A 60 MN build-up force transfer system

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Abstract: The paper described principle, construction and main specifications of a 60 MN force transfer system (FTS), which is used to transfer or calibrate large force over 20 MN, and to do inter-comparison of force standards. The paper has raised additional budget of its connecting to uncertainty of the force measured by the FTS, and non-uniformity of force applied on the FTS.

Keywords: Force transfer system, uncertainty of force ,additional budget, non-uniformity of force.

1. Foreword

The 60 MN build-up force transfer system(60 MN FTS) was established at 2014 in Fujian Province Institute of Metrology(FJIM),China, which is used to transfer or calibrate large force over 20 MN, and to do inter-comparison of force standards. It had been used to compare large force between 60 MN BM, FJIM and 30 MN HM, NPL,UK[1][2][3]. The paper described principle, construction and main specifications of the 60 MN FTS.

2. Principle and construction

The fig.1 shows appearance of the FTS, which is consisted of three HBM 20 MN load cells in parallel, and some connecting parts such as a base, a middle-plate, an upper-plate, and a couple of ball-seat for centering load applied, etc. The FTS has height of 1.23 m, weight of 3.5 t, maximum outside diameter of 0.83 m. The each 20 MN cell was calibrated by a 20 MN hydraulic amplification force standard machine of 20 MN(20 MN HM) in National Institute of Metrology(NIM), of which relative expanded uncertainty is 0.01%, k=3. The calibration of the FTS had been done for two times following ISO 376-2011[4]. An instrument HBM DMP-40 was used in it. In fact, it would be better to use three DMP 40, instead, which could reduce influence of switching on the test results.

The fig.2 shows traceability of standard force generated by the 60 MN BM and the 30 MN HM to the 20 MN HM via the 60 MN FTS

Fig.1 Appearanceof the 60 MN FTS

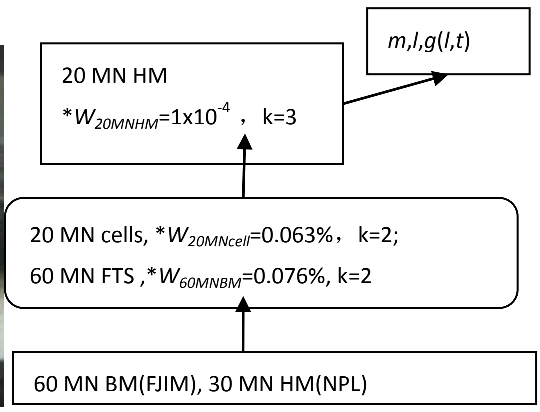


Fig.2 Traceability of the force(* declared)

3. Main specifications

3.1 Specification of the cells

The three 20 MN cells are No. 001,No.002,and No.025, of which the No.001 and the No.002 were calibrated by the NIM 20 MN HM for two times , while the No. 025 for three times following ISO 376-2011. The calibration results were listed in table 1. Eight budgets had contributions on the relative combined uncertainty of output of each cell,including the repeatability, the rotation effect, the resolution of the force, the zero recovery, the interpolation, the temperature effect on output, the long-term stability, and the relative expanded uncertainty of the force generated by the 20 MN HM, etc.

Table 1 Calibration results of the 3 cells

Cell	R %	R_{ot}%	R_{es}mv/v	Z_r mv/v	I_p%	S_t/℃	S_b %	w_{cell}%	W_{cell}%k=2
No.001	0. 010	0.030	0. 00004	0. 00065	0. 001	± 0.01%	0.04	0.03	0.06
No.002	0. 003	0.009		0. 00042	0. 001		0. 06	0. 04	0. 08
No.025	0. 010	0.020		0. 00070	0. 002		0. 01	0. 024	0. 048

Remarks：1）R-an average of the repeatability；R_{ot}-an average of the rotation effect；R_{es}-an average of the resolution；Z_r-an average of the zero recovery；I_p-an average of the interpolation；S_t/℃-temperature effect on output；S_b-the long-term stability for 3 months；w_{cell}-an average of the relative combined uncertainty；W_{cell}-an average of the relative expandeduncertainty. 2）The change of temperature was taken as Δt=±2℃。

3.2 Uncertainty evaluation of the FTS

Since the 3 cells were calibrated by the 20 MN HM, there were correlations among the three outputs. It was assumed that the correlation factors were taken as 1, and relative combined uncertainty w_{3cell} of output-sum of the 3 cells in parallel would be the average of relative combined uncertainty of each cell output as following[5]:

$$w_{3cell}=(w_{cell001}+w_{cell002}+w_{cell025})/3 \qquad (1)$$

where $w_{cell001}$, $w_{cell002}$, $w_{cell025}$: relative combined uncertainty of each cell output.

