Process Measurement Deviation Analysis for Flow Rate due to Miscalibration

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1. Introduction

During a system design test for a nuclear power plant, a possible process measurement deviation was found that flow rate may be indicated lower than the rated flow. An analysis was initiated to identify the root cause, and the exemption of high static line pressure correction to differential pressure (DP) transmitters was one of the major deviation factors. Also the miscalibrated DP transmitter range was identified as another major deviation factor. The analysis calculated the quantities of the deviation due to the miscalibration throughout the whole range of process input with mathematical approach. This paper presents considerations to be incorporated in the process flow measurement instrumentation calibration and the analysis results identified that the DP flow transmitter electrical output decreased by 3%. Thereafter, flow rate indication decreased by 1.9% resulting from the high static line pressure correction exemption and measurement range miscalibration. After re-calibration, the flow rate indication increased by 1.9%, which is consistent with the analysis result.

2. Methods and Results

In this section a case study for a nuclear power plant DP flow measurement system to correct the deviation caused by Rosemount DP flow transmitter miscalibration is introduced. This case study includes flow measurement method [1] and calibration procedure for Rosemount DP flow transmitter [2]. As a result, flow rate deviation error analysis with high static line pressure correction method is described.

2.1 Flow Measurement Method with DP

DP transmitter with orifice plate is used for flow measurement in chemical volume control system or safety injection and shutdown cooling system of nuclear power plant according to 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 between the measured DP (Hw), the fluid density (ρ), and the volumetric flow rate (Q). The equation is from ASME Fluid Meters, 6th edition, equation I-5-38 [3]:

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

2.2 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 comes from orifice design data, and the output is an electrical signal, 4~20 mA. Maximum DP produced by orifice for design flow is provided by orifice vendor [4].

Rosemount DP flow transmitter calibration procedure is as follows [2];

① Zero based span calibration
② Elevated or suppressed zero calibration
③ Correction for high line static pressure

2.3 Process and Instrument Data for Calculation and Analysis

In order to conduct following steps for calculations and analysis, the essential data related to the flow channel operating condition and specifications for flow element and transmitter are summarized in Table I [2, 4].

Table I: 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 ℃
Fluid Type	Borated Water
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

2.4 Effect and Correction for High Static Line Pressure

Rosemount DP transmitters experience a systematic span shift when operated at high static line pressure. However, it is linear and correctable during 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) [2].

2.4.1 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 calculated using the following formula sets;

Corrected output reading (at LRV)

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

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

$$= 4mA$$

Corrected output reading (at URV)

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

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

$$= 20.328mA$$

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

The calculation using the equation (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.

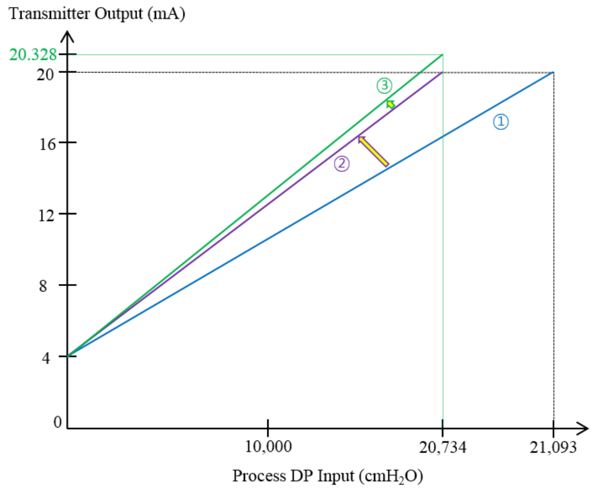

Fig. 1. DP (cmH_2O) versus transmitter electrical output (mA) as calibration proceeded

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 units in proportion to the process DP as a flow rate calculation input data. The signal processor calculates the square root of the input in order to get the flow rate per the equation (1).

2.6 Flow Indication Error Analysis due to Miscalibration

In order to analyze the possible flow rate deviation the calibration data for the flow transmitters were investigated, and analyzed as three typical calibration cases in Table II.

