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ASIA-PACIFIC METROLOGY PROGRAMME
Pneumatic Pressure Comparison from 20 kPa to 105 kPa in gauge mode
Comparison identifier: APMP.M.P-K6.1

Final Report on APMP.M.P-K6.1 Pneumatic Key Comparison from 20 kPa to 105 kPa in gauge mode

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Abstract

This report describes the key comparison APMP.M.P-K6.1 among the three National Metrology Institutes, Center for Measurement Standards-ITRI (CMS-ITRI, Chinese Taipei), SPRING Singapore and National Institute of Metrology (NIMT) in the pressure range from 20 kPa to 105 kPa in gas media and gauge mode executed during the period April 2003 to April 2004. This comparison was conducted by CMS-ITRI and was based on the calibration procedure of APMP Pneumatic Pressure Comparison APMP.M.P-K6. We intended to link to the CCM.P-K6 key comparison through the APMP.M.P-K6 key comparison by using the proposed linkage method in the APMP.M.P-K6 key comparison to determine a linking factor that can transform the quantities measured in the APMP.M.P-K6.1 key comparison. All three participating institutes used pneumatic piston gauges as their pressure standards. Ruska 2465 gas-operated piston-cylinder assembly TL-1409 used as transfer standard offered by CMS-ITRI was calibrated three times by the pilot institute during the comparison period and showed that it was very stable after evaluated. The comparison was conducted on the basis of cross-float experiments to determine the effective area of transfer standards from the national standards of three institutes.

The comparison results (as shown in Table 6) were equivalent to the CCM.P-K6 comparison and the relative bilateral degrees of equivalence between two laboratories were smaller than 39.7×10^{-6} from 20 kPa to 105 kPa. These results showed all participating institutes measuring the same quantity in the whole pressure range lay within their expanded uncertainty with confidence level 95 %.

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1. Introduction

The regional pneumatic comparison program has been agreed with the Technical Committee for Mass and Related Quantities (TCM) of the Asia-Pacific Metrology Programme (APMP) for pneumatic pressure measurements from 20 kPa to 105 kPa in gauge mode. The key comparison was identified APMP.M.P-K6.1 by 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) and APMP. The comparison among Center for Measurement Standards-ITRI (CMS-ITRI, R.O.C.), SPRING Singapore and National Institute of Metrology (NIMT) was based on the calibration procedure of APMP Pneumatic Pressure Comparison APMP.M.P-K6. The transfer standard offered by the pilot institute, CMS-ITRI, was Ruska 2465 gas-operated piston-cylinder assembly (TL-1409) and the effective area of the transfer standard can be determined by the cross-float technique against the participants' primary standards. The comparison activity was started on April 2003 and was completed on April 2004. In order to reach international consistence at same pressure range, this key comparison APMP.M.P-K6.1 will be linked to the CCM.P-K6 key comparison through the APMP.M.P-K6 key comparison.

The protocol prepared by CMS-ITRI was referred to the calibration procedure of APMP.M.P-K6. It was also an important part in the comparison. At first, the transfer standards were transported to SPRING Singapore after the first time of the comparison in CMS-ITRI was carried out, and then the transfer standards were transported to CMS-ITRI after the comparison was performed by SPRING Singapore. Because NIMT Thailand joined the comparison activity at this moment, the protocol was amended and then the transfer standards were transported to NIMT Thailand after the second time of the comparison in CMS-ITRI was carried out. Finally, the transfer standards were transported to CMS-ITRI and the third time of the comparison in CMS-ITRI was performed after the comparison was carried out by NIMT.

This report include description of transfer standard, package and transportation, participants standards, calibration procedure, data calculation, the calibration results of the transfer standard performed at three participating laboratories, analysis of the results and the comparison results.

2. Transfer standard

2.1 Description of transfer standard

The transfer standard was a Ruska (Model 2465) piston pressure gauge base fully equipped with weight set, temperature probe and piston-cylinder assembly (TL-1409) with nominal effective area 335.75 mm^2 used to measure the pressure range from 20 kPa to 105 kPa in the gauge mode using nitrogen gas as the pressure transmitting media. Both piston and cylinder are made of tungsten carbide. All masses were calibrated in mass laboratory with standard mass density of 8,000 kg/cm^3. The handing, mounting, cleaning etc. instructions of piston–cylinder assembly is described in the Ruska 2465 User's Manual[1]. Some points should be concerned about the height difference between reference level of the two compared standards and head correction.

(a) The reference level of piston gage is usually at a line marked on the piston gage base.
(b) To minimize uncertainties in pressure measurement, height difference between the reference levels of the laboratory standards and transfer standards will be kept as low as possible.
(c) The two compared standards placed by CMS-ITRI are in the same level, so that the height correction is zero.
(d) The densities of air and nitrogen should be considered if any height correction is necessary.

