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Force inter-comparison between China and Italy

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Abstract： The paper descriptes the inter-comparison of two force primary standards of 1 *MN* DWMs established by National Institute of Measurement and Testing Technology (NIMTT), Chengdu, China, and Istituto Nazionale di Ricerca Metrologica(INRIM)，Torino，Italy. It was tested that the temperature coefficients of the two cells as transfer standard, and their long-term stability. There were results on the deviation of force generated by the two DWMs as well as their normalized error.

Key words: force inter-comparison; dead-weight machine; temperature coefficient; normalized error

1. Introduction: Since 1980's China has carried out a series inter-comparisons on force standards including PTB/Germany(1983), IMGC/ Italy(1985), PSB/Singapore, UME/Turkey, CENAM/Mexico, NIMT/Thailand, CMC/Chinese-TaiBei, MIKES/Finland, NMIJ/Japan, NPL/UK, KRISS/Korea, etc[1][2][3][4][5]. In order to confirm the force agreement between Chinese primary 1*MN* dead weight force standard machine (1*MN* DWM) and Italian primary 1*MN* DWM, the both of DWM's has been carried out inter-comparison at 05-08/2011. There were two HBM force transducers of Type C18 which have been used as transfer standards, and method used was similar to that used at force key comparisons[6]. Measuring instruments were two sets of DMP 40 belonging to NIMTT and INRIM separately, which were calibrated by BN100 belonging to NIMTT.

1. Comparison method

Table1 lists some information on the force standard machines, force transducers and measuring instruments.

Table 1 Force standard machines, force transducers and measuring instruments

No.	Description	Remarks
1	Dead weight force standard machine 1 *MN*,	NIMTT located at Chengdu/China
2	Dead weight force standard machine 1 *MN*	INRIM located at Torino/Italy
3	Force transducer HBM C18-1*MN* 00282	Belonging to NIMTT
4	Force transducer HBM C18-1*MN* 00283	
5	Indicator HBM	

	DMP40 54320091	
6	Indicator HBM DMP40 060420110	Belonging to INRIM

7	Bridger-calibrator BN100 1773	Belonging to NIMTT

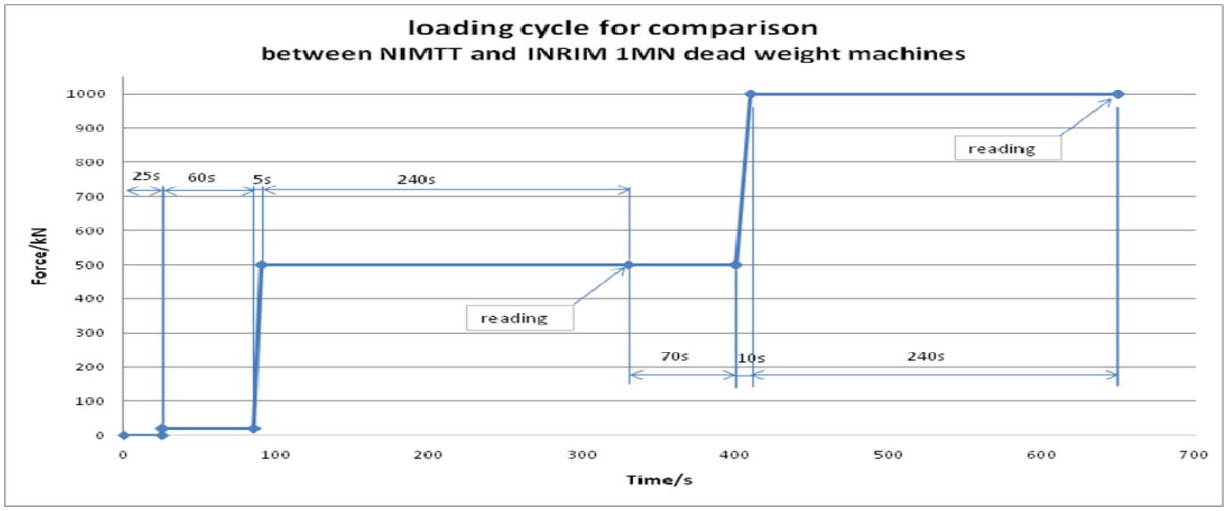


Fig.1 Loading method used at the iner-comparison

Method used in the comparison is described as below (see fig.1).

- At 0^o position, preloading 3 times step by step on the cell under test; preloading 1 time step by step again; measurements for 3 cycles. The reading time was taken as 5 min approx., which covered loading time 1min approx. and waiting time 4 min approx..
- At 60^o position, preloading 1 times step by step on the cell; measurements for 1 cycle. The reading time was as same as at 0^o positon.
- It was same as at 60^o position that the tests were carried out at positions of 120^o, 180^o , 240^o , 300^o and 360^o.

