INVESTIGATION OF UNCERTAINTY FROM CREEP AND CREEP RECOVERY OF FORCE CALIBRATION RESULT IN ACCORDANCE WITH ISO 376:2011

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This paper presents an investigation of the uncertainties from creep and creep recovery of force proving instruments calibrated at NIMT in year 2012 and 2013. In this study, the NIMT's 100kN deadweight force standard machine was used as a standard to calibrate force proving instruments (from various manufacturers and models) in accordance with ISO 376:2011. The comparison of creep uncertainties calculated from creep measured at maximum load ($C_{\max}$), creep recovery measured at zero load (C_{zero}) and reversibility errors were also investigated.

The results of this study show that, for most of the calibration results (>60%), the maximum value between $WC_{\max}/WC_{\text{zero}}$ and $WC_{\text{zero}}/WC_{\max}$ were larger than 2. Indicating that, $WC_{\max}$ and WC_{zero} could not assume to be equal. For the comparison between creep uncertainties calculated from creep error and reversibility error, more than 80% of the calibration results, the creep uncertainties calculated from reversibility were larger than 3 time of the calculated values from creep measurement. These gave conclusion that, for the unknown history of creep and reversibility characteristic of instruments, it is more appropriate to estimate the uncertainty of creep from reversibility error.

Keywords: Force measurement; calibration; DWM; ISO 376; creep.

1. Introduction

In 2011, ISO released a new version of standard for calibration of force proving instrument (ISO 376:2011)^[1]. This version allows calibrations in 4 cases; A) for specific forces and incremental-only loading, B) for specific forces and incremental/decremental

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loading, C) for interpolation and incremental-only loading, D) for interpolation and incremental/decremental loading.

Comparing with the previous version (ISO 376:2004) ^[2], creep property is the additional factor for classification of the force proving instrument. Fig.1a presents the calibration procedure using at the National Institute of Metrology Thailand (NIMT) for calibration of force proving instrument in accordance with ISO 376:2011^[1]. Fig.1b shows the details of measurement for evaluation of creep and creep recovery.

As seen in Fig. 1, creep measurement starts after finishing the X'6 series. The i_{m30} and i_{m300} are recorded at the 30s and 300s after applying maximum force (these will be used to calculate creep error $-C_{\max-}$). The i_{z30} and i_{z300} are record at the 30s and 300s after reducing force to the zero (these will be used to calculate creep recovery error $-C_{\text{zero-}}$).

(a) Calibration procedure according to ISO 376:2011 at NIMT.

(b) Zoom view of the measurement of creep and creep recovery.

Fig.1 Pattern of calibration according to ISO 376:2011.

1.1. Equations

According to the ISO 376:2011^[1], the relative creep error (c) can be calculated by using Eq. (1).

$$c = \left| \frac{i_{300} - i_{30}}{X_N} \right| \times 100 \quad (1)$$

where

- c = is the relative creep error in unit %
- i_{300} = is the reading value of the indicator 300 sec. after applied or removed of the maximum calibration force (i_{m300} , i_{z300})
- i_{30} = is the reading value of the indicator 30 sec. after applied or removed of the maximum calibration force (i_{m30} , i_{z30})
- X_N = is the deflection corresponding to the maximum calibration force.

For easier explaining in this paper, the creep error calculated from maximum force is defined as shown in Eq. (2). And the creep recovery error that is calculated from measurement at zero force is defined as seen in Eq. (3):

$$C_{max} = \left| \frac{i_{m300} - i_{m30}}{X_N} \right| \times 100 \quad (2)$$

$$C_{zero} = \left| \frac{i_{z300} - i_{z30}}{X_N} \right| \times 100. \quad (3)$$

The relative reversibility error (hysteresis), v was calculated from v_1 and v_2 as shown in Eqs. (4), (5) and (6):

$$v_1 = \left| \frac{X'_4 - X_3}{X_3} \right| \times 100 \quad (4)$$

$$v_2 = \left| \frac{X'_6 - X_5}{X_5} \right| \times 100 \quad (5)$$

$$v = \frac{v_1 + v_2}{2}. \quad (6)$$

The calculation uncertainty of creep was explained in ISO 376:2011^[1] and EURAMET cg-4 version 2.0^[3], w_{creep} is estimated as follow:

$$w_{creep} = \frac{c}{\sqrt{3}}. \quad (7)$$

If the creep test is not measured, the uncertainty of creep can be estimated from reversibility error (hysteresis) as seen in Eq. (8):

$$w_{creep} = \frac{v}{3\sqrt{3}}. \quad (8)$$

Define WC_{max} as relative creep uncertainty calculated from C_{max} .