2.2 Package and Transportation

To prevent the package of transfer standard from any damage, all effort should be made by each participant. The instruments must be handled with care. When the package arrives at participating institute, the package must be unpacked, and an inspection of the appearance and the function should be made immediately. The time schedule for the comparison and transportation of transfer standard is shown in Table 1.

Table 1: The time schedule for the comparison and the transportation of transfer standard

No.	Date of arrival	Date of departure	Name of the laboratories
1		9th October, 2003	CMS-ITRI (ROC)
2	13th October, 2003	20th November, 2003	SPRING (Singapore)
3	24th November, 2003	2nd February, 2004	CMS-ITRI (ROC)
4	9th February, 2004	22nd March, 2004	NIMT (Thailand)
5	29th March, 2004		CMS-ITRI (ROC)

2.3 Stability of the transfer standard

To concern about the stability of transfer standard in any international comparison is very important. It took over one year to carry out this comparison from the beginning to the end. The performance of the transfer standard should be affected if it was not stable.

The values of the effective area $A'_{P'}$(23℃, p')(mm^2)versus p'(kPa) which were obtained by CMS-ITRI on April 2003, December 2003 and April 2004 are shown in Fig.1. The standard deviations are indicated through the error bars in order to establish the long-term stability of the transfer standard during one year. Table 2 provides the data of the effective area $A'_{P'}$(23°C, p')(mm^2) versus p'(MPa) of the transfer standard calibrated three times by CMS-ITRI during the comparison time period. Each standard uncertainty was calculated from ten pressure points of five measuring cycles including ascending and descending pressures of the three sets of data(totally 15 standard deviations in Table 2). The maximum difference of the average $A'_{P'}$ in three measurement sets is 1.6×10^{-3} mm^2 at 21.4 kPa. So, we propose the estimated instability contributed from maximum difference (1.6×10^{-3} mm^2) divide by nominal effective area (335.6 mm^2) is 4.8×10^{-6}.

Fig. 1. The stability of transfer standard is indicated in standard deviation of effective area $A'_{P'}$ on April 2003, December 2003 and April 2004.

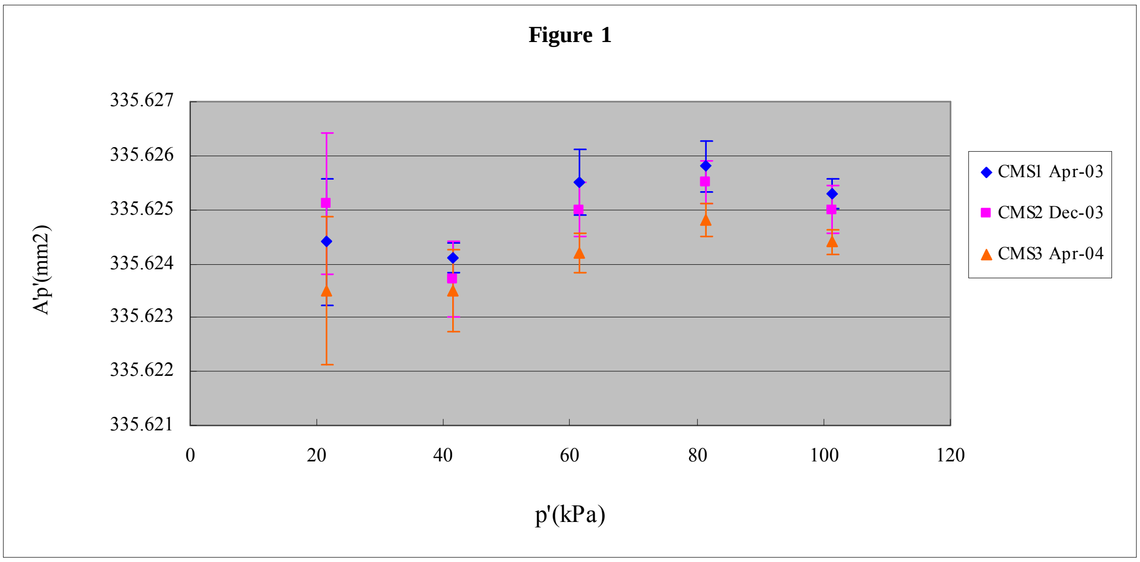

Table 2: The stability data show the effective area of the transfer standard $A'_{P'}$ (mm^2) at 23 °C versus p' (kPa) on April 2003, December 2003 and April 2004.

