ASIA-PACIFIC METROLOGY PROGRAMME

100 MPa HYDRAULIC PRESSURE INTERLABORATORY COMPARISON

Comparison Identifier: APMP.M.P-K7.2

Final Report on Key Comparison APMP.M.P-K7.2 in Hydraulic Gauge Pressure from 10 MPa to 100 MPa

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Abstract

This report describes the result of key comparison in hydraulic pressure 10 MPa to 100 MPa, gauge mode; between National Institute and Metrology (Thailand) / (NIMT) and National Metrology Laboratory-Industrail Technology Development Institute (The Philippines) / (NMLPHIL). The comparison was carried out in the period of October 2015 to March 2016, within the framework of Asia Pasific Metrology Programme (APMP). The purpose of this comparison was to determine the degree of equivalence between the hydraulic pressure standards maintained by NMLPHIL and NIMT in order to evaluate the relationship between the merasurement result made by NMLPHIL and the CCM Key Comparison Reference Value (KCRV) through NIMT measurement result which was found in the key comparison APMP.M.P-K7. In this comparison NIMT was the pilot institute. Two hydraulic pressure transducers belong to NIMT were used as the transfer standard. To ensure the reliability of the artifact, five complete measuremnents were performed before and during the comparison. Therefore behavior of the transfer standards during the comparison period were well characterized. The degrees of equivalence of two national measurement standard were expressed quantitatively by the deviations from key comparison reference values. In conclusion the hydraulic pressure in the range of 10 MPa to 100 MPa, gauge mode, developed by the hydraulic pressure balance reference standards maintained by both participating NMIs were found to be fully equivalence under their claimed uncertainties. It can be concluded that the measurement result in hydraulic pressure 10 MPa to 100 MPa gauge mode, made by NMLPHIL has been corresponsed to the CCM KCRV under the uncertainties claimed.

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1. Introduction

The National Institute of Metrology (Thailand) (NIMT), Thailand, has successfully participated in APMP comparison, APMP.M.P-K7[1] with the results can be linked to CCM KCRV, in the pressure range 10 MPa to 100 MPa, gauge mode; using a pressure balance as a pressure standard. The National Metrology Laboratory – Industrial Technology Development Institute of Philippines (NMLPHIL), has developed a hydraulic pressure standard which was the pressure balance in the same measurement range. A bilateral comparison with NIMT in the range stated above was proposed by NMLPHIL during the APMP TCM Meeting in Korea (September, 2014).

NIMT has been approved by the Technical Committee for Mass and Related Quantities (TCM) of the Asia-Pacific Metrology Programme (APMP) to coordinate the requested interlaboratory comparison as a pilot institute. The comparison has been identified as APMP.M.P-K7.2 by APMP and the Consultative Committee for Mass and Related Quantities (CCM) of the International Committee for Weights and Measures (CIPM), the International Bureau of Weights and Measures (BIPM).

The objective of this comparison is to prove an equivalence of hydraulic pressure standards maintained by the two institutes, NMLPHIL and NIMT, in the pressure range from 10 MPa to 100 MPa in gauge mode in order to evaluate the relationship between the merasurement result made by NMLPHIL and the CCM Key Comparison Reference Value (KCRV) through NIMT measurement result as shown in APMP.M.P-K7. The results of this comparison will be submitted to the Key Comparison Database (KCDB) of BIPM following the rules of CCM.

In this comparison two hydraulic pressure transducers, provided by the pilot institute (NIMT) were used as the transfer standard. To ensure the reliability of the transfer standard, five completed measurements were performed before and during the comparison. Therefore behavior of the transfer standards during the comparison period were well characterized. The comparison protocol[2] was prepared by the pilot institute using the comparison protocols of APMP.M.P-K7[1] and APMP.M.P-K7.1[3] as the references. It was agreed by NMLPHIL before submitting to APMP TCM chair person for the approval process.

2. Participating institutes and description of pressure standards

2.1 List of participating institutes

There are two National Metrology Institutes (NMIs) that participated in this comparison including the pilot institute. The participating institutes along with addresses and contact person are listed in Table 1. The index number in column one is used to identifiy the participating institute in the report.

Table 1. List of participating institutes.

No.	Participating Institutes
1	**Institute :** National Institute of Metrology (Thailand) **Acronym :** NIMT (Pilot institute) **Address :** 3/4 - 5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand **Contact Person :** Mr. Likit Sainoo **Phone :** +66-2577-5100 ext. 2106 **Fax :** +66-2577-3658 **E-mail :** likit@nimt.or.th

2	**Institute :** National Metrology Laboratory- Industrial Technology Development Institute(Philippines) **Acronym :** NMLPHIL **Address :** Metrology Bldg., Gen. Santos Ave., Bicutan, Taguig City, Metro Manila, Philippines **Contact Person :** Mr. Radley F. Manalo **Phone :** +63-2-837-2071 ext. 2264 **Fax :** +63-2-837-6150 **E-mail :** rfmanalo@itdi.dost.gov.ph, radleymanalo@yahoo.com,

2.2 Description of pressure standards

The pressure standards of both participating institutes were pressure balances with different manufacturer and model. The description of pressure standards that were used to calibrate the comparison artifact, including the pressure balance bases, types and material of piston-cylinder assemblies (PCU), the effective areas with associated standard uncertainties, the pressure distortion coefficient with associated standard uncertainties, linear thermal expansion of the PCUs, traceabilities, local gravity values with associated standard uncertainties, the reference temperatures, method and rotation rate of the pistons as listed in Table 2.

Table 2. Description of pressure standards of NIMT and NMLPHIL. All the uncertainties are expressed as the standard one.

j		**1**	**2**
Institute		**NIMT**	**NMLPHIL**
Pressure balance base	Manufacture	RUSKA	DH-Budenberg
	Model	2485-930D	5306
Traceability		Primary pressure standard maintained by NIMT	NIMT
Piston-cylinder unit (PCU)	Indentification number	J143	5959
	Type	Simple	Simple
	Material of Piston	Tungsten Carbine	Tungsten Carbide
	Material of Cylinder	Tungsten Carbine	Tungsten Carbide
Zero-pressure effective area, (A_0) at reference temperature	Value in m^2	7.11100×10^{-6}	9.80495×10^{-6}
	Relative uncertainty in 10^{-6}	13.5	17
Pressure distortion coefficient, (λ)	Value in MPa^{-1}	7.48×10^{-7}	8.86×10^{-7}
	Uncertainty in MPa^{-1}	0.84×10^{-7}	0.92×10^{-7}
Linear thermal expansion of the PCU,($\alpha_p + \alpha_c$) in $^oC^{-1}$		9.1×10^{-6}	9.0×10^{-6}
Reference temperature (t_r) in ^oC		20	20
Piston rotation	Method	by hand	by hand
	Speed in rpm	20-25	21-24

3. Transfer standard

Two types of hydraulic pressure sensor that were used as the transfer standard for this comparison are listed in Table 3 and shown in Figure 1 and Figure 2. These are the reference pressure monitor made by DH Instruments, Inc. and the pressure transducer made by Paroscientific Inc.[4,5]

Table 3. Details of transfer standards used for this comparison.

Transfer standards no.	TS[1]	TS[2]
Name of equipment	Reference pressure monitor	Pressure transducer
Manufacturer	DH Instruments, Inc.	Paroscientific, Inc.
Model	RPM4 A280M/A140M	9000-15K-101 (Transducer) 715-220V (Indicator)
Serial number	556	104765 (Transducer) 924 (Indicator)
Maximum range	140 MPa	100 MPa
Resolution	0.1 kPa	0.1 kPa
Power supply	85 to 264 VAC, 50/60 Hz	

Figure 1. TS[1] hydraulic reference pressure monitor,
Model: RPM4 A280M/A140M, S/N: 556.

Figure 2. TS[2] hydraulic pressure transducer, Model: 9000-15K-101, S/N: 104765 and digital precision indicator, Model: 715-220V, S/N: 924.

4. Chronology of measurements

According to the protocol[2], the transfer standards were circulated during the period of October 2015 to March 2016. Table 4 presents the actual chronology of measurements in the comparison. Before starting the measurement, the transfer standards were checked for stability at NIMT for 3 times during the period of October to December 2015. The transfer standards were measured first by NIMT. Then they were hand-carried to NMLPHIL for measurement. After that they were measured again after returning to NIMT in order to confirm that no significant drift occurred during the transportation. The measurement duration at each participating institute was 12 days (From Monday to Friday in the next week, in principle).

Table 4. Chronology of measurements in this comparison.

No.	Period of Measurement	NMIs
1	October 2015	NIMT, (Stability checked)
2	November 2015	
3	December 2015	
4	January 2016	NIMT
5	February 2016	NMLPHIL
6	March 2016	NIMT

5. Measurement

The general procedure required for both participants to follow during the measurement was described in the comparison protocol[2].

5.1 Preparation

For convenience, the pilot institute provided the adapter to the pressure input connector, with the coned & threaded nipples OD. ¼ inch, made by NOVA Swiss. When the participant needs to connect the pressure tubing to the input connector, the wrench / spanner shall only be positioned to the adapter in order to protect the sensing element of the transfer standards from subjected torque. The pressure standards of both participating institutes were operated at normal operating temperature of each institute. The environmental condition, such as atmospheric pressure, ambient temperature and relative humidity, during the measurement was measured by the participant's environment monitoring system.

Height difference between the reference level of the standard and the tranfer standard should be reduced as much as possible, then measured and recorded. Head correction shall be applied to the measurement result afterward. The reference level of both tranfer standards are shown in Table 5.

Table 5. Reference level of transfer standards.

No.	Transfer standards	Reference level	Installation
TS[1]	Reference pressure monitor DH Instruments, Inc., Model: RPM4 A280M/A140M	at the center of its input connector	Horizontal orientation
TS[2]	Pressure transducer Paroscientific, Inc., Model: 9000-15K-101 (Transducer) 715-220V (Indicator)	at the groove mark of the transducer	Vertical orientation (transducer only)

5.2 Installation of the transfer standard

5.2.1 Prior the installation, the inner volume of the transfer standard should be filled with the oil used with the institute standard.

