ANALYSIS ON THE INFLUENCE OF PRESSURE ADJUSTMENT REFERENCE IN PRESSURE GAUGE CALIBRATION BASED ON DKD-R 6-1: 2014 GUIDELINE

ANALISIS PENGARUH ACUAN PENGATURAN TEKANAN PADA KALIBRASI PRESSURE GAUGE BERDASARKAN PEDOMAN DKD-R 6-1: 2014

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ABSTRACT

DKD-R 6-1: 2014 is a widely used reference document in pressure measuring device (PMD) calibration. However, many users do not understand exactly its substance. For example, the pressure adjustment during the calibration is based on the reference (STD) reading or the unit under test (UUT) reading, according to the DKD-R 6-1: 2014 clause 7 Calibration Method. Therefore, in this research, calibration of barometer as one of PMD, from range 850 hPa to 1,050 hPa, has been performed to analyze the influence of those two methods to the calibration results and the difficulty or ease in measurement process. The result shows that both methods have maximum different correction of 0.01 hPa, relevant with the uncertainty claim of 0.06 hPa at 850 hPa and 0.05 hPa at 1,050 hPa respectively. Measurement by pressure adjustment according to the UUT reading is easier to be performed since UUT has less digit resolution than the reference standard. However, the reading stability of the reference standard needs to be taken into account since it has more digit resolution in order to get more accurate measurement results.

Keywords: pressure gauge, pressure adjustment, barometer, calibration, DKD-R 6-1: 2014

ABSTRAK

DKD-R 6-1: 2014 merupakan dokumen acuan yang umum digunakan dalam kalibrasi alat ukur tekanan. Akan tetapi, tidak sedikit yang masih belum memahami benar substansinya. Salah satunya tentang acuan pengaturan tekanan pada saat kalibrasi, dalam hal ini berdasarkan pembacaan standar (STD) atau pembacaan alat yang dikalibrasi (UUT) sesuai dengan dokumen acuan DKD-R 6-1: 2014 butir 7 tentang metode kalibrasi pressure gauge*. Oleh karena itu, dalam penelitian ini dilakukan pengukuran dan analisis hasil kalibrasi barometer sebagai salah satu alat ukur tekanan pada rentang 850 hPa hingga 1.050 hPa dengan dua metode berbeda, yakni pengukuran dengan pengaturan tekanan mengacu pada pembacaan STD dan pengukuran dengan pengaturan tekanan mengacu pada pembacaan UUT untuk mengetahui pengaruh perbedaan pengaturan tekanan dari kedua metode tersebut terhadap hasil kalibrasi serta bagaimana kemudahan pengambilan datanya. Hasil penelitian menunjukkan bahwa kedua metode tersebut memiliki perbedaan nilai koreksi sebesar 0,01 hPa, relevan terhadap klaim ketidakpastian sebesar 0,06 hPa pada titik 850 hPa serta 0,05 hPa pada titik 1.050 hPa. Pengukuran dengan pengaturan tekanan mengacu pada pembacaan UUT lebih mudah dilakukan karena memiliki resolusi lebih besar dibandingkan resolusi standar. Namun, kestabilan pembacaan pada referensi standar perlu diperhatikan karena memiliki resolusi lebih kecil atau lebih teliti untuk mendapatkan hasil pengukuran yang lebih akurat.*

***Kata* kunci:** *pressure gauge, pengaturan tekanan, barometer, kalibrasi, DKD-R 6-1: 2014*

1. INTRODUCTION

Pressure measurements are important in many industries, for example in oil and gas (Lin & Liang, 2012), blood pressure measuring in medical industries (Greff et al., 2009) or water distribution systems (Yoo, Chang, Jun, & Kim, 2012). Even, pressure measurement is used for predicting tsunami's maximum height and weather forecasting methods (Igarashi et al., 2016). Therefore, an accurate measurement of pressure was required.

There are many types of instrument used to measure pressure, which usually called as pressure measuring devices (PMD). Recently, electromechanical pressure gauges are used as the reference pressure devices in many industries, instead of using pressure balances or dead weight tester (DWT).

Pressure gauges with digital outputs are commonly used to efficiently calibrate pressure measuring device (PMD) due to its usability and versatility (Kajikawa & Kobata, 2015).

