technical monograph 18

Level-Trol Density Transmitter

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FISHER-ROSEMOUNT™

Type 2500-249 Level-Trol

Introduction

Fisher Level-Trol controllers normally applied as displacement type liquid level limits, are also used as density (specific gravity) controllers or transmitters. Practical considerations about density transmitters are presented herein to enable their evaluation for any given application.

Basic Operation

Displacement type density transmitters indicate the change in liquid density by measuring a change in displacement force on a displacer. The following formula is basic to proper understanding:

$$\Delta F = (\Delta d)(\Delta V)$$

or $$\Delta F = (.0361)(\Delta SG)(\Delta V)$$

where –

ΔF = Change in displacement force, lbs.

ΔV = Change in submerged volume of displacer, cubic inch

Δd = Change in liquid density, lbs per cubic inch. May be expressed as (.0361) (ΔSG)

ΔSG = Change in specific gravity

.0361 = Density of water, lb. per cu. in.

It can be seen from this formula that if we are to measure the density change, the other variable, submerged displacer volume, must be held constant. This is done by completely submerging the displacer.

Thus, in operation if the density becomes less, the displacement force decreases; conversely, an increase in density increases the displacement force. The displacement force change affects the torque tube rotation and changes the flapper–nozzle relationship in the transmitter to create a new output signal.

Practical Considerations

Density measurement requires more of the instrument than most level control applications. Special considerations should therefore be given to the following areas:

1. Increased transmitter sensitivity
2. Improved displacer installation
3. Correction for possible significant signal errors

1. Increased Transmitter Sensitivity

Most Fisher Level-Trols are designed to yield full output signal span by measuring a change in displacement force of 3.61 pounds maximum. The value of 3.61 pounds represents the displacement force of a standard 100 cubic inch displacer on water service. The basic formula applies:

$$\Delta F = (\Delta d)\ (\Delta V) = (.0361)\ (100) = 3.61 \text{ lbs.}$$

The equivalent density change of 1.0 is much too large for most density measurement applications. Generally, full output signal span will be required on density changes less than 20% and even down to 1% of designed maximum input. Therefore, special means must be provided to increase the sensitivity of the Level-Trol density transmitter. Three means can be used:

a. Reduce the spring rate of the torque tube. A special thin wall torque tube produces twice the angular movement for the same displacement force change. It is twice as sensitive, thereby doubling the transmitter gain.

b. Increase the displacer volume. A larger displacer, where physically possible, increases the gain by the ratio of its volume to the standard 100 cubic inch displacer. For example, a 300 cubic inch displacer will triple the transmitter gain.

c. Narrow the proportional band dial setting. A lower proportional band dial setting increases the transmitter gain. The gain can be increased five times by this method.

$$Gain\ \ Change = \frac{Initial\ \ Proportional\ \ Band\ \ Setting}{New\ \ Proportional\ \ Band\ \ Setting}$$

$$Gain\ \ Change = \frac{100\%}{20\%} = 5$$

Note: 20% proportional band setting is the minimum recommended design setting. Controllers with less than 20% setting run greater risk of process instability.

Since gain increases can be multiplied, use of a thin wall torque tube, a 300 cubic inch displacer and 20% proportional band dial setting will make the Level-Trol 30 times (2 x 3 x 5) more sensitive than the standard transmitter on water service. In practice, the desired sensitivity is generally obtained by using a thin wall torque tube and an oversized displacer and keeping the proportional band dial setting as high as needed to give the desired linearity between density and output signal (see Performance section).

2. Improved Displacer Installation

Since density transmitters are relatively high gain instruments in comparison with a normal liquid level transmitter, it is extremely important that the only force acting on the displacer be that which results from a change in density. The following points need careful attention in design and installation.

Vessel Mounted Displacers

To avoid measurement error or instability, the displacer must be located where liquid agitation is sufficient to give adequate sampling of density but not so turbulent to produce an erratic signal. Where no vessel location seems suitable, a stillwell is sometimes added to the vessel to reduce the effect of internal velocity forces.

When the displacer is hung on a long vertical stem, the stem may be subject to liquid level changes as well as density changes. This may produce an undesirable and significant secondary error. For example, a level change of only one foot on a 1/4” diameter stem could produce a displacement force change of .022 pounds. On a unit with high sensitivity (thin wall torque tube and 20% proportional band setting) this force of .022 pounds would create a change in output signal equal to 6% of output span.

Flow Line Mounted Displacer

A continuous flow past the displacer may be tolerated such as might be found on a flow line below a mixing control. For these installations, however, the following requirements are made:

1. Flow rate must be low enough to prevent erratic output or undesirable offset.

2. Flow rate change must not produce undesirable offset.

Fully caged styles are normally used which admit flow at the bottom and are able to discharge air bubbles upward. Straight top and bottom equalizing connections are advisable to avoid the turbulence of sharp entrance elbows. Similarly, reducing bushings are avoided because of impinging abnormal velocities.

