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Research on static force calibration technology of fatigue test system

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Abstract. The fatigue test system is the main equipment to test the fatigue load performance of anchorage, but for a long time, due to the lack of calibration basis and the lack of effective traceability way, it is unable to calibrate the equipment. This paper analyzes the structure and working principle of the fatigue test system, and determines its measurement technical indicators and requirements through investigation and test verification. The calibration method of static force value is studied and verified by experiments. The uncertainty of static force calibration results is evaluated, and the static force calibration technology of fatigue test system with uncertainty better than 0.50% is formed, which lays a good foundation for the calibration of this kind of equipment.

1 Introduction

In recent years, the prestressed technology has developed rapidly in China, especially in highway bridges. Anchorage is a permanent anchorage device used in post-tension structure or structural parts to maintain the tension of steel strand and transfer it to concrete structure or structural component. As an important component of bridge structure, product quality and mechanical performance are directly related to the safety and performance of bridge structure. Therefore, the performance of anchorage is becoming more and more important, and the quality of its test results has attracted more attention in the industry.

JT / T 329-2010 'Anchorages, clamps and connectors for prestressed steel strands of highway bridges' and GB / T 14370-2015 'Anchorages, clamps and connectors for prestressed reinforcing steel' both put forward clear requirements for fatigue load performance of anchorages. The fatigue test system adopts the excitation mode of hydraulic pulse, configures the appropriate control system, applies the axial cyclic force to the anchorage according to the specified frequency[1], and measures its fatigue load performance.

Fatigue test system, as the main equipment to test the fatigue load performance of anchorage, is used to evaluate the quality and working performance of anchorage, but its own accuracy has not been effectively guaranteed for a long time. This paper studies the measurement traceability technology of fatigue test system, analyzes its structure, defines its calibration technical indicators and requirements, forms the static force value calibration method, carries out relevant test verification, and analyzes the uncertainty. The accuracy of the static force calibration technology studied in this paper reaches 0.50%.

2 Determination of measurement technical indicators

The fatigue test system is composed of frame (including guide beam and loading moving beam), hydraulic device (including oil pump and exhaust device), control device (including data acquisition and display device), force measuring device, displacement measuring device, auxiliary test device (anchor plate), safety protection and protection device[2]. Its structural diagram is shown in Figure 1. The fatigue test system adopts the hydraulic pulse excitation mode, and applies the axial cyclic force to the anchorage according to the set frequency.

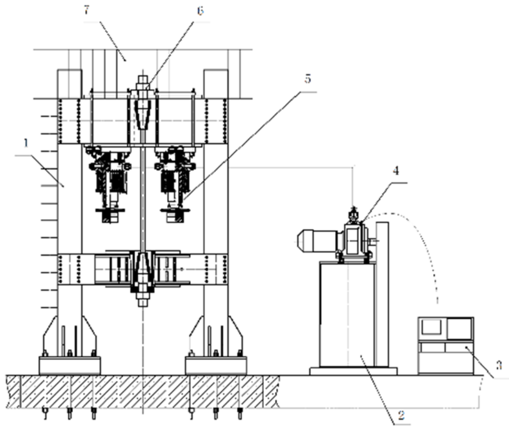

Fig. 1 Structure diagram of fatigue system.1-supporting structure; 2-hydraulic device; 3-control device; 4-measuringforce device; 5-displacement measurement devices; 6-auxiliary device; 7-safety protection and protective devices

The fatigue test system is mainly composed of steel supporting parts, and the outer surface is coated. There is no large area corrosion, obvious roughness and other

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damage affecting function. The force measuring device is the core part of the fatigue test system to measure the mechanical properties of the anchorage, including data acquisition and display functions, which can display and record the test load and force speed in real time, accurately display the force value in real time, and should be able to save the force value. At the same time, for the display function of data acquisition and display device, it is also required that "the data and graphics should be clear and easy to read. In the process of applying force, the indication of test force should be stable, without impact and jumping phenomenon."

The general functional requirements of force measuring device refer to GB / T 16826-2008 'electro hydraulic servo universal testing machine', mainly from the basic functions, including the way of force measurement, whether it has the function of force speed indication, zero adjustment and clearing, real-time indication and recording of test force. At the same time, it is also required that the indication should be normal in the process of applying force, which does not affect the test.

Investigate the fatigue test system in the transportation industry. According to the level requirements of the testing machine, it is basically level 1. Refer to the level 1 technical index in JJG 139-2014 'verification regulation of tension, pressure and universal testing machine', as the technical index requirements of the force measuring device. The relative resolution of the test force of the force measuring device shall not be greater than 0.5%, the zero drift shall be ± 1, and the maximum allowable errors of the test force shall comply with the provisions in Table. 1.

