Research and Application of Dynamic Torque Calibration for Torque Test Bench of Electric Actuator in Nuclear Power Plant

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Abstract. In view of the current status of electric actuator torque test benches commonly used in domestic nuclear power plants to test the output torque of electric actuators, according to the requirements of the value traceability chain, the actual working state of the test bench is the factor that determines the accuracy of electric actuator torque. In order to accurately judge the actual working condition error of the torque test bench of the electric actuator of the nuclear power plant, this paper introduces an overall dynamic calibration method and device design scheme of the torque test bench of the electric actuator of the nuclear power plant. The device reproduces the actual working conditions during the calibration process, obtains the overall indication error of the test bench, and can also evaluate and judge the mechanical cooperation and functional status of the test bench to ensure that the comprehensive performance of the test bench can meet the actual work needs.

1. Introduction

The electric valve uses electrical energy as power to connect the opening of the electric actuator to drive the valve, and realize the switching and adjustment of the valve (including flow, pressure, temperature, liquid level and other media parameters and environmental conditions) to control the entire production process. Due to the advantages of simple structure, long service life, wide application range, high temperature resistance, chemical corrosion resistance, and low explosion-proof costs, electric valves are widely used in many industrial fields at this stage. Similarly, a large number of electric valves are installed in nuclear power plants Valves are used to control the state of media in various pipelines.

From the structural point of view, the electric valve itself can be divided into two parts, the upper half is the electric actuator, and the lower half is the valve. Among them, the electric actuator is the central control unit of the electric valve, and the automatic control device that can remotely control the valve is an indispensable important link in the industrial control system. It can be seen that the electric actuator directly affects the working performance of the electric valve. Most of the electric actuators used at this stage are intelligent electric actuators, which can adjust the opening and closing of the valve according to the set torque value. The output torque setting of the electric actuator is to ensure that the valve is properly opened and closed. Torque, that’s to ensure the tightness of the switch of the valve, to ensure that the valve can be normally controlled without excessive damage to the valve.
Therefore, the action torque of the electric actuator has been used as an important technical indicator for daily inspection and verification.

At present, most domestic nuclear power plants use electric actuator torque test benches (hereinafter referred to as test benches) to detect the torque of various electric actuators to open and close valves on site. The test bench uses machinery such as tendon sheaths, couplings, flanges, etc. The structure installs the electric actuator and the torque sensor in series. The torque sensor detects the output torque value of the electric actuator and evaluates whether the performance parameter of the electric actuator can meet the set requirements. In order to ensure the on-off state of the on-site electric valve, according to the value traceability chain, the torque parameters of the test bench need to trace the value to the more advanced measuring instruments, so as to be able to judge its accuracy and reliability.

2. Dynamic torque traceability scheme

Due to the large size and weight of the electric actuator torque test bench itself, it’s not easy to carry, but it’s necessary to disassemble its internal torque sensor separately, and send it to the measurement technical agency for calibration of the static torque value. After completion, reinstall it back into the test bench. There are many drawbacks to the static calibration method of the torque sensor. First of all, static calibration can only be read through an independent calibration module in the supporting software of the test bench, which fails to truly reflect the torque value measured by the test bench under actual dynamic conditions. Secondly, static can only get the error of the display value of the sensor itself, and cannot evaluate the error caused by the internal mechanical cooperation of the test bench. The data obtained by the calibration cannot accurately reflect the overall accuracy of the test bench. Finally, repeated disassembly and assembly multiple times increase the risk of damage to internal components and reduce the service life of the equipment.

The accuracy level of the torque test stand for electric actuators is 1.0. The original method was to calibrate the torque sensor of the test stand separately using the 0.03 level torque standard device. According to the technical requirements of the torque standard machine in the JJG924-2010 "Torque and Speed Measurement Device Verification Regulations", a torque standard device with a level of not less than 0.3 should be selected to implement the value traceability. JJG 2047-2006 "Torque Measuring Apparatus Verification System Table" 0.03 torque standard device is already the highest level in the measurement standard, there are also 0.05, 0.1 and 0.3 levels below, referring to the conventional measurement standard and working measurement instruments. The selection principle of the accuracy level of the general measurement standard is 1/3 to 1/10 of the working measurement instrument. It can be seen that the original traceability of the 0.03 level torque standard device is unnecessary. The 0.3 level torque standard device is more reasonable.

The original value traceability chain is shown in Figure 1.