5.2.2 The right location to install the system shall be wisely chosen in order to reduce disturbing effects such as vibration, magnetic fields, direct sunlight and air draughts due to air-conditioning system.

5.2.3 The transfer standard and the reference standard to be used shall be placed on a highly stable workbench, which is appropriate in size and height for the measurement work.

5.2.4 Place the transfer standard as close as possible to the reference standard, and get them connected using a proper pressure rated tubing with the largest possible internal diameter.

5.2.5 A proper valves may be installed in the hydraulic circuitry if it would make the measurement work easier and more efficient. However it shall be prepared by the institute.

5.2.6 All valves and tubing that are going to be used shall be free from lint, particle, dirt etc. which would introduce erroneous measurement results.

5.3 Working fluid

Di(2)-ethyl-Hexyl-Sebacate (DHS) was used as the pressure transmitting fluid for both participants in this comparison.

5.4 Warm up of the transfer standard

After setting up, the transfer standard should be left in the measurement room to reach the ambient temperature. The transfer standard must be switched on at least 24 hours before starting the measurement.

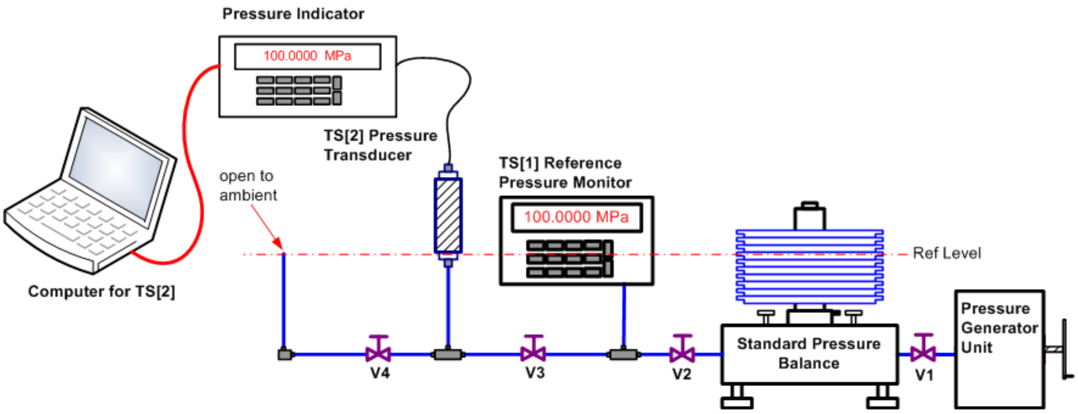

Figure 3. The example of measurement setup.

5.5 Applying pressure and leak check

After installation, the transfer standard system should be pressurized using the participant's standard up to the maximum pressure, which is 100 MPa. At the same time the functionality of the pressure monitor and indicator of the pressure transducer comparison artifacts shall be checked. Concurrently with the functionality check, leakage check of the system shall also be conducted. Fix if necessary.

5.6 Height difference and head correction

The pressure generated by a pressure standard at the reference level of transfer standard, P, is represented by the following equation:

$$P = P_e + [(\rho_f - \rho_a) \times g_l \times \Delta h] \quad (1)$$

where,

P_e is the gauge pressure generated by the participant's pressure standard at its reference level, Pa

ρ_f is the density of the working fluid, kg/m^3

ρ_a is the air density, kg/m^3

g_l is the local acceleration due to gravity, m/s^2

Δh is the vertical distance between the reference levels of the two compared standards (institute standard and transfer standard), m

Δh is positive if the level of the institute's standard is higher.

To minimize uncertainties in pressure measurement, the height difference between the reference levels should be kept as low as possible. It is also highly recommended to measure the height difference in accurate manner. For the height difference, each institute has to make appropriate corrections to the reference level of the transfer standard, and include their contributions to the uncertainty of the applied pressure.

5.7 Measurement method

At nominal pressure points of 0 MPa, 10 MPa, 20 MPa, 30 MPa, 40 MPa, 50 MPa, 60 MPa, 70 MPa, 80 MPa, 90 MPa and 100 MPa, the pressure applied and the readings of the transfer standard were measured. The values, together with the respective measurement uncertainties, were the main basis of the comparison.

5.7.1 Measurement at 0 MPa

- Open the reference side of the transfer standards to the atmosphere by opening valves V3 and V4 (see Figure 3).
- Wait for 10 minutes.
- After the waiting time, within 5 minutes, measure the reading of each transfer standard, which is the resulting average for 20 measurements and its corresponding standard deviation, σ. Also, measure the environment condition. Record these data in the cell on the sheet for the measurement results, in the form attached in the comparison protocol[2]. (The example are shown in Table 6.)

5.7.2 Measurement at 10 MPa, 20 MPa, 30 MPa, 40 MPa, 50 MPa, 60 MPa, 70 MPa, 80 MPa, 90 MPa and 100 MPa

- Close valve V4 and open valves V1, V2 and V3 to apply the pressure generated by the participant's standard pressure balance.
- Apply the pressure to the transfer standards using the participant's standard pressure balance. The relative difference between the actual applied pressure and the nominal value should be below 10^{-3}.
- After applying the pressure, keep the pressure to stabilize the pressure for 10 minutes. The pressure balance piston position should be kept in the floating range by using the device such as a hand pump.
- After the waiting time, within 5 minute, measure the reading of each transfer standards, which is the resulting average for 20 measurements and its corresponding standard deviation, σ. Also, measure the environment condition. Then, calculate the applied pressure with the associated standard uncertainty ($k=1$) at the reference level of transfer standard. Any influence quantity for the laboratory system must be taken into account and included in the appropriate uncertainty estimation. The correction by the differential height of the reference levels between the participant's standard pressure balance and the transfer standards should be considered. Record these data in the cell on the sheet for the measurement results in the form attached in protocol[2]. The example is shown in Table 6.

Table 6. Example of measurement recording at 0 MPa and 100 MPa.

Nom Pres. [MPa]	Local Time	Atm Temp. [°C]	Atm R.H. [%]	Atm Pres. [kPa]	Reading *R_TS[1]* [kPa]		Reading *R_TS[2]* [kPa]		Applied Pressure P^{*1} [kPa]	$u(P)^{*2}$ (k=1) [kPa]
					Average	σ	Average	σ		
0	9:00	20.0	55.0	101.3	1.0	0.1	-1.0	0.2	Not required	
100	14:30	20.0	55.0	101.3	100010.0	0.3	99999.8	0.2	100004.9	6.2

**1 P* is the pressure developed by the participant's standard pressure balance at the local gravity, g_l , and the local air density, ρ_a , that should be calculated at the reference level of the TS using equation (1).
*2 Standard uncertainty of *P*, (k=1).

5.7.3 Complete measurement cycle

One complete measurement cycle consists of recording the transfer standard readings for 11 points from 0 MPa to 100 MPa for ascending pressure, 1 point at 0 MPa, and 11 points from 100 MPa to 0 MPa for descending pressure as shown in the Figure 4. The ascending pressure measurement cycle must be started from 0 MPa while the decending pressure measurement cycle must be started from 100 MPa. The results of measurement cycle should be recorded on the measurement result sheet as shown in the form attached in protocol[2]. Totally, for one cycle the 23 measurement points will be obtained.

<u>It is recommended that one complete measurement cycle should be performed continuously without any interruption in a day. Three complete measurement cycles were required for this comparison. Each cycle can be measured on a separate day.</u>

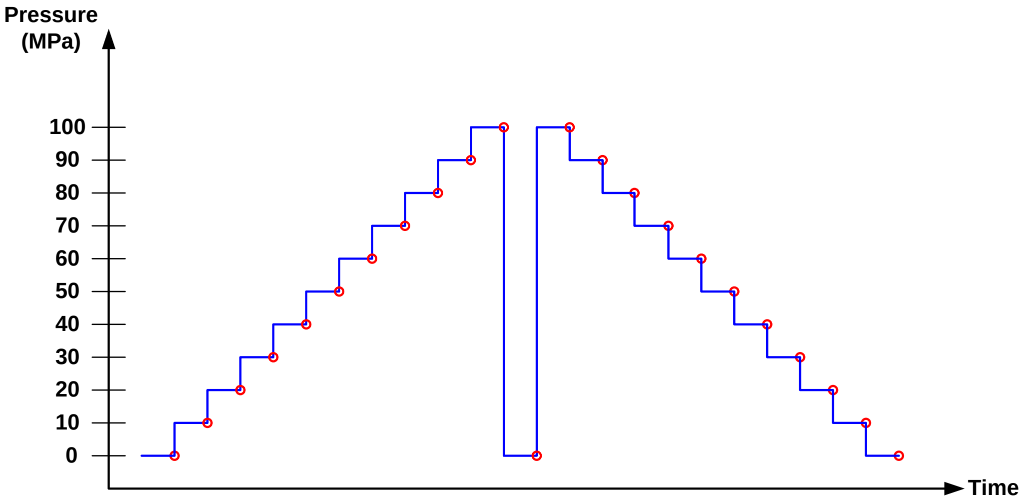

Figure 4. Pressure measurement cycle.

6. Results to be reported

After the measurements were completed at the participating institute, the measurement result shall be transmitted to the pilot institute. These were as follows:

(i) Measured and calculated at the nominal pressures specified, each with an uncertainty of the mesurement and the date(s) on which the measurement cycle was performed (three cycles).

(ii) Details of the participating institute's standard used in the comparison together with its traceability to the SI unit (shown in Table 2).

(iii) Details of the parameters used for the comparison. These were local gravity, difference in height of bot hreference levels and density of the pressure transmitting fluid used during the comparison together with their measurement uncertainties (shown in Table 7).

(iv) Uncertainty budget of the pressure measurement shall be estimated by following the DKD R 6-1 guidelines.[6]

6.1 Parameters used by both participating institute

Details of the parameters used by both participating institute are listed in Table 7. The name of participating institute, the local gravity, the height difference, and the fluid density with their associated standard uncertainties are presented.

