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UNCERTAINTY ANALYSIS FOR DETERMINATION OF LONG-TERM DRIFT AND MOUNTING POSITION FOR PRESSURE TRANSMITTER CALIBRATION

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Abstract. *A reliable estimation of standard uncertainty can provide an assurance to instrument calibration process. This paper focuses on analyzing the influences of long-term drift of calibration standard and mounting position of instrument under test on standard uncertainty of pressure transmitter calibration in order to verify whether these factors are significant sources of Type B uncertainty. The mathematical model for estimating the standard uncertainty from major sources including two interested influence factors is developed. Based on the proposed model, the standard uncertainties were calculated using historical data of calibrated transmitters from a calibration laboratory in Thailand during the year 2014 to 2017. The influences of the long-term drift of the standard pressure source and standard instrument since their last calibration as well as the effects of the mounting position type of instrument under test can be examined from the estimated uncertainties. The analysis results show that the mounting position of the transmitter being calibrated should be considered during calibration process. The proposed uncertainty model is helpful for calibration stakeholders to understand more about the influences on standard uncertainty to achieve more reliable estimation when calibrating pressure transmitters with electrical output.*
Keywords: Calibration, Standard uncertainty, Type B evaluation, Long-term drift, Mounting position, Pressure transmitter

1. **Introduction.** Periodical calibration is an essential activity to maintain instrument accuracy for effective plant performance and safety management in process industries such as paper and pulp, food and beverage, oil and gas, and chemical processing [1]. There are several calibration uncertainty standards, guides, and resources available [2-7]. The uncertainty in measurement results for instrument calibration can come from various sources such as the reference standard (or calibrator), the device being calibrated (or unit under test), the calibration method, the person making the measurements, and environmental conditions. There are two common methods in estimating standard uncertainty: Type A and Type B. The former evaluation of standard uncertainty is based on the statistical analysis of a series of independent observations, while the latter evaluation of standard uncertainty is based on other than the statistical analysis of a series of independent observations. Thus, the Type A evaluation can be obtained by calculation, but the Type B evaluation can be obtained by estimation. The successful evaluation of Type B standard

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uncertainties depends on the detailed knowledge of measurement process as well as the experience of the person making the measurements [2]. An approach based on curve fitting and data regression for establishment of measurement uncertainty for pressure dial gauges and transducers has been introduced [8]. A structured, step-by-step method to determine measurement uncertainty parameters for micrometer and pressure gauge has been also proposed [9]. Moreover, a technique based on modified strength-weakness-opportunities-threats (SWOT) analysis for managing calibration intervals for temperature and pressure transmitters has been presented [10]. In order to be an alternative guideline for calibrating pressure transmitters with electrical output, this paper aims at analyzing whether long-term drift of calibration standard and mounting position of device under test are significant sources of Type B uncertainty. The pressure transmitter calibration process at a calibration laboratory in Thailand was utilized as a case study for the proposed uncertainty analysis. The long-term drifts of standard pressure source (or pressure calibrator) and standard instrument (or electric pressure calibrator) as well as four types of transmitter mounting position are interested influence factors. The mathematical model to estimate the standard uncertainty including interested uncertainty sources for calibration process is presented. The historic data obtained during pressure calibration in 2014-2017 from the studied calibration laboratory were used to calculate the standard uncertainties for the calibrated transmitters by employing the proposed model. The influences of the interested uncertainty sources can be investigated from the results obtained from the proposed model.

The rest of this paper is organized as follows. The pressure transmitter calibration and possible influence quantities for standard uncertainty evaluation are introduced in Section 2. The proposed uncertainty model and the analysis results and discussion are described in Section 3 and Section 4, respectively. The conclusions are given in Section 5.