Define WC_{zero} as relative creep uncertainty calculated from C_{zero} .

Define Wv_{max} as relative creep uncertainty calculated from maximum reversibility error (v_{max}).

As known that creep behavior of material typically depends on type of material, loading pattern and time, the question is that which equation from Eq. (2) and Eq. (3) is the best for estimation of creep error. And the creep uncertainty should be calculated from creep measurement or from reversibility error. There are only few studies on the creep measurement of force proving instrument. Hasan *et al.* studied on the effect of loading schemes on creep and creep recovery for force measurement^[4]. They found that creep effect was approximately 20% of the hysteresis value. Stenner studied on the comparison results between old and new version of ISO 376^[5]. He found the differences could be more or less depended on type of transducer.

2. Experimental Measurement Design

In order to study creep and creep recovery of force proving instrument, the creep measurement data were collected from actual load cell's calibrations at NIMT in year 2012 and 2013. There are totally 98 calibration results of force proving instruments from various types and manufacturers. In this study, the NIMT's 100 kN deadweight force standard machine was used as a standard to calibrate force proving instruments according to ISO 376:2011^[1]. These results were separated in 3 groups; 1) high precision load cell with AC bridge amplifier, 2) high precision load cell with DC bridge amplifier and 3) industrial type load cell and proving ring. Each of these groups was also separated to 2 types, which are compression and tension mode calibrations.

2.1. Equipments

Fig. 2 presents the deadweight force standard machine (DWM), which was used for calibration of force proving instruments. This machine had 100 kN maximum capacity with 4 selectable calibration ranges as 10 kN, 20 kN 50 kN and 100 kN. The relative uncertainty of DWM is 0.0035%^[6].

The environment condition at NIMT's force laboratory was controlled at the temperature 23 ± 1 °C and relative humidity is 55 ± 15 %.

Fig.2 Deadweight force standard machine 100 kN at NIMT.

3. Result and Discussion

The calibration results of force transducer are divided into 3 groups as follows.

3.1. Precision load cell with AC bridge amplifier

Table 1 shows the data from the equipment of precision force transducer carried out with precision digital measuring unit (AC bridge) for compression mode calibration. The table shows the calculation of relative creep uncertainty calculated from the creep measurement at maximum force (WC_{max}), creep recovery (WC_{zero}) and the maximum value of relative reversibility error (Wv_{max}). In order to compare in term of magnitude, WC_{max}/Wv_{max} and WC_{zero}/Wv_{max} were calculated in the table.

Table 1: Comparison of relative creep uncertainties for AC-bridge amplifier (compression mode).

No.	Relative creep uncertainty (w_{creep})			WC_{max}/Wv_{max}	WC_{zero}/Wv_{max}
	WC_{max} (%)	WC_{zero} (%)	Wv_{max} (%)		
1	0.0058	0.0046	0.0090	0.6417	0.5134
2	0.0006	0.0003	0.0106	0.0544	0.0272
3	0.0020	0.0003	0.0086	0.2331	0.0333
4	0.0022	0.0012	0.0064	0.3403	0.1881
5	0.0005	0.0002	0.0036	0.1298	0.0487
6	0.0169	0.0019	0.0995	0.1697	0.0196
7	0.0003	0.0009	0.0058	0.0500	0.1500
8	0.0004	0.0001	0.0335	0.0129	0.0043
9	0.0000	0.0035	0.0154	0.0000	0.2246
10	0.0029	0.0017	0.0371	0.0780	0.0468
11	0.0006	0.0012	0.0058	0.1000	0.2000
12	0.0002	0.0002	0.0073	0.0316	0.0316
13	0.0009	0.0002	0.0019	0.4689	0.0907
14	0.0010	0.0000	0.0029	0.3528	0.0101
15	0.0033	0.0030	0.0238	0.1366	0.1257
16	0.0010	0.0001	0.0039	0.2591	0.0148
17	0.0003	0.0003	0.0028	0.1138	0.0931
18	0.0026	0.0014	0.0125	0.2076	0.1153
19	0.0017	0.0006	0.0091	0.1893	0.0631
20	0.0009	0.0012	0.0111	0.0782	0.1043

