Research on Guarantee Technology of Measuring Accuracy of Highway Bridge Expansion and Contraction Installation Test System

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Abstract. The highway bridge expansion and contraction installation is the guarantee for the stability of the bridge structure, using a reasonable detection methods is the key to ensure the accuracy of the test of highway bridge expansion and contraction installation. This paper through the investigation and summary of the status quo of the use and measurement of the highway bridge expansion and contraction installation test system, the accuracy of the measurement results of the highway bridge expansion and contraction installation test system is tested and determined, the measurement technical parameters are determined. Through the establishment of the “highway bridge expansion and contraction installation-highway bridge expansion and contraction installation test system standard dynamometer-national force measurement standard” traceability chain, it can meet the needs of calibration of highway bridge expansion and contraction installation test system.

Keywords. Highway bridge expansion and contraction installation, test system, accuracy, value traceability, guarantee technology.

1. Introduction
Highway bridge expansion and contraction installation (referred to as installation) is an important part of the bridge. The definition is “the general term of various devices installed at the expansion and contraction joints of the bridge deck to enable vehicles to pass through the bridge deck smoothly and meet the needs of bridge deck deformation” [1,2]. The installation is composed of a force transmission support system and a displacement control system. Its function is to transfer the vertical and horizontal loads of the vehicle to the beam body through the support structure. On the other hand, it adapts to the change of the longitudinal and transverse displacement of the bridge and the change of the angle of the beam end warping. According to its operational characteristics, highway bridges will be affected by a series of factors such as temperature change, concrete deformation, and dynamic load and so on, which result in deformation of beam body. In order to adjust the displacement between superstructures caused by vehicle loads, environmental characteristics and physical properties of building materials and to maintain smooth connection between superstructures, the installation should be installed. Because the installation plays a
The role of the bridge, so it is necessary to test its relevant performance before it can be put into use.

The highway bridge expansion and contraction installation test system (referred to as the test system) is a test system that applies a force value in a hydraulic manner and uses a closed-loop control to measure the mechanical performance parameters of the installation. Through the test system, the testing institutions in the transportation industry test the maximum horizontal friction resistance, uniformity of deformation during tension and compression, maximum vertical deformation deviation of each unit during tension and compression, and dislocation performance under the conditions of horizontal friction resistance and uniformity of deformation, and comprehensive evaluation of the performance of the installation. Therefore, the test system, as an indispensable equipment for the performance test of the installation, must be effectively guaranteed for its accuracy.

JT/T 327-2016 General technical requirements of expansion and contraction installation for highway bridge, JT/T 723-2008 Unit sparse plate bridge expansion joint for multi-direction-displacement and JT/T 1064-2016 Damping multi-directional displacement comb telescopic device for bridges all put forward clear requirements for the mechanical properties of the installation. According to the classification requirements of metrology, the mechanical properties belong to the force value, which should be traced back to the national force measurement standard through the uninterrupted traceability chain[3,4].

2. Principle and Structure of the Test System

JT/T 327-2016 “General Technical Requirements of Expansion and Contraction Installation for Highway Bridge” put forward requirements for deformation performance such as maximum horizontal friction resistance during stretching and compression of all types of expansion devices. In order to complete the measurement of all performance tests of the installation, the test system must have a 6-part structure of the frame, the force measuring device, the hydraulic device, the control device, the data acquisition and display device, and the safety device. Through the investigation of domestic test system, the description can meet the needs[5]. The structural diagram of the test system of the highway bridge expansion and contraction installation is shown in figure 1.

![Figure 1. Test system structure diagram.](image)

1--Rack, 2--Force measuring device, 3--Hydraulic device, 4--Control device, 5--Data acquisition and display device, 6--Safety device.

In the testing process of the test system, some technical indicators or performance requirements will be put forward for the function of each structure, and the performance of the test system is judged by the conclusions obtained in the test.

The test system is large-scale equipment. The physical diagram is shown in figure 2. It is mainly...
assembled from steel parts and components, with coating on the outer surface. In terms of appearance, the requirements are mainly put forward in the aspects of no rust, no obvious roughness and other damages.