2. **Pressure Transmitter Calibration.** Pressure transmitters are commonly used in the process industry sector for measuring pressure, flow, and level in monitoring and control systems. The pressure transmitter can be calibrated in the plant field or at the workshop bench [11]. For field calibration, the portable calibration equipment is used to calibrate the instrument from its installed location on site. For workshop calibration, the instrument was removed from its installed location and taken into the workshop to calibrate by using stationary calibration equipment. Additionally, a combination of field calibration and workshop calibration is sometimes preferable to calibrate the instruments out of the field by using portable calibration equipment. In order to achieve accreditation for calibration process, the instruments should be calibrated in a calibration lab under controlled environmental conditions. As the rule, recalibration should be performed at

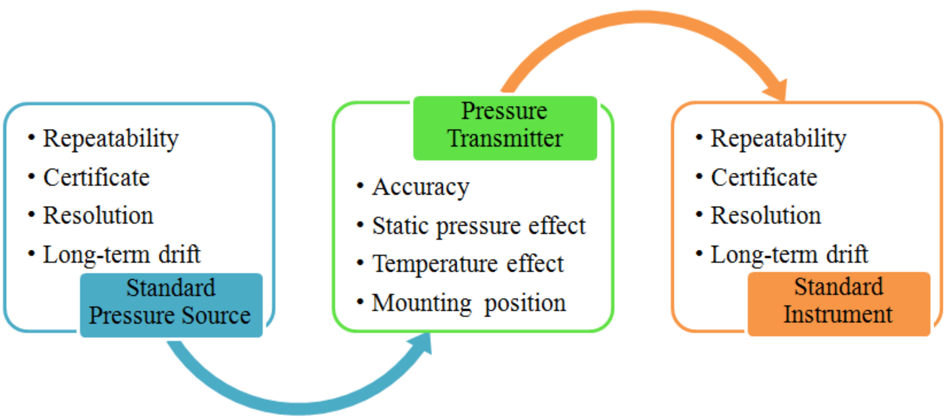
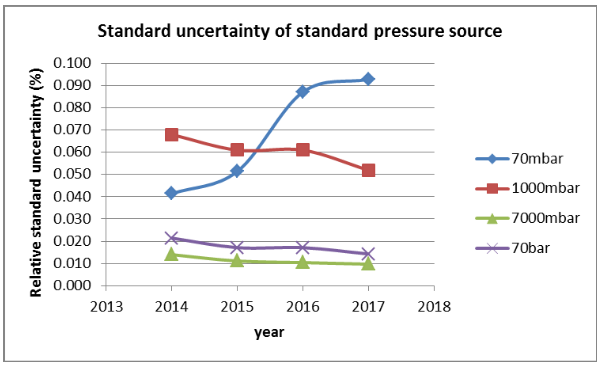
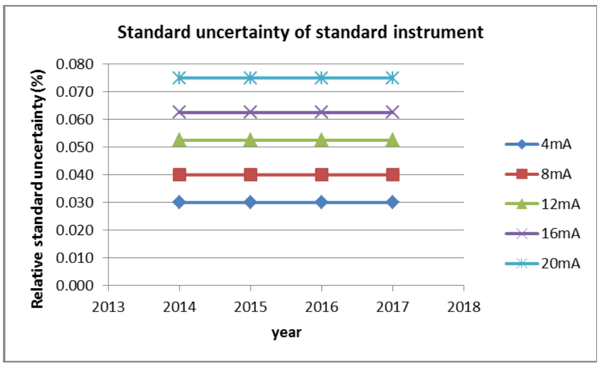


