

A Solution for Measuring Liquid Levels with Differential Pressure/Pressure Transmitters

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Various meters are used for measuring liquid levels depending on the measurement fluid, pressure, temperature, and installation conditions. They include the non-contact ultrasonic type and radar type, and contact float type and pressure type. Since contact type level meters directly contact the liquid to be measured, the materials of wetted parts and the specifications of the connection for measuring pressure vary, and thus it is difficult to maintain the quality and design of these products in accordance with customers' diverse requirements. Meanwhile, customers are seeking to increase the operation efficiency of their plant production. To satisfy these needs, meter manufacturers are required to offer a product lineup that flexibly responds to such requirements. This paper introduces Yokogawa's solution to level measurement by using differential pressure and describes the digital remote sensor (DRS) differential pressure transmitter which solves problems regarding level measurement.

INTRODUCTION

Among level measurement applications using differential pressure/pressure transmitters, capillary-type level measurement requires the corrosiveness, pressure, and temperature of fluids to be measured. Moreover, there are various standards and sizes for process connections (flange connection, screw connection, etc.). Thus, a wide variety of specifications are requested for differential pressure/pressure transmitters⁽¹⁾⁽²⁾⁽³⁾ for level measurement. Furthermore, there is increasing demand for higher accuracy.

This paper introduces Yokogawa's combination-type products to handle diverse conditions of level measurement, and describes the digital remote sensor (DRS) differential pressure transmitter developed for highly accurate, efficient level measurement.

LEVEL MEASUREMENT WITH DIFFERENTIAL PRESSURE/PRESSURE TRANSMITTERS

Level measurement deals with the vertical position of the physical boundary between fluids filled in containers or tanks, such as gas and liquid, gas and powder, and liquid and liquid. Various level meters are used for level measurement depending on the target fluid, measurement principle, structure, and purpose. The float type, displacer type, pressure type, ultrasonic type, and radar type are common examples of such meters.

Pressure-type level meters can directly measure levels because pressure is proportional to the height from the reference level to the boundary as long as the density of the fluid is uniform (Figure 1). In the case of pressurized tanks, differential pressure meters can eliminate the influence of internal pressure and measure levels accurately. However, since there is a wide variety of shapes and installation conditions, as well as pressure and temperature conditions of target fluids of tanks in customers' plants, various product specifications are required to satisfy all such measurement conditions.

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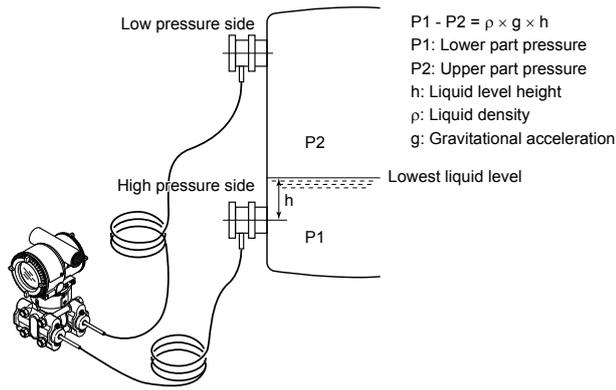


Figure 1 Example of tank level measurement with a pressure-type level meter

COMBINATION-TYPE PRODUCTS

Problems Involving Integral Type Products

Conventionally, a transmitter for level measurement was carefully selected from the existing specifications by taking into account the characteristics of fluids such as corrosiveness and viscosity, conditions of level measurement, and installation environment in the plant. Then, differences between customers' diverse requests and the manufacturability of transmitters were bridged. Such transmitters are called integral type products.

In order to flexibly adapt to the diverse requirements of the market, manufacturers must be able to offer a broad product lineup. However, it is difficult to judge whether a particular specification requested by a customer is applicable to others. If existing specifications do not address a customer's request, specifications must be customized to each request.

