Research on Technology of Accuracy Related Tests of Pressure Transmitters on Rolling Stocks

Li Zihua\textsuperscript{1*}, Cao Yu\textsuperscript{1}, Ding Xiebin\textsuperscript{2}, Zhao Dongsheng\textsuperscript{2}

\textsuperscript{1}Standards & Metrology Research Institute, China Academy of Railway Sciences Corporation Limited, Beijing, China
\textsuperscript{2}Locomotive & Car Testing and Inspection Laboratory, China Railway Test & Certification Center Limited, Beijing, China
\* Corresponding author: thisislizihua@163.com

Abstract—Many pressure transmitters are used on rolling stocks, and their reliability and accuracy are of importance to the safety of the railway systems. In this paper, the technical solutions of accuracy related tests of different types of pressure transmitters and the effect of temperature on accuracy are studied and are carried out to verify that the test results meet the requirements in the relevant standards.

1. INTRODUCTION
Pressure transmitter, or pressure transducer, is a transducer that converts pressure into an analog electrical signal. It can also be used to measure such pressure-related parameters as density and liquid level, and even flow when used with throttle. It is widely used in various industrial fields to measure the pressure of gases and/or liquids. Currently, various types of pressure transmitters are applied on rolling stocks, and their reliability and accuracy are of great effect on the normal operation of railway systems. The test technology on accuracy related test items of pressure transmitter and the effect of temperature on accuracy are studied thoroughly in this paper [1][2][3].

2. TEST REQUIREMENTS AND SOLUTIONS

2.1 Test Requirements
At present, the tests of pressure transmitters used on rolling stocks are carried out according to Q/CR 322. The accuracy related test items include basic error, non-linearity, hysteresis, repeatability, etc. The basic concepts of the above-mentioned items are shown and explained in Table 1 according to [4] and [5].
TABLE 1. TERMS AND DEFINITIONS

| Term               | Definition                                                                 |
|--------------------|---------------------------------------------------------------------------|
| Measured error     | Largest positive or negative value of error of the average upscale or downscale values at each point of measurement. |
| Non-linearity      | Property of a device or instrument whereby it gives different output values in relation to its input values depending on the directional sequence in which the input values have been applied. |
| Hysteresis         | deviation from linearity<sup>a</sup>.                                      |
| Non-repeatability  | Deviation from repeatability<sup>b</sup>.                                  |

<sup>a</sup> The ability of a measuring instrument to provide an indication having a linear relationship defined quantity other than an influence quantity.

<sup>b</sup> Closeness of agreement between the results of successive measurements of the same measurand, carried out under the same conditions of measurement.

There are 3 expressions of non-linearity, i.e., terminal based non-linearity, independent non-linearity and zero based non-linearity. Considering the calibration in the factory and adjustment in the field, only the terminal based non-linearity is practical. Therefore, terminal based non-linearity is adopted to express the non-linearity of the pressure transmitter under test in this paper.

Technical specifications of above-mentioned items in Q/CR 322 are shown in Table 2 [6]. This part of the test is conducted in accordance with the methods and requirements in GB/T 17614.1 and GB/T 18271.2. In addition, the dry heat test and the cooling test are carried out respectively at the temperature of 70 ℃ and of -25 ℃ according to GB/T 2423.1 and GB/T 2423.2.

TABLE 2. TECHNICAL SPECIFICATIONS

| Item                | Accuracy Class |
|---------------------|----------------|
|                     | 0.25 | 0.5  | 1.0  | 2.0  | 3.0  |
| Measured error (%)  | ±0.25| ±0.50| ±1.0 | ±2.0 | ±3.0 |
| Non-linearity (%)   | ≤0.15 | ≤0.25 | ≤0.50 | ≤1.5 | ≤2.0 |
| Hysteresis (%)      | ≤0.10 | ≤0.15 | ≤0.25 | ≤1.0 | ≤1.0 |
| Non-repeatability (%)| ≤0.10 | ≤0.15 | ≤0.25 | ≤1.0 | ≤1.0 |