FIGURE 1. Possible influence quantities for uncertainty evaluation

least once a year. The possible influence quantities for standard uncertainty evaluation of the pressure transmitter calibration are illustrated in Figure 1. In this paper, both the long-term drifts of the standard pressure source (or pressure calibrator) and standard instrument as well as the mounting position of the transmitter being calibrated are interested to investigate their influences on the standard uncertainty evaluation. The long-term drifts of four different standard pressure sources providing different maximum output values of 70 mbar, 1,000 mbar, 7,000 mbar, and 70 bar, respectively, were observed through their calibration certificates for four successive years (2014-1017). Similarly, the long-term drift of the standard instrument providing the output range of 4-20 mA was observed through its calibration certificates in 2014-1017. The Type B standard uncertainties of the standard pressure source and standard instrument can be calculated as the standard deviation of the rectangular probability distribution. The plots of the relative standard uncertainty of the studied standard pressure sources and standard instrument are shown in Figures 2(a) and 2(b), respectively. From Figure 2(a), it is evident that the long-term drifts occur in all studied standard pressure sources, especially, the drift in the standard source providing maximum output of 70 mbar occurs very fast. From Figure 2(b), it is seen that no long-term drift occurs in the standard instrument, and its output appears to be stable. There are various types of pressure transmitters such as differential, absolute, gauge, and vacuum. The location for installing the pressure transmitter in relation to the process pipe is dependent on the process. The pressure transmitter can typically be mounted in any of four positions, depending on the application requirement, as shown in Figure 3: direct mount (called type A), flush mount (called type B), flange mount (called type C), and remote diaphragm seals (called type D). From Figure 3, the pressure transmitters should be calibrated in the vertical position. Mounting the transmitter in any other position will shift the zero point to the equivalent amount of liquid



(a) Standard pressure source



(b) Standard instrument

FIGURE 2. Long-term drifts of reference standard

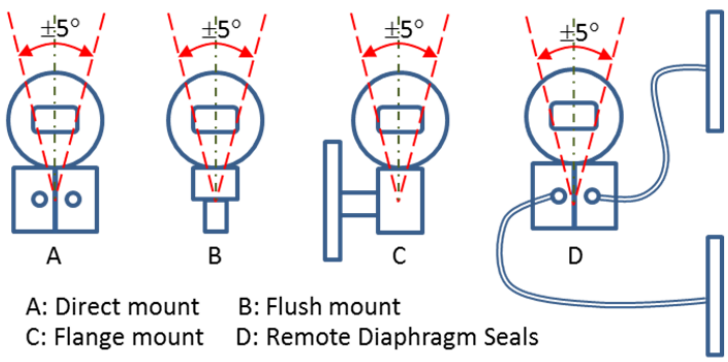


FIGURE 3. Mounting position types of pressure transmitter

head pressure caused by the varied mounting position [12]. The mounting position of pressure or differential pressure transmitter is critical as the transmitter spans become smaller. For example, the maximum zero shift of 2.5 mmHg for the absolute transmitter or 1.5 inH_2O for the draft range transmitter can result from the mounting position, which is rotated 90 degrees from vertical. In addition, the typical zero shift of 0.12 mmHg or 0.20 inH_2O can occur for the 5-degree rotation from vertical (θ_v) [13]. If it is possible to assess only the upper and lower bounds of an error, the rectangular probability distribution should be assumed for the uncertainty associated with this zero shift error.

3. **Proposed Uncertainty Model.** For analyzing whether long-term drift of calibration standard and mounting position of instrument under test are significant sources of Type B uncertainty for calibrating pressure transmitters with electrical output, the new uncertainty model to estimate the standard uncertainty including Type A and Type B methods can be expressed by

$$\begin{aligned} S_x = C_p\left(\Delta P_u + \Delta P_r + D_p\right) + S_r + \Delta S_u + \Delta S_r + D_m \\ + C_p\Delta PT_a + C_p\Delta PT_s + C_p\Delta PT_t + C_v\theta_v \end{aligned} \tag{1}$$

where C_p and C_v denote the sensitivity coefficients, which can be stated as

$$C_p = \Delta C_s/\Delta C_p \quad \forall\, \Delta P_u, \Delta P_r, D_p \tag{2}$$

$$C_v = \Delta C_s/\Delta C_v \quad \forall\, \theta_v \tag{3}$$

The notation of the parameters in (1)-(3) is summarized in Table 1. The proposed model is particularly suitable for calibrating the pressure transmitter, which is configured its indicator display in engineering unit according to its purpose of measurement. To save space, only one transmitter with maximum output of 50 mbar is used as an example for showing the uncertainty analysis by using the proposed uncertainty model when calibrating this transmitter example. The knowledge regarding the input/influence quantities is preferably summarized in Table 2, which is the uncertainty budget to illustrate the components that contribute to the standard uncertainty in measurement results in calibrating the transmitter example. It should be noted that the reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$ for providing a coverage probability of approximately 95%. The uncertainty evaluation was carried out in accordance with the UKAS requirements [2].