However, when pressure gauges are used as the reference device, it should be calibrated first using a higher accuracy class pressure gauge or by using dead weight tester for more precise and accurate pressure measurement (Islam, Danish, & Khan, 2016). Technical requirement and calibration of PMD has been described clearly in DKD-R 6-1: 2014, BS-EN 837-1, and EURAMET/cg-17/v.01. In the DKD-R 6-1 point 7 for pressure gauge calibration method, it is said that the comparison of the reference standard or working standard (STD) with the unit under test (UUT) can be performed in two different methods, which are adjustment of the pressure according to the indication of the calibration item (UUT), or adjustment of the pressure according to the indication of the standard (DKD, 2014). However, there is no further explanation about discrepancies results between both calibration methods, neither in the DKD-R 6-1: 2014 nor in any scientific publication.

The purpose of this paper is to analyze the effect if the pressure readings from either STD or UUT in each calibration point are adjusted to the nominal pressure alternately. Instead of DWT, a high accuracy class of digital manometer is used as STD to compare with the reading from digital barometers as UUT since DWT is difficult to be adjusted.

Some comprehensive investigation and recommendation will be made since many calibration laboratories perform calibration of PMD using PMD with digital outputs as the reference standard.

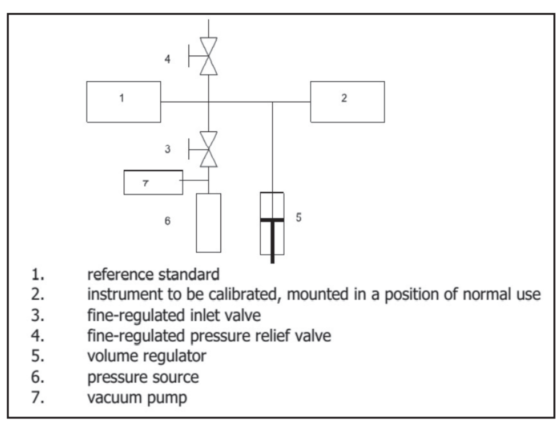
2. THEORY

A barometer measures the air pressure of the Earth’s atmosphere. The atmospheric pressure is generated by the Earth’s gravity acting on mass of air in the atmosphere. The atmospheric pressure depends on the local environmental conditions such as air temperature, altitude, and weather pattern (Fitzgerald & Jack, 2008).

Barometers come in many different types, from mercury filled glass instruments (Ooiwa, Ueki, & Kaneda, 2005), mechanical aneroid instruments to resonant sensors made using silicon fabrication technology (Cheng et al., 2014). Digital barometers are commonly used in the industry recently due to its usability and versatility. All digital barometers have pressure transducer that converts the force generated by the pressure into an electrical signal using analog-digital converter (ADC). The most common type of transducer is a thin metal diaphragm with the atmospheric pressure on one side and a vacuum on the other side. The changing atmospheric pressure deflects the diaphragm. Currently, the best performing barometers are based on silicon or quartz resonant sensors whose frequency depends on the applied pressure.

Source: Wikipedia (2005)

Figure 1. Barometer, One of PMD



Source: EURAMET (2017)

Figure 2. Set Up Installation of PMD Calibration

The installation set up for PMD, including barometer calibration, is basically described in Figure 2 (EURAMET, 2017). Reference standard (1) is connected with the instrument to be calibrated or UUT (2). Between them, there are two valves, which one valve (4) as fine-regulated pressure relief valve for venting or isolating with the open atmospheric pressure. The other valve (3) is a fine-regulated inlet valve for supplying the pressure from the pressure source (6) or for vacuuming the system through the vacuum pump (7). A volume regulator (5) is useful for fine-adjusting the pressure during the calibration. Vacuum gauge is necessary to measure the residual pressure of the system after being evacuated using vacuum pump (EURAMET, 2017).

