However, subsequent variations in the differential pressure caused by the effect of temperature changes on the density of the fill fluid

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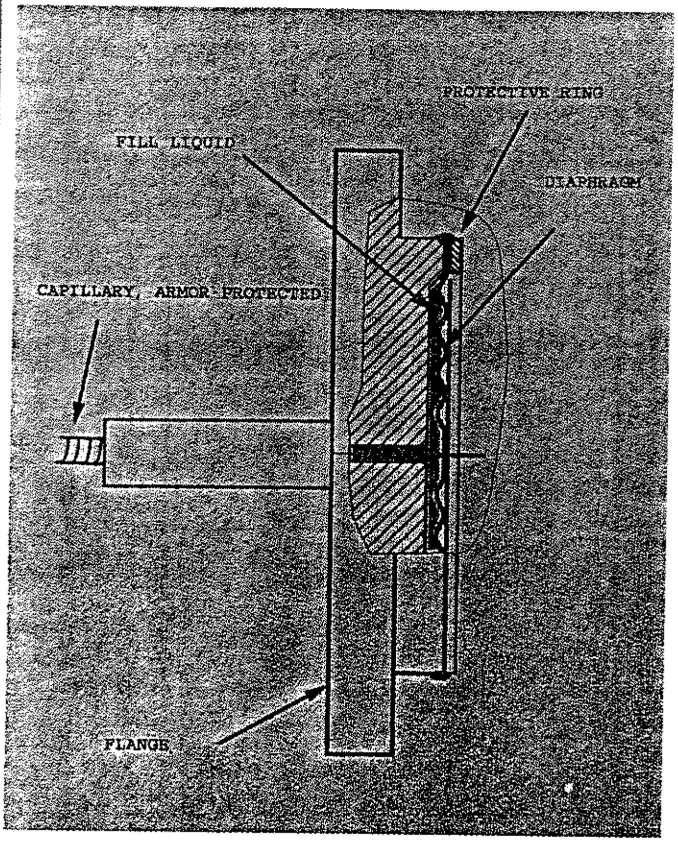

Figure 3. *A stiffer seal diaphragm on the high pressure side and increased fill volume on the low pressure side can help compensate for pressure measurement errors introduced by ambient temperature variations.*

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are not compensated for in typical symmetrical designs.

Recognizing that the specific gravity of a typical silicone fluid is about 0.93 and that the specific gravity changes about 2% for each 40°F change in temperature, it is easy to see that the resulting error will be significant. For example, assuming a separation of the elements of 140-in. and a transmitter span of 100-in. w.c., the change in instrument zero for a 40°F change in average temperature of the capillary will be 2.2-in. w.c.—equal to 2.2% of the instrument span. Thus, a remote seal liquid level transmitter with a symmetrical arrangement of its components has a relatively large and uncompensated temperature error when the temperature of the capillaries changes.

How to compensate

This potential error can be reduced by using care in designing the application and then by using an asymmetrical construction for the transmitter.

First, keep the vertical separation of the seal elements as small as is practical for the process installation. Although this will not eliminate the source of error, reducing the initial head pressure imposed on the sensor will also reduce the effect of density change in the fill fluid that is caused by temperature change. In the above example, reducing the vertical separation of the elements in the above example from 140-in. to 110-in. will reduce the density error in the low side leg from 2.8% to 2.0% for the same 40°F change in average temperature of the low side capillary.

Now consider how to reduce the error that is left. Introduce differential temperature effects between the two capillary systems such that the low side error is equal and opposite to the error caused by the accompanying change in density of the fill fluid. This is done by abandoning the symmetrical design approach and introducing asymmetry in two ways: use unequal volumes of fill liquid in the high low side seal systems, and use a stiffer, lower compliance diaphragm on the low side seal (Figure 3).

Unequal fill volumes can be created easily. First, reduce the length of capillary on the high side to a minimum; then increase the diameter and length of the low side capillary without increasing the vertical distance separating the two seal elements. With this relatively greater volume of fill liquid on the low side, a temperature change will induce a greater volume change and, hence, a greater pressure change on the low side. This pressure change will be in a direction to reduce the accompanying density change in the fill liquid.

Expect that the diaphragm used for the low side seal is already made as compliant as is practical, because this reduces the effect of process fluid temperature on the accuracy of the measurement. But for this compensation scheme, a compliant diaphragm in the low side seal mean that a larger liquid volume change must occur with temperature to develop a modest internal pressure change. With a less compliant, stiffer diaphragm, a given change in fill liquid volume with temperature creates a greater compensating pressure change. The compliance of the low side diaphragm can be decreased somewhat by using a thicker diaphragm, by using a diaphragm with deeper convolutions, or by using a smaller diameter diaphragm.

There is a trade-off for reducing the compliance of the low side seal diaphragm—the effect of any temperature change at the seal itself will be increased. Therefore, there will be some practical limit to decreasing the diaphragm compliance on the low side. However, a general balance between increased volume in the low side and decreased diaphragm compliance on the low side can improve stability of the measurement markedly when the temperature of the capillary changes.

Conclusion

Remote seal liquid level transmitters can have a large uncompensated temperature error caused by change in specific gravity of the fill liquid. This inherent error is proportional to the vertical separation of the seal elements and is uncompensated for in conventional symmetrical seal designs.

An asymmetrical system with reduced high-side capillary volume, increased low-side capillary volume, and decreased compliance of the low-side seal diaphragm can compensate—in whole or in part—for changes in the specific gravity, thereby providing improved performance in remote seal level applications. □

***Howard R. Jaquith**, principal, Jaquith Associates, Rushville, N.Y., is an independent consultant in engineering and management.*