Standardization is the process by which frequently requested specifications are added to the standard product lineup. However, the existing product code system may be unable to accommodate all these specifications, thereby hindering the standardization process. Therefore, manufacturers must take time to study a specification requested by customers and determine the manufacturability, cost, and lead time on a case by case basis. This process delays delivery and increases production costs and prices.

Customized Transmitters for Level Measurement

A transmitter for level measurement comprises two parts: the main body and a diaphragm seal part. The vast majority of customized specifications requests are related to the diaphragm seal part. An analysis of frequently requested specifications shows that most of the requested specifications are satisfied by combining a standard unit or an existing customized unit with the main body in various ways. This explains the wide variety of customized specifications. For example, when one customized diaphragm seal part is combined with the main body of a differential pressure transmitter or a pressure transmitter, three different specifications are created (Figure 2).

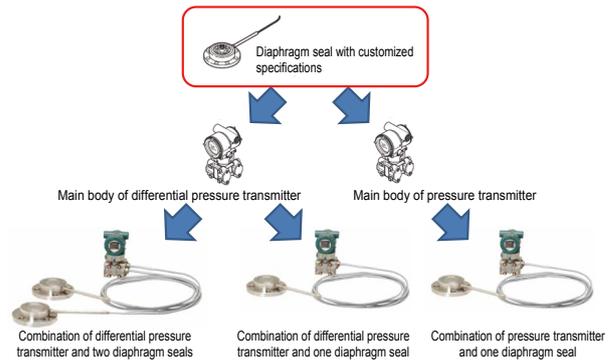


Figure 2 Example of customized product design

From Customized Specification to Standard Specification

It is necessary to customize the design and development of integral type products so that they comply exactly with the requested specifications. However, the situation changes if a manufacturer often receives orders for the same customized specifications from various customers.

Such frequently requested specifications are not a customer's need but a market need, and manufacturers should aim to include these specifications in their product lineup as standard, with specification details, delivery period, and price clearly defined, for customers to select products easily.

Manufacturers establish standard specifications in terms of design, development, manufacturing, and after-sales service, and it is not difficult to maintain the quality of standard products. In contrast, customized specifications require specific know-how of design and development. In general, know-how is often held by a limited number of people and can be difficult to transfer even among engineers, which makes after-sales service and maintaining product quality difficult. To respond to a wide variety of requests while maintaining product quality, it is essential to convert custom specifications into standard specifications as much as possible.

Developing Combination-type Products

A variety of requests may be satisfied by branching product models as shown in Figure 2. However, several hundred different models may be required to satisfy the wide variety of requests. An excessive number of different models requires a significant amount of time and labor for operation and maintenance, control of quality and procurement, and service for the products.

As stated previously, various combinations of diaphragm seal parts and main transmitter bodies increase the number of specifications for level measurement. If each diaphragm seal part and main body is offered as an independent product, customers can select the combination that caters specifically to their application. This is the concept of combination-type products. Yokogawa has embraced combination-type products to offer customers highly flexible solutions.

The first step towards embracing combination-type products is to expand the product lineup of diaphragm seal products based on customers' requests. By combining these

diaphragm seals with the main bodies of differential pressure/pressure transmitters, Yokogawa can respond to customer requests easily (Figure 3).

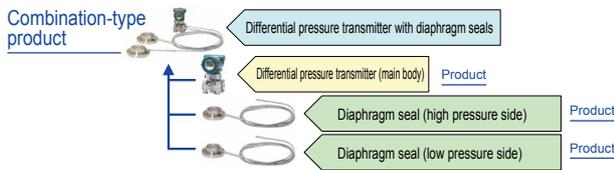


Figure 3 Configuration of product codes of combination-type products

Combination-type products reduce the time spent on customized specifications in design, development, and manufacturing processes and make it possible to design and develop standard products. In the manufacturing process, the process of checking the quality of each customized product can be replaced by standard quality-checking processes, thereby making it easier to maintain uniformity and excellent quality. Standardized products ensure clearly defined specifications, quick delivery, low prices, and so on.