The data from Table 1 was plotted as shown in Fig. 3(a). The x-axis represents the ratio between WC_{max} and Wv_{max} . The y-axis shows the ratio between WC_{zero} and Wv_{max} . If the x-axis of 0.33 indicating that the creep uncertainty calculated from reversibility error was about 3 times of the creep uncertainty calculated from creep measurement at max force. The graph also represents the ratio between WC_{zero} and C_{max} . In case that an experiment data point is on the line $y=0.5x$ (slope=0.5), the magnitude of WC_{max} will be 2 times of the WC_{zero} . As seen in Fig. 3(a), from 20 experiments data, 16 of them have Wv_{max} larger than 3 times of WC_{max} or WC_{zero} . In term of slope, there are 3 points of data in the region above the line $y=2x$ and there are 8 points of data in the region below the line $y=0.5x$.

Fig. 3(b) shows data of precision load cell with AC type amplifier for tension mode. From 12 experiments data, 11 of them have Wv_{max} larger than 3 times of WC_{max} or WC_{zero} . In term of slope, there are 7 points of data in the region below the line $y=0.5x$.

Fig.3 Relationship between creep uncertainties calculated from C_{max} , C_{zero} and v_{max} for precision load cell with AC bridge amplifier.

3.2. Precision load cell with DC bridge amplifier

Fig. 4 shows data of precision load cell with DC bridge amplifier in both compression and tension mode.

Fig.4 Relationship between creep uncertainties calculated from C_{max} , C_{zero} and v_{max} for precision load cell with DC bridge amplifier.

3.3. Industrial load cell DC bridge amplifier and proving ring

Fig. 5 presents the calibration results from typical industrial load cell (IN) connected with the DC bridge amplifier. And also shows results of proving rings (PR) that the deflection were read from dial gauge or digital dial gauge.

Fig.5 Relationship between creep uncertainties calculated from C_{max} , C_{zero} and v_{max} for industrial load cell and proving ring (IN & PR).

3.4. Summary of results

To evaluate creep uncertainties calculated from 3 difference sources (WC_{max} , WC_{zero} and Wv_{max}), the results from Fig. 3, Fig. 4 and Fig. 5 were grouped with 2 criteria.

First, to compare agreement between WC_{max} and WC_{zero} , the results will agree with criteria I if the maximum between (WC_{max}/WC_{zero}) and (WC_{zero}/WC_{max}) were less than or equal to 2.

Second, to compare size of creep uncertainties calculated from creep measurement and reversibility error, the results will agree with criteria II if the maximum between WC_{max} and WC_{zero} divide by Wv_{max} were larger than or equal to 1/3.

If the result agree with criteria I, it could be assumed that WC_{max} close to WC_{zero} . In case of agreement with criteria II, it could be assumed that the difference of creep uncertainty calculated from creep measurement and from reversibility error were not significant. The grouping results were shown in Fig. 6.

Fig.6 Grouping of experiments based on creep uncertainties calculated from difference sources according to ISO376:2011.

As seen in Fig. 6, from 98 experiments, 36 of them agree with criteria I. For criteria II, only 15 results agree. Moreover, only 4 results agree with both criteria. Indicating that, the creep uncertainties calculated from difference sources (according to ISO376:2011) could not be assumed equivalent. Based on the summary results, the creep properties should be represented by the maximum between C_{max} and C_{zero} . For unknown history of creep and reversibility characteristic of instruments, it should be more appropriate to estimate creep uncertainty from reversibility error.

4. Conclusions

1. Some of the results have zero values of either creep or creep recovery. Those zero values would possibly give some mistakes in uncertainty calculation.
2. More than 80% of experimental results reveal that the relative creep uncertainties estimated from reversibility error were more than 3 times of the relative creep uncertainties calculated from creep measurement.
3. There are only 4 from 98 of the experiments results of creep uncertainty (Fig. 6) agree both defined criteria.

4. The values calculation from three sources of creep uncertainty are much different, thus those values could not be assumed equivalent to use.
5. From the experiment results, creep uncertainties calculated from reversibility were largest compare with the other sources. This give a conclusion that, for any load cell with unknown history of creep property, the reversibility error should be more appropriate to be use for calculation of creep uncertainty.

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