<sup>a</sup> percent of ideal output span, same below

2.2 Test Solutions

2.2.1 Types of Pressure Transmitters

2.2.1.1 According to the type of output signal, there are voltage output and current output pressure transmitters.

2.2.1.2 According to the number of pins, there are 2-pin, 3-pin, and 4-pin pressure transmitters.

2.2.2 Test Equipments

Considering that there are two kinds of output signals of pressure transmitters: voltage and current, 34970A Agilent data acquisition instrument with 34901A Agilent data acquisition module is adopted for measurement. There are 22 channels in this module, which consists of 20 voltage channels and 2 current channels. It can measure voltage and current ranging to 300 V and 1 A. The air source pressure is accurately controlled by the Druck PACE6000 pressure controller and CM2 pneumatic control module. The module can either measure or control the gauge pressure from -0.1 MPa to 3.5 MPa with an accuracy of 0.005 %FS.

Test systems dealing with different types of pressure transmitters that with different numbers of pins are shown in Fig. 1 where the Device Under Test (DUT) is pressure transmitter. The input for the pressure transmitter is given by the pressure controller, and the output value of the pressure transmitter is recorded by the data acquisition.
3. TEST PROGRAM

Take some type of a 1.0 accuracy-class pressure transmitter with 3 pins as an example. Connect it and build up the test system according to Fig. 1. The input range of the pressure transmitter is from 0 MPa to 1 MPa, the output signal is current, and its range is from 0 mA to 10 mA.

3.1 Preparation before the test

Before the test, the built test system and the pressure transmitter are placed at room temperature (in this case, it is 20 °C) for a sufficient time to permit thermal stabilization of the whole test system.

3.2 Test Steps

3.2.1 Initially, an input pressure that equals to the lower range value (0% of input span) is provided, and then the input shall be slowly increased (without overshoot) to the first test point. After a proper stabilization period, the corresponding output signal is recorded.

3.2.2 After the output at current test point is recorded, the input shall be slowly increased (without overshoot) to reach the next test point and the corresponding output signal is recorded after a proper period of stabilization.

3.2.3 The process in step 2) shall be repeated at each predetermined test points until the input reaches its upper range value(100% of the input span). After the output at this point is recorded, the input shall be...
slowly decreased to the next test point that belows the upper range value, and then to the rest test points in turn down until it reaches the lower range value, thus closing a measurement cycle.

3.2.4 The process from step 1) to step 3) is repeated at different temperature, in this case, it is at 70 °C and -25 °C. The pressure transmitter is placed in temperature chamber for a sufficient time for its thermal stabilization before the measurement.

3.3 Some Attentions
Considering the test duration and economic efficiency, the measurement cycles and the test points shall be as few as possible, and the number of increasing and decreasing test points shall be the same at each test point and at each cycle, except for the lower and upper range values, which can only be reached when moving downscale or upscale.

3.4 Test Data
The predetermined input pressure values for the pressure transmitter are precisely given by the pressure controller, so that the output value moves upscale and downscale three times which covers the full range of the output signal. The increment between every two adjacent test points is 20% of input span. The output value from the pressure transmitter is recorded by the data acquisition automatically.

According to all the measured data, the errors at 20 °C are calculated, and are organized into Table 3, and the error curves can be plotted consequently, which is shown in Fig. 2. The results of dry heat test and cooling test are shown in Table 4, Fig. 3, and Table 5, Fig. 4, respectively.

| Input (in % span) | 0 | 20 | 40 | 60 | 80 | 100 |
|-------------------|---|----|----|----|----|-----|
| Ideal Output (mA) | 0 | 2  | 4  | 6  | 8  | 10  |

