Flow Rate Measurement Deviation Analysis considering Process Fluid Density Inconsistency for Differential Pressure Transmitter

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Abstract: During cold hydro test for a nuclear power plant, a possible process measurement deviation was found that flow rate may be indicated lower than the rated flow. The previous analysis had been performed to identify the root cause, and as a result of the analysis, the exemption of high static line pressure correction to differential pressure (DP) transmitters was one of the major deviation factors [1].
Additionally, it was identified that the process fluid density for the test was not same as the normal operating process fluid density. This paper presents considerations, such as process fluid density compensations, to be incorporated in the process flow measurement due to the process fluid density variations which may occur in the cold hydro test stage. The process fluid density deviations may be induced by fluid type difference between the test and the actual operation, and by temperature and pressure variations during the test and the actual operation, thereafter, flow rate indication decreased by 1.21%.
Keyword: Fluid Density, Flow Rate Measurement, Differential Pressure Transmitter

1 Introduction

In the previous analysis, a case study for a nuclear power plant differential pressure (DP) flow measurement system to correct the deviation caused by Rosemount DP flow transmitter miscalibration was introduced [1]. The analysis showed -1.85% flow rate indication error due to the miscalibration and no correction of high static line pressure.
This paper introduces another case study for possible flow rate deviation factor due to the process fluid density inconsistency between the plant normal operating condition and the test condition. The case study includes flow rate measurement method and calibration procedure for Rosemount DP flow transmitter [2][3].

As a conclusion, the flow rate deviation error analysis with fluid density inconsistency between the normal operating and the test condition is described.

2 Flow Measurement Method with DP

A DP transmitter with orifice plate is used for the flow measurement in reactor coolant system, chemical volume control system or safety injection system, and etc., of nuclear power plant based on Bernoulli's equation. The basic flow equation used in these calculations is based on Bernoulli's streamline energy equation and may be written as a relationship among the measured DP (H_w), the fluid density (ρ), and the volumetric flow rate (Q). The equation is from equation I-5-38 in ASME Fluid Meters, 6th edition [4]:

$$Q = 358.93\left[CY_A d^2 F_a \Big/ \sqrt{1-\beta^4}\right]\sqrt{H_w/\rho} \qquad (1)$$

2.1 Rosemount DP Flow Transmitter Calibration Procedure

Any process instrument has at least one input and one output. For a DP flow transmitter, the input process parameter is the flow DP, and the output is an electrical signal, 4~20 mA. Maximum DP produced by orifice for design flow is provided by orifice vendor [5].

Rosemount DP flow transmitter calibration procedure is as follows [3];

a. Zero based span calibration
b. Elevated or suppressed zero calibration
c. Correction for high line static pressure

2.2 Process and Instrument Data for Calculation and Analysis

In order to conduct the above procedure, the essential data related to the flow channel operating condition and specifications for the orifice flow element and transmitter are summarized in Table 1 [1][3][5].

Table 1 Data for Calculation and Analysis

Flow Channel Operating Condition	
Max. Measurement Range	0 ~ 5678 l/min
Normal Operating Pressure	144.1 kg/cm^{2}G (2050 psig)
Normal Temperature	10 ~ 48.9 ℃ (50~120 ℉)
Fluid Type	Borated Water 2.5%wt.
Flow Element (Orifice Plate) Specification	
Manufacturer	EVOQUA
Design Flow	5678 l/min
DP @ Design Flow	20,734 cmH_2O
Pipe Size	4” SCH.160
DP Transmitter Specification	
Manufacturer	Rosemount
Model	3152ND4
Accuracy	± 0.20 % span
Upper Range Limit (URL)	21,093 cmH_2O
High Static Line Pressure Span Correction Factor	1.00% input reading per 1000 psi

2.3 High Static Line Pressure Effect and Correction

Rosemount DP transmitters experience a systematic span shift when operated at the high static line pressure. However, its characteristic is linear and correctable during the calibration. Thus it is required to be calibrated out the high static line pressure span effect by the user. If it is not calibrated out, the possible error associated with the high static line pressure span effect according to Rosemount manual is 1.00% of input reading per 1000 psi (6.89 MPa) [3].