Two important forces are exerted on the displacer in steady flow service. An end thrust is developed upward by the diverging and converging of fluid into and out of the annular section around the displacer. Frictional drag also acts upward due to the flow along the length of the displacer. The magnitude of both forces is a function of velocity.

A plain cage is quite limited in allowable flow rate as may be seen from the Performance section. Because of the slow flow rate, the cage is normally installed in a bypass line which may sample the desired portion of total flow with a pump or restrictive orifice supplying the pressure.

Piezometer ring cages are sometimes used when the maximum capacity of the plain cage does not provide adequate sampling and/or flow rate is extremely variable. This design, Figure 1, partially equalizes the effect of divergence and drag by introducing the flow at six points around the periphery and center of the cage. The outlet flow is taken from each end of the cage through flow balancing hand valves to reconverge the flow in the process.

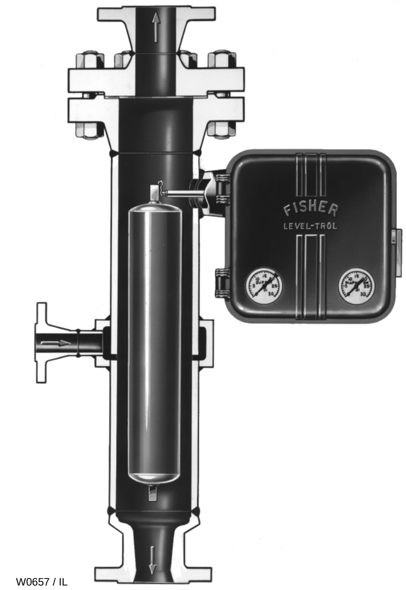

Figure 1. Type 2500-259B with Piezometer Ring

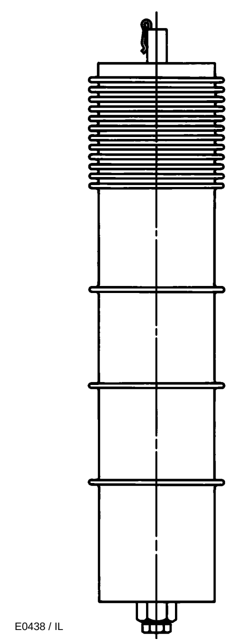

Figure 2. Temperature Compensated Displacer

Displacer Subject to Temperature Change

Many processes vary temperature enough to affect the output signal of a density transmitter because of the cubical coefficient of expansion of the fluid. This error can be compensated for automatically by use of a special bellows type displacer (Figure 2). This displacer must be filled with the process fluid or a fluid with the same coefficient of expansion and approximately the same density. As the process fluid warms, its density goes down; then, as the fluid in the displacer warms, it expands the bellows to a larger volume. When the temperatures are equalized, the displacement force increase due to displacer volume change equals the displacement force decrease due to the lower density of the process fluid. The effect of temperature change is thereby nullified.

3. Correction for Possible Significant Signal Errors

Since the density transmitter is a relatively high gain instrument, it is more sensitive to damage and error than the equivalent liquid level transmitter. Consider the following points:

a. On all Level-Trol units, except some top mounted units, the torque tube and knife edge bearing will always be submerged, creating the possibility of increased corrosion. On thin wall torque tubes at low proportional band dial settings, a smaller amount of torque tube corrosion yields a given output offset.

b. The wall thickness of thin wall torque tubes is 1/64” on most units which is about one half the thickness of the standard torque tube. Localized corrosion will therefore result in more rapid failure.

c. Oversized displacers generally have too much “dry” weight for the torque tube to support. Overloading the torque tube can yield the metal in torsion, causing an increased corrosion rate and an inability to read over the proper input range. Travel stops must be provided as part of the cage construction to prevent overstressing the torque tube.

d. Since the displacer is completely submerged, it can collect settling solids on its top which can change the zero reading of the transmitter.

e. Solid formation on the knife edge bearing and displacer rod ball joint may increase hysteresis. A flushing connection could be provided to prevent such deposits. Solid formation on the cage wall could interfere with the displacer and cause erratic measurements. This is especially true for a bellows type displacer because of its small annular clearance.

f. Torque tube materials are subject to a change in Modulus of Rigidity with a change in temperature. Increasing temperature lowers the modulus and thus allows the displacer arm to sag down. The changes, however, are completely repeatable and a correction curve could be applied.

g. If a bellows type displacer contains a bubble of air or vapor, the output signal would be sensitive to pressure. For this reason, it is necessary to fill the bellows very carefully to make sure that all air or vapor is expelled. The liquid fill should be evaluated to see that no gas will evolve from corrosion and that there is no chance of vaporization. Trapped air or vapor bubbles will expand on dropping pressure, increasing the buoyancy of the displacer and indicating a higher than actual density. In extreme cases, bubbles may rupture the bellows on decompression.

