ACTA IMEKO
ISSN: 2221-870X
December 2020, Volume 9, Number 5, 133 - 136

NEW STUDY ON FORCE TRANSDUCER'S TEMPERATURE BEHAVIOUR

Kui Gan[1], Hong Jiang[2], Hongjiang Chen[3], Hao Zhang[4], William Huang[5]

[1] Hunan Institute of Metrology and Test, Changsha, China, fancygk@163.com
[2] Shanghai Institute of Quality Inspection and Technical Research, Shanghai, China, jianghong@sqi.org.cn
[3] Hunan Institute of Metrology and Test, Changsha, China, 31862083@qq.com
[4] Hunan Institute of Metrology and Test, Changsha, China, 664074026@qq.com
[5] GTM China Office, Shanghai, China, william.huang@gtmchina.cn

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 TK_0 (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.

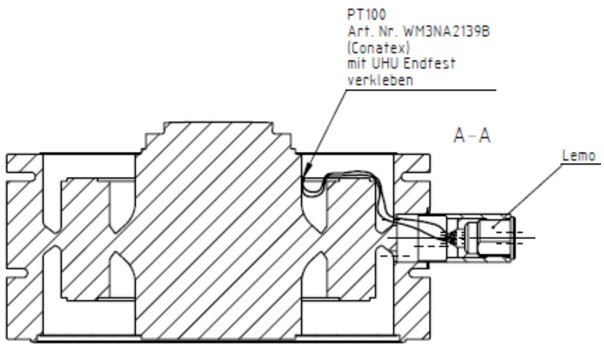

Figure 1: PT100 inside the transducer

The transducer has two measurement circuits: one is for force (F_z) 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 $U_{rel} = 0.5$ °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.

2. Under temperature of 20 °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.

Collect all the data.

4. DATA ANALYSIS

The data from test 3.1 is plotted in Figure 4 and Figure 5.

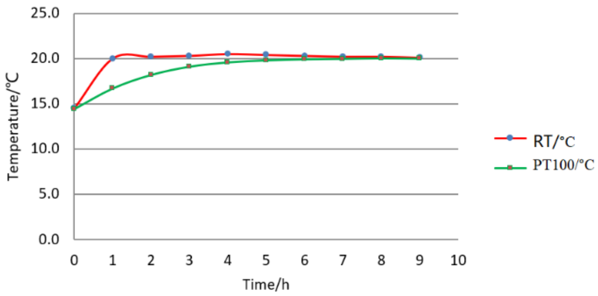

Figure 4: Temperature measurement 1 of 3.1

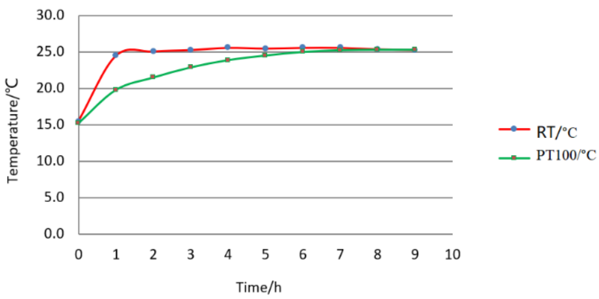

Figure 5: Temperature measurement 2 of 3.1

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').

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

F	Run 1	Run 2	Run 3	Mean	b'
kN	mV/V	mV/V	mV/V	mV/V	%
30	0.200 076	0.200 074	0.200 067	0.200 072	0.004
50	0.333 453	0.333 453	0.333 450	0.333 452	0.001
100	0.666 888	0.666 883	0.666 882	0.666 884	0.001
150	1.000 302	1.000 298	1.000 288	1.000 296	0.001
200	1.333 701	1.333 690	1.333 680	1.333 690	0.002
250	1.667 053	1.667 045	1.667 040	1.667 046	0.001
300	2.000 347	2.000 333	2.000 325	2.000 335	0.001

Table 2: Test at 25 °C (PT100 = 25.35 °C)

F	Run 1	Run 2	Run 3	Mean	*b'*
kN	mV/V	mV/V	mV/V	mV/V	%
30	0.200 105	0.200 111	0.200 111	0.200 109	0.003
50	0.333 514	0.333 535	0.333 526	0.333 525	0.006
100	0.667 014	0.667 050	0.667 038	0.667 034	0.005
150	1.000 502	1.000 549	1.000 533	1.000 528	0.005
200	1.333 968	1.334 027	1.334 005	1.334 000	0.004
250	1.667 377	1.667 439	1.667 410	1.667 409	0.004
300	2.000 722	2.000 792	2.000 760	2.000 758	0.003

This transducer was made according to Class 00 of ISO 376. The repeatability in Class 00 is *b*' < 0.025 %. We can see that *b*' at 15 °C is ≤ 0.004 %, and *b*' at 25 °C is ≤ 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 *TKc* was calculated as in Table 3.

Table 3: Calculation of *TKc*

F	mV/V	mV/V	*TKc*
kN	Ave at 15.24 °C	Ave at 25.35 °C	% / 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

TKc 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 *TKc* = 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 *TKc* is taken as 0.022 % / 10 K.

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

As mentioned, *TKc* is 0.022 % / 10 K for this transducer according to test 3.2.1. Using this value, its performance at a temperature of 11.49 °C is corrected to an expected performance at a temperature of 19.53 °C, with the results given in Table 5.

Table 4: Deviation from test 3.2.2

F	mV/V	mV/V	Deviation
kN	at 11.49 °C	at 19.53 °C	%
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

Table 5: Corrected value

F	mV/V	mV/V
kN	at 11.49 °C	corrected to 19.53 °C
30	0.200 061	0.200 096
50	0.333 434	0.333 493
100	0.666 842	0.666 960
150	1.000 236	1.000 413
200	1.333 607	1.333 843
250	1.666 944	1.667 239
300	2.000 219	2.000 573

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

Table 6: Deviations between corrected and measured values

F	mV/V	mV/V	Deviation
kN	corrected to 19.53 °C	measured at 19.53 °C	%
30	0.200 096	0.200 094	-0.001
50	0.333 493	0.333 492	0.000
100	0.666 96	0.666 969	0.001
150	1.000 413	1.000 422	0.001
200	1.333 843	1.333 859	0.001
250	1.667 239	1.667 253	0.001
300	2.000 573	2.000 583	0.000

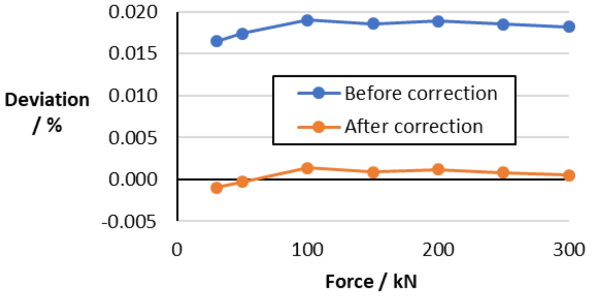

Figure 6: Deviation before correction vs after correction

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 *TKc* 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 JJG 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 *TKc*. Therefore, the data by the manufacturer should be considered by the user during the calibration. At different room temperatures, the value of *TKc* 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

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