The relative expanded uncertainty W_{3cell} of output-sum of the 3 cells in parallel was equal to $2w_{3cell}$, k=2, the confidence level of 95% approx. Based on the data in table 1, it was obtained W_{3cell}=0.063%.

After considering influence of the connecting of the FTS on the relative expanded uncertainty W_{3cell}, it was taken 1.2 times of W_{3cell} as final relative expanded uncertainty W_{fts} as:

$$W_{fts}=1.2W_{3cell}=0.076\% \qquad (2)$$

which had been confirmed in the inter-comparison of the force standards between China and UK.

3.3 Additional budget to W_{3cell}

There was an additional factor to the relative expanded uncertainty, which was caused by the connecting of the FTS, and expressed as α_{FTS}.

The α_{FTS} was evaluated as $1\leqslant\alpha_{FTS}\leqslant1.5$.

When a FTS is used as a reference standard to measure or control force generated by a build-up machine, it was called “Force Measuring System-FMS”, and recalled as α_{FMS} being equal to the α_{FTS}.

3.4 Non-uniformity of load applied

There was another factor called non-uniformity β_i which is caused by eccentricity of the load applied. β_i was represented non-uniformity of the load applied on the i^{th} cell as following:

$$\beta_i=f_i/\Sigma f_i-1/n=f_i/F-1/n \qquad (3)$$

where

f_i- the load applied on the i^{th} cell, MN or kN;

$\Sigma f_i=F$-a total load applied on a FTS or a FMS;

n-number of cells in parallel, usually 3.

Based on experiments, while the total load is applied on the FTS or FMS, it is not equal that each cell is loaded, which means $\beta_i \neq 0$. When it is $\beta_i > 0$, the load applied on the ithcell is bigger than the average of load applied on each cell, namely $f_i > F/n$; while$\beta_i < 0$, and $f_i < F/n$.

While the full scale load is applied on the FTS or FMS, it would be concentrated that the maximum value of the β_i expressed as $\beta_{max\text{-}fs}$. When $\beta_{max\text{-}fs}$=3.3%（n=3，same bellow）, the responsible cell would be applied as much as 110%FS. Similarly if the 10%FS is applied on the FTS or FMS, it would be considered that the minimum value of the β_i expressed as$\beta_{min\text{-}10\%fs}$. While $\beta_{min\text{-}10\%fs}$=-16%, the responsible cell would be applied as low as 5%fs of the cell

4. Examples

4.1 Example 1

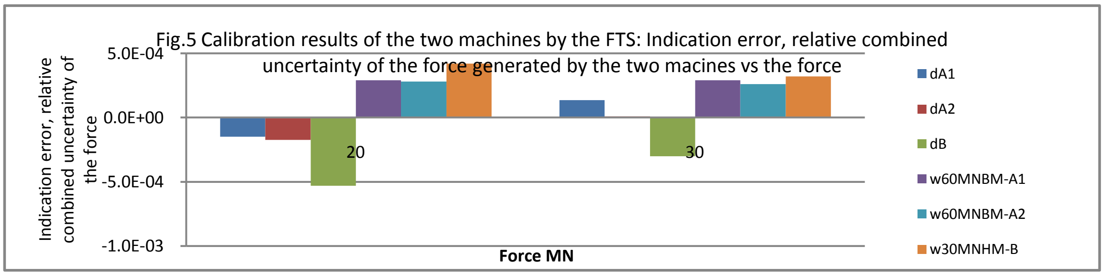
The 60 MN FTS was used to make inter-comparison of the 60 MN BM (see Fig.3), FJIM and 30 MN HM (see Fig.4), NPL in Sept, 2014.