![Figure 2. The picture of test system.](image_url)

The general requirements of the force measuring device are mainly considered from the basic functions, including the way of measuring force, whether there is an indication of the afterburning speed, zero adjustment and zero clearance, and the function of recording the test force in real time. At the same time, it is required that during the process of exerting of force, the indication should be displayed normally without affecting the test.

The main function of the hydraulic device is to provide power to the system by changing the pressure. Its general requirements are also considered from the basic functions, the parameters are normal, there is no pressure loss and flow loss, no holes, no cavitation, etc. and other phenomena, it can normally exchange energy to generate power without affecting the test.

The control devices of the test system in the industry are all automatic control mode, so the closed-loop control mode is specified. According to the requirements of JT/T 327-2016 General technical requirements of expansion and contraction installation for highway bridge, vertical and horizontal loads, stresses and frictional resistances should to be output. Therefore, it is proposed to draw the bearing loading capacity-time and friction resistance-time curves. In addition, in order to facilitate the inspection and calibration of the test system, the control software should have the function of inspection or self-verification[6].

As the acquisition and output part of the test results of the test system, the data acquisition and display device must be able to display and record the test load and loading speed in real time, accurately display the frictional resistance value in real time, and should be able to preserve the maximum frictional resistance value when the sample is expanding. At the same time, for the display function of the data acquisition and display device, put forward the request for “data and graphics should be clear and easy to read. In the process of applying force, the indication of test force should be stable, no impact and jitter.

The function of the safety device is to stop the machine automatically when it is overloaded or abnormal, so as to protect the equipment and avoid personal injury. At present, there are two kinds of adjustment of loading beam on the market, namely manual and automatic. With the progress of science and technology, electric mode is recommended.
3. Test and Verification Method of Guarantee Technology

In the test, in addition to the appearance of the test system and the basic performance of some devices, the related technical indexes of the hardness and force of the loading platen are also required.

3.1 Platen Hardness Testing

The loading platen is the working surface for applying the test force to the telescopic device during the test. It requires good wear resistance and compression resistance, so the hardness of the loading platen is required. Refer to ISO 7500-1 for the hardness requirements of the loading platen, and in combination with the verification test, the hardness of the loading platen should not be less than 55HRC. Considering that the hardness loss of the loading platen is less in use, the surface of the platen will be uneven after repeated hardness testing. Therefore, only the first calibration is carried out, and no subsequent calibration is carried out.[7,8]. The hardness test of the loaded platen is shown in figure 3. The test results are shown in table 1.

![Loading platen hardness test.](image)

Table 1. Loading platen hardness test results.

| The device number | Platen number | Test value 1 (HRC) | Test value 2 (HRC) | Test value 3 (HRC) | Average value (HRC) |
|-------------------|---------------|-------------------|-------------------|-------------------|---------------------|
| SSFT-400 (201701) | Platen 1      | 56.2              | 56.3              | 56.3              | 56.27               |
|                   | Platen 2      | 56.2              | 56.2              | 56.2              | 56.20               |
|                   |               | 56.2              | 56.2              | 56.4              | 56.27               |
| SSFT-400 (201801) | Platen 1      | 55.4              | 55.3              | 55.3              | 55.33               |
|                   | Platen 2      | 55.6              | 55.6              | 55.3              | 55.50               |
|                   |               | 55.8              | 55.7              | 55.8              | 55.77               |

The hardness of the loading platen is tested at two different times for the same test system. As can be seen from the test results, the hardness value of the pressure plate is relatively stable. And the hardness...
value is greater than 55HRC, it can meet the requirements of its wear resistance and compression resistance.

3.2. Force Measuring Device Test

The force measuring device is the main structure of the test system. Its main parameters include relative error of indication value, relative error of indication repeatability, relative error of zero-point, relative resolution and zero drift. The test system in the survey industry is basically level 1 according to the level requirements of the test machine. Therefore, the technical index of the level 1 in JJG 139-2014 “Tension, Compression and Universal Testing Machines” is used as the technical index requirement of the force measuring device. Specific requirements are as follows: the relative resolution should be no more than 0.5%; the zero drift is within ±1.0%; the relative error of the indication is within ±1.0%; the relative error of indication repeatability is not more than 1.0%; the relative error of zero is within ±0.1%.