DRS DIFFERENTIAL PRESSURE TRANSMITTER

Yokogawa has developed the DRS differential pressure transmitter as its latest combination-type product. To solve the problems involving the differential pressure transmitter with a capillary-type diaphragm seal (see below), the DRS transmitter has two pressure sensors (the master at the high pressure side and the slave at the low pressure side), and connects them via a dedicated communication cable so that they can communicate with each other for measuring differential pressure (Figure 4). The two transmitter main bodies can be connected in various ways including the basic “screw and screw,” “flange and flange,” “screw and flange,” “sanitary fitting and sanitary fitting,” and so on (Figure 5).



Figure 4 DRS differential pressure transmitter



Figure 5 Various combinations of DRS differential pressure transmitter

Problems Involving Capillary-type Differential Pressure Transmitters

Since the diaphragm seal part which receives pressure is connected to the main transmitter body via a capillary tube filled with fill fluid (Figure 6), the capillary-type differential pressure transmitter can avoid clogging or leaking in the pressure-conducting tube. Pressure-receiving diaphragm seal parts are connected directly to the process piping with flanges. Connecting tubes are not required.



Figure 6 Capillary-type differential pressure transmitter

However, a few factors need to be taken into consideration when using a capillary-type transmitter.

(1) Mounting

The capillary-type transmitter uses a capillary tube filled with fill fluid. Due to the density of the fill fluid, capillary tubes cannot be arranged with a vertical distance exceeding 10 m, otherwise Torricellian vacuum affects the measurement accuracy.

(2) Temperature drift

Changes in ambient temperature result in expansion or contraction of the fill fluid, affecting its density and volume and resulting in measurement errors. In particular, non-uniform temperature conditions, such as an outdoor application in which only one capillary tube is exposed to sunlight, may cause large errors in measurement value.

(3) Response time

Response time is mainly determined by the length and inner diameter of the capillary tube and the viscosity of the fill fluid. However, under low temperature conditions in particular, the response time can be slowed down by several seconds to several tens of seconds. This delay may negatively affect measurement results.

Features of the DRS Differential Pressure Transmitter Outline

Different from the capillary-type, the DRS differential pressure transmitter has two pressure sensors: one at the high pressure side and one at the low pressure side. The two sensors are connected via a data communication cable instead of a capillary tube, and transmit and receive pressure information between the two sensors. This feature solves the problems involving the capillary-type transmitter as follows.

(1) Mounting

When the capillary-type is used for measuring the tank level, the effect of atmospheric pressure (Torricellian vacuum) limits the vertical distance between the pressure

receiving parts (high pressure side and low pressure side) and the main body to 10 m. Meanwhile, the DRS differential pressure transmitter is not affected by atmospheric pressure because it uses a data communication cable instead of capillary tubes filled with fill fluid. Therefore, this transmitter can be used for applications with a vertical distance greater than 10 m.

(2) Temperature drift

Sunshine considerably affects the output of the capillary-type when it is used for outdoor tanks. In contrast, expansion and contraction of the fill fluid is negligible for the DRS differential pressure transmitter because the liquid is used only for pressure-receiving parts and sensors. In addition, each pressure sensor has a temperature sensor that corrects the measurement output against changes in ambient temperature. Thus, the DRS-type minimizes the effect of ambient temperature and ensures stable level measurement.

Figure 7 shows the effect of temperature drift due to sunshine on both the DRS and capillary-type differential pressure transmitters. The effect of sunlight was simulated by changing the temperature only within the area extending 1 m from the end of the capillary tube and the diaphragm seal on the low pressure side.

When the temperature of the low pressure side rose by 30°C, the output of the capillary-type dropped by 2.0% in the 100 kPa measurement range. Meanwhile, the output of the DRS differential pressure transmitter increased by only 0.2%, which is one-tenth of the change in the capillary-type.

Note that if this simulation was carried out in the 10 kPa range, the change in the output of the capillary-type measurement would be ten times larger, which would greatly affect the measurement data.