Fig.3 A photo of the 60 MN BM in FJIM

Fig.4 A photo of the NPL 30 MN HM

The test method used was similar to the Key-comparison of the force [6][7][8][9], of which 20 MN and 30 MN were taken as test points.

The test results were showed in fig.5, which covered 1) indication error for each machine including the first test(δA1) and the second test (δA2) on 60 MN BM,which were less than ∣±0.02%∣; the test on 30 MN HM(δB), which were less than∣±0.055%∣; 2) the relative combined uncertainty of the force generated by each machine being less than 0.03% for the 60 MN BM, 0.041% for the 30 MN HM, of which budgets were repeatability and rotation error of the force, resolution of the FTS, zero recovery of the each cell in parallel, the indication error of the machine, and relative expanded uncertainty of the FTS.



The fig.6 showed that non-uniformity calculated of the force generated by the 60 MN BM on the 60 MN FTS(It was tested for three times on 0° position, 1 time on 120° as well as 240° and 360°, same as below). It could be seen that the maximum value of the non-uniformity was β_{max-30}=3.32% appearing at 240° position of the FTS on the machine (seeβ_{53}in the fig.6), which was responsible to the cell No. 025.

The fig.7 showed that non-uniformity calculated of force generated by the 30 MN HM on the 60 MN FTS. It could be seen that β_{max-30}=β_{51}=1.42%,appearing at 240°,which was responsible to the cell No. 001.

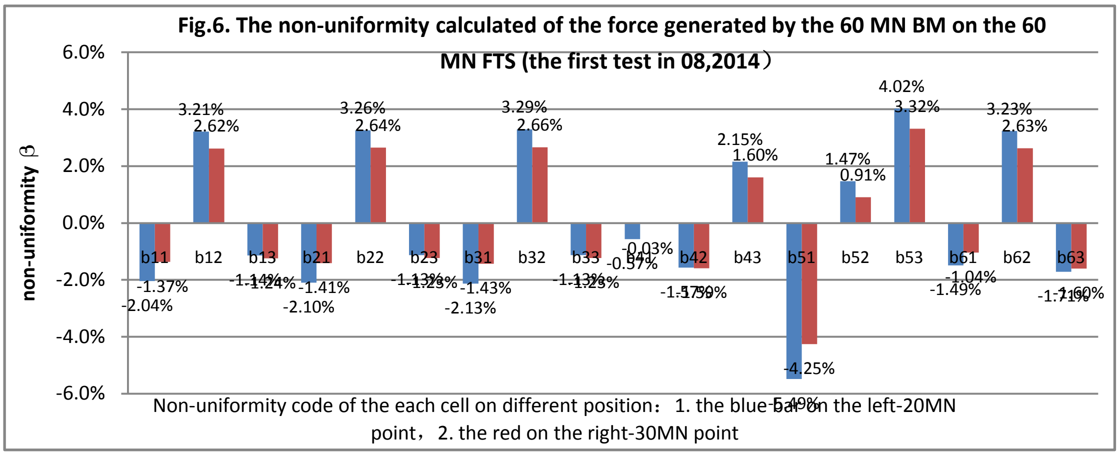


Fig.6. The non-uniformity calculated of the force generated by the 60 MN BM on the 60 MN FTS (the first test in 08,2014）