Lab. Name	CMS-ITRI					
Nominal Pressure	Date (Period) 2 April. 2003 to 7 April 2003		Date (Period) 8 Dec. 2003 to 12 Dec. 2003		Date (Period) 8 April 2004 to 13 April 2004	
	Average of $A'_{P'}$	Standard deviation of $A'_{P'}$	Average of $A'_{P'}$	Standard deviation of $A'_{P'}$	Average of $A'_{P'}$	Standard deviation of $A'_{P'}$
(kPa)	(mm^2)	(10^{-6})	(mm^2)	(10^{-6})	(mm^2)	(10^{-6})
21.4	335.6244	3.5	335.6251	3.9	335.6235	4.1
41.4	335.6241	0.8	335.6237	2.1	335.6235	2.3
61.4	335.6255	1.8	335.6250	1.5	335.6242	1.1
81.4	335.6258	1.4	335.6255	1.2	335.6248	0.9
101.4	335.6253	0.8	335.6250	1.3	335.6244	0.7

2.4 Participants standards

The characteristics of all participants standards used in this comparison were shown in the Table 3.

Table 3: The characteristics of all participants standards used in this comparison.

Institute		CMS-ITRI	SPRING	NIMT
Country		(Taiwan R.O.C)	Singapore	Thailand
Pressure balance base	Manufacturer	Ruska	Ruska	Ruska
	Model	2465	2465	2465
Piston-cylinder	Type	Simple	Simple	Simple
	Material (Piston/Cylinder)	Steel/WC	Steel/WC	Steel/WC
$A_{e,}$ Effective Area	Value (mm^2)	335.750	335.728	335.664
	Relative Uncertainty (10^{-6}) (k=2)	29	21	15.2
Ref. temp	t_r(℃)	23	20	20
Distortion coefficient λ	Value (kPa^{-1})	0	0	0
Traceability		CMS-ITRI *	NPL	PTB

* The laboratory has the primary standard "laser interferometer mercury manometer".

3 Calibration procedure and data calculation

3.1 Calibration procedure

The transfer standard was cross-floated against the measurement standard[2,3]. The standard pressures (P') are the pressure generated at the reference level of the transfer standard by the measurement standard. The effective area ($A'_{P'}$) of the transfer standard can be determined by the standard pressures and forces (F') exerted on the transfer standard.

The comparison was conducted on the basis of cross-float experiment to determine the effective area of transfer standard by carrying out five measuring cycles with clockwise rotation. The comparison was performed at the nominal pressures (in kPa) of 21.4, 41.4, 61.4, 81.4 and 101.4(ascending pressure), 101.4, 81.4, 61.4, 41.4 and 21.4(descending pressure) in each measuring cycle. There are only 5 nominal pressures after we average the ascending pressure and descending pressure in this comparison results.

3.2 Data Calculation

The standard pressure measured at the reference level of laboratory standard is expressed as[1]

$$P = \frac{\sum_i M_i g\left(1 - \rho_a/\rho_{M_i}\right)}{A_0\left[1 + \left(\alpha_p + \alpha_c\right)\left(T - T_0\right)\right]\left[1 + \lambda P\right]} \tag{1}$$

Where

A_0: The effective area of the laboratory standard

M_i: The individual mass of each weight applied on the measurement standard

g: The local acceleration due to gravity

ρ_a: The air density at time of measurement

ρ_{Mi}: The density of the individual mass of laboratory standard

α_p: The thermal expansion coefficient of the laboratory standard piston

α_c: The thermal expansion coefficient of the laboratory standard cylinder

λ: The pressure distortion coefficient piston cylinder assembly

T: The temperature of the laboratory standard during measurement

T_0: The reference temperature

The pressure measured by the laboratory standard at the transfer standard reference level is

$$P' = P \pm \left(\rho_f - \rho_a\right)gh \tag{2}$$

Where

ρ_f: The density of pressure transmitted medium

h: The height difference between reference level of the two standards

The force on transfer standard is expressed as:

$$F' = \sum_i M'_i\, g\left(1 - \rho_a/\rho'_{M_i}\right) \tag{3}$$

In equilibrium condition between the two standards and by reversing the above formula and using the pressure P' measured by the laboratory standard at the reference level of the transfer standard, we obtain the effective area of the transfer standard

$$A'_{P'} = \frac{F'}{P'} = \frac{\sum_i M'_i\, g\left(1 - \rho_a/\rho'_{M_i}\right)}{P'\left[1 + \left(\alpha'_p + \alpha'_c\right)\left(T' - T'_0\right)\right]} \tag{4}$$

Where

$A'_{P'}$: The effective area of the transfer standard

M'_i: The individual mass of each weight applied on the transfer standard

$\rho'_{M'i}$: The density of the individual mass of transfer standard

α_p': The thermal expansion coefficient of the transfer standard piston

α_c': The thermal expansion coefficient of the transfer standard cylinder

T': The temperature of the transfer standard during measurement

T'_0: The reference temperature of the transfer standard piston

The average value of the effective areas $A'_{P'}$ (mm^2) at 23°C of the transfer standard for each participating laboratory is calculated by averaging the experimental determinations at each nominal pressure point of five measurement cycles. The averages values of the effective area of the transfer standard $A'_{P'}$ (mm^2) at 23°C and p' versus p'(MPa) for all the participating laboratories are shown in Table 4.