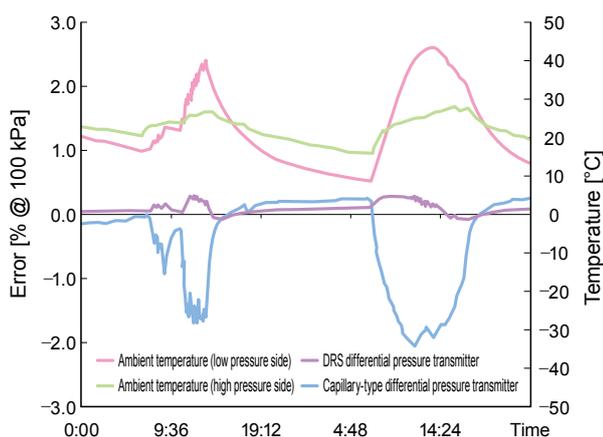


Figure 7 Comparison of the effect of sunlight

(3) Response time

Depending on the usage environment, the response time of the capillary-type may increase due to the length and inner diameter of the capillary tube and the viscosity of the fill fluid. In contrast, the DRS differential pressure transmitter

offers stable measurement with a constant response time because it sends digital information via a data communication cable. The two sensors are synchronized in terms of measuring pressure and transmit data several times per second, thus the measurement output is not affected.

(4) High differential pressure measurement

The demand for high differential pressure measurement has been increasing in recent years particularly for upstream applications and high-pressure turbine applications. However, conventional differential pressure transmitters can only measure differential pressures of 10 to 20 MPa. In contrast, the DRS differential pressure transmitters use sensors that can measure up to 50 MPa for both the high pressure side and the low pressure side, thereby satisfying the demand for high differential pressure measurement.

New Technologies in the DRS Differential Pressure Transmitter

New counting method

To lower the power consumption, the DRS differential pressure transmitter uses a new technology, Λ (lambda) frequency counter, for processing sensor signals.

It is necessary to increase the operating clock frequency of a frequency counter whose accuracy determines the measurement accuracy of a sensor. Increasing the operating clock frequency increases the accuracy but consumes more power, yet transmitters are required to operate with very low electric power. To solve this trade-off relation and achieve both low power consumption and high accuracy, a new technology is needed for frequency counters.

Conventional transmitters use Π (pi) counters (Figure 8 left side). A Π counter counts the total number of signals to be measured within a gate time, and calculates the total cycles from the detected times of the first signal and the last signal within the gate time. The cycle of one signal waveform is obtained by dividing the latter by the former, and the reciprocal quotient is the signal frequency. This method is a popular algorithm called reciprocal counting. In addition, conventional transmitters use a ΔT fraction extension circuit to improve the measurement accuracy of the frequency counter and satisfy the two requirements of low power consumption and high measurement accuracy.

In contrast, the DRS differential pressure transmitter uses two sensors for measurement and thus needs to operate two counters to process signals from the two sensors with the same electric power as conventional transmitters.

To reduce the power consumption of the two sensors, the DRS differential pressure transmitter uses a Λ counter (Figure 8 right side), which uses a different algorithm from a Π counter; a Λ counter divides a gate time into multiple intervals and averages the signal frequency over the gate time. Fluctuations in the signal (jitter) are canceled out, allowing the Λ counter to deliver more accurate measurement than a Π counter.

