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INTERCOMPARISON BETWEEN DEADWEIGHT MACHINES IN CHINA AND UK UP TO 1 MN

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Abstract:

This paper describes a tripartite comparison at forces of 250 kN, 500 kN, and 1 MN between deadweight force standard machines located at FJIM (China), NIMTT (China), and NPL (UK). Two different transfer standards were used, and the results demonstrated good agreement between the three machines, with E_n values of significantly lower magnitude than one.

Keywords: deadweight machine, comparison, uncertainty, E_n value

1. INTRODUCTION

In order to investigate the agreement between the large force standards established by China and the United Kingdom (UK), an intercomparison was carried out from September to November 2019. The new 2 MN deadweight machine (DWM) established in 2018 by FJIM has a stated uncertainty of 0.002 % (k = 3) and is shown in Figure 1.
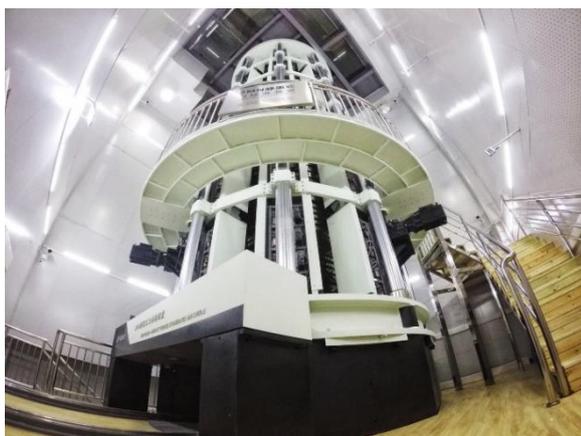

Figure 1: 2 MN DWM at FJIM

In order to give support to the uncertainty claims, it was agreed that an international comparison with other machines of suitable capacity and uncertainty should be performed. NIMTT and NPL, the laboratories responsible for maintaining China's and the UK's national force standards at the 1 MN

level, agreed to participate in such a comparison, using machines of the following specifications:

- 1 MN DWM at NIMTT, with a stated uncertainty of 0.002 % (k = 3)
- 1.2 MN DWM at NPL, with a stated uncertainty of 0.001 % (k = 2)

The three test machines are shown in Figure 2. The transfer standards used were a 500 kN TOP Z4A load cell and a 1 MN C18 load cell (Class 00 [1]), both manufactured by HBM. Different HBM indicators (DMP40 and DMP41) were used at the three laboratories, with a single HBM BN100A bridge calibration unit employed to correct the deflections to nominal mV/V values.

Figure 2: Tests at FJIM, NIMTT, and NPL

2. COMPARISON METHOD

The comparison method was based on that used for CIPM force key comparisons [2], but with a single rotation of the transducer (from 0° to 360°) rather than two rotations (from 0° to 720°). The tests were first carried out by FJIM (A1), then by NIMTT (B1), then by NPL (B2), and finally again by FJIM (A2), in a single loop comparison. The start of the loading cycle is shown in Figure 3.