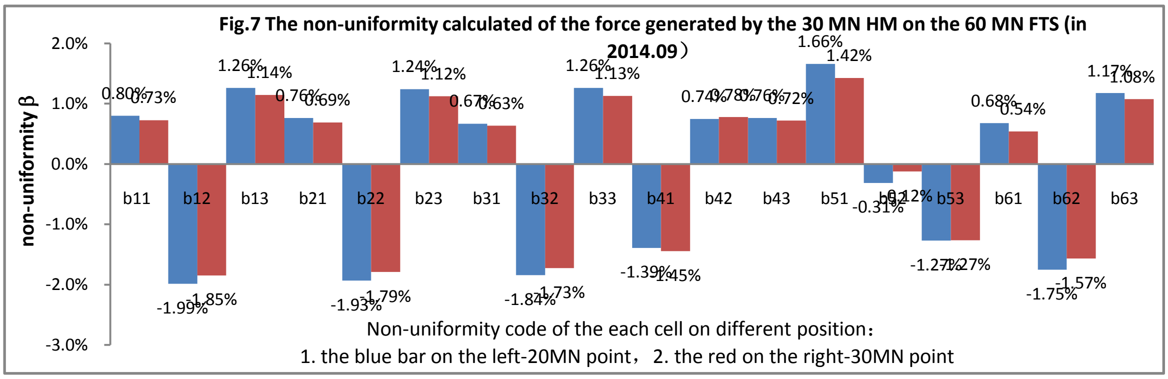


Fig.7 The non-uniformity calculated of the force generated by the 30 MN HM on the 60 MN FTS (in 2014.09）

It could be seen from the fig.6 and 7 that several factors had influence on the non-uniformity, including self-characteristics of the FTS, load applied, position of the FTS on the machines, characteristics of the machines, mutual-influence of the machines and the FTS. It was clearly that the non-uniformity was decreasing with load applied up.

4.2 Example 2

In order to evaluate the relative combined uncertainty of the force generated by the 60 MN BM with the 60 MN FTS by means of the indirect method, as well as its non-uniformity, the 60 MN BM was recalibrated in Oct., 2014. Range of force calibrated was (6-60) MN. The calibration method was as followings: 1) preloading up to the rated force for three times step by step, and testing for three times at the 0° position; 2) turning the FTS around its vertical axial at 120°, then 240°and 360°, preloading and testing once on each position; 3) reading time at the non-zero load was taken as 2 min., and 3 min. at the zero load.

Table 2 listed the calibration results of the 60 MN BM and its uncertainty evaluation. Fig.8 showed the indication error and the relative expanded uncertainty of the force. It could be seen that the indication error was less than｜±

0.05% ∣ , the relative expanded uncertainty was less than 0.1%, k=2, confidence level 95% approx..

Table 2 Calibration results of the 60 MN BM, and its uncertainty evaluation

Force MN	R	R_{ot}	R_{prd}	δf	w_{60MNBM}	W_{60MNBM} k=2
6	1.6E-04	5.4E-04	0	3.1E-04	4.6E-04	9.3E-04
10	9.3E-05	4.5E-04	2.0E-05	1.3E-04	4.2E-04	8.4E-04
20	6.6E-05	2.0E-04	-1.8E-16	1.4E-04	4.0E-04	7.9E-04
30	5.6E-05	1.1E-04	1.0E-05	3.4E-04	4.3E-04	8.6E-04
40	5.2E-05	8.5E-05	0	2.7E-04	4.1E-04	8.3E-04
50	4.5E-05	6.6E-05	2.0E-06	2.4E-04	4.1E-04	8.1E-04
55	4.3E-05	5.6E-05	-1.1E-05	2.8E-04	4.1E-04	8.3E-04
60	5.3E-05	5.7E-05	3.3E-06	3.2E-04	4.2E-04	8.5E-04

Remarks: R- Repeatability of the 60 MN BM; R_{ot}-Rotation effect of the 60 MN BM; R_{prd}-Reproducibility at position 0°; δf-the Indication error of the 60 MN BM; Z_r/fs=0.00002/fs-the zero recovery divided by the rated output ; R_{es}-the resolution=0.2 kN which was taken at the pick to the pick of output as the fluctuation of the 60 MN BM; w_{FTS}=0.038%, relative combined uncertainty of the 60MN FTS.