Table. 1 Maximum allowable errors of test force

Relative error of indication	Relative error of indication repeatability	Relative error of zero point
±1.0%	1.0%	±0.1%

3 Study on the calibration method

3.1 Calibration of relative resolution of test power

At present, all fatigue test systems adopt digital indicating device. The determination method of resolution of digital indicating device is[3]: start the force measuring device. Under zero load condition, if the change of indication value is not more than one increment, the resolution (r) is an increment; if the change of indication value is more than one increment, the resolution (r) is half of the change range plus one increment. The lower limit of the measurement range of the test force is calculated according to JJG 139-2014 'verification regulation of tension, pressure and universal testing machine', which is 200 times of the resolution. Start the test system, read the resolution (r) of the test power, and calculate the relative resolution according to (1).

$$a = \frac{r}{F_{\mathrm{L}}} \times 100\% \quad (1)$$

In the formula above:

a ---The relative resolution of the test power;

r ---The resolution of experimental power, kN;

F_L---The lower limit of measurement range of test force is determined according to JJG 139. The lower limit of measurement range of level 1 test system is 200 × r, kN.

During the test, the variation values of all sensors of the force measuring device are not more than one increment. The relative resolution test data and calculation of the test power are shown in Table. 2.

Table. 2 Relative resolution of test power

Sensor number of force measuring device	PMW-2000(01)	PMW-2000(02)
Maximum value of test force measurement range(kN)	1000	1000
An incremental value (kN)	0.001	0.001
Resolution(kN)	0.001	0.001
Lower limit of measurement range of test force(kN)	0.2	0.2
Relative resolution $a = \frac{r}{F_L} \times 100\%$	0.50%	0.50%

3.2 Calibration of maximum allowable errors of test force

Refer to ISO 7500-1 'Metallic materials-Calibration and verification of static uniaxial testing machines-Part1: tension/compression testing machines-Calibration and verification of the force-measuring system'. The test steps for determining the maximum allowable errors of the test force are as follows[4]: (a) Connect with the standard dynamometer and apply the maximum load 3 times; (b) Starting from 20% of the maximum test load, five test points should be selected and evenly distributed; (c) After the force measuring device and standard force measuring instrument are adjusted to zero, the test shall be carried out point by point according to the increasing order of test force, and unloading shall be started after reaching the maximum test load until the test force is completely removed; (d) Repeat steps a and b three times, the relative errors of indication and repeatability of test force at five test points were calculated; (e) Read the indication F_i of the force measuring device and the indication f_i of the standard force measuring instrument respectively, calculate the relative error of single indication of test force according to (2);

$$\delta_i = \frac{f_i - F_i}{F_i} \times 100\% \quad (2)$$

In the formula above:

δ_i---Relative error of indication value in the i-test of test force, i=1, 2, 3;

F_i---Force value of the i-test of standard dynamometer, kN;

F_i---Force value of the i-test of the force measuring device, kN.

(f)The arithmetic mean value of the relative error of the single indication of the three test forces is taken as the relative error of the indication of the test force at the test point; (g)The maximum value of relative error of single indication of three test forces at the same test point is δ_{max}, and the minimum value is δ_{min}. Calculate the relative error of indication repeatability according to (3);

$$b = \delta_{max} - \delta_{min} \tag{3}$$

In the formula above:

b ---Relative error of repeatability of test force indication;

δ_{max}---The maximum value of relative error of three test force indication at the same test point;

δ_{min}---Minimum value of relative error of three test force indication at the same test point.

(h)After the test force is completely removed for 30s, read the zero value, calculate the single zero relative error F_{io} according to (4), and take the arithmetic mean value of three times as the zero relative error of the test force.

$$z_r = \frac{F_{io}}{F_L} \times 100\% \tag{4}$$

In the formula above:

z_r ---Single zero relative error of test force;

F_{io} ---After the test force is removed, the residual indication of the i-th test of the force measuring device, kN.

Connect the standard dynamometer with the force measuring device and apply the maximum test force three times. The test points of force measuring device are 200kn, 400kN, 600kN, 800KN and 1000KN.After the force measuring device and standard force measuring instrument are adjusted to zero, the test is carried out point by point according to the increasing order of test force until the maximum test force. Then unload until the test force is completely removed, and read the zero value after about 30s. The test force collection is shown in Figure. 2.

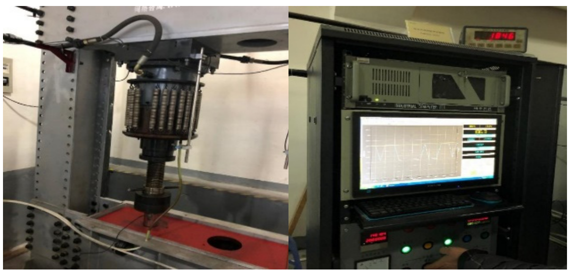

Fig. 2 Test force collection diagram

3.3 Calibration of zero drift

Preheat the fatigue test system to make it in good working condition, adjust the force value and display it as 0, and observe the maximum drift value of the force value within 15 minutes. The calibration diagram of the zero drift value of the test force is shown in Figure 3.