Table 1. Parameters in the proposed uncertainty model

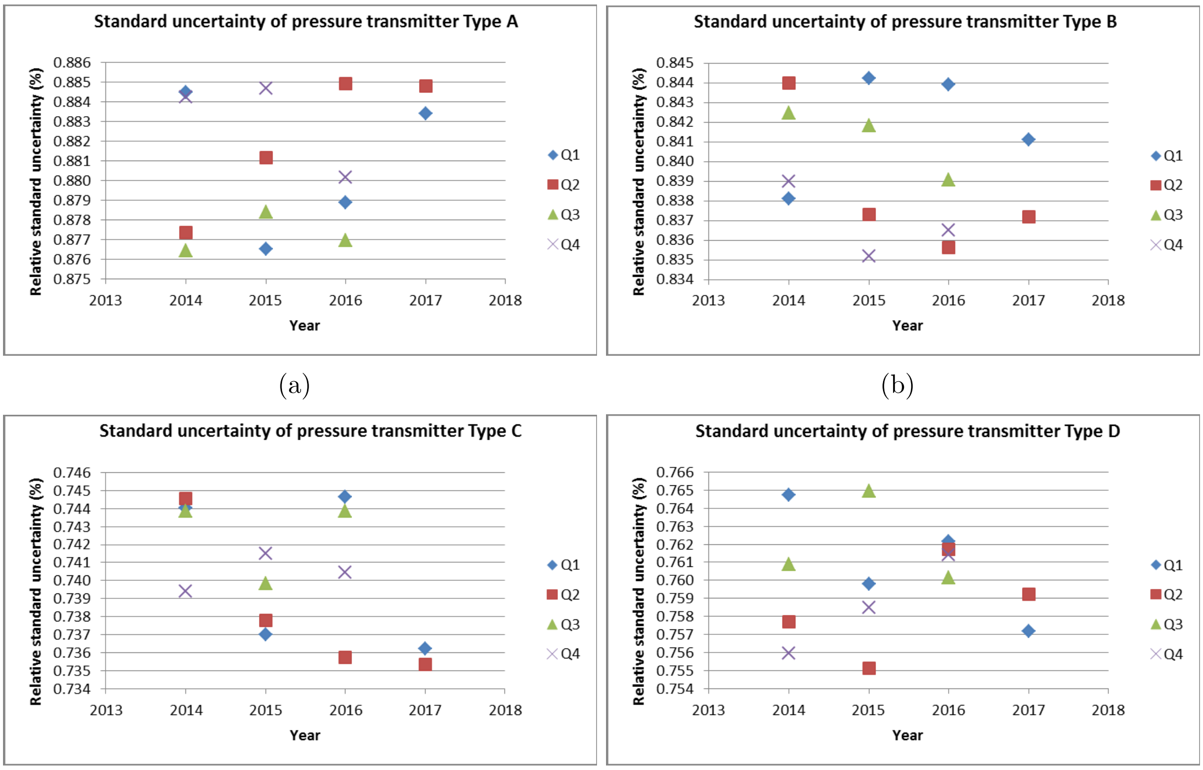
Parameter	Description	Unit
S_x	Output signal	mA
ΔP_u	Certificate of standard pressure source calibration	bar
ΔP_r	Resolution of standard pressure source	bar
D_p	Drift of the standard pressure source since last calibration	bar
S_r	Repeatability of standard instrument	mA
ΔS_u	Certificate of standard instrument calibration	mA
ΔS_r	Resolution of standard instrument	mA
D_m	Drift of the standard instrument since last calibration	mA
ΔPT_a	Pressure transmitter accuracy	bar
ΔPT_s	Combined zero and span static pressure effect	bar
ΔPT_t	Combined zero and span temperature effect	bar
θ_v	Mounting position effect	Degree
ΔC_s	Sensitivity coefficient of output signal span	mA
ΔC_p	Sensitivity coefficient of input signal span	bar
ΔC_v	Sensitivity coefficient of input signal span	Degree