The first test was carried out at NIMTT at 05-06/2011 at 500 *kN* and 1 *MN* applied on the cell. At the same time there were some tests on the temperature coefficients of the cells at 15 ^oC, 20 ^oC and 25 ^oC approx. Calibration of the NIMTT's DMP40 had been done with the NIMTT's bridge-calibrator BN100 before testing the cells and after, which aimed to calculate correction coefficients of the DMP40 used in the test. Besides that above, long-term stability of the two cells had been tested before the formal inter-comparison carried out.

The test at INRIM was carried out at the end of June, 2011 at Torino, which covered 1) testing the two cells, 2) calibration of the INRIM's Indicator DMP40 with the bridge-calibrator BN100.

The second test was carried out at NIMTT at 07/2011, which was same as first one exception of temperature test.

3. Test results

3.1 Calibration results of DMP40

There are calibration results in table 2 including the correction coefficients calculated, which shows as followings:

- The correction coefficients were at rang of （2.5E-07—1.2E-05） mv/v, of which its relative value was not over ±6.1E-06. It means that it is necessary to test the correction coefficients of DMP 40 as long as to obtain less than influence of 1.0E-06.
- There was a few different of correction coefficients between the two DMP 40s.
- The correction coefficients had changed with time which was within its accuracy ±5E-06.

Table 2 Correction coefficient $\Delta_{DMP40corr}$ of DMP40

	BN100-DMP40	(BN100-DMP40)/BN100

	(Correction coefficient) mv/v			
Range	1.0 *mv/v*	2.0 *mv/v*	1.0 *mv/v*	2.0 *mv/v*
NIMTT1-54320091	1.0E-06	2.5E-07	1.0E-06	1.3E-07
NIMTT2-54320091	5.0E-07	-2.7E-06	5.0E-07	-1.4E-06
INRIM-060420110	2.7E-06	1.2E-05	2.7E-06	6.1E-06

Table 3 Testing results on Temperature coefficients and its standard deviations

Cell	HBM C18-1*MN* 00282		HBM C18-1*MN* 00283	
Force *kN*	α /℃	σ_α /℃	α /℃	σ_α /℃
500	2.2E-06	6.5E-08	1.20E-05	6.3E-07
1000	3.9E-06	2.0E-07	1.15E-05	4.5E-07

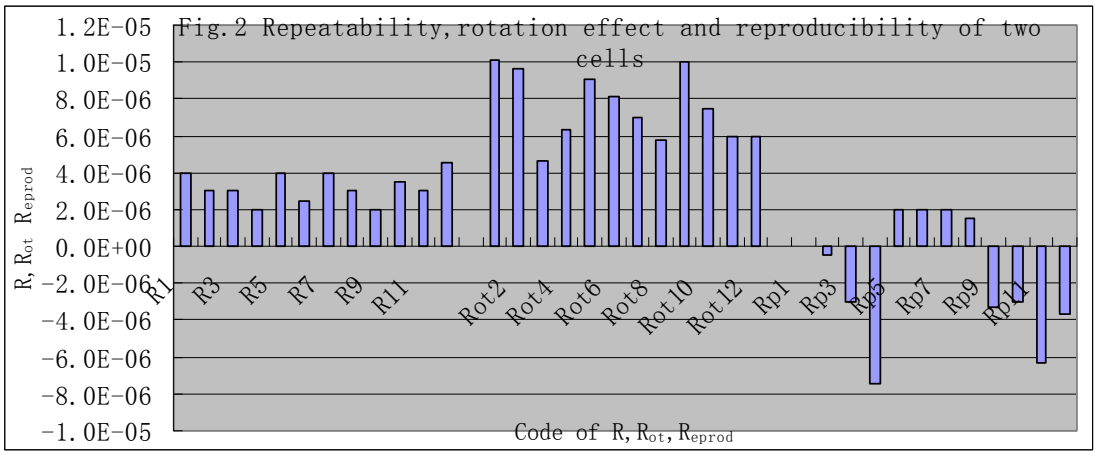
3.2 Temperature coefficients

Based on the tests at the 15 ^oC, 20 ^oC and 25 ^oC approx. the temperature coefficients have been calculated as well as its standard deviations [7][8], of which the results are shown in the table 3.

It could be seen from the table3 that 1) the temperature coefficients of the two cells are different as much as one order; 2) its standard deviations are one or two orders less than the temperature coefficients; 3) the temperature coefficient changes with load applied, especially for HBM C18-1*MN* 00282 being near two times.

3.3 Metrology characteristics of the cells

The total calibration data are attached in the Appendix A (omitted). The specifications of the 2 cells tested by NIMTT for two times and by INRIM for one time are attached in the Appendix B (omitted), of which repeatability, rotation effect and reproducibility are shown in the fig.2.



