NEW STUDY ON FORCE TRANSNUCER’S TEMPERATURE BEHAVIOUR

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Abstract:
This paper describes a new study about the temperature behaviour of force transducers. A special force transducer with a PT100 for temperature measuring was developed by GTM. The curve of heating was created, and test data indicates the time for attaining the stable temperature. Meanwhile the different sensitivity of the transducer under different temperatures was obtained, thus the temperature effect on characteristic value per 10 K (so-called TKc) was calculated. At the end, the correction of force transducer at different temperatures was made by the TKc factor of temperature.

Keywords: force transducer; temperature measurement; temperature effect

1. INTRODUCTION

As is well known, the transducer temperature is not exactly the same as the room temperature during calibration. ISO 376:2011 [1] states that “sufficient time shall be allowed for the force-proving instrument to attain a stable temperature”, but there is no guarantee that the temperature of the transducer’s whole body has reached room temperature, even after several hours. Normally the temperature of the surface of the transducer will then be the same as room temperature, but the temperature inside the transducer is unknown.

Additionally, every manufacturer of transducers provides data sheets specifying TKc (temperature effect on characteristic value per 10 K) and TK0 (temperature effect on zero signal per 10 K) in their catalogues or instruction manuals. However, it is not easy for the end user to know if this is true or if something may change after several years’ usage of the transducer.

In the past some similar studies [2, 3] have been done and the papers also describe the temperature behaviour of the transducer. They measured the temperature of the chamber or the laboratory, but the temperature of the transducer was never measured directly. All the data of temperature mentioned were the room temperature.

Therefore, it makes sense to do a new study with special design of the transducer with temperature measurement on its body.

2. EQUIPMENT

A special transfer standard force transducer was designed and manufactured by GTM based on the type KTN-D. A PT100 sensor was attached inside this transducer on the elastomer, as shown in Figure 1.

Figure 1: PT100 inside the transducer

The transducer has two measurement circuits: one is for force (Fz) and the other is for temperature (PT100), as in Figure 2.

Figure 2: Force transducer with PT100 inside
This is a transfer standard force transducer of 300 kN capacity, Class 00 according to ISO 376. We use a 300 kN deadweight machine with $U_{rel} \leq 0.005 \% (k = 2)$ in the force laboratory. The amplifier is DMP41 for force and a monitor for PT100. The uncertainty of the temperature measurement is $U_{rel} = 0.5 \, ^\circ C (k = 2)$.

3. PROCEDURE

We have done two calibration tests, with the transducer and amplifier in the same room.

3.1. Temperature Measurement Only - Without Load

1. At the beginning, the room temperature is around 15 °C. Increase the temperature to 20 °C using the room’s air conditioning. Record the values of both the PT100 and the thermometer every hour for nine hours.

Figure 3: Temperature measurement

2. At the beginning, the room temperature is around 15 °C. Increase the temperature to 25 °C using the room’s air conditioning. Record the values of both the PT100 and the thermometer every hour for nine hours.

3.2. Calibration Test With Load

3.2.1. Test from 15 °C to 25 °C

1. Under temperature of 15 °C, calibrate the transducer according to ISO 376, but without change position. That means no rotation position. Pre-load up to 300 kN. Three calibration series, and the calibration steps are: 30 kN, 50 kN, 100 kN, 150 kN, 200 kN, 250 kN and 300 kN. The holding time of each step is 30 s.

2. Under temperature of 25 °C, test the transducer, according to ISO 376, but without change position. That means no rotation position. Pre-load up to 300 kN. Three calibration series, and the calibration steps are: 30 kN, 50 kN, 100 kN, 150 kN, 200 kN, 250 kN and 300 kN. The holding time of each step is 30 s.

3.2.2. Test from 10 °C to 20 °C

1. Under temperature of 10 °C, test the transducer according to ISO 376, but without change position. That means no rotation position. Pre-load up to 300 kN. Three calibration series, and the calibration steps are: 30 kN, 50 kN, 100 kN, 150 kN, 200 kN, 250 kN and 300 kN. The holding time of each step is 30 s.

Both curves show that it takes around eight hours for the transducer body (PT100) to reach room temperature (RT).

The data from test 3.2.1 is given in Table 1 and Table 2, including the repeatability of the transducer ($b^\prime$).

Table 1: Test at 15 °C (PT100 = 15.24 °C)

| Force (kN) | Run 1 mV/V | Run 2 mV/V | Run 3 mV/V | Mean mV/V | $b^\prime$ % |
|-----------|------------|------------|------------|------------|-------------|
| 30         | 0.200076   | 0.200074   | 0.200067   | 0.200072   | 0.004       |
| 50         | 0.333453   | 0.333453   | 0.333450   | 0.333452   | 0.001       |
| 100        | 0.666888   | 0.666883   | 0.666882   | 0.666884   | 0.001       |
| 150        | 1.000302   | 1.000298   | 1.000288   | 1.000296   | 0.001       |
| 200        | 1.333701   | 1.333690   | 1.333680   | 1.333690   | 0.002       |
| 250        | 1.667053   | 1.667045   | 1.667040   | 1.667046   | 0.001       |
| 300        | 2.000347   | 2.000333   | 2.000325   | 2.000335   | 0.001       |

Figure 4: Temperature measurement 1 of 3.1

Figure 5: Temperature measurement 2 of 3.1
This transducer was made according to Test 3.2.1. The repeatability in Class 00 of ISO 376 is $b^* < 0.025 \%$. We can see that $b^*$ at 15 °C is $\leq 0.004 \%$, and $b^*$ at 25 °C is $\leq 0.006 \%$, meeting Class 00 of ISO 376.