Performance of Density Transmitters

1. Linearity

The linearity of a pneumatic Level-Trol pilot varies with the proportional band dial setting. It is expressed as the maximum deviation from a straight line through the end points of the calibration curve, a plot of the output pressure as a function of the input (displacement force or density change). Maximum deviation occurs at the center of the input span. Practically all points on the calibration curve lie below the straight line. The maximum deviations shown below are anticipated values since the calibration curve will vary slightly with each Level-Trol. Exact determination of linearity requires an experimental calibration curve for a particular unit.

Proportional Band Setting, %	Maximum Deviation, % of Output Span
100	1
90	2
80	3
70	4
60	5.5
50	6
40	6
30	6
20	5.5

2. Dead Band

Dead band is described as the range through which the input signal can be varied without initiating response. In Level-Trols, friction at the torque tube knife edge bearing and also at the displacer ball joint suspension introduces dead band. It can be expressed in terms of the displacement force change required. Maximum dead band is 0.018 pound displacement force.

Dead band is also present in the pneumatic pilot, due mainly to the relay. Maximum dead band, expressed as a percentage of the output pressure span, is 0.75%(20% proportional band setting) and 0.15%(100% proportional band setting).

3. Sensitivity

By definition, sensitivity is the ratio of a change in output to the change in input. For a Level-Trol density transmitter, consider the output to be the full output pressure change (normally 12 psi) and the input to be the displacement force change required to give full output pressure change. With a standard torque tube, the required input (displacement force)will be between 3.61 pounds (at 100% proportional band setting) and 0.72 pound (at 20% proportional band setting). With a thin wall torque tube, the input would be between 1.81 pounds (at 100% proportional band setting) and 0.36 pound (at 20% proportional band setting). The sensitivity is then established by dividing the output by the input.

The actual input is obtained by the basic formula from Page 3.

4. Temperature Errors

The Modulus of Rigidity of the torque tube material changes with temperature, thereby affecting the torsional deflection, giving false indication of displacement force, and creating errors in the output pressure. In the range of 70^{o}F. to 400^{o}F., standard torque tube materials exhibit the following characteristic:

a. **K-Monel,** for each 100^{o}F increase in temperature, experiences an error equal to 1.75% of the net load on the torque tube.

b. **316 Stainless Steel,** for each 100^{o}F increase in temperature, experiences an error equal to 3% of the net load on the torque tube.

The net load, sometimes called bias weight, on the torque tube is the difference between the dry weight of the displacer and the displacement force when submerged. The magnitude of the error is directly proportional to the net load on the torque tube. The smaller the net load, the smaller the error. This error is sensed in the pilot as an apparent reduction in displacement force on rising temperatures. A temperature change will cause a larger error the more sensitive the controller is sized and adjusted.

For a temperature compensated, bellows type displacer, the time required to equalize temperatures depends on the velocity, the temperature difference, and the heat transfer coefficients of the materials. In still water a 3” x 14” displacer will equalize 90% of the temperature change in 10 minutes.

5. Velocity Effects in Caged Units in Flow Lines

Extensive testing has not been conducted to determine the effects of velocity in relation to the viscosity of the liquid and the many geometric configurations of cages available for flowing applications. The following data represents merely the expected overall performance of a typical construction on water-like liquids.

For Level-Trol cages with top and bottom equalizing connections, the effect of the velocity on displacement force is as follows:

Velocity ft/min	Error Change of Displacement Force, lb.	
	Without Piezometer Ring	With Piezometer Ring[1]
2	0.001	0.001
4	0.002	0.001
6	0.004	0.002
8	0.007	0.003
10	0.010	0.005
12	– – –	0.007
14	– – –	0.009
16	– – –	0.011

1. Velocity as calculated for each flow leg.

To convert the above velocities into corresponding flows in gallons per minute, the annular area between the displacer and cage must be utilized. The cage and displacer diameters must be known. Some typical diameters are as follows:

Cage

Type	Diameter, Inch	Area, Sq. In.
249	4-1/4	14.2
249B	3-13/16	11.4
249C	2-7/8	6.5
259B	3-13/16	11.4

Displacer

Description	Diameter, Inch	Area, Sq. In.
2-3/8 x 14, Cylindrical	2-3/8	4.4
3 x 14, Cylindrical	3	7.1
3-1/2 x 32, Cylindrical	3-1/2	9.6
3 x 14, Bellows Type	3[1] / 3-15/32	7.1 / 9.5

1. Actual diameter across bellows is 3-15/32 inch. Use 3-inch diameter in calculations involving displacer sizing. Use 3-15/32 for cage flow calculations.

Use the following formula to determine the flow –

$$Q = 0.052Av$$

where:

Q =	flow, gallons per minute
A =	annular area, square inches (Difference between cage area and displacer area)
v =	velocity, feet per minute
0.052 =	constant dimensional conversion factor

Conclusion

Density transmitters are many times more sensitive than similar instruments used for simple level control. The increased sensitivity creates certain areas of concern which have been outlined in this manual. Applying the principles and solutions presented herein will enable proper evaluation of the Level-Trol as a density transmitter.

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D350402X012 / Printed in U.S.A. / 1974

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