Table 7. Details of the parameters used by each participating institute. All the uncertainties are expressed as the standard ones.

j	Institute	Local gravity, g		Height diff., Δh		ρ_f	
		Value [m/s^2]	Unc. [x10^{-6}]	Value [mm]	Unc. [m]	Value [kg/m^3]	Unc. [%]
1	NIMT	9.7831243	0.5	1.2	0.005	Eq.(1)	10
2	NMLPHIL	9.783551	20	13.0	0.005	Eq.(2)	10

Eq.(1): $\rho_f = 914 \times [1 - 0.00078 \times (t - 20)] \times (1 + 0.00008 \times P)$

Eq.(2): $\rho_f = 914 \times (1 + 0.000086 \times P)$

where : ρ_f = desity of Di(2)-ethyl-Hexyl-Sebacate (DHS), kg/m^3,

t = temperature, °C

P = pressure, bar

7. Analysis of reported data

Data obtained from one complete measurement cycle consists of the recordings of pressure obtained from the transfer standard, the pressure applied by the standard and environment parameters for the 23 points. Therefore, the following data sets were obtained from the reported results.

$$\{R\ (j,m,y,w,i,n),\ P\ (j,y,w,i)\}$$

where the meanings of the parameters are as follows:

R = Raw reading of the transfer standard, MPa

P = Applied pressure at the reference level of the transfer standard by pressure standard j, MPa

j = Index for the participating institute, 1= NIMT, 2= NMLPHIL

m = Index for the transfer standard TS[1] or TS[2], m = 1 or 2

y = Index for the measurement cycle

w = Index for the indicating ascending or decending measurements, w =1 or 2

i = Index for the indicating pressure , i x 10 MPa, i = 0 – 10

n = Number of the days from the beginning date, 26 October 2015, which was defined for purpose of evaluating a long-term shift with time of the transfer standard to the date which the calibration was performed.

In this section, the reduction and analysis of the data are described in the following sequence:

7.1 Corrected by the zero-pressure offsets,
7.2 Corrected by the difference between nominal pressure and actual pressure,
7.3 Corrected to the reference temperature,
7.4 Corrected by long-term shift of the transfer standard,
7.5 Normalize the mean ratio of the transfer standard,
7.6 Calculate the normalized mean ratio of the participating institute,
7.7 Calculate the expected mean pressure of the participating institute,
7.8 Estimate the measurement uncertainty of the participating institute,

7.1 Corrected by the zero-pressure offsets

There were three 0 MPa pressure points in each measurement cycle. From measurement results performed at pilot institute, it was comfirmed that the reproducibility of the reading of transfer standard at an intermediate 0 MPa point was not better than those at first or last 0 MPa points. The reading at an intermediate 0 MPa point was susceptible to the history suffered at the past pressure points. The reading for ascending and descending pressure points of each cycle are offset by the readings at the first and last 0 MPa points of each cycle, respectively. By subtracting the offset from the raw reading R, the corrected reading R_{c0} can be obtained as follow:

$$R_{c0}\,(j,m,y,w,i,n) = R\,(j,m,y,w,i,n) - R\,(j,m,y,w,0,n) \tag{2}$$

7.2 Corrected by the difference between nominal pressure and actual pressure

R_{c0} was the reading of the TS then corrected by the zero-pressure offset according to equation (2). Since the pressure standard was requested to be within a hundredth parts per million of each target pressure. Therefore deviation of pressure standard of each participant from each target pressure was occurred. Then ratio of the pressure standard to the R_{c0} at each nominal pressure of all participants was obtained.

From experiment by the pilot institute found that the linearity of the transfer standard was linear in a very small range as a hundredth parts per million of the required target pressure. When an exact nominal pressure P_n was applied as the common measurement result of the transfer standard for all participants, the predicted reading of the transfer standard, R_{c1}, can be calculated by :

$$R_{c1}(j,m,y,w,i,n) = \frac{R_{c0}(j,m,y,w,i,n)}{P(j,y,w,i)} \cdot P_n(i), \tag{3}$$

Where R_{c0} and P were the simultaneous readings of the transfer standard and the actual pressure applied, respectively. Then ratio of each measurement point of each participant can be used to correct the reading for deviations of the pressure standard from the nominal pressure without significant effect.

7.3 Correction to reference temperature

An effect to the transfer standards caused by different in environment temperature between the participating institutes was proven by the pilot institute. The experiment was done before starting the comparison by measurement the transfer standard for 3 completed cycles at ambienttemperature 20 °C and 23 °C. The result of error difference of each transfer standard were shown in Figure 5.

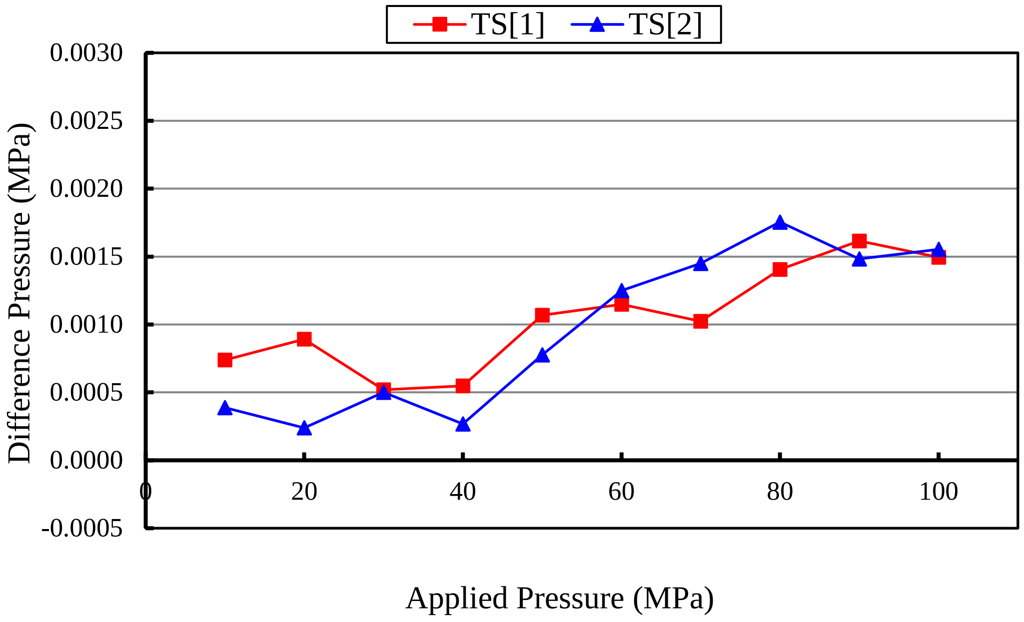

Figure 5. Error difference of the transfer standard that was measured at ambient temperature 23^{o}C compared to the measurement result at 20^{o}C, as a function of nominal target pressure.

Since ambient temperature in participating institute was different , the pilot institute has been maintained 20°C while participating institute was 23°C. The uncertainty of the difference temperature was added in the combined uncertainty of NMLPHIL measurement result.

Table 8. Average ambient temperatures measured by the participating institutes for nominal target pressures.

		Average ambient temperature [°C]	
j		1	2
i	[MPa]	NIMT	NMLPHIL
0	0	20.4	22.7
1	10	20.5	22.8
2	20	20.5	22.7
3	30	20.5	22.8
4	40	20.5	22.7
5	50	20.4	22.7
6	60	20.4	22.8
7	70	20.5	22.7
8	80	20.4	22.7
9	90	20.5	22.6
10	100	20.5	22.8
Average		20.4	22.7

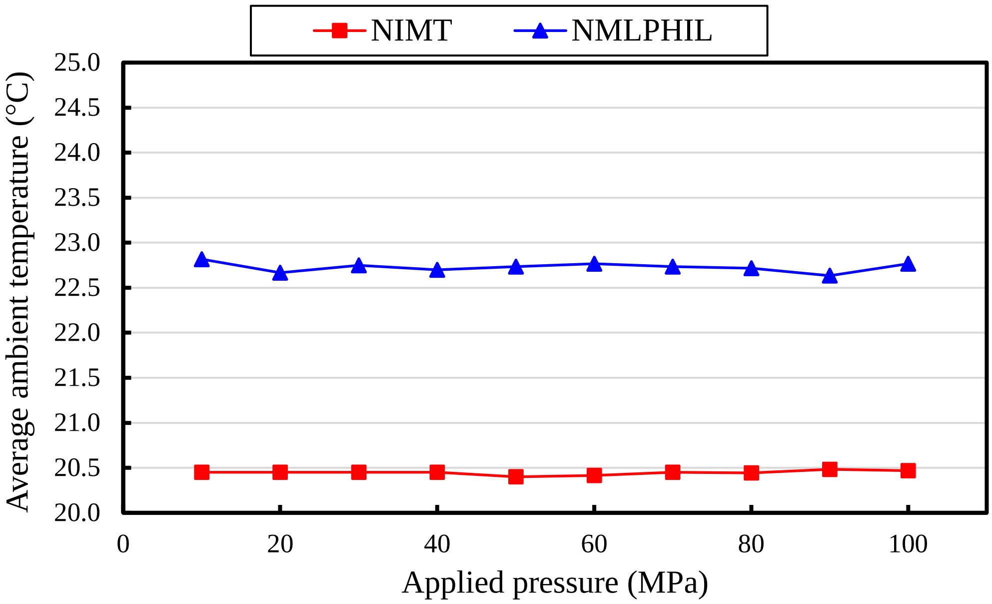

Figure 6. The average ambient temperatures measured by the participating institutes for nominal target pressures.

7.4 Corrected by long-term shift of the transfer standards

According to the selected measurement data on the transfer standards which was performed 5 times in different dates at the pilot institute before and during this comparison. Characteristic of each transfer standard regarding long-term drift with time was obtained. It shows that the amount of drift due time difference of the transfer standard would not affect significantly to the comparison result. The pilot institute confirmed the stability of the pressure standard used for this comparison by cross-floating against the national standard pressure balance in the period of this comparison and found that there was no systematic shift occurred on the pressure standard used.