The relative combined standard uncertainty, u_{rc} and the relative expanded uncertainty, U_{re} of $A'_{P'}$ (mm^2) at 23°C, p' and each nominal pressure point in the calibration procedure for each laboratory are estimated from the equation[3] as follows,

$$U_{re} = ku_{rc} = k\sqrt{\left(u_{rA'}{}^2 + u_{rT'}{}^2 + u_{rp'}{}^2\right)} \qquad (5)$$

Where

$u_{rA'}$: The relative standard uncertainty of effective area

$u_{rT'}$: The relative standard uncertainty of temperature

$u_{rp'}$: The relative standard uncertainty of standard pressure

k: Coverage factor (k = 2.)

The relative expanded uncertainty of pressure ($u_{rp'}$) and the relative standard uncertainty of temperature ($u_{rT'}$) at each nominal pressure point were offered by the participating laboratories. Table 4 shows the relative expanded uncertainty U_{re} at k=2 of all the participating laboratories.

Table 4: Average values of the effective area $A'_{P'}$ (mm^2) and relative expanded uncertainty (U_{re}) of the transfer standard at k=2 for all laboratories.

Lab. Name	CMS-ITRI		SPRING		NIMT	
Nominal Pressure	Average of $A'_{P'}$	Relative Expanded Uncertainty (U_{re}) of $A'_{P'}$ (k=2)	Average of $A'_{P'}$	Relative Expanded Uncertainty (U_{re}) of $A'_{P'}$(k=2)	Average of $A'_{P'}$	Relative Expanded Uncertainty (U_{re}) of $A'_{P'}$(k=2)
(kPa)	(mm^2)	(10^{-6})	(mm^2)	(10^{-6})	(mm^2)	(10^{-6})
21.4	335.6235	30.2	335.6339	22.0	335.6351	18.6
41.4	335.6235	30.0	335.6322	21.8	335.6368	18.0
61.4	335.6242	30.0	335.6329	21.4	335.6364	17.8
81.4	335.6248	30.0	335.6312	21.2	335.6368	17.8
101.4	335.6244	30.0	335.6322	21.2	335.6367	17.8

4. Analysis of the results

4.1 Method of linking

SPRING Singapore participated both in APMP.M.P-K6 key comparison and PMP.M.P-K6.1 key comparison, is the linking laboratory. We used the proposed linkage method [3,5] in the APMP.M.P-K6 key comparison to determine a linking factor (r_{APMP}) that can transform the quantities measured in the APMP.M.P-K6.1 key comparison. Table 5 shows a comparison data of SPRING both in the APMP.M.P-K6 and APMP.M.P-K6.1 key comparisons and CCM.P-K6 key comparison reference value (KCRV). Where $x^{k6.1}_{SPRING}$ (mm^2) are the SPRING calculated effective areas of the APMP.M.P-K6.1 transfer standard and $u(x^{k6.1}_{SPRING})$ their standard uncertainties. x^{k6}_{SPRING} (mm^2) are the SPRING calculated effective areas of the APMP.M.P-K6 transfer standard and $u(x^{k6}_{SPRING})$ their standard uncertainties. x^{kc}_{0} are the reference values of key comparison (KCRV) in the CCM.P-K6 and $u(x^{kc}_{0})$ their standard uncertainties. A correlation coefficient ρ_{SPRING} of 0.7 had also been estimated between the two sets of the SPRING results. Then the linking factor (r_{APMP}) and the standard uncertainty $u(r_{APMP})$ at a given measure pressure (say 21 kPa) can be calculated.

$$r_{APMP} = x^{k6}_{SPRING} / x^{k6.1}_{SPRING} = 335.7375\ mm^2/335.6339\ mm^2 = 1.000309 \qquad (6)$$

$u(r_{APMP})$=

$$\sqrt{\left[\left(\frac{u(x^{k6}_{SPRING})}{x^{k6.1}_{SPRING}}\right)^2 + \left(\frac{x^{k6}_{SPRING}\times u(x^{k6.1}_{SPRING})}{\left(x^{k6.1}_{SPRING}\right)^2}\right)^2 - 2\left(\frac{1}{x^{k6.1}_{SPRING}}\right)\left(\frac{x^{k6}_{SPRING}}{\left(x^{k6.1}_{SPRING}\right)^2}\right)\left(\rho_{SPRING}\times u(x^{k6}_{SPRING})\times u(x^{k6.1}_{SPRING})\right)\right]}$$

$$= \sqrt{\left(1.92\times10^{-5}\right)^2 + \left(1.10\times10^{-5}\right)^2 - 2\left(1.48\times10^{-10}\right)^2} = 13.9\times10^{-6} \qquad (7)$$

Table 5. A comparison data of SPRING both in the APMP.M.P-K6 and APMP.M.P-K6.1 key comparisons and CCM.P-K6 key comparison reference value (KCRV).

