Pressure Transmitter Basics: DP Transmitters

How a variety of process parameters can be measured with DP transmitters

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Pressure transmitters are widely used throughout the chemical process industries (CPI). Although pressure in and of itself is an important process parameter, differential pressure (DP) measurements enable the inference of other important parameters as well. This article presents a concise overview of how DP transmitters can be put to work in CPI plants.

Versatility of DP measurements

DP transmitters are highly useful for determining the value of multiple chemical plant variables, such as differential pressure, flowrate, level and density. These transmitters have two pressure ports (high and low) and can measure gage pressure (see definitions in box above), absolute pressure and the difference between two pressures (differential pressure or DP). If the low-pressure (LP) port connects to vacuum, the high-pressure (HP) port measures absolute pressure. If the LP port connects to the ambient atmosphere, the other measures gage pressure. Otherwise the transmitter simply measures DP, the difference in pressure connected between the two ports.

Flow. DP transmitters are commonly used to measure fluid flowrate through a pipe. A primary flow element, such as an orifice within the pipe (Figure 1), reduces the cross sectional area through which the process fluid flows. This restriction increases the fluid velocity through it, increasing its kinetic energy. Other types of common restrictions include Venturi flow elements, nozzles, wedges and flow tubes.

Conservation of energy requires the downstream side of the restriction to drop in line or static pressure. Taps placed on either side of the restriction see a differential in static pressure. A pressure transmitter connected to the taps measures this differential pressure, which can be related to the volumetric flowrate of the fluid.

This differential pressure does not vary linearly with the flowrate, but with its square root. Industrial DP pressure transmitters are generally capable of performing the arithmetic conversion to make the output signal linear with flowrate. But this limits the range ability of these kind of flow measurement. In the case of an orifice, for example, the range ability may be five to one.

Liquid level. A DP pressure transmitter can measure the level of liquid in a tank, whether open or closed. In the case of an open tank (Figure 2, left), the pressure of the liquid in the tank at any depth depends directly on the depth value and the liquid density. So if the HP port of a DP transmitter connects

DEFINITIONS

Here are some important common terms and their definitions. For additional general information on pressure transmitters, see Part 1 on pp. 34–39:

Atmospheric (barometric) pressure. This is the pressure that is exerted by the atmosphere surrounding the earth. Atmospheric pressure at sea level equals 14.695 psia. This value decreases with increasing altitude.

Hydrostatic pressure. Hydrostatic pressure is encountered in liquid level applications. It is the pressure below the liquid surface exerted by the liquid above.

Line, static or working pressure. Static pressure is the force per unit area exerted on a surface by the flow parallel to a pipe wall.

Absolute pressure. Absolute pressure is a measurement referenced to a full, or perfect vacuum. Zero absolute pressure (0 psia) represents a total lack of pressure, such as occurs in outer space.

Gage pressure. Gage pressure is a measurement referenced to atmospheric pressure. Gage pressure represents the positive difference between measured pressure and ambient atmospheric pressure. One can convert gage pressure to absolute pressure by adding the actual atmospheric pressure value to the gage pressure reading. For example 10 psig is equivalent to (10 + 14.7 psia) or 24.7 psia at sea level.

Vacuum pressure. A vacuum pressure measurement is referenced to atmospheric pressure, but below it. The units of vacuum pressure are generally centimeters or inches of water (in. H_2O). For example, 14.7 psia equates to 407.5 in. H_2O. So a pressure of 10 in. H_2O vacuum would be equivalent to 397.5 in. H_2O absolute. Vacuum pressure is typically measured using a gage pressure transmitter with an elevated zero calibration. ❑