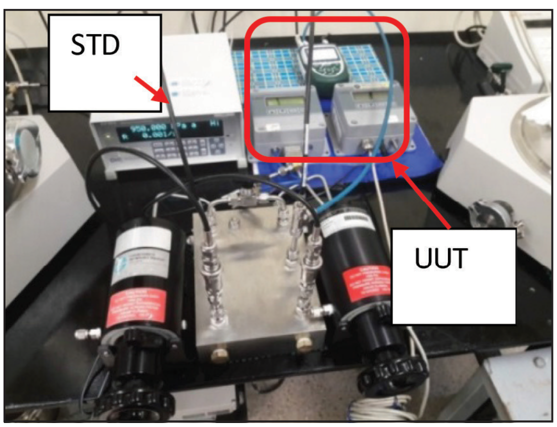


Figure 3. Method 1: Pressure Adjustment to the Indication of STD

3. METHODOLOGY

In this research study, multicalibration of three digital barometers (Vaisala PTB220AAC2A1A2BB, Vaisala PTB200AD, and Almemo 2590) in the range of 850–1050 hPa are performed using Reference Pressure Monitor RPM4 A160k manufactured by DH Instruments, Inc. (now manufactured by Fluke) as the reference standard. The measurement takes three cycles with eleven measurement points and interval step of 20 hPa.

The calibration is performed alternately using two methods, refers to the DKD-R 6-1: 2014 point 7 for pressure gauge calibration method. In the first method, the pressure indication of the RPM4 A160k as the reference standard is adjusted to the nominal pressure in each measurement point, as shown in Figure 3 and Figure 4. The UUT reading is taken after the RPM4 A160k reach the nominal target pressure and stabilized, indicated by the rate of pressure 0,000 hPa per second. Height difference between STD and UUT is adjusted to zero in order to eliminate head correction, even though the effect is small due to the density of the nitrogen gas as the pressure medium.

In the second method, the pressure indication of UUT is adjusted to the nominal pressure in each measurement point. Since the UUT consists of three digital barometers, one of the UUTs is selected to be adjusted (Figure 5), which in this case is Vaisala PTB220AAC2A1A2BB (marked as red dotted line), as shown in Figure 6.

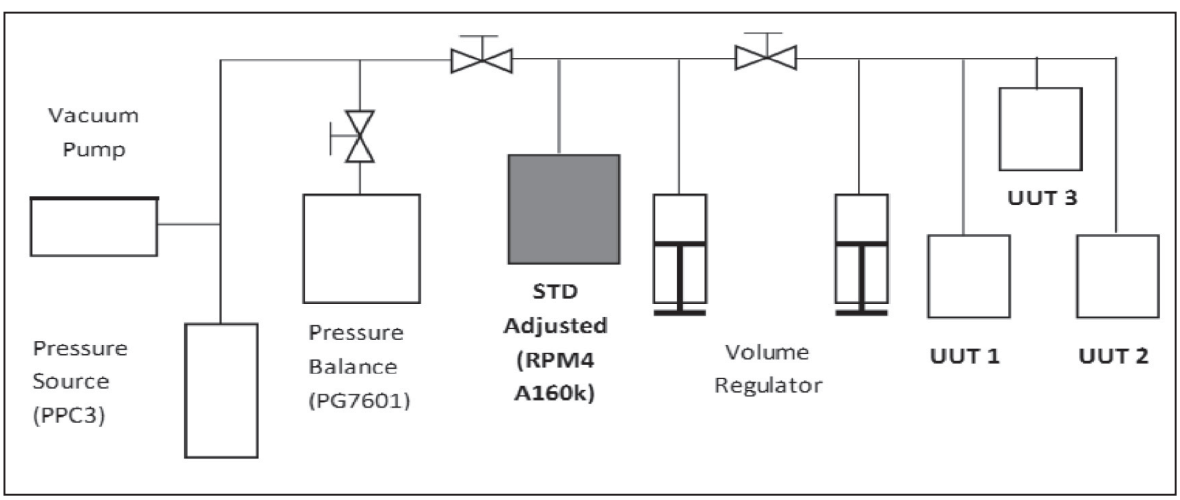


Figure 4. Set Up Calibration of Method 1 (Pressure Adjustment to the Indication of STD)