It could be seen that the repeatability obtained was less than 5E-6, which was calculated with maximum deviation of the three outputs on 0^o position. The rotation effect was less than or equal to 1E-5, which was calculated by "Bessel formula" taking first output at 0^o position and outputs at positions of 60^o,120^o,180^o,240^0,300^o. The reproducibility was within ±8E-6, which was calculated with deviation of outputs on 0^0 and 360^o.

Combined uncertainty of output of a cell was evaluated by "indirect method". There are five influences covering repeatability R, rotation effect R_{ot}, zero recovery Z_r, sensitivity R_{es}, expanded uncertainty W_{DWM} of the force generated by the DWM. Table 4 shows calculation results of NIMTT1 as an example.

Table 4 Evaluation of relative uncertainty of output $x_{22.7}$

F *kN*	R	R_{ot} =rel.stdev	Z_r *mv/v*	R_{es} *mv/v*	W_{DWM} k=3	w	W k=2
500	4.00E-06	1.00E-05	1.20E-06	1.00E-06	2.00E-05	8.00E-06	1.60E-05
1000	3.00E-06	9.60E-06	1.20E-06	1.00E-06	2.00E-05	7.80E-06	1.60E-05

$$w_{output} = \sqrt{(W_{DWM}/3)^2 + (R/(1.64\sqrt{3}))^2 + (R_{ot}/\sqrt{6})^2 + (R_{es}/(2\sqrt{3}x))^2 + (Z_r/(x_n\sqrt{3}))^2} \quad (1)$$

Table 5 Sum of relative combined uncertainty and relative expanded uncertainty (k=2, confidence level 95% approx.)

Load kN	$w_{NIMTT282-1}$	$w_{NIMTT282-2}$	$w_{NIMTT283-1}$	$w_{NIMTT283-2}$	$w_{INRIM282}$	$w_{INRIM283}$
500	8.0E-06	7.0E-06	7.8E-06	7.4E-06	8.7E-06	8.2E-06
1000	7.8E-06	7.2E-06	7.5E-06	7.2E-06	8.3E-06	8.3E-06
Load kN	$W_{NIMTT282-1}$	$W_{NIMTT282-2}$	$W_{NIMTT283-1}$	$W_{NIMTT283-2}$	$W_{INRIM282}$	$W_{INRIM283}$
500	1.6E-05	1.4E-05	1.6E-05	1.5E-05	1.7E-05	1.6E-05
1000	1.6E-05	1.4E-05	1.5E-05	1.4E-05	1.7E-05	1.7E-05
Remarks	W=2w, k=2, confidence level 95% approx.					

The total relative combined uncertainty is listed in the table 5 as well as relative expanded uncertainty (k=2, confidence level 95% approx.). All of relative combined uncertainty was less than 9E-6, and the relative expanded uncertainty was less than 2E-5.

4. Agreement of the two DWM's

4.1 Relative deviation

In order to make the comparison of the two DWM's, it had been done that correction of DMP 40 as well as temperature (see table 2 and table3). Since the both corrections were much less than the outputs taken originally, it could be ignored that the contribution of the two corrections on the relative combined uncertainty of the output. There is a table 6 showing original outputs x_t , outputs x_{23} calculated on 23 ^oC, and outputs $x_{23.corr}$ corrected with DMP 40 correction coefficients, as well as long-term stability S_b.

Table 6 Outputs x_t,x_{23},$x_{23.corr}$ and S_b

F *kN*	NIMTT1 *mv/v*		NIMTT2 *mv/v*		INRIM *mv/v*	
Cell	$x_{22.7}$ 282	$x_{22.9}$ 283	$x_{23.2}$ 282	$x_{23.2}$ 283	$x_{23.6}$ 282	$x_{23.6}$ 283
500	1.000323	1.000679	1.000325	1.000686	1.000327	1.000689
1000	2.001009	2.002259	2.000996	2.002227	2.000984	2.002220
F *kN*	X_{23}	X_{23}	X_{23}	X_{23}	X_{23}	X_{23}
500	1.000323	1.000680	1.000324	1.000684	1.000325	1.000681
1000	2.001011	2.002261	2.000994	2.002222	2.000979	2.002206
F *kN*	$x_{23.corr}$	$x_{23.corr}$	$x_{23.corr}$	$x_{23.corr}$	$x_{23.corr}$	$x_{23.corr}$
500	1.000324	1.000681	1.000325	1.000684	1.000328	1.000684
1000	2.001011	2.002262	2.000992	2.002219	2.000991	2.002218
F *kN*	S_{b-282}	S_{b-283}	Remarks: $X_{23}=X_t[1-(t-23)\quad)]$ (2) $X_{23.corr}=X_{23}+\quad_{BMP40corr}\quad S_b=(X_{nimtt2}-X_{nimtt1})/X_{nimtt2}$			
500	4.0E-07	2.7E-06				
1000	-9.8E-06	-2.1E-05				