### TABLE 3. TEST DATA (AT 20 °C)

| Actual Output (mA) | Input (in % span) | Ideal Output (mA) | 0 | 20 | 40 | 60 | 80 | 100 |
|--------------------|-------------------|-------------------|---|----|----|----|----|-----|
| 1<sup>st</sup> cycle | Up actual | — | 1.973 | 3.964 | 5.953 | 7.938 | 9.919 |
| | Down actual | 0.000 | 1.973 | 3.964 | 5.953 | 7.938 | — |
| 2<sup>nd</sup> cycle | Up actual | — | 1.973 | 3.964 | 5.953 | 7.938 | 9.920 |
| | Down actual | 0.000 | 1.972 | 3.964 | 5.953 | 7.939 | — |
| 3<sup>rd</sup> cycle | Up actual | — | 1.973 | 3.964 | 5.953 | 7.938 | 9.920 |
| | Down actual | 0.000 | 1.973 | 3.965 | 5.953 | 7.938 | — |

| Error (%<sup>a</sup>) | Input (in % span) | Ideal Output (mA) | 0 | 20 | 40 | 60 | 80 | 100 |
|------------------------|-------------------|-------------------|---|----|----|----|----|-----|
| 1<sup>st</sup> cycle | Up actual | — | -0.27 | -0.36 | -0.47 | -0.62 | -0.81 |
| | Down actual | 0.00 | -0.27 | -0.36 | -0.47 | -0.62 | — |
| 2<sup>nd</sup> cycle | Up actual | — | -0.27 | -0.36 | -0.47 | -0.62 | -0.80 |
| | Down actual | 0.00 | -0.28 | -0.36 | -0.47 | -0.61 | — |
| 3<sup>rd</sup> cycle | Up actual | — | -0.27 | -0.36 | -0.47 | -0.62 | -0.80 |
| | Down actual | 0.00 | -0.27 | -0.35 | -0.47 | -0.62 | — |
| Average of the cycles | Up average | — | -0.27 | -0.36 | -0.47 | -0.62 | -0.80 |
| | Down average | 0.00 | -0.27 | -0.36 | -0.47 | -0.62 | — |
| Average | — | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |

| Non-repeatability (%) | Input (in % span) | Ideal Output (mA) | 0 | 20 | 40 | 60 | 80 | 100 |
|------------------------|-------------------|-------------------|---|----|----|----|----|-----|
| Up | — | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| Down | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | — |

| Hysteresis (%) | Input (in % span) | Ideal Output (mA) | 0 | 20 | 40 | 60 | 80 | 100 |
|---------------|-------------------|-------------------|---|----|----|----|----|-----|
| — | 0.01 | 0.01 | 0.01 | 0.01 | — |

<sup>a</sup> percent of ideal output span, same below
Figure 2. Error Curves (at 20 °C)

### TABLE 4. TEST DATA (AT 70 °C)

| Input (in % span) | 0 | 20 | 40 | 60 | 80 | 100 |
|-------------------|---|----|----|----|----|----|
| Ideal Output (mA) | 0 | 2  | 4  | 6  | 8  | 10  |
| Actual Output (mA) | | | | | | |
| 1st cycle | Up actual | — | 1.953 | 3.950 | 5.945 | 7.938 | 9.929 |
| | Down actual | 0.000 | 1.953 | 3.950 | 5.945 | 7.939 | — |
| 2nd cycle | Up actual | — | 1.953 | 3.950 | 5.945 | 7.938 | 9.928 |
| | Down actual | 0.000 | 1.952 | 3.950 | 5.944 | 7.938 | — |
| 3rd cycle | Up actual | — | 1.952 | 3.949 | 5.944 | 7.937 | 9.928 |
| | Down actual | 0.000 | 1.951 | 3.949 | 5.944 | 7.937 | — |
| Error (%) | | | | | | |
| 1st cycle | Up actual | — | -0.47 | -0.50 | -0.55 | -0.62 | -0.71 |
| | Down actual | 0.00 | -0.47 | -0.50 | -0.55 | -0.61 | — |
| 2nd cycle | Up actual | — | -0.47 | -0.50 | -0.55 | -0.62 | -0.72 |
| | Down actual | 0.00 | -0.48 | -0.50 | -0.56 | -0.62 | — |
| 3rd cycle | Up actual | — | -0.48 | -0.51 | -0.56 | -0.63 | -0.72 |
| | Down actual | 0.00 | -0.49 | -0.51 | -0.56 | -0.63 | — |
| Average of the cycles | Up average | — | -0.47 | -0.50 | -0.55 | -0.62 | -0.72 |
| | Down average | 0.00 | -0.48 | -0.51 | -0.55 | -0.62 | — |
| Average | 0.00 | -0.48 | -0.51 | -0.55 | -0.62 | -0.72 |
| Non-repeatability (%) | Up | — | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| | Down | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | — |
| Hysteresis (%) | — | 0.01 | 0.01 | 0.01 | 0.00 | — |