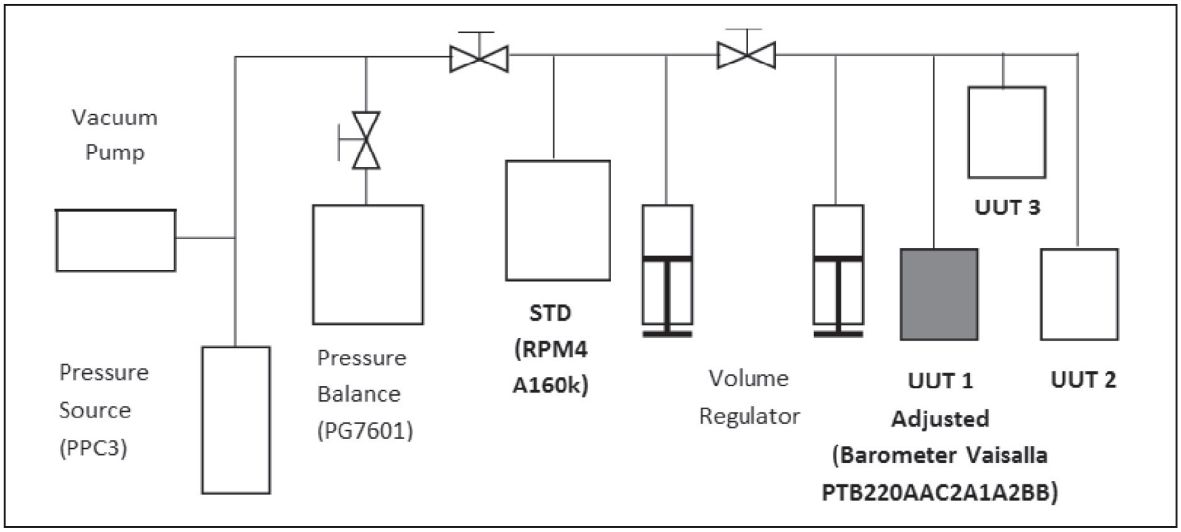


Figure 5. Set Up Calibration of Method 2 (Pressure Adjustment to the Indication of UUT)

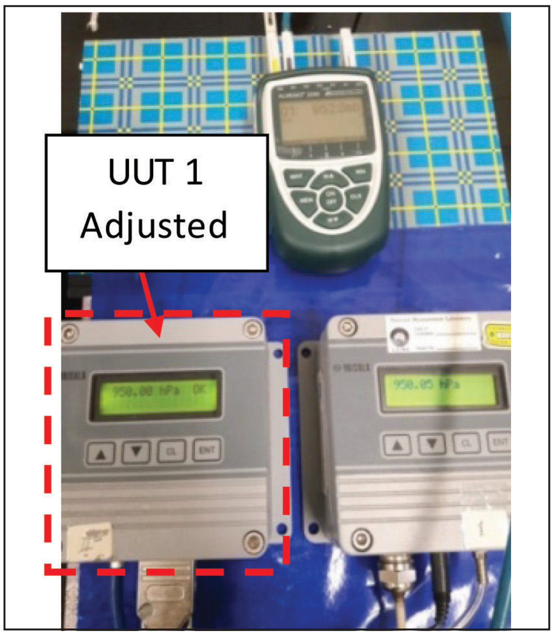


Figure 6. Method 2: Pressure Adjustment to the Indication of UUT

The reading is taken after pressure is stabilized, indicated by the "OK" on the Vaisala LCD display, also after RPM4 A160k indication is stabilized.

Error and uncertainty are calculated based on mathematical model using equation (1) below.

$$\Delta p_{mean} = p_{ind.mean} - p_{standard} + \sum_{i=1}^{3} \delta p \quad \text{......... (1)}$$

where:

Δp_{mean} = error of pressure reading

$p_{ind.mean}$ = pressure reading from UUT

$p_{standard}$ = pressure reading from STD

$p_{ind.mean}$ implies the uncertainty of UUT from its resolution, while $p_{standard}$ implies the uncertainty of STD from traceability of the STD itself, along with the instability of STD from recalibration history. Uncertainty of the resolution from the STD is already included the uncertainty of STD, therefore it does not need to be recalculated again. Other components, noted with $\sum_{i=1}^{3} \delta p_i$, gives uncertainty contribution, which comes from repeatability, zero deviation, and hysteresis. Reproducibility can also be included if there is different treatment in calibration, like reinstallation with different torque (Ega & Samodro, 2014).