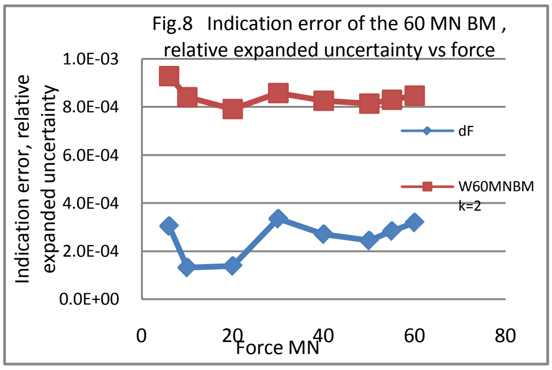


Fig.8 Indication error of the 60 MN BM , relative expanded uncertainty vs force

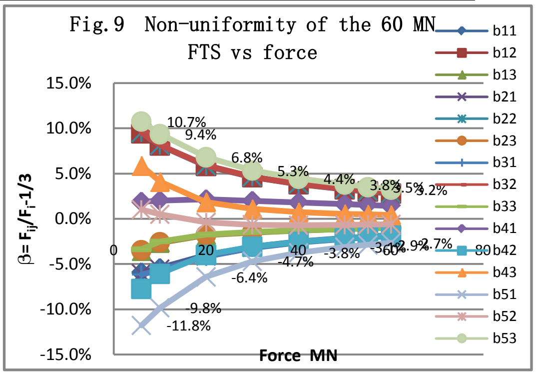


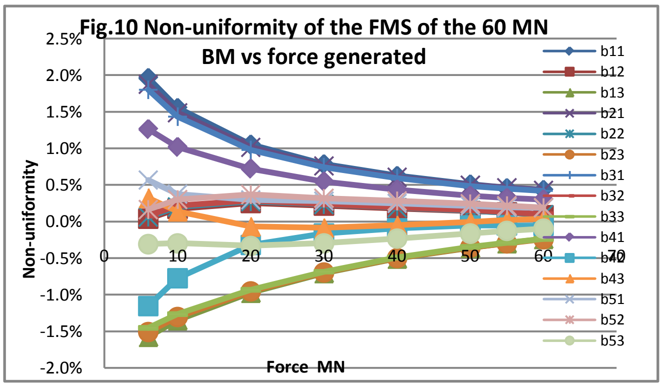
Fig.9 Non-uniformity of the 60 MN FTS vs force

Fig.9 showed the non-uniformity of force applied on the 60 MN FTS. It could be seen that: 1) the absolute value of the non-uniformity was decreasing with the force applied on the FTS increasing; 2) at the force point of 10%fs, 6 MN, the$\beta_{min.10\%fs}$=β_{51}=-11.8%, the responsible cell was No.001,the FTS was located on the position 240°, the cell was applied at 1.3 MN. Since then, each cell would be calibrated as low as 5%fs=1MN, otherwise, the specifications of the cells could be effected; 3) at the force point of 100%fs, 60 MN, the $\beta_{max.fs}$=β_{53}=3.2%, the responsible cell was No.025,the FTSwas located on the position 240°, the cell was applied at 21.9 MN. Since then, each cell would be calibrated as much as 110%fs, 22MN,otherwise, the specifications of the cells could be effected; 4) It would be consequent that the$\beta_{min.10\%fs}$and$\beta_{max.fs}$were located at the same position of the FTS.

The fig.10 showed the non-uniformity of force applied on the 60 MN FMS of the 60 MN BM, which consisted of three HBM 20 MN cells as the force measuring system.

It could be seen that: 1) the absolute value of the non-uniformity was decreasing with the force applied on the FMS increasing; 2) at the force point of 10%fs, 6 MN, the

$\beta_{min.10\%fs}$=β_{13}=-1.58%, the responsible cell was located on the position 0°, the cell was applied at 1.91 MN. Since then, it was accepted that each cell was calibrated as 10%fs, 2MN. 3) at the force point of 100%fs, 60 MN, the $\beta_{max.fs}$=β_{11}=0.43%, the responsible cell was located on the position 0°, the cell was applied at 20.26 MN. Since then,it was accepted that each cell was calibrated as 100%fs, 20MN



4 Conclusion

It has been raised that 1) the additional factor of the relative expanded uncertainty of the FTS or FMS, which was caused by the connecting of the FTS or FMS, and expressed as α_{FTS} or α_{FMS}. The α_{FTS} or α_{FMS} was evaluated as $1\leqslant\alpha_{FTS}\leqslant1.5$; 2) the non-uniformity of load applied on the cells of FTS or FMS. It had been found while full-scale load is applied on the FTS or FMS, and $\beta_{max\text{-}FS}$=3.3% for a cell, the each cell of FTS or FMS in parallel would be calibrated as much as 110%FS; while 10%FS load applied on the FTS or FMS, and $\beta_{min\text{-}10\%FS}$=-16% for a cell,the each cell would be calibrated as low as 5%FS.

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