The test of various errors of the force measuring device adopts the test method of the universal testing machine. The method has been specified in the relevant national verification regulations of the test, and which is mature and stable. Factory inspection survey of domestic manufacturers also uses this method to force measuring device test system for testing.

In the test verification stage, according to the specified test procedure, the relative resolution of the test force of the force measuring device, the zero drift, the relative error of the test force, the relative error of the indication repeatability, and the relative error of the zero point are tested. The schematic diagram of the standard dynamometer installation is shown in figure 4, and the test diagram of the test force is shown in figure 5.

3.2.1. Test Force Relative Resolution Test. At present, the test systems used in the industry all use digital indicating devices. The method for determining the resolution of the digital pointing device is: Start the force measuring device, in the case of zero load, if the change of the indication value is not more than 1 increment, the resolution \( r \) is one increment; If the variation of the indication value is greater than one increment, the resolution \( r \) is half of the variation range plus one increment. During the test, all sensors do not change more than one increment. The lower limit of the test force measurement range is based on the provisions of JJG 139-2014 Tension, Compression and Universal Testing Machines, calculated according to 200 times the resolution. The relative resolution test data and calculation of the test force are shown in...
Table 2. Relative resolution of test force.

| Sensor number of the force measuring device | Maximum value of test force measurement range (kN) | An increment value (kN) | Resolution (kN) | Minimum value of test force measurement range (kN) | Relative resolution |
|-----------------------------------------------|-----------------------------------------------|------------------------|----------------|-----------------------------------------------|-------------------|
| SSFT-400 (01)                                | 50                                           | 0.001                  | 0.001          | 0.2                                           | 0.50%             |
| SSFT-400 (02)                                | 50                                           | 0.001                  | 0.001          | 0.2                                           | 0.50%             |
| SSFT-400 (03)                                | 100                                          | 0.001                  | 0.001          | 0.2                                           | 0.50%             |
| SSFT-400 (04)                                | 100                                          | 0.001                  | 0.001          | 0.2                                           | 0.50%             |
| SSFT-400 (05)                                | 200                                          | 0.001                  | 0.001          | 0.2                                           | 0.50%             |
| SSFT-400 (06)                                | 200                                          | 0.001                  | 0.001          | 0.2                                           | 0.50%             |

3.2.2. Zero Drift. Preheat the test system to make it in good working condition, and adjusts the force value, show 0, and observe the maximum drift value of force value within 15 min. The test data and calculation of the zero-drift value of the test force are shown in table 3.

Table 3. Zero-drift of test force.

| Sensor number of the force measuring device | Maximum value of test force measurement range (kN) | Zero indication value (kN) | Zero point drift | Minimum value of test force measurement range (kN) | Zero drift |
|-----------------------------------------------|-----------------------------------------------|------------------------|----------------|-----------------------------------------------|------------|
| SSFT-400 (01)                                | 50                                           | 0.000                  | 0.2            | 0.2                                           | 0          |
| SSFT-400 (02)                                | 50                                           | 0.000                  | 0.2            | 0.2                                           | 0          |
| SSFT-400 (03)                                | 100                                          | 0.000                  | 0.2            | 0.2                                           | 0          |
| SSFT-400 (04)                                | 100                                          | 0.000                  | 0.2            | 0.2                                           | 0          |
| SSFT-400 (05)                                | 200                                          | 0.001                  | 0.2            | 0.2                                           | 0.50%      |
| SSFT-400 (06)                                | 200                                          | 0.001                  | 0.2            | 0.2                                           | 0.50%      |
3.2.3. Indication Error and Repeatability Error. Connect the standard dynamometer to the force measuring device and apply the maximum test force 3 times. The test points of the force measuring device are determined to be 40 kN, 80 kN, 120 kN, 160 kN, and 200 kN. After zeroing the force measuring device and the standard dynamometer, the test is performed point by point in increasing order of test force until the maximum test force. Then unload until the test force is completely removed, read the zero-point value after about 30 seconds. The indication error test data and calculation are shown in table 4.