Since a Λ counter algorithm improves the measurement

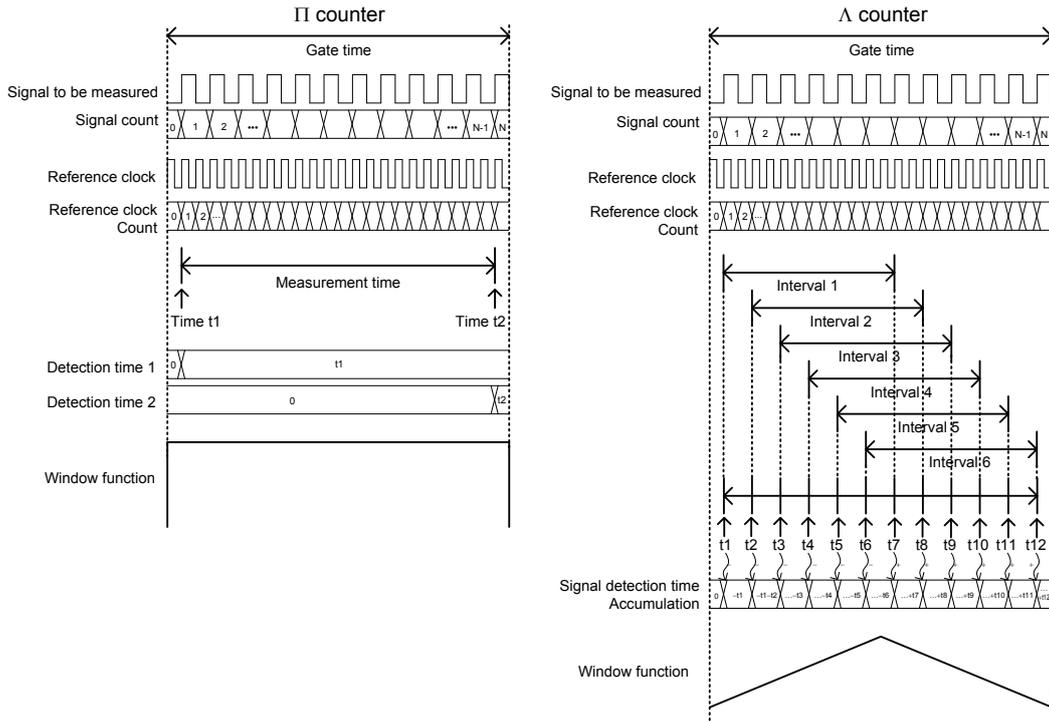


Figure 8 Π counter and Λ counter

accuracy, there is no need for ΔT circuits, thus reducing power consumption. This enables a transmitter to drive two counters with the same power consumption as the conventional transmitters.

Polygonal line approximation

When the horizontal cross section of a tank is not constant over the height, the pressure reading is not proportional to the fluid volume in the tank. Figure 9 shows the relation between the volume and the pressure of a spherical tank. The relation indicated by the blue curve is not proportional.

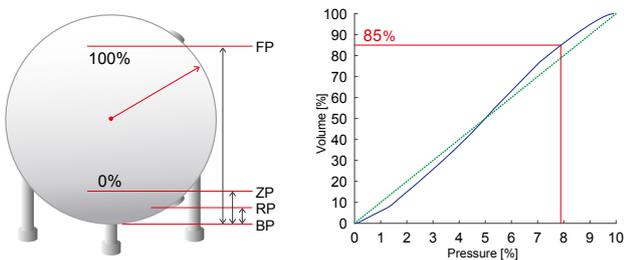


Figure 9 Polygonal line approximation

The transmitter output is required to correct according to the tank shape in order to ensure proportionality between the output and the fluid volume in the tank. For the DRS differential pressure transmitter, FieldMate enables easy setting for polygonal line approximation according to the tank shape. When users input various parameters such as the shape and height of the tank in on-line mode, FieldMate calculates the polygonal line approximation coordinates and creates a

correction table (max. 30 points). By downloading this table into the transmitter and the database, users can make the transmitter output proportional to the fluid volume in the tank.

Flange-mount type transmitter

As shown in Figure 10, three characteristics are required for the DRS transmitter.