2.4 High Static Line Pressure Span Correction Method for Rosemount DP Transmitter

Firstly, the transmitter is required to be initially calibrated as zero based span calibration, thus the status before high static line pressure span correction is as follows;

- Transmitter process input: 0 ~ 20,734 cmH_2O
- Transmitter electrical output: 4 ~ 20 mA

Secondly, the high static line pressure span correction needs to be conducted using the following formula sets;

Corrected output reading (at LRV)

$$= 4mA + \left[\left(S \times \frac{P_S}{1000} \times LRV\right) \div Span\right] \times 16mA \quad (2)$$

$$= 4 + \left[\left(0.01 \times \frac{2050}{1000} \times 0\right) \div 20,734\right] \times 16$$

$$= 4mA$$

Corrected output reading (at URV)

$$= 20mA + \left[\left(S \times \frac{P_S}{1000} \times URV\right) \div Span\right] \times 16mA \quad (3)$$

$$= 20 + \left[\left(0.01 \times \frac{2050}{1000} \times 20,734\right) \div 20,734\right] \times 16$$

$$= 20.328mA$$

Where: S = high static line pressure span correction factor from Table 1
LRV = lower range value (DP_{min})
URV = upper range value (DP_{max})
P_s = static line pressure
Span = calibrated span

The calculation using the Equations (2) and (3) results in 4 mA for the lower range value and 20.328 mA for the upper range value for the transmitter.

Thirdly, the transmitter output is to be adjusted with above calculation result, 0 ~ 20.328 mA, while the input pressure at desired in service DP.

The high static line pressure span correction procedure is shown at Fig.1 which depicted as graphs with process DP versus transmitter electrical output.

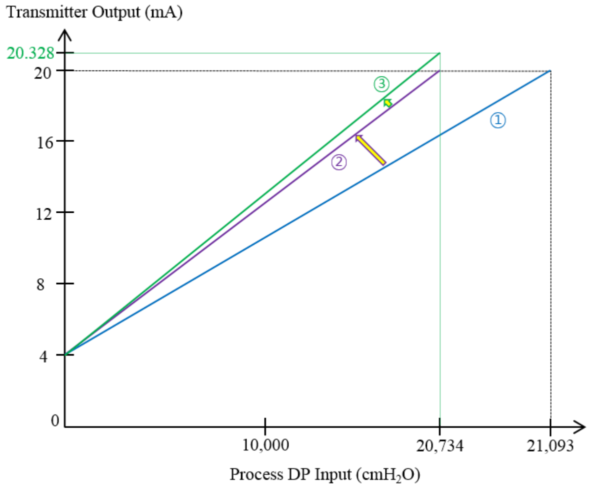

Fig.1 DP (cmH2O) versus transmitter electrical output (mA) as calibration proceeded

2.5 Signal Processing to Calculate Flow Rate with DP

The flow transmitter's output signal, 4~20 mA, is sent to the signal processing unit in proportion to the process DP as a flow rate calculation input data. The signal processing unit calculates the square root of the input in order to get the flow rate per the Equation (1).

3 Flow Indication Error Analysis due to Fluid Density Inconsistency; Calibration vs. Test condition

First of all, in order to analyze the possible flow rate deviation the process fluid types and the pressure and the temperature conditions for the normal plant operation and the test operation were investigated, and summarized in Table 2.

Table 2 shows the deviation of the calibration condition and the test operation condition at the maximum flow rate. Both conditions are at the temperature of 10 ºC (50 ºF), however, operating pressure condition and fluid types are different. During the plant normal operation the pressure is 144.1 kg/cm^2G (2050 psig), while during the test operation the pressure is down to the atmosphere, 1.034 kg/cm^2G (0 psig). Also for the plant normal operation the process fluid is 2.5%wt borated water, while for the test operation the process fluid is demineralized water. These differences bring the process fluid density deviation, which makes the flow rate measurement deviation by 1.21%. Due to this deviation the indication will be 1.21% lower than the actual flow rate.

