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The influence of the unloading rate on creep recovery of force transducers

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ABSTRACT

This paper presents a study of the effect of unloading rate on the creep recovery of force transducers. The creep values increase with increase loading rate and this increasing phenomenon follows a Natural Logarithm function. The creep is highly dependent on the unloading rate from 0.5 mm/min to 5 mm/min while above 5 mm/min up to 20 mm/min the creep values are less dependent. An equation represents the time-loading/unloading rate effect on the creep/creep recovery of the force transducers, is introduced.

1. Introduction

The change of a force transducer's signal at constant load is defined as so called creep. The creep recovery is defined as the change of a force transducer's signal after load removal. Mostly, both creep and creep recovery are equal in magnitude and different in sign. Nowadays the manufacturers of force transducers include the creep as an important characteristic parameter in the datasheet for the uncertainty estimation. 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 loading, C) for interpolation and incremental-only loading, D) for interpolation and incremental/decremental loading. Comparing with the previous version (ISO 376:2004) creep property is the additional factor for classification of the force proving instrument. Force standard machines used to apply known force values on the calibrated force transducers have different loading mechanisms which reflects on the rate of load application and load removal. If the creep is sensitive to the loading/unloading rate then the uncertainty and the classification of the calibrated force transducers are highly affected. Among the characteristics of force or torque transducers used as artifacts in the proficiency testing, the stability of the creep behaviour of force or torque transducers under different loading/unloading rates considered significant. The key comparison CCM.T-K1 [2] considered the significance of creep with a view to know the effect of different loading and waiting times of the participated reference machines on the artifact reading.

The influence of temperature and humidity on the stability of the 3 min creep recovery was studied earlier and found to have a small effect [3]. The influence of temperature and humidity on the 30 min creep, was studied and gives a linear model for the creep value change due to temperature change from 22 °C to 40 °C, the relevant coefficient (K2) varied from 0.00015%/K to 0.00062%/K. With a linear model for the creep value change due to relative humidity change from 50% to 70%, the relevant coefficient (K4) varied from 0.00006%/(% R.H.) to 0.0003%/(% R.H.) [4].

Loading rate is an effective parameter up on the nature of loading (static, quasi static, and dynamic) and hence on the force transducers used to detect these forces. The aim of this research article is to investigate the effects of loading rate variation up on the creep recovery of the force transducers to evaluate the creep performance of these transducers.

2. Design of the experiments

In these experiments the following equipment was used:

- 5 kN universal testing machine classified as 0.5 as per ISO7500-1 was used to generate the required load/unload with predefined accurate loading/unloading rates. The testing machine follows ramp function to reach the steady-state speed.
- Five force transducers (two different types) classified as 00 as per ISO376:2011.
- DMP40 high accuracy measuring amplifier. The settings of the amplifier are: filter of 0.22 Hz Bessel, signal reading is "absolute", measuring range is 2.5 mV/V, and the excitation voltage is 5 V. The 0.22 Hz Bessel low-pass filter is a common used filter setting in force and torque measurements to achieve approximately stable linear phase, linear phase being equivalent to a time delay which is supposed to don't affect the results.

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Each force transducer is subjected to the loading test sequence shown in Fig. 1. The test sequence starts with 3 preloads at 100% rated capacity followed by 6 loadings at 100% capacity. The same loading rate, waiting time and settings are observed for the 6 loadings; the only changed parameter is the unloading rates (mm/min) which are 0.5, 1, 2, 5, 10 and 20 sequentially. The same 100% capacity test is followed by the 50% rated capacity test with the same sequence as shown in Fig. 1. To appreciate the complexity of having a constant load on the tested force transducers for a certain time due to the effect of stiffness and properties of the different universal testing machine's parts, the measurements were carried out for unloading direction.

All the experiments were conducted under laboratory environmental conditions of 21 °C ± 0.5 K and (45 ± 5)% humidity.

3. Results and discussion

Figs. 2–6 show the effect of unloading rate on the creep recovery of the 5 force transducers unloaded from 100% rated capacity. Figs. 7–11 show the effect of unloading rate on the creep recovery of the 5 force transducers unloaded from 50% rated capacity. In all the figures, the *x*-axis is the time in seconds (s), the *y*-axis is the creep recovery (10^{-6} mV/V).

Figs. 2–6 show that the creep recovery of force transducers unloaded from 100% rated capacity, increases with increase the unloading rate which means if the unloading rate increases, the creep recovery will increase.

In order to test the effect at different unloading capacity, the measurements are repeated at unloading capacity of 50% rated capacity. Figs. 7–11 show that the creep recovery of force transducers unloaded from 50% rated capacity is also increases with increase the unloading rate.