4. RESULTS AND DISCUSSION

From three measurement cycles with eleven measurement points and interval step of 20 hPa, the average reading of the STD and the UUT from Method 1 and Method 2 are described in Table 1. Bold marks on the reading values indicate that the pressure was adjusted to the nominal pressure. The indication reading of the STD (RPM4 A160k) in this case has been calibrated and corrected from the certificate calibration results using pressure balance DHI PG7601 as the primary pressure standard. From Table 1, it can be seen that adjusting the STD reading to the nominal pressure is far more difficult, compared to adjust the UUT reading. Therefore, method 2 which is to adjust the UUT reading to the nominal pressure in each measurement point is easier and more practical.

Table 1. Average Raw Calibration Data of Both Methods from Three Cycle Measurements

Method 1		Method 2	
STD Reading (hPa)	UUT Reading (hPa)	STD Reading (hPa)	UUT Reading (hPa)
850.007	850.25	849.843	**850.00**
870.004	870.25	869.828	**870.00**
890.002	890.26	889.831	**890.00**
910.002	910.26	909.818	**910.00**
930.003	930.27	929.812	**930.00**
950.002	950.28	949.809	**950.00**
970.003	970.28	969.797	**970.00**
990.004	990.29	989.801	**990.00**
1010.001	1010.29	1009.786	**1010.00**
1030.003	1030.29	1029.791	**1030.00**
1050.002	1050.28	1049.793	**1050.00**

Table 2. Calibration Results of the Vaisala PTB220AAC2A1A2BB Using Method 1 (Pressure Adjusted to the Indication of STD)

UUT Reading (hPa)	Correction (hPa)	Uncertainty (hPa)
850.25	-0.17	0.06
870.25	-0.17	0.05
890.26	-0.18	0.05
910.26	-0.18	0.05
930.27	-0.19	0.05
950.28	-0.20	0.05
970.28	-0.20	0.05
990.29	-0.21	0.05
1010.29	-0.21	0.05
1030.29	-0.21	0.05
1050.28	-0.20	0.05

Table 3. Calibration Results of the Vaisala PTB220AAC2A1A2BB Using Method 2 (Pressure Adjusted to the Indication of UUT – Vaisala PTB220AAC2A1A2BB)

UUT Reading (hPa)	Correction (hPa)	Uncertainty (hPa)
850.00	-0.16	0.06
870.00	-0.17	0.06
890.00	-0.17	0.05
910.00	-0.18	0.05
930.00	-0.19	0.05
950.00	-0.19	0.05
970.00	-0.20	0.05
990.00	-0.20	0.05
1010.00	-0.22	0.05
1030.00	-0.21	0.05
1050.00	-0.21	0.05

The measurement results from the both methods (Method 1 and Method 2) are shown in Table 2 and Table 3 respectively. It can be seen that the measurement result, with two different methods of pressure adjustment in the pressure measuring device calibration, in slightly different calibration results with maximum difference correction of 0.01 hPa is relevant with the expanded uncertainty claim of 0.06 hPa at 850 hPa and 0.05 hPa at 1050 hPa respectively. Also, in other measurement points from 850 hPa until 1050 hPa, the difference between both methods are also not significant.

Both methods show the same characteristic as the greater correction value along with the increasing nominal pressure, as described in the Figure 7. The uncertainty budget for both