Nominal Pressure	APMP.M.P-K6 (SPRING)		APMP.M.P-K6.1 (SPRING)		CCM.P-K6 (KCRV)	
(kPa)	x_i^{k6} (mm^2)	$u(x_i^{k6})/x_i^{k6}$ $\times 10^{-6}$	$x_i^{k6.1}$ (mm^2)	$u(x_i^{k6.1})/x_i^{k6.1}$ $\times 10^{-6}$	x_0^{kc} (mm^2)	$u(x_0^{kc})$ (mm^2)
20	335.7375	19.2	335.6339	11.0	335.7444	0.0007
40	335.7353	19.2	335.6322	10.9	335.7441	0.0009
60	335.735	19.2	335.6329	10.7	335.7443	0.0005
80	335.7348	19.2	335.6312	10.6	335.7445	0.0006
100	335.734	19.1	335.6322	10.6	335.7445	0.0009

4.2 Degree of equivalence

The degree of equivalence of a laboratory (say CMS at 21 kPa) link to the CCM.P-K6 key comparison through the APMP.M.P-K6 key comparison was obtained in the following equation

$$D_{CMS} = r_{CCM} \times r_{APMP} \times x_{CMS} - x_0^{kc} = -0.0105\ mm^2 \quad (8)$$

Where r_{CCM} = 1.000020 (PTB linking factor in APMP.M.P-K6), r_{APMP} = 1.000309 (SPRING linking factor), x_{CMS} = 335.6235 mm^2, x_0^{kc} = 335.7444 mm^2 (KCRV).

And its expanded uncertainty (k=2)

$$U(D_{CMS})=2\sqrt{(x_{CMS}\times r_{APMP}\times u(r_{CCM}))^2+(x_{CMS}\times r_{CCM}\times u(r_{APMP}))^2+(r_{CCM}\times r_{APMP}\times u(x_{CMS}))^2+u(x_0^{kc})^2}$$

$$= 0.0141\ mm^2 \quad (9)$$

Where $u(r_{CCM})$ = 3.9$\times$10^{-6}, $u(r_{APMP})$= 1.000309, $u(x_{CMS})$ = 13.9$\times$10^{-6}, $u(x_0^{kc})$ = 0.0007 mm^2.

The relative degree of equivalence was then obtained

$$\frac{D_{CMS}}{x_0^{kc}} \times 10^6 = -31.28 \quad (10)$$

and its relative expanded uncertainty

$$\frac{U\left(D_{CMS}\right)}{x_0^{kc}} \times 10^6 = 42.01 \qquad (11)$$

Similar estimations can be obtained for the other participating laboratories and are shown in Table 6.

Table 6: The degrees of equivalence (D_i) and their expanded uncertainties $U(D_i)$ (k=2) of participating laboratories linking to the CCM.P-K6 key comparison through the APMP.M.P-K6 key comparison. The degrees of equivalence of SPRING in APMP.M.P-K6 key comparison reported in the KCDB are also shown in the table.

Nominal Pressure	CMS/ITRI (APMP.M.P-K6.1)		SPRING (APMP.M.P-K6)		NIMT (APMP.M.P-K6.1)	
(kPa)	D_i mm^2	$U(D_i)$ mm^2	D_i mm^2	$U(D_i)$ mm^2	D_i mm^2	$U(D_i)$ mm^2
21.4	-0.0105	0.0141	-0.0001	0.0132	0.0011	0.0116
41.4	-0.0108	0.0141	-0.0021	0.0132	0.0025	0.0116
61.4	-0.0118	0.0140	-0.0031	0.0131	0.0004	0.0115
81.4	-0.0101	0.0140	-0.0037	0.0131	0.0019	0.0115
101.4	-0.0127	0.0141	-0.0049	0.0132	-0.0004	0.0115

4.3 Bilateral degree of equivalence

Bilateral degree of equivalence (D_{ij}) of the participating laboratories in the APMP.M.P-K6.1 comparison can be estimated from the degree of equivalence between two laboratories.

$$D_{ij} = D_i - D_j = r_{CCM} \times r_{APMP} (x_i - x_j) \qquad (12)$$

And the bilateral expanded uncertainty (k=2) is

$$U(D_{ij}) = 2 \sqrt{\left(r_{APMP}\left(x_i - x_j\right)\times u(r_{CCM})\right)^2 + \left(r_{CCM}\left(x_i - x_j\right)\times u(r_{APMP})\right)^2 + \left(r_{CCM}\times r_{APMP}\right)^2 \times \left(u(x_i)^2 + u(x_j)^2\right)} \qquad (13)$$