Table 2. Uncertainty budget for the transmitter used as an example for calibration

Symbol	Source of uncertainty	Value (±)	Prob. Dist.	Divisor	C_i	$U_i(S)$ (mA)	V_i or V_{eff}
ΔP_u	Certificate of standard pressure source calibration	0.075	Nor.	2	0.320	0.0120	∞
ΔP_r	Resolution of standard pressure source	0.100	Rec.	1.732	0.320	0.0185	∞
D_p	Drift of the standard pressure source since last calibration	0.014	Rec.	1.732	0.320	0.0043	∞
S_r	Repeatability of standard instrument	0.006	Nor.	1	1.000	0.0062	2
ΔS_u	Certificate of standard instrument calibration	0.00012	Nor.	2	1.000	0.0001	∞
ΔS_r	Resolution of standard instrument	0.001	Rec.	1.732	1.000	0.0006	∞
D_m	Drift of the standard instrument since last calibration	0.000	Rec.	1.732	1.000	0.0000	∞
ΔPT_a	Pressure transmitter accuracy	0.020	Rec.	1.732	0.320	0.0037	∞
ΔPT_s	Combined zero and span static pressure effect	0.081	Rec.	1.732	0.320	0.0150	∞
ΔPT_t	Combined zero and span temperature effect	0.163	Rec.	1.732	0.320	0.0300	∞
θ_v	Mounting position effect	1.000	Rec.	1.732	0.0996	0.0575	∞
$u_c(S)$	Combined standard uncertainty		Nor.			0.071	> 500
U	Expanded uncertainty		Nor.			0.141	> 500

4. **Analysis Results and Discussion.** At the studied calibration laboratory, more than 3,000 pressure transmitters, used in the paper and pulp manufacturers, were calibrated during 2014-2017. Some obtained calibration data were used to estimate the standard uncertainties by utilizing the proposed uncertainty model. The results of standard uncertainty analysis for four mounting position types of calibrated transmitters are shown in Figure 4, where Q1, Q2, Q3 and Q4 represent four transmitters calibrated by using the same reference standard at different months for setting $\theta_v = 1°$. For example, the transmitters Q1, Q2, Q3, and Q4 were calibrated on February, May, August, and November, respectively, and these transmitters were recalibrated once a year during 2014-2017. Figures 4(a)-4(d) display the plots of the relative standard uncertainty from calibrating the type A, type B, type C, and type D transmitters, respectively. Figure 5(a) shows the plots of the relative standard uncertainty of the transmitter Q1 of four mounting position types in Figure 4, where the transmitters were calibrated by the same reference standard at the same month during 2014-2017. Figure 5(b) illustrates the different between the relative standard uncertainties of the transmitter Q1 of two successive years. Figure 6 displays the plots of the relative standard uncertainties of the transmitter Q1 of four mounting position types, where these uncertainties were estimated using the proposed model as (1) by setting θ_v to be 0°, 1°, 2°, 3°, 4°, and 5°. Figure 6(a) shows the radar chart of the estimated uncertainties by using the values of θ_v to be represented on the axes, while Figure 6(b) shows the radar chart of the estimated uncertainties by using the mounting position type to be represented on the axes.