3.2.4. Zero Value Relative Error. Three groups of measurements are carried out with increasing force. Each group should be adjusted to zero-point before measurement. The zero-point reading should be measured in the last group. The force is completely removed after 30 s, and the zero relative error test data are shown in table 5.

| Device name | Maximum range of test force measurements (kN) | Residual indication of the measuring device after unloading (kN) | Minimum range of test force measurements (kN) | Zero relative error |
|-------------|-----------------------------------------------|---------------------------------------------------------------|-----------------------------------------------|---------------------|
| SSFT-400 (05) | 200                                           | 0                                                             | 0.2                                           | 0                   |
| SSFT-400 (06) | 200                                           | 0                                                             | 0.2                                           | 0                   |

Through several main parameters of the force measuring device, indication relative error, indication repeatability relative error, zero relative error, relative resolution and zero drift measurement results, can see that the results basically meet the requirements; the accuracy of the test system force measuring device is good[9].
| Standard value 1 (kN) | Indication error 1 (%) | Measured value 2 (kN) | Standard value 2 (kN) | Indication error 2 (%) | Measured value 3 (kN) | Standard value 3 (kN) | Indication error 3 (%) |
|-----------------------|------------------------|-----------------------|-----------------------|------------------------|-----------------------|-----------------------|------------------------|
|                       |                        |                       |                       |                        |                       |                       |                        |
| 200.52                | 0.04                   | 156.71                | -0.22                 | -0.28                  | 119.16                | 119.53                | 80.88                  |
|                       |                        |                       |                       |                        |                       |                       |                       |
| 196.84                | -0.42                  | 157.58                | 0.21                  | -0.3                   | 119.86                | 119.54                | 40.106                 |
|                       |                        |                       |                       |                        |                       |                       |                       |
| 197.69                | -0.04                  | 157.22                | -0.03                 | 0.3                    | 119.54                | 119.16                | 40.23                  |
|                       |                        |                       |                       |                        |                       |                       |                       |
| 200.57                | 0.11                   | 159.94                | 0.12                  | -0.12                  | 119.47                | 119.32                | 40.106                 |
|                       |                        |                       |                       |                        |                       |                       |                       |
| 201.98                | -0.7                   | 160.13                | 0.23                  | 0.23                   | 119.192               | 119.32                | 40.23                  |
|                       |                        |                       |                       |                        |                       |                       |                       |
| 200.89                | 0.22                   | 159.94                | 0.27                  | -0.27                  | 119.47                | 119.32                | 40.106                 |
|                       |                        |                       |                       |                        |                       |                       |                       |
| 201.46                | -0.36                  | 160.13                | -0.31                 | -0.31                  | 119.192               | 119.32                | 40.23                  |
|                       |                        |                       |                       |                        |                       |                       |                       |
| 198.09                | 0.33                   | 159.94                | 0.07                  | 0.07                   | 119.47                | 119.32                | 40.106                 |
|                       |                        |                       |                       |                        |                       |                       |                       |
| 200.50                | 0.74                   | 156.71                | 0.04                  | 0.04                   | 119.16                | 119.53                | 80.88                  |

4. Establishment of Traceability System

4.1. Evaluation of Uncertainty

4.1.1. Measurement Methods. Calculate the average value of the force of the standard dynamometer
calibration test system and the output force of the test system, the difference between the average value and the standard value output by the standard dynamometer is taken as the indication error of the measurement results. Take 20% of the measurement points as an example to evaluate the uncertainty.

4.1.2. Measurement Model

\[ \delta_i = \frac{f_i - F_i}{F_i} \]

In the equation:
\( \delta_i \) — Relative error of indication value of the i-th test of test force;
\( f_i \) — The force value of the i-th test of the standard dynamometer, in kN;
\( F_i \) — The force value of the i-th test of the force measuring device, in kN.