Figure. 3 Zero drift calibration test diagram

4 Evaluation of uncertainty

Measurement uncertainty is a parameter associated with the measurement results[5], which is used to characterize the dispersion of the measured value reasonably given. It represents the degree of doubt or uncertainty about the credibility and effectiveness of the measurement results, and is a parameter that quantitatively describes the quality of the measurement results. The purpose of measurement is to determine the measured value. The quality of measurement results is the most important basis to measure the reliability of measurement results. Measurement uncertainty is the quantitative characterization of the quality of measurement results, and the usability of measurement results largely depends on its uncertainty. Therefore, the expression of measurement results must include both the measurement uncertainty given to the measured value and the measurement uncertainty related to the value, which is complete and meaningful.

The force value of the fatigue test system is calibrated with the 0.3 level standard dynamometer[6]. The difference between the average output force value of the fatigue test system and the standard output value of the standard dynamometer is taken as the indication error of the measurement result. Taking 20% of the measurement points as an example, the uncertainty was evaluated. See formula (5) for the measurement model of uncertainty evaluation.

$$\delta_i = \frac{f_i - F_i}{F_i} \tag{5}$$

In the formula above:

δ_i ---Relative error of indication in the i-test of test force;

F_i---The force value of the i-th test of the standard dynamometer（kN）;

F_i---Force value of the i-th test of the force measuring device（kN）.

4.1 Evaluation of standard uncertainty

The sources of measurement uncertainty are: (1) the uncertainty component introduced by the repeatability of the indication of the calibrated fatigue test system; (2) the standard uncertainty component introduced by the standard dynamometer; (3) the uncertainty component introduced by the resolution of the display device of the calibrated fatigue test system.

(1) The component of measurement uncertainty introduced by measurement repeatability of fatigue test system is u_1

When the load is 40kN, the process indication values of the fatigue test system are 200.4, 200.7 and 200.8, respectively, and the relative repeatability error is $b = (F_{max} - F_{min})/F = (200.8 - 200.4)/200 = 0.2\%$. According to JJF 1059.1-2012 'evaluation and expression of uncertainty in measurement', the time of three times of measurement by range method is found, *C*=1.69.

There are $u_1 = \frac{b}{C} = \frac{0.2\%}{1.69} = 0.12\%$

(2) Uncertainty introduced by standard dynamometer is u_2

According to the calibration certificate of the standard dynamometer, the expanded uncertainty is $u_{rb} = 0.3\%$, k = 2, and the uncertainty introduced by the standard dynamometer is:

$$u_2 = 0.3\% \div 2 = 0.15\%$$

(3) Uncertainty component u_3 introduced by the resolution of the display device of the calibrated fatigue test system

The resolution of the fatigue test system is 0.001 kn. The half width of the system is estimated to be uniform distribution, and the relative standard uncertainty introduced by the system is:

$$u_3 = \frac{\Delta}{2\sqrt{3}}/200 = \frac{0.001}{2\sqrt{3}}/200 = 0.0014\%$$

4.2 Evaluation of combined uncertainty

The uncertainty component introduced by the resolution of the display device of the calibrated fatigue test system is compared with the measurement uncertainty component introduced by the measurement repeatability of the fatigue test system, and the larger one is taken. Therefore, the uncertainty component u_3 introduced by the resolution of the display device of the calibrated fatigue test system is not included.

Because the measurement uncertainty component introduced by the measurement repeatability of the fatigue test system is uncorrelated with the standard uncertainty component introduced by the standard dynamometer, the sensitivity coefficient is 1 and - 1, and the combined uncertainty is:

$$u = \sqrt{{u_1}^2 + {u_2}^2} = \sqrt{0.12\%^2 + 0.15\%^2} = 0.19\%$$

4.3 Evaluation of expanded uncertainty

If *k* = 2, the expanded uncertainty is:

$$U = u \times k = 0.19\% \times 2 = 0.38\%$$

4.4 Measurement uncertainty report

The uncertainty of indication error of fatigue test system at the measuring point (200kn) is as follows:

$$U_r = 0.50\%, k=2$$

5 Conclusion

(1) The technical indexes of static force measurement of fatigue test system are determined, including relative resolution of test force, zero drift, relative error of indication of test force, relative error of repeatability of indication of test force and relative error of zero point of test force.

(2) The static force value calibration method of fatigue test system is formed by using 0.3 level standard dynamometer, which can carry out the calibration work for this kind of equipment.

(3) According to the uncertainty analysis and evaluation of the force calibration results, the traceability chain of the fatigue test system was established, and the accuracy of the static force calibration technology reached 0.50%.

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