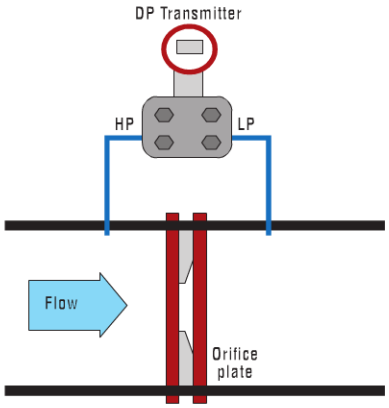

FIGURE 1. A DP transmitter can be configured to measure flowrate

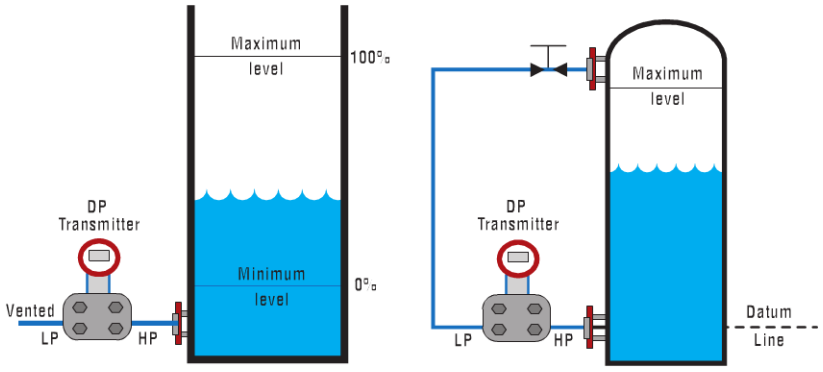

FIGURE 2. A DP transmitter can be used to measure the liquid level in either an open (left) or closed (right) tank or vessel

to a tap at the bottom of the tank and the LP port to atmosphere, the output signal can be related to the tank liquid level.

Since the tank is open, any change in the atmospheric pressure affects pressures within the tank liquid. But the LP port of the pressure transmitter also connects to atmosphere, cancelling out the effects of atmospheric pressure on the open tank fluid level. The liquid density must be constant or be accounted for.

In the case of a closed tank or vessel that is sealed from the atmosphere (Figure 2, right), the low-pressure side of the transmitter can be piped to the top of the tank rather than to atmosphere. Otherwise, when a process fluid fills or leaves a closed tank, the pressure inside may go from positive to vacuum, which would adversely affect the level measurement. Connecting the LP port of the transmitter to the tank top easily compensates for any changes in tank pressures.

A bubble tube of pipe offers another way to measure liquid level with a DP transmitter in open and closed tanks (Figure 3). A tube inserted into the tank maintains a constant pressure of air or some gas compatible with the tank contents. As the liquid level changes, the backpressure measured by the transmitter directly corresponds to the tank level. The advantage here is that only the tube or pipe material comes in contact with the process liquid — not the pressure transmitter. A second advantage here is that it requires no connections to the bottom of the vessel. However, the process liquid cannot be sensitive to the gas bubbling through it. A disadvantage is that a source of air pressure is required.

Level calculations. To calculate the pressure at the bottom of the tank in Figure 3, you must know the value of h, the distance from the liquid level to the end of the bubble tube. For example, if h is 50 in., and the material in the tank is water, then we can express the pressure at the bottom as 50 in. H_2O or about 1.8 psig. But if the liquid in the tank is not water, a conversion must be made to specify in inches of H_2O.

The formula for this conversion is:

$$h = h' \times SG \qquad (1)$$

Where:
h = liquid head, in. H_2O
h' = actual liquid head, in.
SG = specific gravity (dimensionless) of the fluid in the tank

Recall that specific gravity is the relative weight of a unit volume of liquid compared to the same volume of water. Gasoline, for example, has an SG of about 0.8. So a gallon of gasoline weighs 80% of the weight of a gallon of water. The point is that you must consider the liquid's density when measuring liquid level with a DP transmitter.

Interface level measurement. Figure 4 shows a technique for measuring the level of the interface between two liquids of different densities, such as oil and water. The total level in the tank must remain above the top tap of the DP transmitter and the distance h must be constant. As the interface level changes, the lower tap sees a density change along with a corresponding change in the hydrostatic pressure. Newer methods of performing this measurement have evolved in the relatively recent past.

Density. From the discussion above, it follows that if the liquid in the tank of Figure 5 is homogenous, then any changes in the process liquid density will be reflected as a change in static pressure. Again, as long as tank level remains above the top pressure-transmitter tap and as long as the distance between LP and HP sensors, h, is constant, the transmitter will respond linearly to changes in density. Typically, as in level measurement, chemical plants use a sensitive DP transmitter because the spans are relatively small.

Remote seals

Generally, the sensing element within a DP transmitter comes in direct contact with the process fluid. The sensing element, such as a diaphragm within the transmitter, responds to the force created by the process fluid pressure. An associated sensor generates a low-level

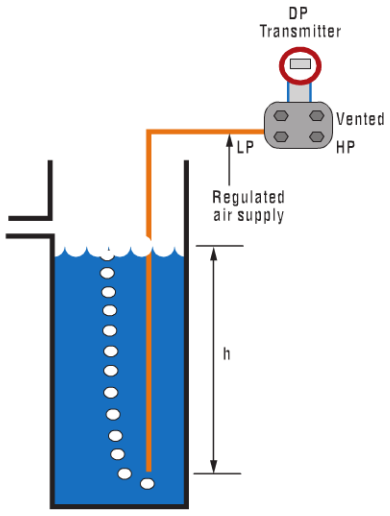

FIGURE 3. Liquid level can also be determined using a bubble tube

electronic signal related to flexing of the diaphragm. A secondary electronic package acts on this signal, producing a standard transmission signal, such as 4–20 mA. Remote seals have been developed to widen the applicability of the DP pressure transmitter beyond its limitations of maximum temperature and dirty, corrosive or abrasive process fluids.