Table II: Three Typical Cases of DP Flow Transmitters' Calibration Status & Error Analysis

		Case 1*	Case 2**	Case 3***
Calibration Status	Process Input (cmH_2O)	0~20,734	0~20,734	0~21,093
	Tx. Output (mA)	4~20.328	4~20	4~20
Flow Rate Indication @ Max. process DP (20.734 cmH_2O) (l/min)		0~5678	0~5620.7	0~5572.7
Calibration Error (%)		0	-1.61	-2.95
Indication Error (%)		0	-1.01	-1.85

*Case 1: High static line pressure effect corrected (ideal case)
**Case 2: High static line pressure effect not corrected
***Case 3: High static line pressure effect not corrected and calibrated by transmitter URL, not process input

Table II shows the calibration and indication errors in the three calibration cases at the maximum DP condition, 20,734 cmH_2O. The case 1 has no errors on the calibration and indication, while the case 2, which was not high static line pressure corrected, has the -1.61% calibration error, and resulted in -1.01% indication error. And the case 3, which was not high static line pressure corrected and calibrated by URL, has -2.95% calibration error, and resulted in -1.85% indication error. Due to these calibration errors the indication resulted in the lower flow rate indication than the actual flow rate by -1.01% to -1.85%.

Fig. 2 shows the transmitter electrical output trend analysis per the three calibration cases. This graph indicates that, at the maximum DP condition, the transmitter output in case 2 is 20.000 mA and that in case 3 is 19.728 mA, while that in case 1 is 20.328 mA. In other words, the transmitter output in case 2 and 3 deviate by -1.61% and -2.95% from that in case 1, respectively, at the maximum DP condition.

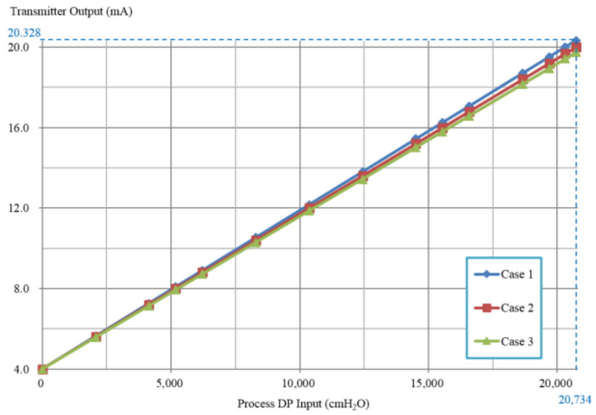

Fig. 2. Transmitter electrical output (mA) trend per case 1, 2 and 3

Fig. 3 shows the flow rate indication trend analysis per the three calibration cases. This graph indicates that, at the maximum DP condition, the flow rate indication in case 2 is 5,260.7 l/min and that in case 3 is 5572.7 l/min, while that in case 1 is 5,678 l/min. In other words, flow rate indication in case 1 and 2 deviate by -1.01% and -1.85% from that in case 1, respectively, at the maximum DP condition.

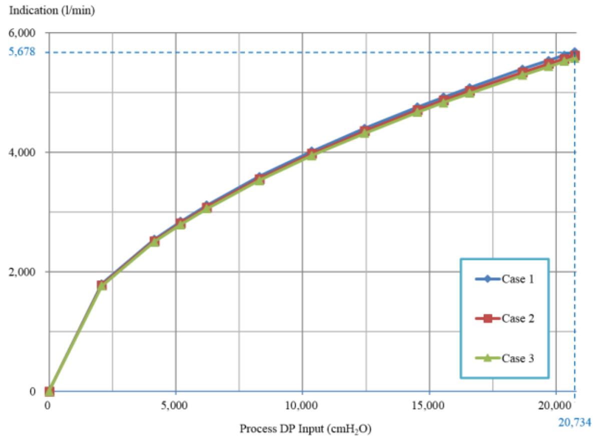

Fig. 3. Flow rate indication (l/min) trend per case 1, 2 and 3

3. Conclusions

This paper presents the brief calibration procedures for Rosemount DP flow transmitter, and analyzes possible three cases of measurement deviation including error and cause. Generally, the DP transmitter is required to be calibrated with precise process input range according to the calibration procedure provided for specific DP transmitter. Especially, in case of the DP transmitter installed in high static line pressure, it is important to correct the high static line pressure effect to avoid the inherent systematic error for Rosemount DP transmitter. Otherwise, failure to notice the correction may lead to indicating deviation from actual value.

REFERENCES

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