1. High accuracy and long-term stability
2. Wetted parts that can measure fluids at temperatures up to 315°C
3. Vibration resistance

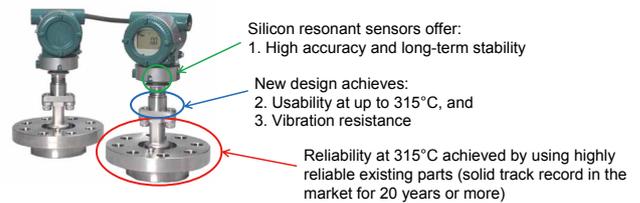
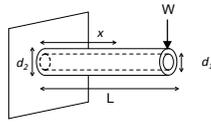


Figure 10 Characteristics and design concept required for the DRS differential pressure transmitter

The connecting part of the main body has been designed to satisfy requirements 2 and 3 above. To make it vibration-resistant, the connecting part was assumed to be a cylindrical cantilever beam. The second moment of area, “I”, which is the rigidity of a beam against bending moment, and the bending stress, σ , at an arbitrary position of the beam, are expressed by the equations in Figure 11. Based on these equations, the vibration-resistant connecting part between the main body and

the flange was designed so that the bending stress on the beam does not exceed 255 MPa (fatigue limit of the metallic material used) while the wetted part can measure fluids at temperatures up to 315°C.

$$I = \frac{\pi}{64} (d_2^4 - d_1^4)$$

$$\sigma = \frac{W \times L \times y}{I} \times \left(\frac{L-x}{L}\right) \text{ [N/mm}^2\text{]}$$


I: Second moment of area [mm⁴]
 d₂: Cylinder outer diameter (= 45.4) [mm]
 d₁: Cylinder inner diameter (= 43.0) [mm]
 σ: Stress [MPa]
 W: Load = transmitter weight × resonance acceleration [N]
 L: Beam length (= 240) [mm]
 y: Distance from the center to the edge of the beam in the cross section (= d₂/2 = 22.7) [mm]
 x: Arbitrary position on the beam (= 40) [mm]

Figure 11 Vibration-resistance characteristics

Notes on DRS Differential Pressure Measurement

In contrast to the capillary-type measurement in which one sensor directly measures differential pressure, DRS differential pressure measurement employs two sensors and requires consideration of the static pressure on each sensor. Measurement accuracy significantly differs between the two methods particularly when the static pressure is high and the differential pressure is low.

Assume a high-pressure, low-density fluid in a tank; its measurement involves high static pressure (10 MPa, for example) and low differential pressure (100 kPa, for example). In this case, the diaphragm seal type can measure the differential pressure with stable accuracy using a sensor with a span of 100 kPa. In contrast, the two sensors of the DRS differential pressure transmitter receive pressure at the high pressure side and low pressure side respectively, so these sensors must have a span of more than 10 MPa (static pressure plus differential pressure). When these sensors measure a differential pressure of 100 kPa, the turndown ratio becomes high (100:1) and affects the measurement accuracy. Therefore, users should consider the required accuracy before selecting sensors (Figure 12).

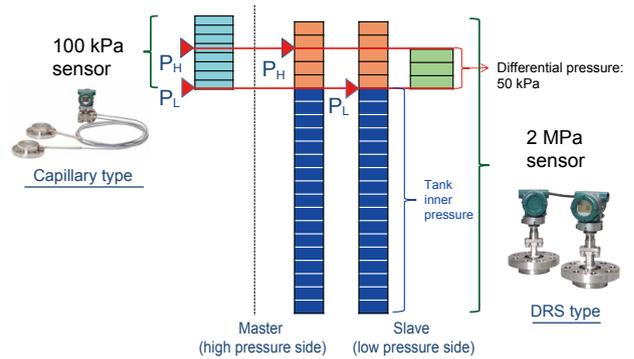


Figure 12 Comparison of measurement ranges between the capillary method and the DRS method

CONCLUSION

This paper described Yokogawa’s solution towards satisfying diverse customer requirements associated with differential pressure transmitters for level measurement, as well as the features of the DRS differential pressure transmitter.

Leveraging the release of combination-type transmitters for level measurement including the DRS transmitters, Yokogawa will flexibly offer diverse solutions in response to customer feedback on products.

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