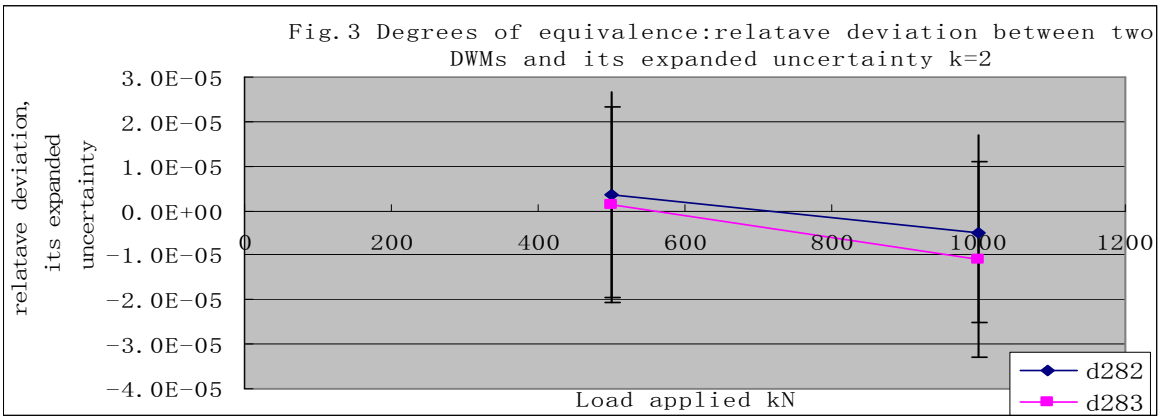
The reference value was taken as the average of two outputs obtained at two times by NIMTT(see table7). Since the two tests were carried out with the NIMTT 1 *MN* DWM, there was correlation amount of the two outputs of the cells [9] when considering combined uncertainty of its average outputs, which was calculated with equation (3) as below:

$$w_{ref}=(w_{NIMTT1}+w_{NIMTT2})/2 \quad (3)$$

Table7 shows the reference values and theirs relative combined uncertainties , the relative deviation of the two DWM's, which is less than ±1.5E-5(also see fig. 3).

Table7 Relative deviation between NIMTT 1 *MN* DWM and INRIM 1 *MN* DWM

Cell	282	283	282	283	282	283	282	283
F *kN*	$x_{ref-282}$	$x_{ref-283}$	$w_{ref-282}$	$w_{ref-283}$	$_{282}$	$_{283}$	W_{282} k=2	W_{283} k=2
500	1.000324	1.000683	7.5E-06	7.6E-06	3.5E-06	1.2E-06	2.3E-05	2.2E-05
1000	2.001001	2.002240	7.5E-06	7.3E-06	-5.2E-06	-1.1E-05	2.2E-05	2.2E-05



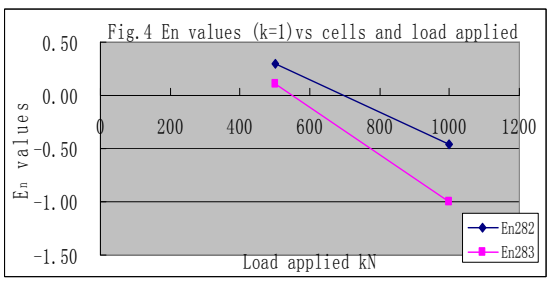
4.2 Normalized error E_n and degrees of equivalence

The normalized error E_n was calculated by equation (4) as below:

$$E_n = \delta_{INRIM.ref} / \sqrt{W_{INRIM}^2 + W_{ref}^2} \quad (4)$$

Where $\delta_{INRIM.ref} = (x_{INRIM} - x_{ref}) / x_{ref}$

The total E_n values are shown in the fig.4, where the coverage factor was taken as k=1, and all E_n were within range of ±1. It means that the two DWMs are quite agreement.



The degrees of equivalence means that the deviation of the two DWMs, and its expanded uncertainty (k=2), which are listed in table 7, and shown in fig.3. The total expanded uncertainty (k=2) of the deviation is less than 2.3E-5.

5. Conclusion

The inter-comparison of NIMTT 1 *MN* DWM and INRIM 1 *MN* DWM has been carried out, which covered two tests by NIMTT, one test by INRIM, temperature test, calibration of two sets of DMP40 with BN 100. The degrees of equivalence is that the deviation of the two DWMs is less than ±1.5E-5 , and its expanded uncertainty (k=2) is less than 2.3E-5 with confidence level 95% approx.

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