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INVESTIGATION OF THE EFFECT OF WAITING TIME IN FORCE STEPS DURING FORCE CALIBRATION

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Abstract:
In this study, the effects of the waiting time in the force steps on the calibration results during the calibration of force measuring devices was investigated. For measurements, strain gauge force measuring device and piezoelectric force measuring device were selected. Both force transducers are calibrated to the ISO 376 standard. The waiting times in force steps during calibration were taken as 1 s, 10 s and 60 s. The effects on the results obtained at different waiting times was investigated. Changes in results for both sensors were examined.

Keywords: ISO 376; strain gauge; piezoelectric; waiting time

1. INTRODUCTION

Methods and measuring instruments of physical size are also evolving, depending on the developments in industry, science, and technology. One of the physical dimensions that is important for many sectors such as aircraft, construction, machinery, ships, defence, automotive, and medical is force.

Force can be defined as an effect that can change the motion, shape, and pressure of objects. Force applications are made in many of the engineering studies, including the manufacturing phase of the designs, quality control, and product tests. This makes it important to accurately measure the magnitude of the applied force. The methods used for force measurements are as follows:

A. Known load balancing
B. Utilising force-induced deformation on the flexible body
C. Benefiting from the change of physical properties with the effect of applied force

Many devices that work with these methods are manufactured. The devices used for force measurements can be listed as follows:

A. Mechanical force measuring devices
  1) Martens mirrored force measuring devices
  2) Proving rings
  3) Hydraulic force measuring devices
  4) Vibration strength meters
  5) Resonator force measuring devices
  6) Gyroscopic force measuring devices
B. Electrical force measuring devices
  1) Resistive strain gauge measuring devices
  2) Piezoelectric force measuring devices
  3) Capacitive force measuring devices
  4) Inductive force measuring devices
  5) Electromagnetic force measuring devices
  6) Electrodynamic force measuring devices
  7) Magnetoelastic force measuring devices
  8) Galvanomagnetic force measuring devices
  9) Acoustic force measuring devices

The various types of force gauges are selected and used according to their use and the suitability of measurement capabilities [1], [2], [3], [4], [5], [6].

Characteristics of sensors and measuring devices and hence measurement uncertainties. It should be calibrated at regular intervals as it may change over time due to usage, aging and environmental factors. This process involves comparing the measured value with an agreed reference value, also called the calibration standard. The result of calibration can be used to transfer the actual values of the measurements to the readings or to determine correction factors for them.

Calibration involves determining the relationship between a known input variable (N) and a measured output variable (pC, mV). The procedure is fully defined and the conditions under which the calibration will be performed are determined (ambient temperature, humidity, etc.).

Calibration of force measuring devices is carried out according to ISO 376 and ASTM E74 standards [7], [8]. These standards describe the reference device, calibration method, ambient conditions, and evaluation of measurement results. However, no specific identification was made for the waiting times in the force steps during the calibration.

In this study, the effects of waiting time on the results of force steps during force calibration were investigated. For this study, strain gauge force measuring device and piezoelectric force measuring device were selected. Both force transducers are calibrated to the ISO 376 standard. The waiting times in force steps during calibration were taken as

1 s, 10 s and 60 s. A force measuring device was calibrated three times using these times and its certificate was prepared. The effects of waiting time on the results obtained were investigated. The changes in the results for both sensors are presented.

2. EQUIPMENT AND MEASUREMENT PROCEDURE

Two types of force measuring devices, with piezoelectric and strain gauge principles, were used for measurements. Piezoelectric force measuring device was Kistler brand, model 9333 A, and had a measurement range of (0-50) kN. The sensitivity value of the device is -4.011 pC/kN. A Kistler brand, 5015A model, and 0.01 kN resolution device was used as a charge amplifier.

Strain gauge force measuring device HBM brand, Z4 model, and (0 - 50) kN measuring range device was used. GTM brand, LT Digitizer model, 0.000 01 mV/V resolution, 5 V supply voltage, and measuring range (0 - 5) mV/V was used as the display system.

The strain gauge type force measuring device was mounted on the calibration machine before starting the measurement. A loading pad was placed on the transducer as it will be calibrated in the compression direction. The transducer was connected to the display system 30 minutes before calibration and waited in operation.

The piezoelectric force measuring device was mounted on the calibration machine before starting the measurement. The transducer was connected to the display system 30 minutes before calibration and waited in operation. Just before calibration, the charge amplifier was reset and measurement was then started.