Such rheological models have been used to study the viscoelastic behaviour of materials [5], which are adapted later to study the creep behaviour of load cells [6,7]. The particular model proposed is a network of Voigt elements in series. This model gives a very good approximation for the creep behaviour due to the typical form of the exponential functions as shown in the following equation.

$$Creep(t) = A_1(1-e^{-K_1 t}) + \ldots + A_n(1-e^{-K_n t}) \quad (1)$$

For simplicity only one exponential term was used to approximate the creep behaviour. Values of the two coefficients, A_1 and K_1 are tabulated in Table 1. The solver function in Microsoft Excel was used, as an iterative method to estimate the values of A_1 and K_1 for each transducer. The effect of unloading rate on the 100% rated capacity is approximately double that of the 50% rated capacity, as shown in Table 1. Table 1 shows that the influence at 100% rated capacity for unloading rate 0.5 mm/min is varied from $(-22$ to $-39)10^{-6}$ mV/V then increased with increasing rate to reach $(-82$ to $-125)10^{-6}$ mV/V at 20 mm/min rate. Figs. 12 and 13 show the application of the Eq. (1) with only one exponential term to fit two examples of the tested force transducers at 100% rated capacity.

Fig. 14 shows the effect of the loading rate on the relative errors, in percent, of creep and residual zero. The relative error of creep is of a vertical section view of the application of Eq. (1) on the 5 force transducers at 100% rated capacity to show the relation between the creep recovery at t = 180 s and the unloading rate. The relative error of zero is calculated at t = 30 s. As shown in Fig. 14 the creep/zero in-

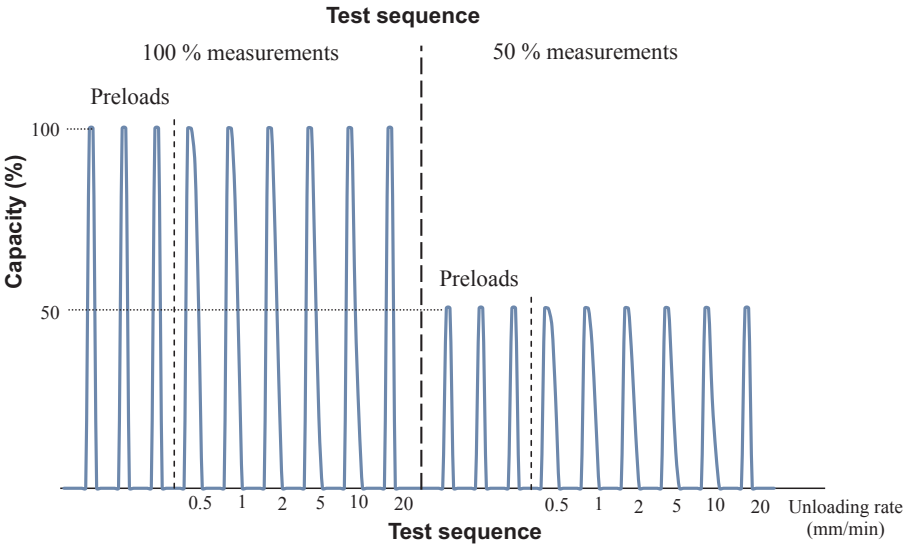

Fig. 1. Measurement sequence.

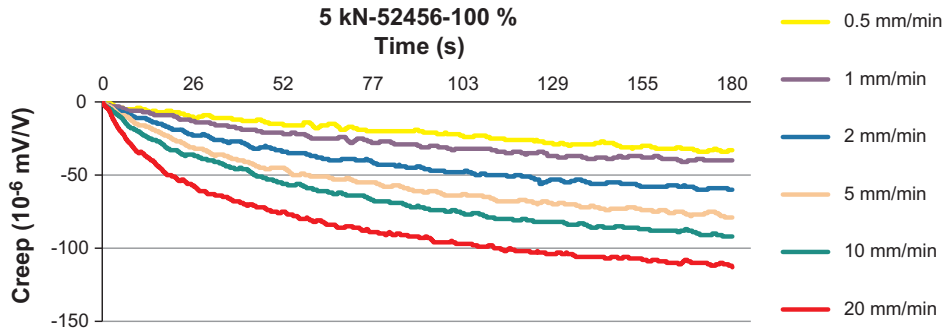

Fig. 2. Effect of unloading rate on the creep recovery of the 5 kN force transducer (Serial No.:52456) at 100% rated capacity.