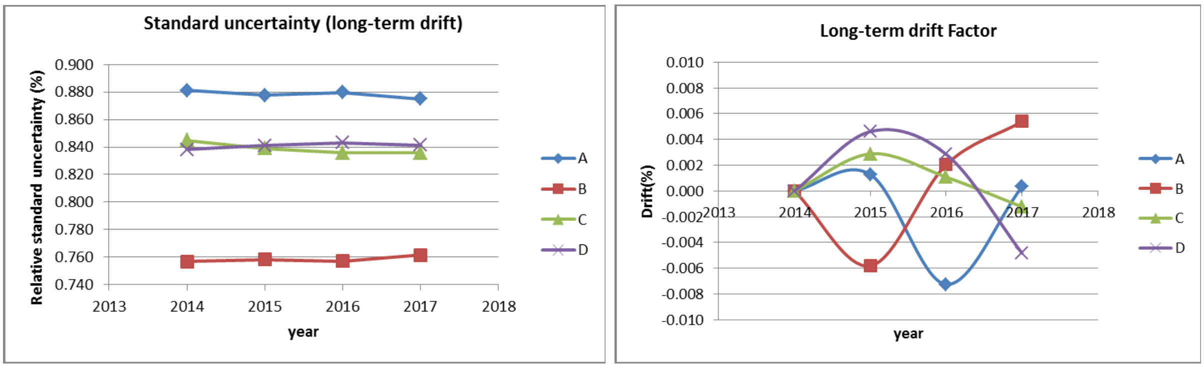
It is apparent that the standard uncertainty is slightly influenced by the long-term drift of the standard pressure source, whereas it is largely influenced by the mounting position of transmitter being calibrated. Thus the mounting position of instrument under test is



(a) (b)

(c) (d)

FIGURE 4. Estimated standard uncertainties of the studied transmitter calibration

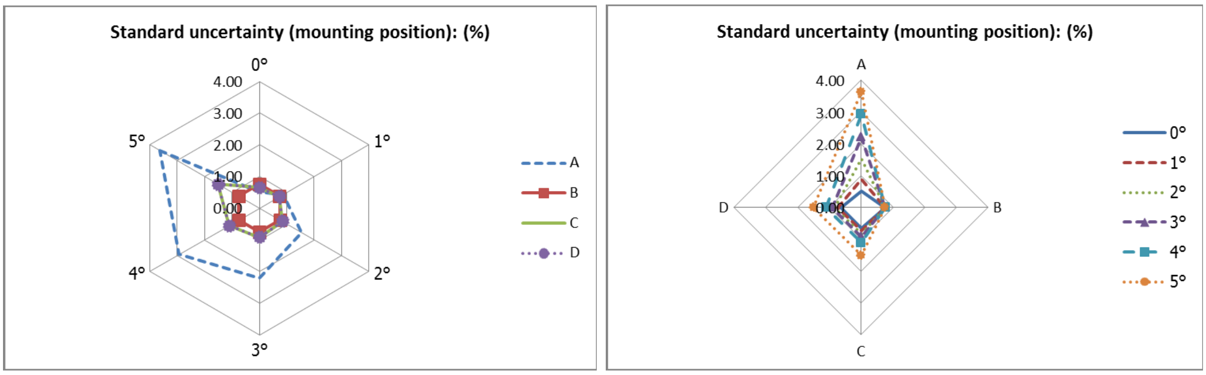


(a) (b)

FIGURE 5. Trends of relative standard uncertainty influenced by the long-term drift of standard pressure source

more significant than the long-term drift of calibrator standard for considering as one of uncertainty sources for Type B evaluation.

5. **Conclusions.** For calibrating pressure transmitters with electrical output, the mathematical model to estimate the standard uncertainty has been presented. Based on the proposed model, the influences of the long-term drifts of standard pressure source and standard instrument as well as the types of transmitter mounting position have been analyzed. The obtained analysis results demonstrate the mounting position of device under test should be considered when calibrating the pressure transmitters. It is recommended that the transmitter being calibrated should be mounted in the same actual position where it is used.



(a) (b)

FIGURE 6. Radar charts of standard uncertainty influenced by the mounting position type

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