Measurements were carried out according to the ISO 376 standard, Figure 1. Measurements were performed in the static calibration of the force measuring device in the direction of compression in the three mounting positions (by rotating the transducer 120°). Ten equal force steps from 10 % to 100 % were applied. In order to receive data in the force steps, the waiting time was taken as 1 s, 10 s, 60 s, and three calibrations were performed separately. Creep error measurements were taken after the maximum calibration force was removed. The calibration measurements used the deadweight force standard machine located in the TÜBİTAK UME force laboratory. All measurements were performed at an ambient temperature of 21 ˚C ± 1 ˚C.

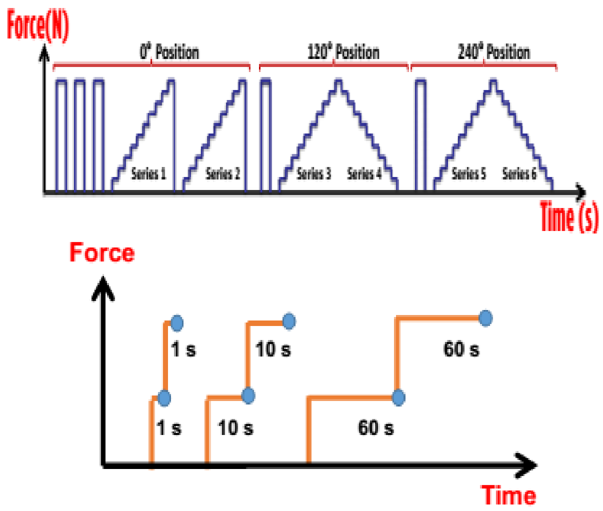

Figure 1: ISO 376 loading shape and waiting time profile

3. RESULTS

The output as a result of force calibration according to ISO 376 standard is shown in Figure 2, [9], [10]. Strain gauge and piezoelectric principle force measuring device have been calibrated according to ISO 376 standard. It has created a separate calibration certificate for three different waiting times.

According to the data received at three different waiting times, the rotated average values (X_r) from the 50 kN force measuring device with strain gauge principle are given in Table 1. Similarly, the rotational mean values (X_r) obtained as a calibration result of the 50 kN force measuring device with piezoelectric principle are also given in Table 2.

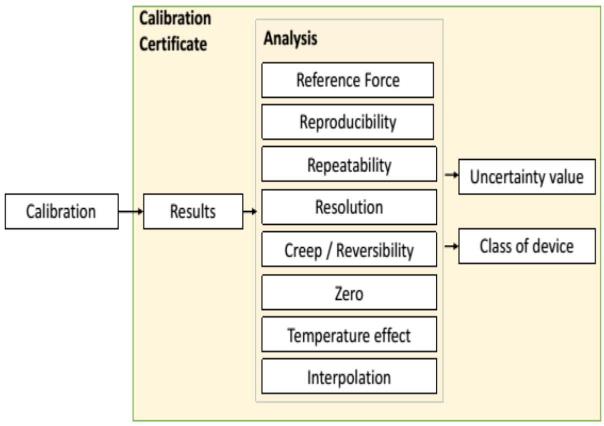

Figure 2: Calibration outputs according to ISO 376

Table 1: The results of 50 kN HBM strain gauge force measuring device

Strain gauge	Waiting time		
	1 s	10 s	60 s
***F* / kN**	**X_r / mV/V**	**X_r / mV/V**	**X_r / mV/V**
5	0.199 28	0.199 24	0.199 24
10	0.398 50	0.398 50	0.398 48
15	0.597 89	0.597 84	0.597 81
20	0.797 32	0.797 25	0.797 25
25	0.996 63	0.996 59	0.996 57
30	1.196 05	1.195 98	1.195 99
35	1.395 42	1.395 39	1.395 36
40	1.594 83	1.594 77	1.594 73
45	1.794 28	1.794 20	1.794 17
50	1.993 70	1.993 65	1.993 62

Table 2: The results of 50 kN Kistler piezoelectric force measuring device

Piezo	Waiting time		
	1 s	10 s	60 s
***F* / kN**	**X_r / kN**	**X_r / kN**	**X_r / kN**
5	4.970	4.980	4.973
10	9.980	9.990	9.987
15	15.013	15.013	15.013
20	20.037	20.037	20.053
25	25.097	25.110	25.117
30	30.120	30.137	30.153
35	35.203	35.227	35.247
40	40.290	40.313	40.330
45	45.383	45.390	45.423
50	50.500	50.533	50.557

The reproducibility error values calculated from the data of force measuring device with strain gauge principle at three different waiting times are given in Figure 3. The reproducibility error values for the piezoelectric force measuring device are shown in Figure 4. Similarly, graphs of repeatability, interpolation and reversibility error are given below (Figure 5 to Figure 10).