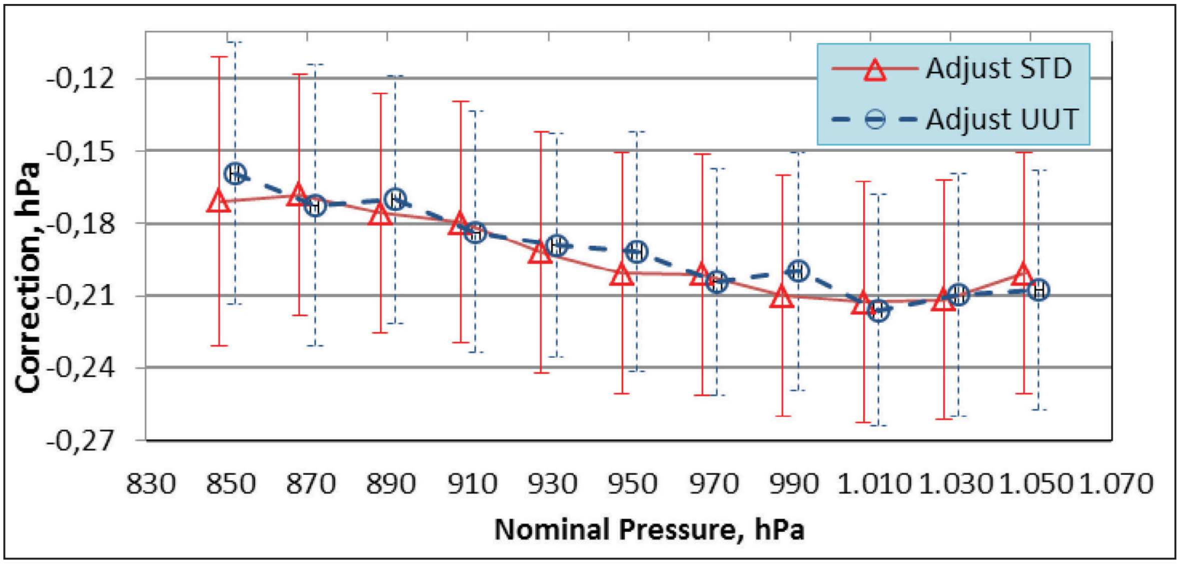


Figure 7. Comparison of Method 1 and Method 2 Calibration Results (The nominal pressures are separated to distinguish both differences)

Table 4. The Uncertainty Budget at 1050 hPa Nominal Pressure for Method 1

Uncertainty source	Unit	Dis-trib.	U 2a	Divi-sor	Vi	Std. Uncert. Ui	Sens. Coeff. Ci	$c_i.u_i$	$(c_i.u_i)^2$	$(c_i.u_i)^4$/ vi
Standard	hPa	nor-mal	0.048	2	60	0.024	-1	-2.4E-02	5.8E-04	5.5E-09
Instability	hPa	Rect.	0.005	3.46	50	0.002	1	1.5E-03	2.4E-06	1.1E-13
Delta density	kg/m^3	Rect.	0.121	3.46	50	0.035	4.9E-04	1.7E-05	2.9E-10	1.7E-21
Gravity	m/s^2	Rect.	0.000	3.46	50	0.000	6.0E-05	8.5E-10	7.3E-19	1.1E-38
Head corr.	m	Rect.	0.005	3.46	50	0.001	1.2E-01	1.7E-04	2.9E-08	1.7E-17
Residual	hPa	Rect.	0.000	3.46	50	0.000	1	0.0E+00	0.0E+00	0.0E+00
Zero deviation	hPa	Rect.	0.000	3.46	50	0.000	1	0.0E+00	0.0E+00	0.0E+00
Resolution	hPa	Rect.	0.010	3.46	50	0.003	1	2.9E-03	8.3E-06	1.4E-12
Repeatability	hPa	Rect.	0.008	3.46	50	0.002	1	2.3E-03	1.9E-05	7.0E-12
Hysteresis	hPa	Rect.	0.004	3.46	50	0.001	1	1.1E-03	8.3E-06	1.4E-12
Reproducibility	hPa	Rect.	0.000	3.46	50	0.000	1	0.0E+00	0.0E+00	0.0E+00
								Sums	5.9E-04	5.5E-09
								Combined uncertainty, uc_1	0.024	
								Effective degree of freedom, veff	63.61	
								Covered factor for CL=95%	2.00	
								Expanded unc, U(unit)	0.048	