For the 21 kPa example, we can calculated below (say CMS/ITRI – SPRING)

$$D_{CMS\text{-}SPRING} = D_{CMS} - D_{SPRING} = -0.0105 - (-0.0001) = -0.0104\ mm^2 \qquad (14)$$

$$U(D_{CMS\text{-}SPRING}) = 2 \sqrt{\left(r_{APMP}\left(x_{CMS} - x_{SPRING}\right)\times u(r_{CCM})\right)^2 + \left(r_{CCM}\left(x_{CMS} - x_{SPRING}\right)\times u(r_{APMP})\right)^2 + \left(r_{CCM}\times r_{APMP}\right)^2 \times \left(u(x_{CMS})^2 + u(x_{SPRING})^2\right)}$$
$$= 0.0125\ mm^2 \qquad (15)$$

The relative bilateral degree of equivalence was calculated by the following equation

$$\frac{D_{CMS-SPRING}}{x_0^{kc}} \times 10^6 = -30.99 \tag{16}$$

and its relative expanded uncertainty

$$\frac{U\left(D_{CMS-SPRING}\right)}{x_0^{kc}} \times 10^6 = 37.35 \tag{17}$$

The calculated relative bilateral degrees of equivalence at 21 kPa, 41 kPa, 61 kPa, 81 kPa and 101 kPa between any two laboratories for the transfer standard are shown in Table 7 to Table 11.

Table 7: The relative bilateral degrees of equivalence between two laboratories at 21 kPa.

	p' = 21 kPa	Labj					
		CMS-ITRI		SPRING		NIMT	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
Labi	CMS-ITRI			-31.0	37.4	-34.6	35.5
	SPRING	31.0	37.4			-3.6	28.8
	NIMT	34.6	35.5	3.6	28.8		

Table 8: The relative bilateral degrees of equivalence between two laboratories at 41 kPa.

TL-1409	p' =41 kPa	Labj					
		CMS-ITRI		SPRING		NIMT	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
Labi	CMS-ITRI			-25.9	37.1	-39.6	35.0
	SPRING	25.9	37.1			-13.7	28.3
	NIMT	39.6	35.0	13.7	28.3		

Table 9: The relative bilateral degrees of equivalence between two laboratories at 61 kPa.

TL-1409	p' =61 kPa	Labj					
		CMS-ITRI		SPRING		NIMT	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
Labi	CMS-ITRI			-25.9	36.8	-36.3	34.9
	SPRING	25.9	36.8			-10.4	27.8
	NIMT	36.3	34.9	10.4	27.8		

Table 10: The relative bilateral degrees of equivalence between two laboratories at 81 kPa.

TL-1409	p' =81 kPa	Labj					
		CMS-ITRI		SPRING		NIMT	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
Labi	CMS-ITRI			-19.1	36.7	-35.8	34.9
	SPRING	19.1	36.7			-16.7	27.7
	NIMT	35.8	34.9	16.7	27.7		

Table 11: The relative bilateral degrees of equivalence between two laboratories at 101 kPa.

TL-1409	p' =101 kPa	Labj					
		CMS-ITRI		SPRING		NIMT	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
Labi	CMS-ITRI			-23.2	36.7	-36.6	34.9
	SPRING	23.2	36.7			-13.4	27.7
	NIMT	36.6	34.9	13.4	27.7		

The degrees of equivalence of CCM.P-K6, APMP.M.P-K6 and APMP.M.P-K6.1 together at different nominal pressures are shown in Figure 2 to Figure 6.

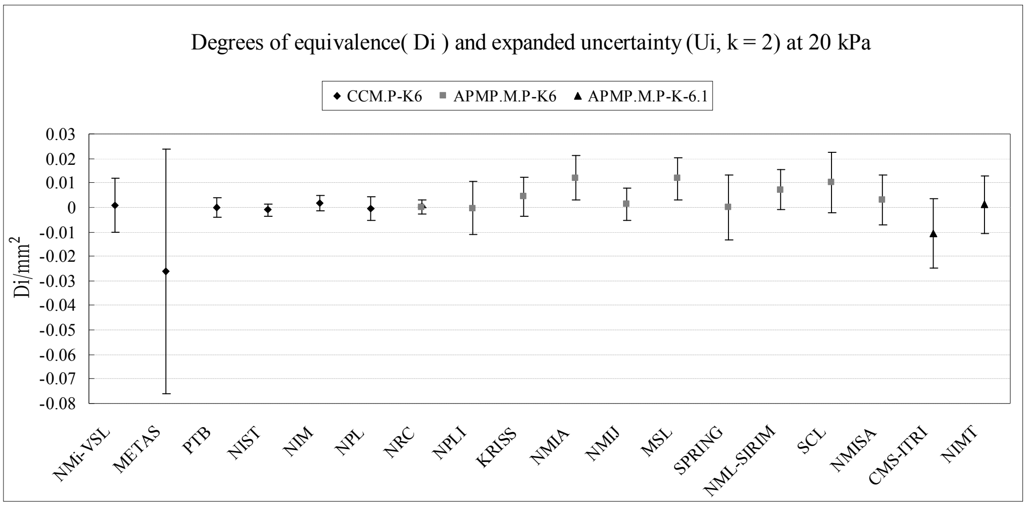

Fig.2. The degrees of equivalence of the CCM.P-K6, APMP.M.P-K6 and APMP.M.P-K-6.1 at nominal pressure 20 kPa.