According to the Chinese calibration guideline JJG 144 [4], the repeatability is 0.01 \% and 0.03 \% (Class 0.01 and Class 0.03).

The data of Table 1 and Table 2 are compared, thus $TK_c$ was calculated as in Table 3.

Table 3: Calculation of $TK_c$

| $F$ (kN) | Ave at 15.24 °C (mV/V) | Ave at 25.35 °C (mV/V) | % / 10 K |
|----------|-------------------------|-------------------------|----------|
| 30       | 0.200 072               | 0.200 109               | 0.018    |
| 50       | 0.333 452               | 0.333 525               | 0.022    |
| 100      | 0.666 884               | 0.667 034               | 0.022    |
| 150      | 1.000 296               | 1.000 528               | 0.023    |
| 200      | 1.333 690               | 1.334 005               | 0.023    |
| 250      | 1.667 046               | 1.667 409               | 0.022    |
| 300      | 2.000 335               | 2.000 758               | 0.021    |

$TK_c$ is one specificity of the transducer with strain-gauge technology. Every manufacturer provides this data in the product catalogue. This transducer of KTN-D also gives the value of $TK_c = 0.02 \% / 10$ K in the datasheet. Now we can see the value by the test is 0.023 \% (maximum) and 0.018 \% (minimum).

From Table 3, the average value of $TK_c$ is taken as 0.022 \% / 10 K.

The data from test 3.2.2 were collected and compared as shown in Table 4.

Table 4: Deviation from test 3.2.2

| $F$ (kN) | Ave at 11.49 °C (mV/V) | Ave at 19.53 °C (mV/V) | Deviation % |
|----------|-------------------------|-------------------------|-------------|
| 30       | 0.200 061               | 0.200 094               | 0.016       |
| 50       | 0.333 434               | 0.333 492               | 0.017       |
| 100      | 0.666 842               | 0.666 969               | 0.019       |
| 150      | 1.000 236               | 1.000 422               | 0.019       |
| 200      | 1.333 607               | 1.333 859               | 0.019       |
| 250      | 1.666 944               | 1.667 253               | 0.019       |
| 300      | 2.000 219               | 2.000 583               | 0.018       |

Now the corrected and measured values were compared, with the calculated deviations given in Table 5. The two curves are also shown in Figure 6.

Table 5: Corrected value

| $F$ (kN) | Ave at 11.49 °C (mV/V) | Ave corrected to 19.53 °C (mV/V) |
|----------|-------------------------|----------------------------------|
| 30       | 0.200 061               | 0.200 096                        |
| 50       | 0.333 434               | 0.333 493                        |
| 100      | 0.666 842               | 0.666 969                        |
| 150      | 1.000 236               | 1.000 423                        |
| 200      | 1.333 607               | 1.333 843                        |
| 250      | 1.666 944               | 1.667 239                        |
| 300      | 2.000 219               | 2.000 573                        |

Figure 6: Deviation before correction vs after correction
The value of after correction is nearly the same as the measurement at 19.53 °C (the deviation is -0.001 %), meaning that the value of $TK_c$ is reliable.

Other corrections have also been performed between different temperatures. For a correction at 15.24 °C based on the measurement value at 11.49 °C, the deviation between the corrected value and the measured value is around 0.003 %.

5. SUMMARY

This special transducer helps to prove the description in ISO 376 about enough time: around eight hours should be suitable. Indeed, the Chinese calibration guideline JG 144 [4] also suggests that the time which the transducer put at the laboratory is “more than eight hours”. For the transducer of high accuracy class, any time less than eight hours is not recommended.

The temperature behaviour of each force transducer is given by its value of $TK_c$. Therefore, the data by the manufacturer should be considered by the user during the calibration. At different room temperatures, the value of $TK_c$ can be used to make corrections.

The deviation between the value after correction and measurement directly is same or less than the value of repeatability.

6. REFERENCES

[1] ISO 376, Metallic materials — Calibration of force proving instruments used for the verification of uniaxial testing machines, 2011.
[2] D. Röske, “The influence of temperature and humidity on the creep of torque transducers”, IMEKO 23rd TC3, 13th TC5 and 4th TC22 International Conference, Helsinki, Finland, 30 May to 1 June 2017.
[3] Min-Seok Kim, “Simultaneous determination of temperature and humidity sensitivity coefficients of torque transfer standards in ambient conditions”, IMEKO 23rd TC3, 13th TC5 and 4th TC22 International Conference, Helsinki, Finland, 30 May to 1 June 2017.
[4] JG 144, Verification Regulation for Standard Dynamometers, SAQSIQ, China, 2007.