Table 5. The Uncertainty Budget at 1050 hPa Nominal Pressure for Method 2

Uncertainty source	Unit	Dis-trib.	U 2a	Divi-sor	Vi	Std. Uncert. Ui	Sens. Coeff. ci	$c_i.u_i$	$(c_i.u_i)^2$	$(c_i.u_i)^4$/ vi
Standard	hPa	nor-mal	0.048	2	60	0.024	-1	-2.4E-02	5.8E-04	5.5E-09
Instability	hPa	Rect.	0.005	3.46	50	0.002	1	1.5E-03	2.4E-06	1.1E-13
Delta density	kg/m³	Rect.	0.121	3.46	50	0.035	4.9E-04	1.7E-05	2.9E-10	1.7E-21
Gravity	m/s²	Rect.	0.000	3.46	50	0.000	6.0E-05	8.5E-10	7.3E-19	1.1E-38
Head corr.	m	Rect.	0.005	3.46	50	0.001	1.2E-01	1.7E-04	2.9E-08	1.7E-17
Residual	hPa	Rect.	0.000	3.46	50	0.000	1	0.0E+00	0.0E+00	0.0E+00
Zero deviation	hPa	Rect.	0.000	3.46	50	0.000	1	0.0E+00	0.0E+00	0.0E+00
Resolution	hPa	Rect.	0.010	3.46	50	0.003	1	2.9E-03	8.3E-06	1.4E-12
Repeatability	hPa	Rect.	0.015	3.46	50	0.004	1	4.3E-03	1.9E-05	7.0E-12
Hysteresis	hPa	Rect.	0.010	3.46	50	0.003	1	2.9E-03	8.3E-06	1.4E-12
Repro-ducibility	hPa	Rect.	0.000	3.46	50	0.000	1	0.0E+00	0.0E+00	0.0E+00
								Sums	6.1E-04	5.5E-09
								Combined uncertainty, uc_1	0.025	
								Effective degree of freedom, veff	68.02	
								Covered factor for CL=95%	2.00	
								Expanded unc, U(unit)	0.05	

methods is described in Table 4 and Table 5 respectively.

It can be seen that both methods have the same uncertainty components according to the reference document DKD-R 6-1: 2014, which are standard, resolution, zero deviation, repeatability, hysteresis, and reproducibility.

Hysteresis is added into the uncertainty budget since the measurement results using an average reading from both increasing and decreasing sequence. Repeatability in this uncertainty evaluation is calculated from the error or deviation between UUT and the reference standard instead of the UUT reading. This is because the indication of UUT depends on the reference standard. The indication of the reference standard can be changed or different in each measurement due to the room condition or the reference standard instability. For more investigation regarding repeatability from the error or correction, it will be made in the future paper publication.

From Table 4 and Table 5, it can be seen that Method 1 (Adjust STD) gives slightly smaller uncertainty compared with the Method 2 (Adjust UUT) with difference of 0.002 hPa at the nominal pressure of 1050 hPa. The uncertainty of repeatability and hysteresis from the Method 1 is smaller compared with Method 2, as the STD is more stable than the UUT when used as the adjusted reading value. However, judging from the similarity of the calibration results from both methods, it shows that Method 2 gives calibration result nearly as well as Method 1.

As described before, the indication reading of the reference standard RPM4 A160k in this case has been calibrated and corrected from the certificate calibration results using pressure balance DHI PG7601 as the primary pressure standard. The calibration result of the RPM4 A160k is presented in Table 6.

Therefore, it can also be concluded that the measurement result of the barometer in this study is traceable to SI unit since the reference standard RPM4 A160k used for calibration has been calibrated at first using pressure balance as the primary pressure standard and

Table 6. Calibration Results of RPM4 A160k Using Pressure Balance as the Reference Standard

UUT Reading (hPa)	Correction (hPa)	Uncertainty (hPa)
852.916	0.074	0.041
872.967	0.075	0.041
892.785	0.077	0.042
912.836	0.077	0.043
932.957	0.077	0.043
953.009	0.077	0.044
973.315	0.076	0.045
993.365	0.076	0.046
1013.487	0.076	0.046
1033.537	0.077	0.047
1052.212	0.079	0.048

has been corrected in the analysis of barometer measurement result.

5. CONCLUSION

A comprehensive study of two methods in calibrating barometer, one of pressure measuring device, based on the DKD-R 6-1: 2014 article 7 has been done in order to analyze the effect of adjusting pressure, according to the indication of the reference standard or according to the indication of the UUT in pressure measuring device calibration, and to investigate discrepancies results between both calibration methods.

From the results and analysis, it can be concluded that both Method 1 and Method 2 gives slightly different results with maximum difference correction between both methods is 0.01 hPa, relevant with the expanded uncertainty claim of 0.06 hPa at 850 hPa and 0.05 hPa at 1050 hPa respectively.

Therefore, for pressure measuring device calibration, both methods can be performed independently. Method 2 is easier and more practical to be done, especially for many calibration and laboratory tests. However, the reading stability of the reference standard need to be considered in order to get more accurate measurement results.

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