In order to minimise the effects of creep, each test was carried out in accordance with a strictly-timed loading profile, including the three preloads which were always performed at the start of each test and a preload after each rotation of the transducer in the machine. One value of deflection was obtained at each of six orientations, and the mean deflection was calculated as the mean of these six deflections.
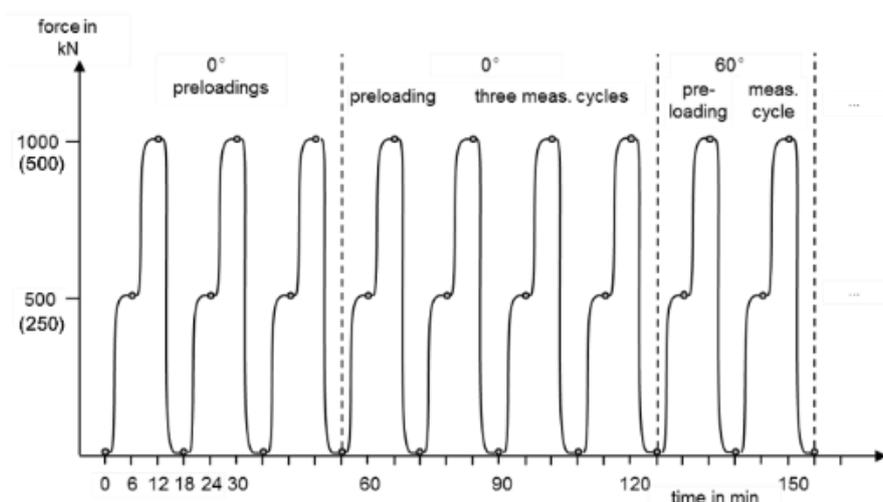
Figure 3: Loading cycles for the two load cells

Before the comparison, the effect of temperature on transducer sensitivity was determined. The reference temperature of the comparison is 20 ℃, and each transducer was calibrated at temperatures of 15 ℃, 20 ℃, and 25 ℃, to obtain its temperature sensitivity characteristics. The period between the A1 and A2 tests was about two months, and the transducer drift was calculated to the day, assuming a linear trend. These two factors were used in the normalization of test results to make them comparable.

3. TEST RESULTS

3.1. Measured Values

The measurement results are summarised in Table 1 and Table 2. In the tables, all effects resulting from indicator sensitivity, temperature, and transducer drift have been corrected for.

Table 1: Results obtained at FJIM and NMITT

Transfer standard	Force / kN	FJIM mean deflection / mV/V	NIMTT mean deflection / mV/V
TOP Z4A	250	0.999 821	0.999 834
	500	1.999 952	1.999 978
C18	500	1.000 706	1.000 682
	1 000	2.001 870	2.001 804

Table 2: Results obtained at FJIM and NPL

Transfer standard	Force / kN	FJIM mean deflection / mV/V	NPL mean deflection / mV/V
TOP Z4A	250	0.999 813	0.999 833
	500	1.999 935	1.999 942
C18	500	1.000 698	1.000 677
	1 000	2.001 854	2.001 812

3.2. Uncertainty Analysis

For the calculation of the E_n value, the correct uncertainty contributions obtained at the three laboratories must be included in the analysis [3]. The E_n value is defined by equation (1).

$$E_n = \frac{x_1 - x_2}{\sqrt{U^2(x_1) + U^2(x_2)}},\qquad(1)$$

where x_i is the mean deflection at a given laboratory and $U(x_i)$ is its expanded uncertainty ($k = 2$).

It is therefore imperative that the correct uncertainty contributions are included in the analysis - the following sections detail the uncertainty components which have been considered in this exercise and explain how each has been dealt with in the analysis.

The uncertainty components that have been considered in this exercise include: the applied force; transducer drift; instrumentation; repeatability; reproducibility; resolution; and temperature.

Uncertainty of Applied Force

This component is simply the claimed expanded uncertainty of the force generated by the machine, divided by the relevant value of k.

Drift of Transducer Sensitivity

Because the quality of the comparison is dependent upon the three measurements made during each loop, the stability of each transducer's sensitivity is critical. The A1 and A2 calibrations of the transducers at FJIM provide results of the drift in the transducer sensitivity throughout the exercise, and this drift is contributed into the FJIM uncertainty value as a component.

Instrumentation

It was assumed that the voltage ratios generated by the BN100A remained constant throughout the intercomparison, to enable corrections to be made,

but the uncertainty associated with this assumption is included in the budget.

Repeatability

The repeatability of the transducer is calculated at the 0° orientation in each test. Some of this variation may be due to the repeatability of the calibration force, but some will also be due to the transducer performance. The repeatability is estimated as a rectangular distribution, with a width equal to the spread of deflections.