4.1.3. Evaluation of Standard Uncertainty. A summary of the source of measurement uncertainty analysis is shown in table 6.

**Table 6. Uncertainty component summary.**

| Serial number | Source of uncertainty | Category | Distributed |
|---------------|-----------------------|----------|-------------|
| 1             | Uncertainty introduced by the repeatability of the test system | A        | /           |
| 2             | Standard uncertainty introduced by standard dynamometer | B        | Normal      |
| 3             | Uncertainty introduced by the resolution of the test system display device | B        | Evenly      |

(1) The measurement uncertainty component introduced by the test system measurement repeatability is \( u_1 \).

At 40 kN, the process values of the test system are 40.082, 40.026, 40.078, respectively, and the repeatability relative error is \( b = (F_{\text{max}} - F_{\text{min}}) / F = (40.082 - 40.026) / 40 = 0.14\% \). According to JJF1059.1-2012 "Evaluation and Expression Uncertainty in Measurement", \( C = 1.69 \) is found when the range measurement method is used for 3 measurements. Then there is \( u_1 = \frac{b}{c} = \frac{0.14\%}{1.69} = 0.085\% \).

(2) The uncertainty introduced by the standard dynamometer is \( u_2 \).

According to the calibration certificate of the standard dynamometer, the extended uncertainty is \( u_{SP} = 0.3\% \), \( k=2 \), and the uncertainty introduced by the standard dynamometer is: \( u_2 = 0.3\%/2 = 0.15\% \).

(3) The uncertainty component introduced by the resolution of the display system of the test system is \( u_3 \).

The resolution of the test system is 0.001 kN, half of its width, estimated to be evenly distributed, and the relative standard uncertainty introduced is: \( u_3 = \frac{\Delta}{2\sqrt{3}} / 40 = \frac{0.001}{2\sqrt{3}} / 40 = 0.0007\% \).

4.1.4. Evaluation of Synthetic Uncertainty. Comparing the uncertainty component introduced by the
resolution of the test system display device with the measurement uncertainty component introduced by the test system repeatability, whichever is bigger. Therefore, the uncertainty component $u_3$ introduced by the resolution of the display device of the tested system is not counted.

Because the measurement uncertainty component introduced by the test system measurement repeatability is not related to the two components of the standard uncertainty component introduced by the standard dynamometer, the sensitivity coefficients are 1 and -1, and the synthesis uncertainty is:

$$u = \sqrt{u_1^2 + u_2^2} = \sqrt{0.085\%^2 + 0.15\%^2} = 0.17\%.$$  

4.1.5. **Extended Uncertainty Assessment.** Taking $k=2$, the extended uncertainty is:

$$U = u \times k = 0.17\% \times 2 = 0.34\%. $$

4.2. **Establish Metrological Traceability Diagram**

In the process of repeating the test of the force measuring device, the value of the standard force measuring device is taken as the reference value (standard value) of the force value, and the measured value of the force value of the force measuring device to be verified is compared with the reference value (standard value) to achieve traceability of the measurement. The standard dynamometer is the main standard in measurement. The measurement traceability of the force value is shown in figure 6.

![Metrological traceability diagram](image)

**Figure 6.** Metrological traceability diagram.

In the figure, the test system belong to the working measuring instrument should be compared with the
standard dynamometer of the measuring standard, and finally traced to the national force value measurement standard.

5. Conclusions
(1) The measurement technical parameters of the test system are relatively complete and sufficient, which can ensure the assessment of various measurement performances such as accuracy. After calibration, the accuracy and reliability of test results can be guaranteed.
(2) Through the various tests on the calibrated test system, it is verified that the calibration method is rigorous and reliable, and it has strong operability.
(3) The traceability source path of the highway bridge expansion and contraction installation-highway bridge expansion and contraction installation test system standard dynamometer-national force measurement standard is in line with the actual implementation of the measurement system measurement work, and can solve the problem of traceability of the value of such equipment. The guarantee system for measuring the accuracy of the test system described in the paper is effective.

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