In this analysis, the amount of drifting due to time was calculated by a least-squares-best fitting straight line using R_{c1} taken during the measurement against the pressure standard at the pilot institute.

$$R_e\,(m,w,i,n) = a_0(m,w,i)\cdot n + a_1(m,w,i), \tag{4}$$

where R_e was the predicted reading at the date which the measurement cycle being performed after n days from the beginning date, 26 October 2015 while a_0 and a_1 are coefficients from fitting.

Table 9. Coefficients a_0 and a_1 calculated by the least-square fit for pressure transducers.

			Coefficients for long-term shift, a_0 [MPa/day], a_1 [MPa]			
m			1		2	
TS			TS[1]		TS[2]	
w	*i*	[MPa]	a_0	a_1	a_0	a_1
1	1	10	-9.368297E-06	1.000009E+01	-1.512955E-05	1.000091E+01
1	2	20	-2.485201E-06	1.999984E+01	-1.792781E-05	2.000059E+01
1	3	30	-1.002839E-05	3.000161E+01	-2.407950E-05	3.000040E+01
1	4	40	-1.249798E-06	4.000047E+01	-2.251141E-05	3.999887E+01
1	5	50	-1.190471E-06	5.000148E+01	-2.467725E-05	4.999959E+01
1	6	60	-3.093362E-06	6.000209E+01	-2.427543E-05	5.999872E+01
1	7	70	-5.559329E-06	7.000285E+01	-2.584242E-05	6.999780E+01
1	8	80	-4.091017E-06	8.000292E+01	-3.003800E-05	7.999705E+01
1	9	90	-1.177553E-05	9.000460E+01	-2.849721E-05	8.999455E+01
1	10	100	-1.289429E-05	1.000048E+02	-2.710993E-05	9.999646E+01
2	10	100	-6.701255E-06	1.000047E+02	-2.795944E-05	9.999655E+01
2	9	90	-1.883878E-05	9.000482E+01	-1.336261E-05	8.999429E+01
2	8	80	-1.123052E-05	8.000315E+01	-5.575159E-06	7.999661E+01
2	7	70	-1.431985E-05	7.000312E+01	3.761527E-06	6.999724E+01
2	6	60	-1.259087E-05	6.000238E+01	7.961372E-06	5.999808E+01
2	5	50	-1.157913E-05	5.000175E+01	7.419796E-06	4.999893E+01
2	4	40	-1.006389E-05	4.000067E+01	5.448019E-06	3.999829E+01
2	3	30	-2.114110E-05	3.000187E+01	-1.595255E-06	2.999992E+01
2	2	20	-1.274093E-05	2.000006E+01	-3.398743E-06	2.000025E+01
2	1	10	-1.892877E-05	1.000030E+01	-1.153482E-05	1.000080E+01

The predicted reading, once determined by the simultaneous measurement, could be used to convert all comparison data. The table 9 listed the coefficients a_0 and a_1 that was calculated with the least-squares fit for the long-term shift obtained from 5 simultaneous measurements at the pilot institute before and during this comparison. Figure 7 shown the coefficients a_0 obtained from the ascending sequence.

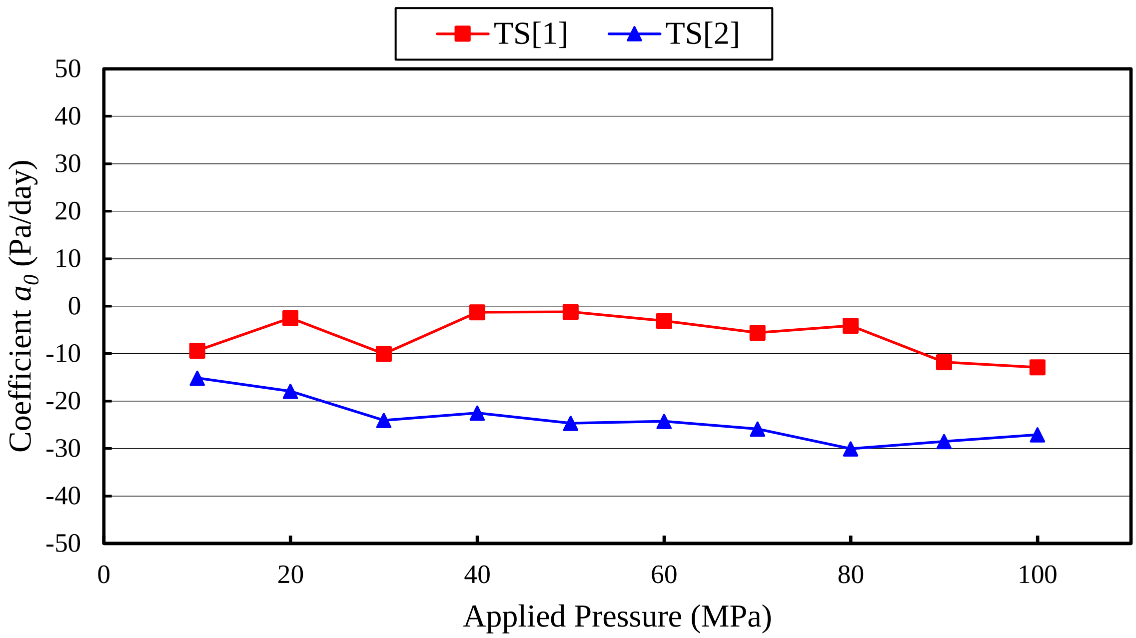

Figure 7. Coefficients $a_0(m,1,i)$ calculated with the least-squares fit for the long-term shifts as a function of nominal target pressure.

7.5 Normalization of the mean ratio of transfer standard

By taking the ratio of R_{c1} to R_e, the normalized mean ratio of each measurement point, s_0, was calculated by:

$$s_0(j,m,y,w,i) = \frac{R_{c1}(j,m,y,w,i,n)}{R_e(m,w,i,n)} \tag{5}$$

By taking the average of s_0 for ascending and descending pressures of 3 cycles, the normalized mean ratio of each transfer standard, s_1, was calculated by:

$$s_1(j,m,i) = \frac{1}{6}\sum_{w=1}^{2}\sum_{y=1}^{3} s_0(j,m,y,w,i) \tag{6}$$

There were 2 hydraulic pressure sensors used as the transfer standard. By taking the average of s_1 for the hydraulic pressure sensors, the normalized mean ratio of the transfer standard, s_2, was calculated by:

$$s_2(j,i) = \frac{1}{2}\sum_{m=1}^{2} s_1(j,m,i) \tag{7}$$

From l-th measurement (l means the number of measurement) at the pilot institute $j=1$, the normalization mean ratio $s_1^l(1,m,i)$ and $s_2^l(1,i)$ were obtained using equations (6) and (7). Figure 8 presents the instabilities of transfer standard expressed as the deviation of $s_2^l(1,i)$ from unity, respectively.

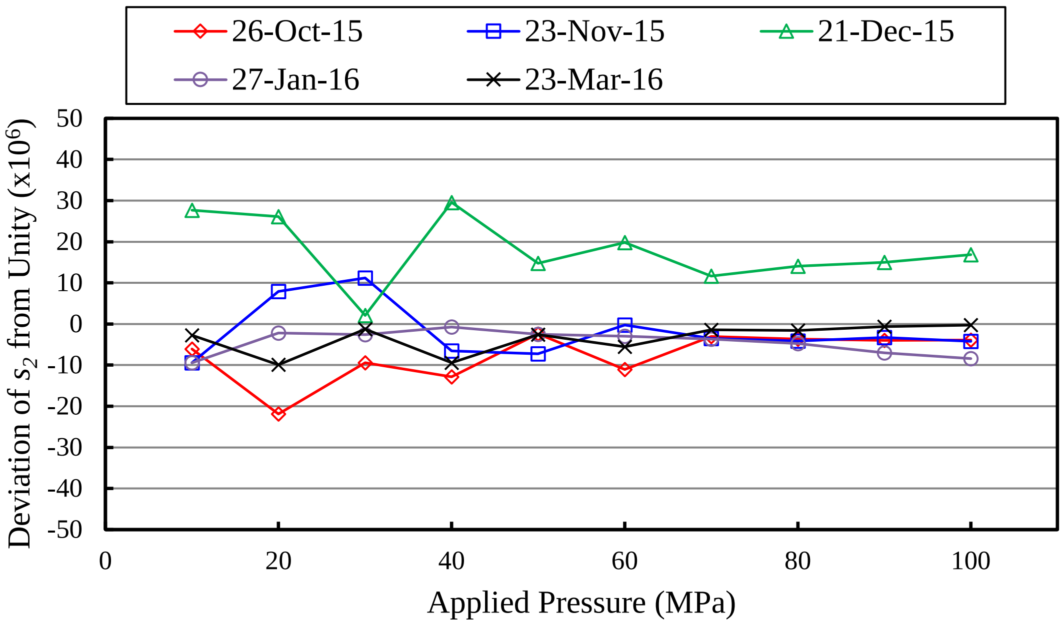

Figure 8. Instability of transfer standard expressed as the deviations of $s_2^l(1,i)$ from unity.

Table 10 and Figure 9 present the instabilities of the transfer standard expressed as the standard deviations, $\sigma\{s_1^l(1,m,i)\}$and $\sigma\{s_2^l(1,i)\}$ calculated from 5 values of $s_1^l(1,m,i)$ and $s_2^l(1,i)$ about their means, respectively. The standard deviations at each pressure are generally less than 40x10^{-6}. From these results, it can be stated that the stability of transfer standard was sufficient to be used as the artifact for comparison purpose. The instabilities of the transfer standard have been incorporated into the uncertainty evaluation of the comparison result that was described in the later subsection.

Table 10. Instabilities of the transfer standard expressed as the standard deviations, $\sigma\{s_1^l(1,m,i)\}$ and $\sigma\{s_2^l(1,i)\}$, which were the standard deviations of 5 values of $s_1^l(1,m,i)$ and $s_2^l(1,i)$ about their means, respectively. $s_1^l(1,m,i)$ and $s_2^l(1,i)$ were the normalized mean ratios obtained from *l*-th simultaneous calibration data set (5 sets in total) performed at the pilot institute.