From the results obtained after different waiting times, an average of 0.002 % change was calculated in the results of the strain gauge force measuring device in the evaluation of the creep error. However, an average of 0.079 % change was determined in the creep error results of the piezoelectric force measuring device.

HBM sensor is strain gauge force measuring device and Kistler sensor is piezoelectric force measuring device The reproducibility (b) error measured averaged 2.9 times more for the Kistler sensor than for the HBM sensor. The average reproducibility error of the Kistler sensor is 0.174 %.

The repeatability (b') error averaged 2.7 times higher for the Kistler sensor than for the HBM sensor. The average repeatability error of the Kistler sensor is 0.01 %.

The main difference occurred in interpolation (f_c) and hysteresis (ν) errors. The interpolation error was found in the HBM sensor -0.001 % and the Kistler sensor at -0.027 %. Hysteresis error values were found at 0.537 % in the Kistler sensor and 16.7 times lower in the HBM sensor at 0.032 %.

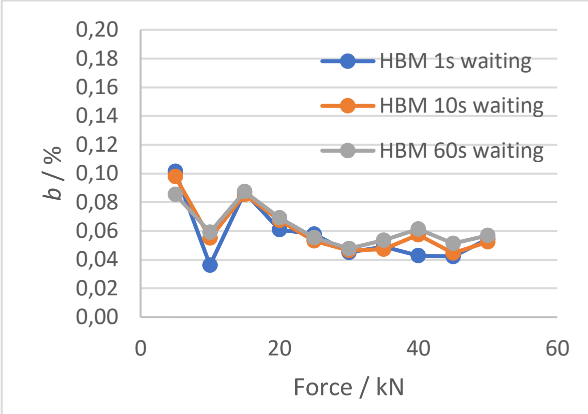

Figure 3: Reproducibility error of strain gauge force transducer

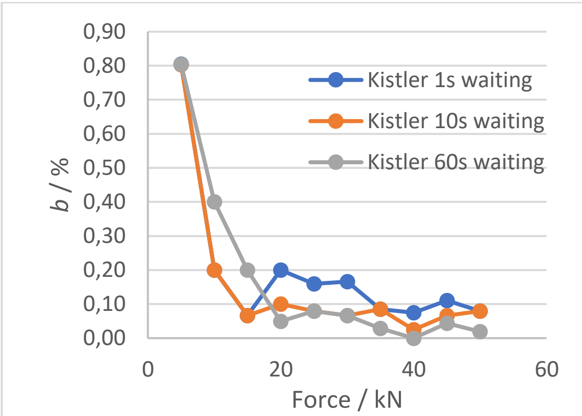

Figure 4: Reproducibility error of piezoelectric force transducer

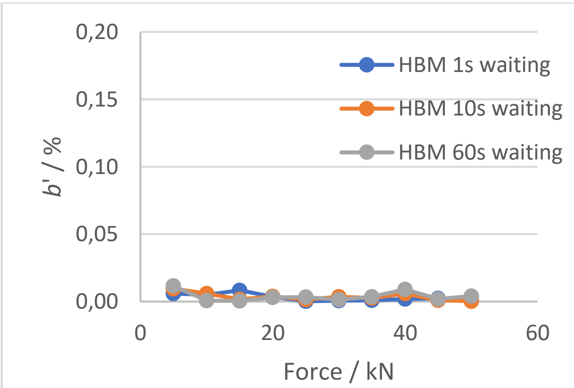

Figure 5: Repeatability error of strain gauge force transducer

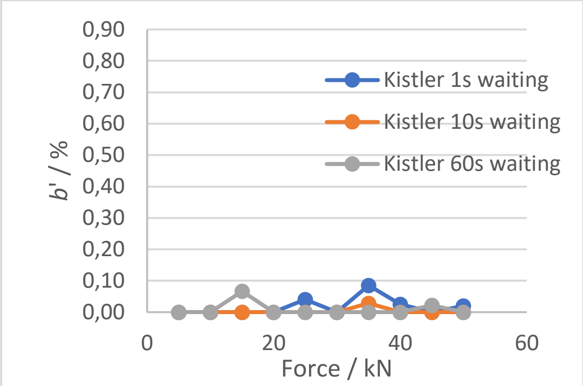

Figure 6: Repeatability error of piezoelectric force transducer

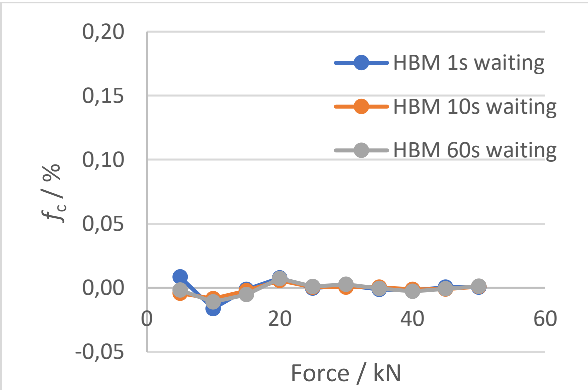

Figure 7: Interpolation error of strain gauge force transducer

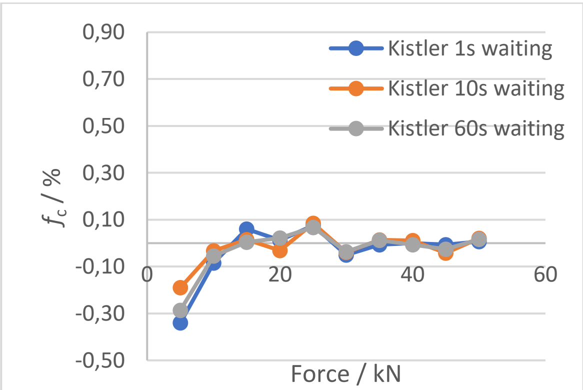

Figure 8: Interpolation error of piezoelectric force transducer

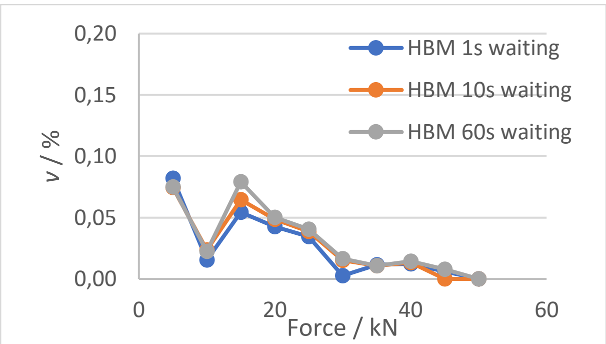

Figure 9: Reversibility error of strain gauge force transducer

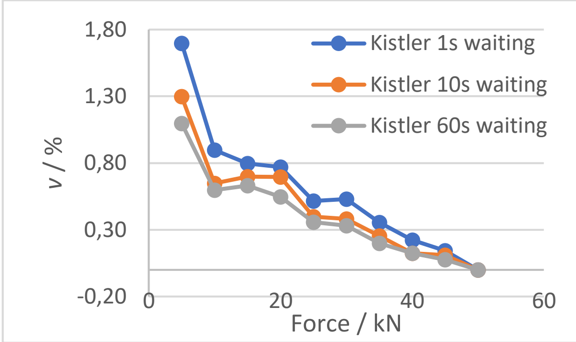

Figure 10: Reversibility error of piezoelectric force transducer

4. CONCLUSIONS

In this study, measurements were carried out in accordance with ISO 376 standard with a force sensor with two different measuring principles at three different waiting times.