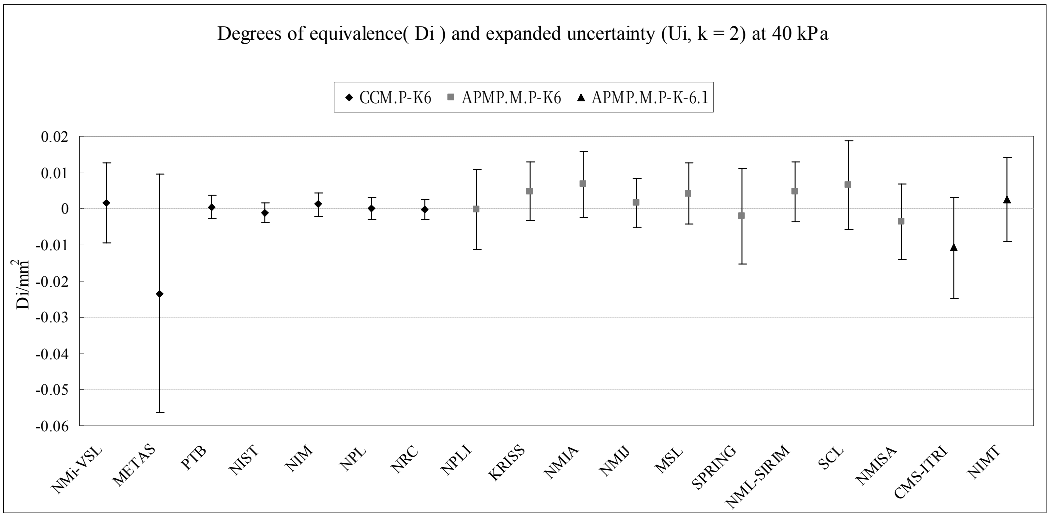

Fig.3. The degrees of equivalence of the CCM.P-K6, APMP.M.P-K6 and APMP.M.P-K-6.1 at nominal pressure 40 kPa.

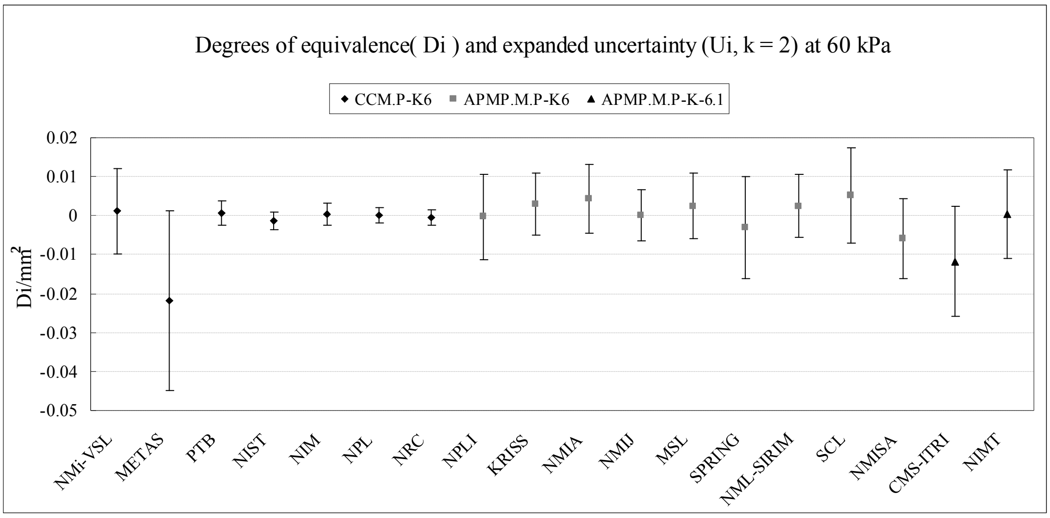

Fig.4. The degrees of equivalence of the CCM.P-K6, APMP.M.P-K6 and APMP.M.P-K-6.1 at nominal pressure 60 kPa.