a. percent of ideal output span, same below
Figure 3. Error Curves (at 70 °C)

| TABLE 5. Test Data (at -25 °C) |
|--------------------------------|
| Input (in % span) | 0 | 20 | 40 | 60 | 80 | 100 |
| Ideal Output (mA) |
| 1st cycle | Up actual | — | 1.989 | 4.022 | 6.051 | 8.075 | 10.095 |
| Down actual | 0.000 | 1.991 | 4.026 | 6.055 | 8.078 | — |
| 2nd cycle | Up actual | — | 1.991 | 4.025 | 6.054 | 8.079 | 10.098 |
| Down actual | 0.000 | 1.992 | 4.026 | 6.056 | 8.081 | — |
| 3rd cycle | Up actual | — | 1.992 | 4.026 | 6.055 | 8.079 | 10.099 |
| Down actual | 0.00 | 1.99 | 4.03 | 6.06 | 8.08 | — |
| Error (%) |
| 1st cycle | Up actual | — | -0.11 | 0.22 | 0.51 | 0.75 | 0.95 |
| Down actual | 0.00 | -0.09 | 0.26 | 0.55 | 0.78 | — |
| 2nd cycle | Up actual | — | -0.09 | 0.25 | 0.54 | 0.79 | 0.98 |
| Down actual | 0.00 | -0.08 | 0.26 | 0.56 | 0.81 | — |
| 3rd cycle | Up actual | — | -0.08 | 0.26 | 0.55 | 0.79 | 0.99 |
| Down actual | 0.00 | -0.08 | 0.27 | 0.56 | 0.81 | — |
| Average of the cycles | Up average | — | -0.09 | 0.24 | 0.53 | 0.78 | 0.97 |
| Down average | 0.00 | -0.08 | 0.26 | 0.56 | 0.80 | — |
| Average | 0.00 | -0.09 | 0.25 | 0.55 | 0.79 | 0.97 |
| Non-repeatability (%) | Up | — | 0.02 | 0.04 | 0.04 | 0.04 | 0.04 |
| Down | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | — |
| Hysteresis (%) | — | 0.02 | 0.03 | 0.04 | 0.04 | — |

a. percent of ideal output span, same below
4. CONCLUSION

Finally, the test results are obtained and shown in Table 6. It can be seen from the test results that the maximum measured error of this type of pressure transmitter is obtained at 100% input span, which is -0.97 %FS (at -25 ℃). The maximum deviation of non-linearity is measured at 20% input span, which is 0.33 %FS (at 70 ℃). It has been verified by the test that the accuracy related parameters of this type of pressure transmitter meets the requirements of related standards. By the research on the technology of accuracy related tests of the pressure transmitter and on the effect of temperature on accuracy, an important guarantee is provided for the safe and reliable operation of the rolling stocks.

| Item                  | Requirement | Test Result |
|-----------------------|-------------|-------------|
| Measured error (%)    | ±1.0        | -0.80       |
|                       |             | -0.72       |
|                       |             | -0.97       |
| Non-linearity (%)     | ≤0.50       | 0.11        |
|                       |             | 0.33        |
|                       |             | 0.28        |
| Hysteresis (%)        | ≤0.25       | 0.01        |
|                       |             | 0.01        |
|                       |             | 0.04        |
| Non-repeatability (%) | ≤0.25       | 0.01        |
|                       |             | 0.02        |
|                       |             | 0.04        |

* TABLE 6. TEST RESULT*

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