		Standard deviations of normalized mean ratios, σs_1^l [x10^{-6}]		
$\sigma(s^1)$		σs_1^l	σs_1^l	σs_2^l
m		1	2	
i	[MPa]	TS[1]	TS[2]	Average
1	10	42	38	40
2	20	30	24	27
3	30	16	21	18
4	40	28	15	21
5	50	14	12	13
6	60	16	13	14
7	70	10	10	10
8	80	13	7	10
9	90	12	9	11
10	100	13	10	12

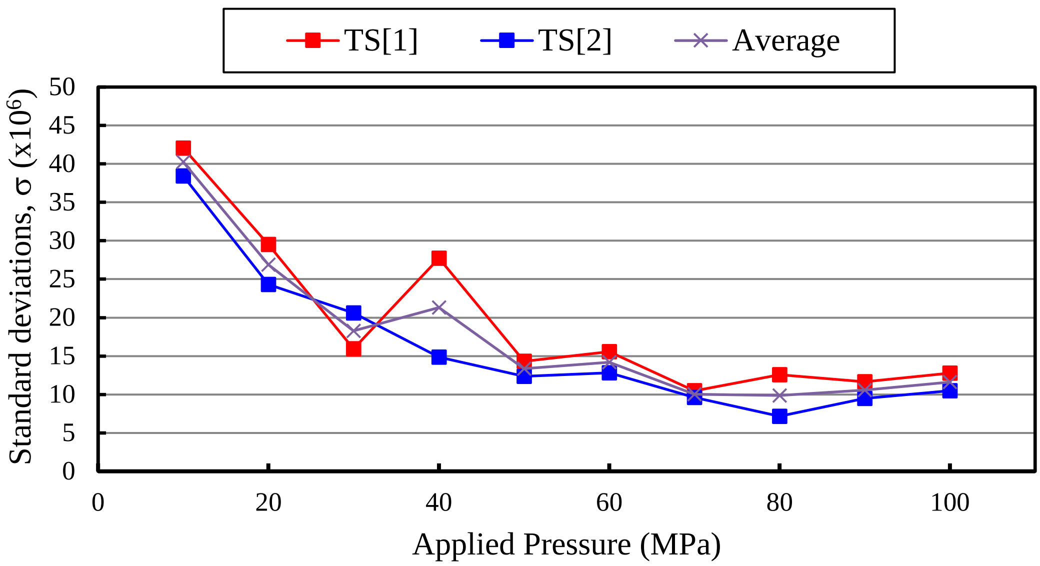

Figure 9. Instabilities of the transfer standard expressed as the standard deviations, $\sigma\{s_1^l(1,m,i)\}$ and $\sigma\{s_2^l(1,i)\}$, as a function of nominal target pressure.

7.6 Calculation of nominal mean ratio of participating institute

Since the predicted reading R_e was determined by the least-squares method using data obtained from 5 simultaneous measurements at the pilot laboratory $j = 1$, the following relation can be derived for transfer standard,

$$\frac{1}{5}\cdot\sum_{l=1}^{5}\left[s_2^l(1,i)\right] = 1 \qquad (8)$$

where s_2^l was the normalized mean ratio of the transfer standard obtained from l-th measurement performed at the pilot institute. Therefore, the relationship between the normalized mean ratio obtained from two hydraulic pressure transducers transfer standard were already compensated to the comparing result of both participants.

For j-th participating institute, the normalized mean ratio of the institute, S, is obtain from

$$S(j,i) = s_2(j,i) \qquad (9)$$

Ratio S provides a common basis for comparing the results reported by participants. For the pilot institute j= 1, S is calculated from

$$S(1,i) = \frac{1}{5}\cdot\sum_{l=1}^{5}\left[s_2^l(1,i)\right] \qquad (10)$$

Table 11 and Figure 10 present the deviations from the normalized mean ratios of the institutes from unity, $S(j,i)$-1, obtained from measurements at the pilot intitute and another participating institute as a function of nominal target pressure.

Table 11. Deviations of the normalized mean ratios of the institutes from unity, S-1 [x10^{-6}], for nominal target pressures.

		Deviations of the normalized mean ratios from unity, $\{S(j,i)-1\}$ [x10^{-6}]	
J		1	2
i	[MPa]	NIMT	NMLPHIL
1	10	0.00	40.52
2	20	0.00	18.22
3	30	0.00	16.96
4	40	0.00	11.62
5	50	0.00	19.97
6	60	0.00	12.99
7	70	0.00	17.30
8	80	0.00	15.21
9	90	0.00	19.71
10	100	0.00	14.85

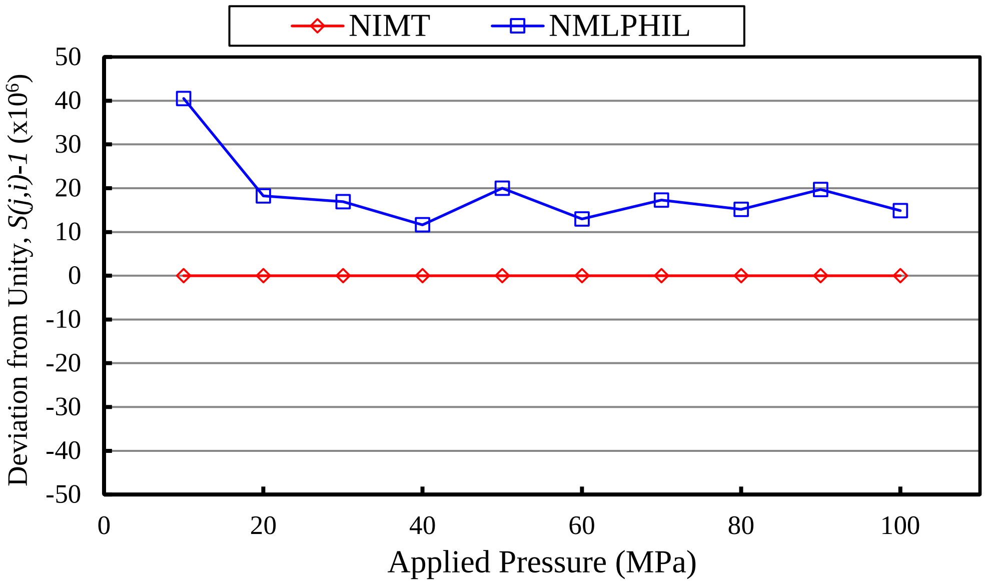

Figure 10. Deviations of the normalized mean ratios of the institutes from unity, *S*-1, as a function of nominal target pressure.

7.7 Calculation of expected mean pressure of participating institute

Expected mean pressure of participating institute, $p(j,i)$ is calculated by

$$p(j,i) = s(j,i) \cdot P_n(i) \tag{11}$$

where $P_n(i)$ is the nominal target pressure.

$p(j,i)$ is taken as an indicator of the expected pressure actually generated by the pressure standard of the participating institute when the institute claims the nominal target pressure. The results for $p(j,i)$, from individual institutes are presented in Table 12

Table 12. Expected mean pressures of the institutes for nominal target pressures.

		Mean Pressure, $p(j,i)$ [MPa]	
j		1	2
i	[MPa]	NIMT	NMLPHIL
1	10	10.00000	10.00041
2	20	20.00000	20.00036
3	30	30.00000	30.00051
4	40	40.00000	40.00046
5	50	50.00000	50.00100
6	60	60.00000	60.00078
7	70	70.00000	70.00121
8	80	80.00000	80.00122
9	90	90.00000	90.00177
10	100	100.00000	100.00148

7.8 Estimation of uncertainties

In this subsection, all the uncertainties are expressed as the standard one. The relative combined standard uncertainty in the normalized mean ratio of *j*-th participating institute, $S(j,i)$, may be estimated from the root-sum-square of four component uncertainties.

$$u_c\{S(j,i)\}=\sqrt{u^2_{std}\{S(j,i)\}+u^2_{rdm}\{S(j,i)\}+u^2_{lts}\{S(j,i)\}+u^2_{tem}\{S(j,i)\}} \tag{12}$$

where $u_{std}\{S\}$ is the uncertainty in S due to systematic effects in pressure standard j, $u_{rdm}\{S\}$ is the uncertainty due to combined effect of short-term random errors of transfer standard used and pressure standard j during measurement, $u_{lts}\{S\}$ is the uncertainty arising from long-term shift in the characteristics of the transducers transfer standard calibrated at *j*-th institute and u_{tem} is the uncertainty of the different from reference temperature.

7.8.1 Uncertainty due to systematic effect in pressure standard

The relative standard uncertainty due to systematic effect in pressure standard j, $u_{std}\{S(j,i)\}$, can be estimated from

$$u_{std}\{S(j,i)\}=\frac{u\{P_{std}(j,i)\}}{P_n(i)} \tag{13}$$

where $P_n(i)$ is the nominal target pressure.

Table 13 and Figure 11 present the estimated relative standard uncertainties arising from systematic effects in the pressure standards used in the comparison, as reported by the participating institutes for nominal target pressures. The uncertainty due to the hydrostatic head correction was considered as included in the uncertainty of the pressure standard. The main contributions in this uncertainty came from the effective area and the pressure distortion coefficient of the pressure standard of the participating institute.

Table 13. Relative standard uncertainties, as claimed by the participants, due to systematic effects in their pressure standards. All the uncertainties are expressed as the standard ones.