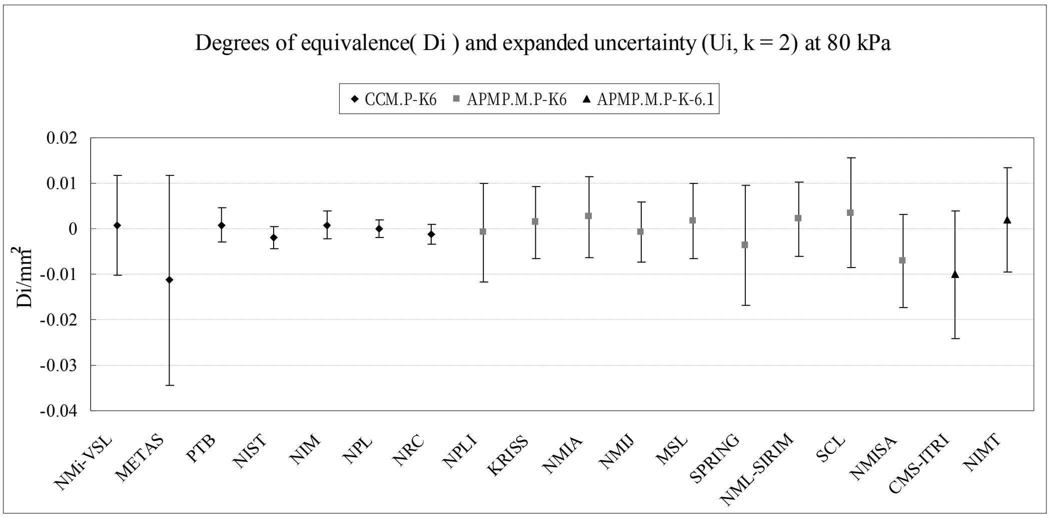

Fig.5. The degrees of equivalence of the CCM.P-K6, APMP.M.P-K6 and APMP.M.P-K-6.1 at nominal pressure 80 kPa.

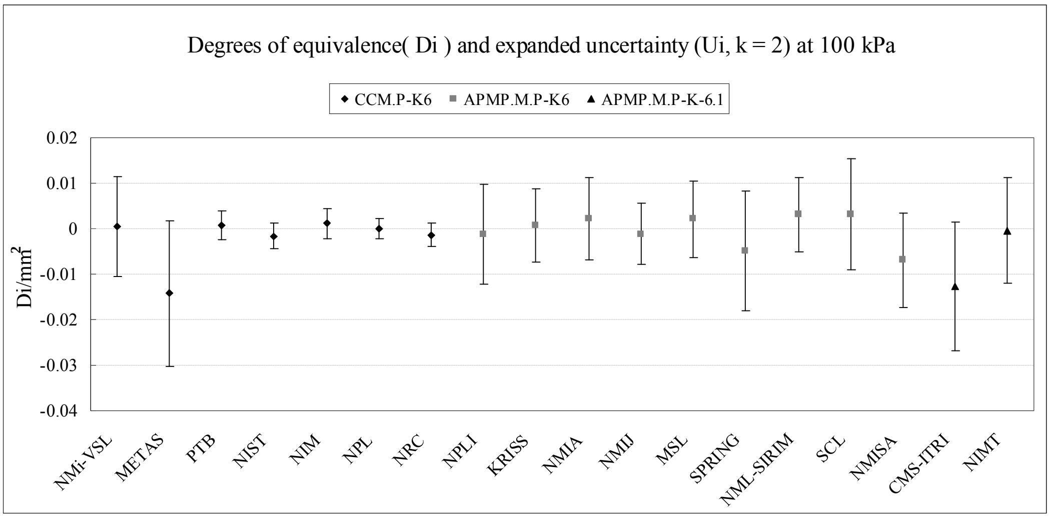

Fig.6. The degrees of equivalence of the CCM.P-K6, APMP.M.P-K6 and APMP.M.P-K-6.1 at nominal pressure 100 kPa.

5. Discussions

Although the NIMT Thailand joined the activity in the middle of the comparison, it did not affect the comparison proceeding because the transfer standard was sent to the pilot laboratory each time after the participating laboratory performed the calibration.

The transfer standard, Ruska 2465 gas-operated piston-cylinder assembly TL-1409, was calibrated three times by the pilot laboratory during these four transits of the comparison period in order to confirm the performance of the transfer standard and showed that it was very stable after evaluated. And we selected the third calibration data to be APMP.M.P-K-6.1 comparison data because of the larger standard deviation among the three calibrations.

The reference value was obtained from the KCRV of CCM.P-K6. And we use the proposed linkage method in the APMP.M.P-K6 key comparison to determine a linking factor ($r_{CCM} \times r_{APMP}$) that can convert the APMP.M.P-K6.1 results directly to the CCM.P-K6 results. SPRING is the only linking laboratory between APMP.M.P-K6 key comparison and APMP.M.P-K6.1 comparison. A coefficient of 0.7 has been assumed for the correlation between the two sets of APMP.M.P-K6 and APMP.M.P-K6.1 SPRING results.

6. Conclusion

For all the laboratories, the relative bilateral degrees of equivalence (D_{ij}) between two laboratories are between 3.5 $\times 10^{-6}$ and 39.7 $\times 10^{-6}$ from 20 kPa to 100 kPa. The comparison results are equivalent to the CCM.P-K6 comparison and the results linking to the CCM.P-K6 key comparison through the APMP.M.P-K6 key comparison at five nominal pressures near 20 kPa, 40 kPa, 60 kPa, 80 kPa and 100 kPa had been established.

7. Acknowledgements

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