When the measurement results were examined, it was determined that different waiting times did not have a significant effect on the repeatability (b') error specified in the ISO 376 standard and did not affect the classification change.

In addition, it was calculated that the reproducibility (b) error caused an average of 8 % variation in the results of the strain gauge force gauge, according to the different waiting time. In piezoelectric force measuring devices, on the other hand, it was determined that the reproducibility (b) error caused an average of 15 % change in the measurement results. As is known, the creep behaviour of piezoelectric sensors is worse than strain gauge sensors. In order to eliminate this, various support parameters have been used in indicator of the piezoelectric force sensors, but even these cannot reach the strain gauge sensor performance. The main reason is the high value of creep error of the piezoelectric force sensor in response to the applied constant force.

It was determined that the reversibility (v) error showed an average of 18 % change in the results of the strain gauge force sensor. The reversibility error results of the piezoelectric force sensor showed an average of 49 % variation too. This difference is due to the creep and drift error of the piezoelectric sensor. However, when evaluating the metrological performance of the piezoelectric force sensor, it is always necessary to consider the entire measuring chain, including the force transducer, cable and load amplifier. In addition, piezoelectric force sensors have directional cross sensitivities that affect the repeatability of measurement at different mounting positions due to the design and anisotropic properties of the piezoelectric material. When working with both sensors, it is recommended to pay attention to all these parameters mentioned above.

This study was prepared to guide researchers working with force sensors with different measurement principles at different waiting times. From the experimental inferences made here, it can be predicted that it will contribute to the formation of a theoretical model in future studies.

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