![Figure 1](image-url)
In order to eliminate the technical blind spot in the static calibration torque sensor, obtain the measurement data of the electric actuator torque test bench under actual working conditions, develop a set of targeted dynamic torque standard devices, and the accuracy level reaches 0.1 to level 0.3, it is used for the overall calibration of electric actuator torque test bench. In the value traceability chain, the dynamic torque calibration device is set between the 0.03 level torque standard device and the 1.0 level electric actuator torque test bench, which plays a role in inheriting and inspiring, making the traceability chain more reasonable, economical and accurate.

The adjusted value traceability chain is shown in Figure 2.

**Figure 2 Adjusted value traceability chain**

3. **Design of dynamic torque calibration scheme**

3.1. **Calibration implementation**

Using the coupling and the flange of the protective sleeve, the dynamic torque standard device is installed in series between the electric actuator and the test bench. In the unstressed state, the forward and reverse full scale and zero frequency values given by the upper-level measuring mechanism perform zero point calibration on the standard device, and clear the indication value of the test bench. By turning the hand wheel of the electric actuator, the standard device and the test bench are rotated together, and the torque values output by the software systems of the two are observed respectively to ensure that the difference displayed by the two is close to or equal to 0 Nm. When large, you need to check the mechanical installation and software settings one by one to ensure that no additional torque values are generated between the components.

The DC current source is used as an external load to connect with the test bench to ensure that the output value of the current source is adjusted step by step from small to large, and the magnetic powder brake in the test bench is activated. After the output of the current source is stable, turn the electric actuator and drive the dynamic torque standard device and the test bench. At the same time, start the control system of both to collect the output real-time torque data and record on the respective software interface (5~10) S dynamic torque value curve.

3.2. **Calculation method of indication error**

The measurement range of torque should generally start at 20% of the rated torque to the upper limit of measurement. The measurement points are generally not less than 5 points, and should be evenly distributed within the measurement range. A DC current source provides an external load for the magnetic powder brake in the test stand. First measure one direction (such as clockwise), adjust the
load current value, and apply it to the upper limit of the measurement step by step according to the selected measurement point, and finally unload the load.

For each calibration point, the applied load is a stable current value, so in theory the output value of the measurement system should also be a constant value. However, because the output is a dynamic torque value, the actual recorded curve still has certain fluctuations. In order to obtain a more accurate torque value and ensure the synchronization of the data, the simultaneous output points of the two sets of system output curves are randomly selected. Calculate the average value of the 3 to 5 measured values, and calculate the average value of the two output torque values according to formula (1) to obtain the indication error of the test bench. After measuring the torque in one direction, continue to measure the other direction. The measurement method and calculation are the same as above.

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W_T = \left( \frac{T_f - T_0}{T_h} \right) \times 100\%
\]

In formula (1): \(W_T\): Torque measurement error; \(T_f\): The average value of the torque value measured by the test bench; \(T_0\): Torque value after the test bench is cleared; \(T_h\): The average value of torque value measured by standard torque calibration device; \(T_h\): Rated torque value of test bench.

4. Application and verification

The dynamic torque standard device developed this time was calibrated by a higher-level measuring mechanism using a 0.03 level torque standard device. The calibration data shows that the maximum indication error of the device is within ±0.2%, according to JJG924-2010 "Torque Speed Measuring Device". The standard for determining the accuracy level of the torque measuring device in the Verification Regulations, the dynamic torque standard device meets the requirements of level 0.2, and also meets the requirements for the traceability of the value to the torque test bench of the electric actuator. The indication error of the traceability of the dynamic torque standard device is listed in Table 1.

| Measuring range (Nm) | Calibration point (Nm) | 20  | 40  | 60  | 80  | 100 |
|----------------------|------------------------|-----|-----|-----|-----|-----|
| (20~100)             | Indication error (%)   | Clockwise: +0.02 +0.02 +0.04 +0.05 +0.05 | Counterclockwise: -0.02 -0.03 -0.04 -0.04 -0.05 |
| (50~300)             | Calibr. point (Nm)     | 50  | 100 | 150 | 200 | 300 |
| (200~1000)           | Indication error (%)   | Clockwise: +0.04 +0.07 +0.07 +0.10 +0.14 | Counterclockwise: -0.04 -0.04 +0.04 +0.04 +0.04 |
| (500~3500)           | Calibr. point (Nm)     | 200 | 400 | 600 | 800 | 1000 |
|                     | Indication error (%)   | Clockwise: +0.02 +0.03 +0.05 +0.06 +0.08 | Counterclockwise: +0.01 -0.02 -0.05 -0.10 -0.13 |