		Relative standard uncertainty reported by participating institute $u_{std}\{S(j,i)\}$ [x 10^6]	
j		1	2
i	[MPa]	NIMT	NMLPHIL
1	10	23.0	30.0
2	20	16.4	29.5
3	30	16.3	29.3
4	40	16.3	29.5
5	50	16.3	29.4
6	60	16.3	29.5
7	70	16.3	29.4
8	80	16.3	29.5
9	90	16.4	29.4
10	100	16.4	29.5

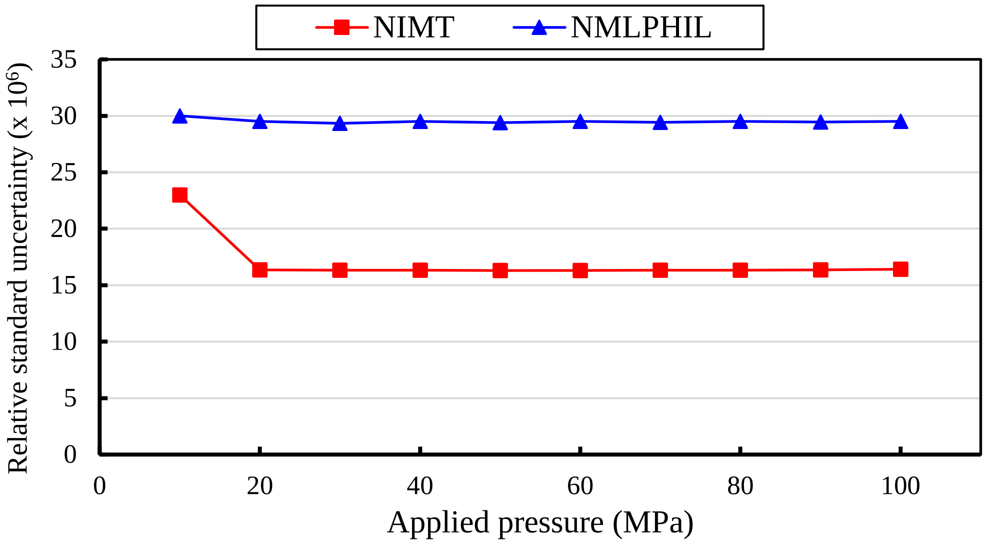

Figure 11. Relative standard uncertainties, as claimed by the participants, due to systematic effects in their pressure standards as a function of nominal target pressure.

7.8.2 Uncertainty due to combined effect of short-term random errors

The standard uncertainty in *S* due to combined effect of short-term random errors of the transfer standard, $u_{rdm}\{S\}$, can be estimated from the corresponding uncertainties in the normalized mean ratios by statistical methods.

For *j*-th non-pilot participating institute, the uncertainty is obtained from

$$u_{rdm}^2\{S(j,i)\} = \sigma^2\{s_0(j,m,y,w,i)\}/12 \tag{14}$$

where $\sigma\{s_0(j,m,y,w,i)\}$ is the standard deviation of 12 values of $s_0(j,m,y,w,i)$ about its mean.

For the pilot institute *j* = 1, the uncertainty is calculated from

$$u_{rdm}^2\{S(1,i)\} = \frac{1}{5}\sum_{l=1}^{5}\left[\sigma^2\{s_0^l(j,m,y,w,i)\}/12\right] \tag{15}$$

where $s_0^l(1,m,y,w,i)$ is the normalized mean ratio obtained from *l*-th simultaneous measurement set (5 sets in total) performed at the pilot institute, $\sigma\{s_0^l(1,m,y,w,i)\}$ is the standard deviation of 12 values of $s_0^l(1,m,y,w,i)$ about its mean.

Table 14 and Figure 12 present the estimated standard uncertainties due to combined effect of short-term random errors calculated from equations (14) and (15).

Table 14. Relative standard uncertainties in the normalized mean ratios due to combined effects of short-term random errors. All the uncertainties are expressed as the standard ones.

		Standard uncertainty due to combined effects of short-term random effects, $u_{rdm}\{S(j,i)\}$[x 10^6]	
j		1	2
i	[MPa]	NIMT	NMLPHIL
1	10	3.6	17.2
2	20	4.9	12.6
3	30	5.5	12.1
4	40	5.4	8.0
5	50	5.1	7.3
6	60	4.5	7.6
7	70	3.8	5.7
8	80	2.9	4.7
9	90	1.7	4.7
10	100	0.8	1.9

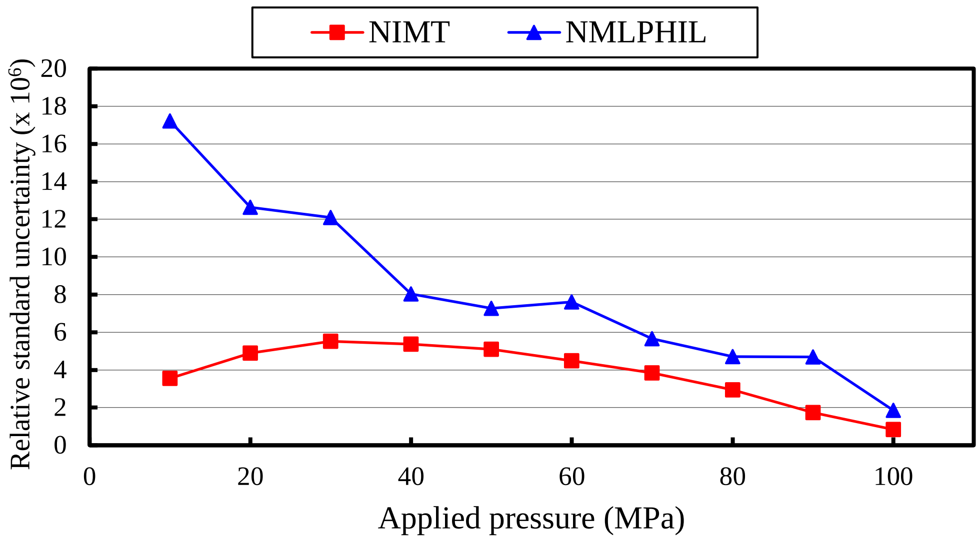

Figure 12. Relative standard uncertainties in the normalized mean ratios due to short-term random errors as a function of nominal target pressure.

7.8.3 Uncertainty arising from the long-term shift

The long-term shift of the pressure transducer between measurements was considered as a part of the uncertainties. The deviations from unity of $s_1(j,m,i)$ and $s_2(j,i)$ obtained from the 5 measurements seemed to be almost random at each nominal target pressure as presented in Figure 8 and 9 . Therefore, the relative standard uncertainty in the normalized mean ratio of *j*-th participating institute due to long-term shift, $u_{lts}\{S(j,i)\}$, was estimated as follows:

In the case that two hydraulic pressure transducers were calibrated at *j*-th participating institute,

$$u_{lts}^{2}\{S(j,i)\}=\sigma^{2}\{s_{2}^{l}(1,i)\} \tag{16}$$

where $\sigma^{2}\{s_{2}^{l}(1,i)\}$ is the square of standard deviation of five values of $s_{2}^{l}(1,i)$ which is listed in Table 10.

At the pilot institute j = 1, the transfer standard were calibrated simultaneously 5 times. The relative uncertainty arising from long-term shifts of the transfer standard for the pilot laboratory, $u_{lts}\{S(1,i)\}$, is estimated as follows:

$$u_{lts}^{2}\{S(1,i)\}=\frac{1}{5}\cdot\sigma^{2}\{s_{2}^{l}(1,i)\} \tag{17}$$

Table 15. Relative uncertainty arising from long-term shifts of the transfer standard. All the uncertainties are expressed as the standard ones.

i	[MPa]	Standard uncertainty due to long-term shifts of the transfer standard, $u_{lts}\{S(1,i)\}$[x 10^6]
1	10	15.7
2	20	18.2
3	30	7.5
4	40	17.1
5	50	8.5
6	60	11.8
7	70	6.6
8	80	7.9
9	90	8.7
10	100	9.9

7.8.4 Uncertainty arising from different ambient temperature

The uncertainty in correcting the reading when different of ambient temperature occurred is estimated from

$$u_{tem}^{2}\{S(j,i)\}=\left(\frac{Error\,between\ 20^{\circ}C\ and\ 23^{\circ}C}{2\sqrt{3}}\right)^{2} \tag{18}$$

Table 16. Relative uncertainty in correcting the reading when different of ambient temperature occurred. All the uncertainties are expressed as the standard ones.

		Standard uncertainty due to correcting the reading when different of ambient temperature occurred, $u_{tem}\{S(j,i)\}$[x 10^6]	
j		1	2
i	[MPa]	NIMT	NMLPHIL
1	10	0.0	11.2
2	20	0.0	3.4
3	30	0.0	4.8
4	40	0.0	1.9
5	50	0.0	4.5

6	60	0.0	6.0
7	70	0.0	6.0
8	80	0.0	6.3
9	90	0.0	4.8
10	100	0.0	4.5

7.8.5 Combined uncertainty in normalized mean ratio of institute

The combined standard uncertainty in the normalized mean ratio of the institute is estimated by combining the component uncertainties using the "root-sum-squares" method according to equation (12) and are presented in Table 17 and Figure 13.

Table 17. Combined standard uncertainties in normalized mean ratios of institutes, $u_c\{S\}$. All the uncertainties are expressed as the standard ones.

		Combined standard uncertainty, $u_c\{S(j,i)\}$[x 10^6]	
j		1	2
i	[MPa]	NIMT	NMLPHIL
1	10	28.1	39.6
2	20	25.0	37.1
3	30	18.8	33.0
4	40	24.3	35.1
5	50	19.1	31.8
6	60	20.6	33.2
7	70	18.0	31.3
8	80	18.4	31.6
9	90	18.6	31.4
10	100	19.2	31.5

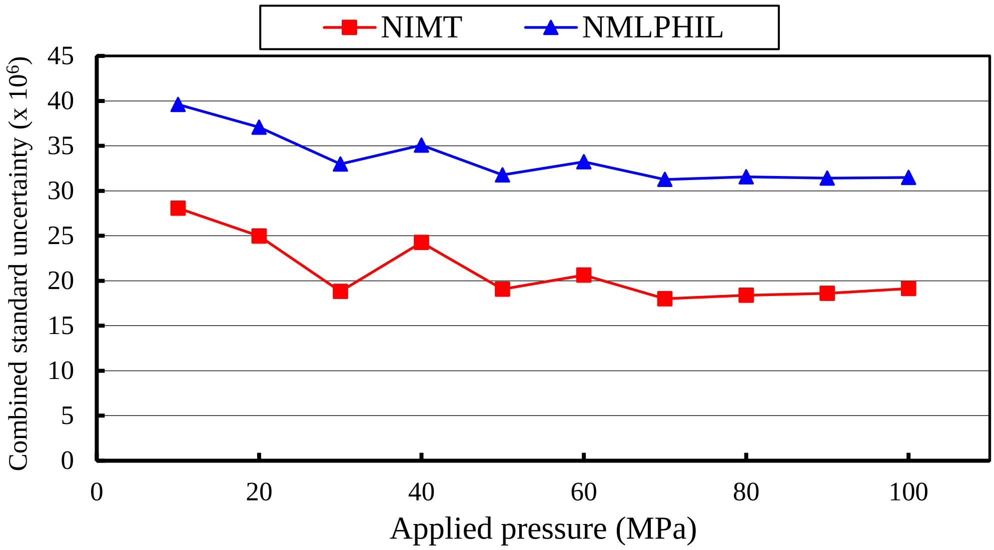

Figure 13. Combined standard uncertainties in normalized mean ratios of institutes as a function of nominal target pressure.