Table 2: Comparison of Calibration Condition and Test Operation Condition

Calibration Condition	
Fluid Type	Borated Water 2.5%wt
Operation Pressure	144.1 kg/cm^2G (2050 psig)
Operation Temperature	10 ºC (50 ºF)
Fluid Density	63.835 lb/ft^3
100% Flow	5678 l/min
Deviation	0 %
Test Operation Condition	
Fluid Type	Demineralized Water
Operation Pressure	1.034 kg/cm^2G (0 psig)
Operation Temperature	10 ºC (50 ºF)
Fluid Density	62.410 lb/ft^3
100% Flow	5746.7 l/min
Deviation	1.21 %

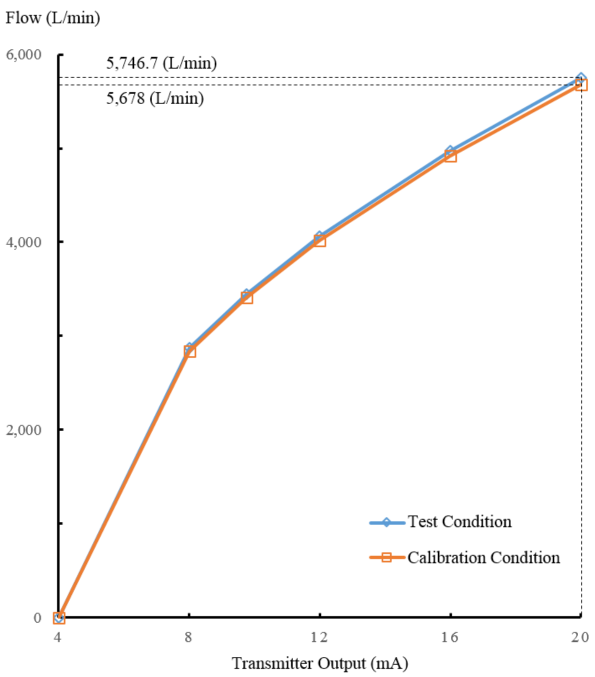

Fig. 2 Flow Rate Trend of Calibration condition and Test Operation condition

Fig. 2 shows flow rate trend versus the transmitter electrical output. This graph indicates that, at the maximum transmitter output, 20 mA, flow rate in the calibration condition is 5,678 l/min, while flow rate in the test operation condition is 5,746.7 l/min. As a result, the flow rate in the test operation condition is 1.21% higher than the calibration condition. In other words, since the same DP flow transmitter is used in both conditions, the test operation indicates 1.21% lower than the actual flow rate.

4 Conclusions

This paper presents the brief calibration procedures for Rosemount DP flow transmitter and analyzes three cases of measurement deviation caused by process fluid density inconsistency. In the plant normal operation, 2.5%wt borated water is used as the process fluid, while the test operation does not adopt the borated water. Since this process fluid type deviation causes the fluid density inconsistency, it affects the actual flow rate so that it may be slightly different from the calibrated flow rate calculation, in case the test is done without considering the fluid density inconsistency.

Because the process temperature and pressure variation is inherent in the plant operation, the careful consideration of the flow rate deviation caused by process fluid density inconsistency should be taken into account during the test period.

References

[1] E. Oh, B. R. Kim, S. H. Jeong, J. H. Choi, Y. C. Shin, and J. H. Yun, "Process Measurement Deviation Analysis for Flow Rate due to Miscalibration," Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October 27-28, 2016.

[2] Bela G. Liptak, Process Measurement and Analysis (Instrument Engineers' Handbook, Third Edition), 1995.

[3] Rosemount 3150 Series Nuclear Pressure Transmitters including the Rosemount 3152, 3153 and 3154 (Reference Manual). Rev. BC, 2015.

[4] Fluid Meters, Report of ASME Research Committee on Fluid Meters, 6th Edition, 1971.

[5] Instruction Manual EVOQUA Water Technologies, 2014.