The term "remote seal" refers to an isolation seal system that protects a pressure transmitter sensor and its process connections from any contact with the measured process fluid. The seal is called "remote" because it permits the transmitter to be located up to some 80 ft from the element connections. Sometimes the transmitter is close-coupled to the process pipe or vessel. Seals in such cases would be more aptly called isolating seals. Other names used are diaphragm seals and chemical seals.

The remote or isolating seal system constitutes a well-engineered, useful accessory, usually ordered in pairs as integral transmitter attachments, and sized for a specific application. The system consists of a flange connection, a stem, and a seal diaphragm connected through a capillary to the flanged chamber of the transmitter. Shown schematically in Figure 6, the seal has two main components: a flexible metallic diaphragm that is exposed to the process fluid and reflects its static pressure plus a liquid-filled capillary tube that connects to the transmitter body.

Seal systems come with a variety of diaphragm diameters, materials and configurations to suit needs of the installation. In some cases the capillary is protected with suitable armor.

Once the individual components are connected, a technician evacuates the air from the system and fills it with an incompressible fluid. In this way when the seal diaphragm experiences process pressure, it deflects and exerts a force against the fill fluid. Since the liquid is incompressible, this force is transmitted hydraulically to the sensing diaphragm within the transmitter body, causing it to deflect in turn. The deflection of the sensing diaphragm of the transmitter is the basis for the pressure measurement.

Specifying remote seals

Certain considerations affect the proper dimensioning of a remote seal system. For one, a full-scale deflection of the seal diaphragm must exceed the displacement capacity within the transmitter; otherwise the seal element cannot drive the transmitter to a full-scale measurement. Additionally, best practice is to minimize the volume of the capillary fill cavity between the seal flange and the primary diaphragm of the transmitter. This minimizes the ambient and process temperature effects on the measurement. Special flanges are available for the transmitters that minimize the cavity volume when connected to a remote seal.

Response time. Engineers must consider the response-time issues when specifying a remote seal. The time constant for a measurement is the time required for an instrument output to reach 63% of the value it will ultimately reach in response to a step change in input (pressure in this case). Normally an instrument will reach 99.9% of full response within a time equal to four times the time constant.

The response time of a DP or gage pressure transmitter can significantly increase when connected to a remote seal. This response time depends on the following:

- The total length of capillary connecting the seal element to the transmitter body: The response time is directly proportional to the length of capillary. So the length of capillary has to be min-

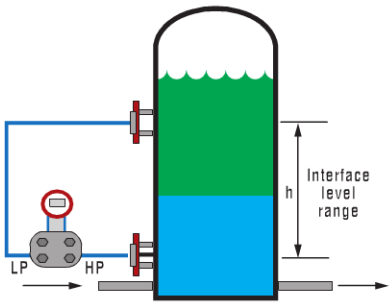

FIGURE 4. The interface between two liquids of different density can be measured with a DP transmitter

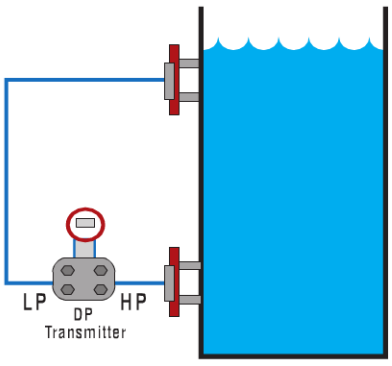

FIGURE 5. Changes in a fluid's density can be monitored with a DP transmitter

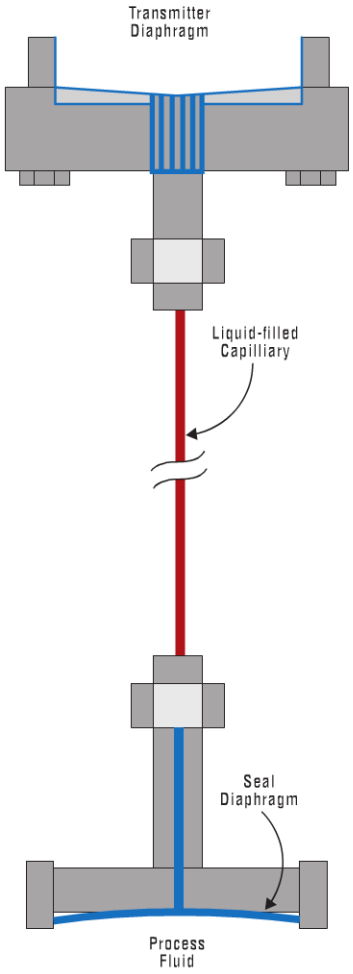

FIGURE 6. A remote (isolation) seal configuration enables a broader range of applications for a DP transmitter