7.8.6 Combined uncertainty in expected mean pressure of institute

The combined standard uncertainty of the expected mean pressure of participating institute, $u_c\{p(j,i)\}$, is calculated from , $u_c\{S(j,i)\}$, by

$$u_c\{p(j,i)\} = u_c\{S(j,i)\} \cdot P_n(i) \tag{19}$$

where $P_n(i)$ is the nominal target pressure. $u_c\{p(j,i)\}$ is presented in Table 18 and Figure 14.

Table 18. Combined standard uncertainties in expected mean pressures of institutes, $u_c\{p\}$. All the uncertainties are expressed as the standard ones.

		Combined standard uncertainty $u_c\{p(j,i)\}$[kPa]	
j		1	2
i	MPa	NIMT	NMLPHIL
1	10	0.281	0.396
2	20	0.499	0.741
3	30	0.564	0.989
4	40	0.970	1.404
5	50	0.954	1.589
6	60	1.237	1.993
7	70	1.261	2.188
8	80	1.472	2.524
9	90	1.675	2.827
10	100	1.916	3.148

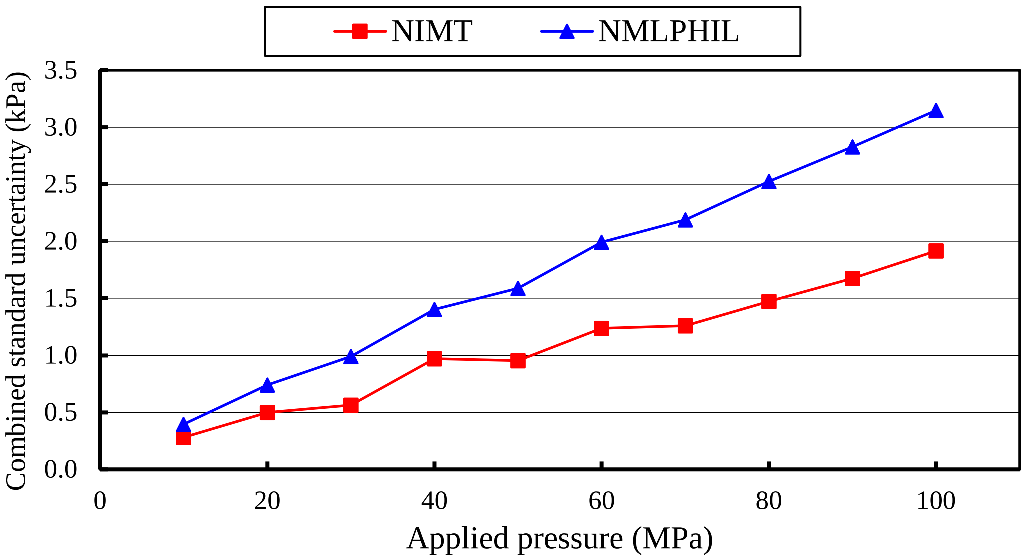

Figure 14. Combined standard uncertainties in expected mean pressures of institutes as a function of nominal target pressure.

8. Linking key comparison APMP.M.P-K7.2 to key comparison CCM.P-K7

This APMP key comparison, APMP.M.P-K7.2, is linked to the corresponding CCM key comparison , CCM.P-K7 by linked through the key comparison APMP.M.P-K7, which has the same pressure range.

The linking institute, NIMT participated in to both comparison APMP.M.P-K7 which reported deviations from the CCM KCRV and APMP.M.P-K7.2. The deviations from CCM KCRV of NIMT were listed in the Table 8.4 in the final report of APMP.M.P-K7.

The values used to link the results from APMP.M.P-K7.2 to CCM.P-K7 through the linkage institute, NIMT are shown in the Table 19.

Table 19. Relative deviations obtained from the linking institute for CCM.P-K7, the uncertainties are expressed as the standard ones.

i	Pressure [MPa]	Results in CCM.P-K7 of NIMT	
		x(NIMT,*i*) [x 10^6]	*u*{*x*(NIMT,i)} [x 10^6]
1	10	14.6	28.9
2	20	6.9	26.4
3	30	10.2	26.7
4	40	1.9	25.8
5	50	-1.9	25.6
6	60	0.0	25.7
7	70	-4.8	25.6
8	80	-4.1	25.6
9	90	-3.4	25.6
10	100	-3.9	25.7

Using the relationship of both quantities, the degree of equivalence of participating institutes in APMP.M.P-K7.2 comparison can be transferred to CCM.P-K7 comparison as follows:

$$D(j,i) = y(j,i) + x(NIMT,i) \qquad (20)$$

where *D(j,i)* is the relative deviation from the CCM.P-K7 reference value of *j*-th institute that participated into APMP.M.P-K7.2 and *y(j,i)* is the relative deviation from APMP.M.P-K7.2 reference value of *j*-th institute from the linkage institute NIMT which shown in Table 11, and *x(NIMT,i)* is the deviation of NIMT from CCM KCRVs as shown in Table 19.

The standard uncertainty of deviation from the CCM.P-K7 can be evalusted as follows

$$u\{D(j,i)\} = \sqrt{u_c^2(j,i) + u_{c.CCM}^2(NIMT,i)} \qquad (21)$$

where *uc(j,i)* is the uncertainty for the participant which shown in the Table 17, $u_{c,CCM}(NIMT,i)$ was shown in Table 8.4 of APMP.M.P-K7 in the final report of APMP.M.P-K7.

The degree of equivalent of the participants can be expressed by the normalize errors (E_n). The equation of E_n from each pressure is shown below:

$$E_n = \frac{|D(j,i)|}{U\{D(j,i)\}} \qquad (22)$$

The relative expanded uncertainty of *D(j,i)*, for the institute participated into APMP.M.P-K7.2 is estimated from

$$U\{D(j,i)\} = k \cdot u\{D(j,i)\} \qquad (23)$$

where k is the coverage factor and k = 2 is adopted.

Table 20 presents respectively the relative deviations from the CCM KCRVs, CCM.P-K7, *D(j,i)*, the expanded uncertainties (k=2) of the relative deviations, *U{D(j,i)}* and the degrees of equivalence, as E_n expressed by the ratios, *D(j,i)/U{D(j,i)}*, for individual participants at all nominal target pressure. A measure of the degree of equivalence is provided by the relative magnitude of the deviation as $E_n \leq 1$.

Figure 15 presents deviations from the CCM KCRVs, *D(j,i)* and the expanded uncertainties (k=2), of the deviations, *U{D(j,i)}*, graphically for the participating institute as a nominal target pressure.

Table 20. Deviations from the CCM KCRVs, *D(j,i)* [upper], the expanded (*k=2*) uncertainties of the deviations, *U{D(j,i)}* [middle] and the degrees of equivalence as expressed by the ratios, *D(j,i)/U{D(j,i)}* [lower].

		Relative deviation from CCM KCRV, *D(j,i)* [x10^6]																
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
i	[MPa]	NMIJ/ AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM	NMLPHIL
1	10	0.0	-11.5	-7.3	-38.2	-11.0	0.3	-19.2	-35.6	-13.0	-22.7	33.7	21.0	2.5	14.6	23.9	-17.3	55.1
2	20	-1.6	-9.7	-14.3	-24.1	-6.2	4.2	-12.0	-22.8	37.4	-14.9	20.9	3.7	1.1	6.9	17.8	-11.4	25.1
3	30	-0.7	-7.9	-10.2	-11.4	-1.9	4.0	-6.1	-16.8	48.1	-18.0	20.3	0.8	0.3	10.2	15.3	-8.6	27.2
4	40	-1.1	-7.6	-8.1	-10.3	0.4	2.2	-6.2	-17.0	34.6	-22.5	17.1	-1.2	0.0	1.9	18.3	-10.1	13.5
5	50	-0.5	-5.2	-8.8	-8.2	0.7	-0.3	-6.0	-16.7	30.7	-27.3	10.4	-2.9	0.6	-1.9	18.3	-9.6	18.1
6	60	-1.3	-4.5	-11.7	-10.6	-0.9	-7.7	-8.0	-19.3	21.6	-33.2	9.1	-7.5	0.0	0.0	13.3	-13.2	13.0
7	70	-0.6	-3.2	-7.4	-6.0	2.7	-8.5	-4.2	-18.6	12.8	-28.9	10.4	-7.3	0.0	-4.8	17.2	-12.7	12.5
8	80	-0.5	-1.8	-8.1	-4.0	2.9	-11.1	-5.0	-20.5	14.5	-27.8	7.4	-8.5	0.0	-4.1	17.0	-15.4	11.1
9	90	0.0	-0.8	-7.2	-2.2	4.0	43.0	-3.7	-21.5	4.5	-27.8	7.9	-10.0	-0.1	-3.4	15.1	-17.3	16.3
10	100	0.0	-0.8	-8.9	-4.3	4.5	52.7	-4.5	-24.7	4.8	-30.3	8.0	-9.3	-0.1	-3.9	15.1	-21.5	10.9