Reproducibility

The reproducibility of the transducer is defined as the variation in deflection at the six different orientations in a single test.

The reproducibility is incorporated into each laboratory's uncertainty budget as the standard deviation of these six deflections, divided by square root of six (the number of values used to calculate this standard deviation).

Resolution

The resolution of the indicator (0.000 001 mV/V for both DMP40 and DMP 41 indicators) is incorporated twice into each deflection uncertainty estimation, once for the zero value and once for the value with the force applied. This is equivalent to a single triangular distribution of width 0.000 002 mV/V.

Temperature

The calibrations at the three laboratories were carried out at different temperatures - from 20.3 °C to 21.4 °C at FJIM, 21.0 °C at NIMTT, and from 20.6 °C to 20.9 °C at NPL. The temperature sensitivities of the transducers have been accurately determined by tests, assuming a rectangular distribution and using the measured temperature difference for each set of tests as the half-width of the distribution.

3.3. Comparison Results

The associated E_n values of tests are plotted in Figure 4, while Figure 5 shows the relative deviations between FJIM and the other two laboratories and their relative expanded uncertainties.

Figure 4 shows that, of the eight points at which the two pairs of machines were compared, all of the resulting E_n values are significantly smaller than one, giving confidence in the claimed uncertainties of the machines at these values.

Figure 5 shows that the relative deviations of the two pairs of machines is less than 3×10^{-5}, with an expanded uncertainty of less than 5×10^{-5} at a confidence level of approximately 95 % ($k = 2$). It also demonstrates that the agreement between NPL and NIMTT is consistently within 1×10^{-5}.
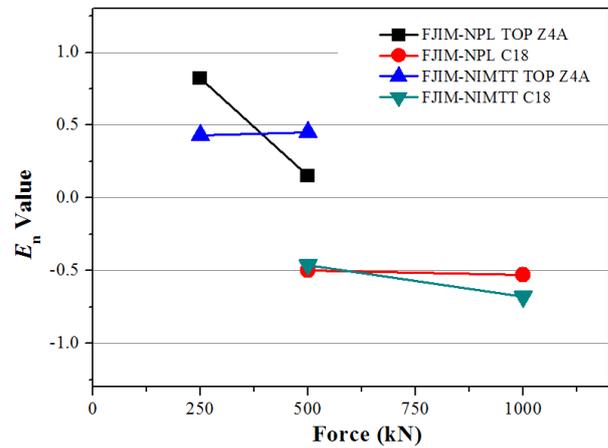

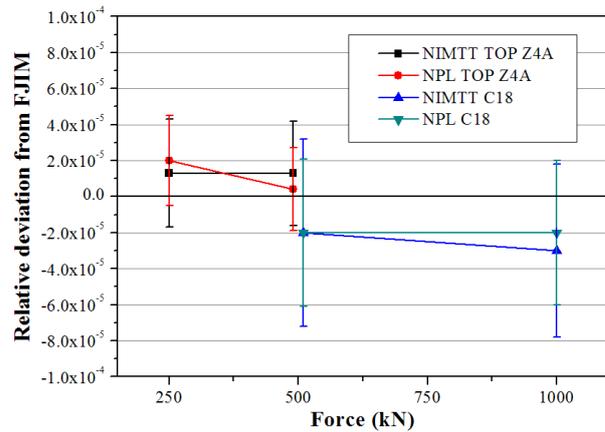Figure 4: Plot of E_n ratio values

Figure 5: Relative deviations from FJIM

4. SUMMARY

The results of a tripartite comparison of force standards between FJIM, NIMTT, and NPL have been detailed, and provide evidence to support the uncertainty claims of the three laboratories.

This comparison is of very positive significance for verifying the consistency of force between China and the UK, and to enhancing the confidence of those who depend on these standards in their respective countries, and providing useful suggestions for future research.

5. REFERENCES

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