imized provided that the application requirements are satisfied
- The inside diameter of the capillary: The response time of the instrument is inversely proportional to the fourth power of the capillary diameter. A smaller capillary section delays the response
- The viscosity of the fill fluid: Obviously a high-viscosity fill fluid increases the time it will take that fluid to transmit an applied force through the system. Also the temperature effect on viscosity (generally the viscosity increases as temperature decreases) must be considered. As the average temperature along the length of the capillary decreases, the system response time lengthens

Temperature effects. Another key consideration when specifying remote seals relates to temperature. The temperature under which the remote seal system was filled is called the reference temperature. Any difference in temperature from this reference that the capillary experiences will cause the fill fluid to expand or contract. The resulting magnitude of the effect depends on the physical properties of the actual fill fluid. The change in volume causes the internal pressure of the system to change. This will in turn cause a deflection in the transmitter diaphragm, which leads to zero shifts and measurement errors.

After installation, this effect can be "zeroed out." However each time a temperature variation in the process or ambient temperature affects the temperature of the remote seal components, a zero shift or measurement error will be induced.

The adverse temperature effects can cancel in the case of a differential-pressure measurement with two remote seals having the same dimensions, including the capillary length. If both branches of the DP transmitter experience the same temperature, the temperature effects compensate each other, minimizing the error.

Another way to attenuate temperature effects is to choose a seal diaphragm with a high spring rate. The spring rate (or flexibility) depends strictly on the diaphragm diameter, thickness, pattern and the material elasticity. The hydraulic circuit of a diaphragm-seal system is a closed volume where fill-fluid expansion causes an increase of the internal circuit pressure. The higher the diaphragm seal spring rate, the more the fill fluid expansion will be absorbed by the diaphragm. Diaphragms with higher spring rates produce a smaller applied pressure increase as a result of a temperature increase. Increasing the diameter of the seal diaphragm increases its spring rate. High spring rates are also recommended for measuring very low pressure spans, as they can withstand only small volumetric changes in fill fluid.

The installation dictates the length of the capillaries. Response times can be decreased by enlarging the capillary internal diameters. But this, together with the length of capillary, increases the total volume of the filling fluid with negative temperature effects. So some tradeoff between response time and optimal temperature performance must be accepted.

Fill-fluid temperature effects. On level measurement applications where the distance from tap to tap is long (greater than 20 ft), an additional temperature effect, called the head effect, must be considered. The head effect relates to the change in specific gravity of the capillary fill fluid caused by temperature variation. For example, the silicon oil commonly used as a filling media has a certain specific gravity at 68°F. When the ambient temperature increases, the specific gravity decreases.

The pressure generated by the hydrostatic column of the fill fluid inside the capillary changes with temperature and its value increases proportionally to the tap distance. Changes in ambient temperature cause the expansion of the fill fluid, which generates a higher internal system pressure. The head effect instead generates a pressure reduction in the system.

Instrument engineers reduce head temperature effects by tailoring the construction of the diaphragm seal system to the real operating conditions of the installation. Typically, a DP transmitter with a direct-mount diaphragm isolation seal exists on the high-pressure side (at the bottom of the tank) with a remote diaphragm seal on the low-pressure side (topside of the tank). Engineers select customized diaphragm spring rates to create an error which is opposed to the one generated by the head effect.

This compensates the transmitter to eliminate the head effect, which will be virtually neutralized by a stiffer diaphragm used on the low-pressure side. These tailored systems can optimize DP level measurements even in deep tanks with very high hydraulic pressures. Otherwise, the remote seals would generate large errors.

Application range

Pressure transmitters come configured for very low to very high pressure ranges, as well as with materials to resist corrosion and chemical reaction. In addition, remote and isolation seals and filled capillaries may be used to isolate the transmitter's pressure diaphragm from the chemical process. Diamond-hard coatings for the pressure diaphragm can resist abrasive action. ■

Edited by Gerald Ondrey

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