		Expanded uncertainty, *U{D(j,i)}* [x10^6] *(k=2)*																
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
i	[MPa]	NMIJ/ AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM	NMLPHIL
1	10	27.0	61.0	33.1	42.7	48.6	48.6	40.4	46.3	76.2	60.2	69.7	85.2	22.0	57.8	65.4	38.0	97.1
2	20	27.0	57.0	26.7	34.7	43.6	36.4	34.9	40.6	74.7	42.0	67.6	72.0	22.0	52.7	52.4	33.6	89.4
3	30	27.0	49.0	26.1	33.7	43.5	36.5	33.5	40.1	71.9	32.6	69.3	68.3	22.0	53.4	55.1	32.2	75.9
4	40	27.0	49.0	25.3	33.7	44.1	37.6	33.5	40.1	62.2	31.8	70.6	66.2	23.0	51.6	51.3	31.1	85.3
5	50	28.0	49.0	24.8	32.4	43.3	38.8	33.3	39.9	61.3	28.6	71.8	64.9	25.0	51.2	48.9	30.0	74.1
6	60	29.0	49.0	24.9	32.4	43.8	41.3	34.1	41.2	57.2	27.6	74.8	64.3	27.0	51.4	51.1	30.1	78.2
7	70	30.0	49.0	24.8	32.5	44.1	43.9	34.7	41.1	55.3	28.2	76.8	66.5	29.0	51.1	49.7	29.8	72.2
8	80	31.0	49.0	25.2	32.9	44.9	46.1	35.6	41.2	54.7	28.4	78.2	65.9	31.0	51.2	51.3	29.7	73.1
9	90	33.0	49.0	24.9	32.7	45.4	96.5	36.4	43.3	54.6	28.1	80.0	65.3	33.0	51.1	50.1	29.6	73.0
10	100	34.0	49.0	25.5	32.8	46.4	104.8	37.7	45.3	55.6	28.3	82.2	65.0	36.0	51.3	49.6	29.8	73.7

		D(j,i)/U{D(j,i)}																
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
i	[MPa]	NMIJ/ AIST	NPLI	CSIR- NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML- SIRIM	KIM- LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM	NMLPHIL
1	10	0.00	-0.19	-0.22	-0.89	-0.23	0.01	-0.48	-0.77	-0.17	-0.38	0.48	0.25	0.11	0.25	0.37	-0.46	0.57
2	20	-0.06	-0.17	-0.54	-0.69	-0.14	0.12	-0.34	-0.56	0.50	-0.35	0.31	0.05	0.05	0.13	0.34	-0.34	0.28
3	30	-0.03	-0.16	-0.39	-0.34	-0.04	0.11	-0.18	-0.42	0.67	-0.55	0.29	0.01	0.01	0.19	0.28	-0.27	0.36
4	40	-0.04	-0.16	-0.32	-0.31	0.01	0.06	-0.19	-0.42	0.56	-0.71	0.24	-0.02	0.00	0.04	0.36	-0.32	0.16
5	50	-0.02	-0.11	-0.35	-0.25	0.02	-0.01	-0.18	-0.42	0.50	-0.95	0.14	-0.04	0.02	-0.04	0.37	-0.32	0.24
6	60	-0.04	-0.09	-0.47	-0.33	-0.02	-0.19	-0.23	-0.47	0.38	-1.20	0.12	-0.12	0.00	0.00	0.26	-0.44	0.17
7	70	-0.02	-0.07	-0.30	-0.18	0.06	-0.19	-0.12	-0.45	0.23	-1.02	0.14	-0.11	0.00	-0.09	0.35	-0.43	0.17
8	80	-0.02	-0.04	-0.32	-0.12	0.06	-0.24	-0.14	-0.50	0.27	-0.98	0.09	-0.13	0.00	-0.08	0.33	-0.52	0.15
9	90	0.00	-0.02	-0.29	-0.07	0.09	0.45	-0.10	-0.50	0.08	-0.99	0.10	-0.15	0.00	-0.07	0.30	-0.58	0.22
10	100	0.00	-0.02	-0.35	-0.13	0.10	0.50	-0.12	-0.55	0.09	-1.07	0.10	-0.14	0.00	-0.08	0.30	-0.72	0.15

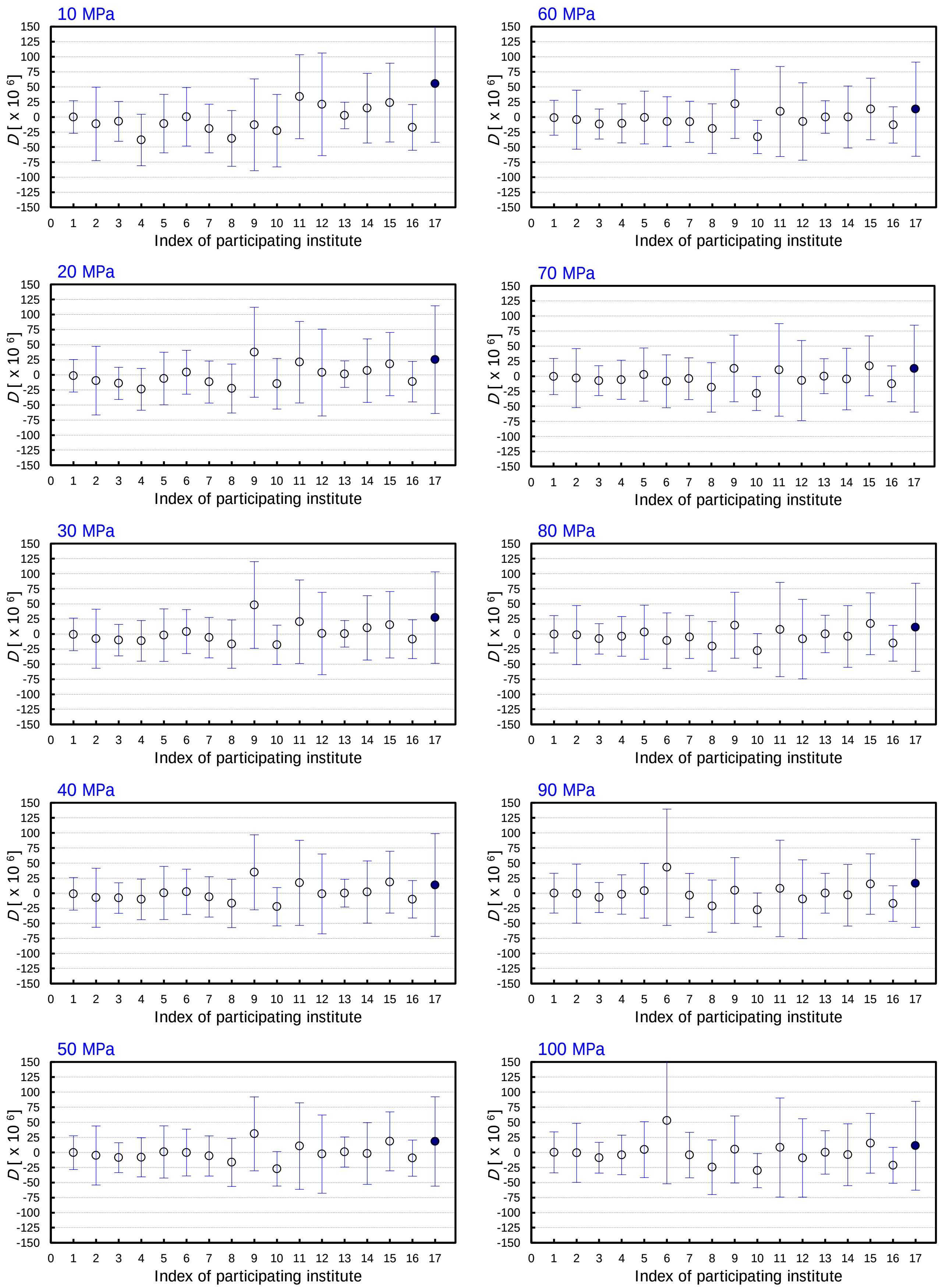

Figure 15. Deviations from the CCM KCRVs, *D(j,i)* and the expanded (k=2) uncertainties of the deviations, *U{D(j,i)}*.

9. Disussions

The results presented in this report are based on data originally sunmitted to pilot institute for preparation of the report. From the measurement data of each participating institute, the expected mean pressure and associated uncertainty were calculated. Both participants measured two hydraulic pressure transducers transfer standard against the pressure balances as shown in table 2 of this report. The key comparison reference in this report was used the results of pilot institute, NIMT from APMP.M.P-K7 key comparison which reported in deviations from CCM KCRV.

Finally the measurement result of the NMLPHIL were linked to CCM KCRV of CCM.P-K7 through the results of NIMT which reported in APMP.M.P-K7 as shown in table 20 and Figure 15 of this report.

10. Conclusions

National Institute and Metrology Thailand (NIMT) and National Metrology Laboratory-Industrail Technology Development Institute (The Philippines) / (NMLPHIL) conducted this APMP key comparison of hydraulic pressure standards from 10 MPa to 100 MPa in gauge mode. Two high-precision hydraulic pressure transducers were used as the transfer standard for this comparison. To ensure the reliability of the transfer standard, five completed measurements were performed before and during the comparison by the pilot institute. Therefore behavior of the transfer standards during the comparison period were well characterized. It was confirmed that the capabilities of the transfer standard were sufficiently stable for the requirements of this comparison.

The degrees of equivalence of hydraulic pressure developed by the hydraulic pressure balance reference standards maintained by the two participating NMIs were obtained. They were expressed quantitatively by the deviations from key comparison reference values. The hydraulic pressure standards in the range from 10 MPa to 100 MPa, gauge mode, maintained by the two participating NMIs (NMIT and NMLPHIL) were found to be fully equivalent within their claimed uncertainties. The results of this APMP key comparison were satisfactory.

The degrees of equivalence in this comparison were also transferred to the corresponding CCM key comparison, CCM.P-K7. The hydraulic pressure standards in the range from 10 MPa to 100 MPa, gauge mode, maintained by the two participating NMIs were equivalent to the CCM KCRV within the claimed uncertainties.

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