In order to further verify the usability of the dynamic torque standard device and the accuracy of the dynamic torque data calibration, the dynamic torque standard device is used to calibrate the electric actuator torque test bench under actual working conditions. According to the established calibration method and calculation method, the overall indication error of the test bench is measured, and compared with the static torque data of the torque sensor that is disassembled separately from the
test bench and sent to the higher-level measurement mechanism to use the 0.03 level torque standard device. It can be seen from Table 2 that static torque can be measured at a fixed calibration point according to the established rules, while dynamic torque can only be selected at a non-fixed calibration point under external load and rotation status. Although the two calibration methods are different, the In contrast, the two data have good consistency. At the same time, in accordance with the provisions of JJF1059.1-2012 "Measurement Uncertainty Evaluation and Expression", the measurement uncertainty of the dynamic torque calibration process is evaluated, and the final calculated expanded uncertainty is 0.25%, which also satisfies the level 1.0 Calibration requirements for electric actuator torque test bench. The comparison between the overall calibration data of the test bench and the calibration data of the torque sensor is listed in Table 2.

Table 2 Comparison of the overall calibration data of the test bench and the calibration data of the torque sensor

| Measuring range (20~100) Nm | Calibration point /Nm | 20   | 40   | 60   | 80   | 100  |
|-----------------------------|------------------------|------|------|------|------|------|
| 0.03 level torque standard device | Indication error (%) | Clockwise | +0.23 | +0.43 | +0.43 | +0.53 | +0.03 |
|                             |                        | Counterclockwise | +0.23 | +0.36 | +0.43 | +0.53 | -0.50 |
| 0.2 level dynamic torque standard device | Calibration point /Nm | Clockwise | 20.54 | 40.43 | 65.21 | 85.66 | 99.60 |
|                             |                        | Indication error (%) | +0.35 | +0.50 | +0.52 | +0.68 | +0.10 |
|                             |                        | Counterclockwise | 21.40 | 44.40 | 65.95 | 84.43 | 98.17 |
|                             |                        | Indication error (%) | +0.24 | +0.26 | +0.44 | +0.65 | -0.67 |
| Measuring range (50~300) Nm | Calibration point /Nm | 50   | 100  | 150  | 200  | 300  |
| 0.03 level torque standard device | Indication error (%) | Clockwise | +0.20 | +0.33 | +0.41 | +0.49 | -0.36 |
|                             |                        | Counterclockwise | -0.53 | -0.46 | -0.41 | -0.35 | -0.32 |
| 0.2 level dynamic torque standard device | Calibration point /Nm | Clockwise | 58.61 | 117.32 | 182.17 | 251.02 | 291.76 |
|                             |                        | Indication error (%) | +0.32 | +0.40 | +0.43 | +0.35 | -0.28 |
|                             |                        | Counterclockwise | 56.45 | 115.66 | 175.11 | 239.94 | 295.41 |
|                             |                        | Indication error (%) | -0.45 | -0.52 | -0.21 | -0.32 | -0.52 |
| Measuring range (100~1000) Nm | Calibration point /Nm | 200  | 400  | 600  | 800  | 1000 |
| 0.03 level torque standard device | Indication error (%) | Clockwise | +0.17 | +0.29 | +0.36 | +0.49 | -0.22 |
|                             |                        | Counterclockwise | -0.27 | -0.19 | -0.15 | -0.10 | -0.37 |
| 0.2 level dynamic torque standard device | Calibration point /Nm | Clockwise | 188.27 | 381.47 | 586.67 | 751.57 | 966.10 |
|                             |                        | Indication error (%) | +0.20 | +0.38 | +0.23 | +0.46 | -0.18 |
|                             |                        | Counterclockwise | 244.97 | 462.20 | 606.73 | 819.70 | 980.33 |
### 5. Conclusion

The dynamic torque calibration scheme further improves the value traceability chain of the electric actuator torque test bench and fills in the missing links in the value traceability chain. This solution reduces the risk of damage caused by repeated disassembly and installation of the test bench. And reduce the cost of manpower, material resources and time in the calibration process. The developed dynamic torque standard device combines the actual needs of the test bench calibration, relying on the series structure of the coupling, equipped with a power source and external load, to achieve the overall calibration of the test bench output dynamic torque, thereby ensuring the nuclear power plant electric valve in a normal state. At the same time, the dynamic torque device has been used to diagnose the actual state of the test bench and the cause of the failure, providing a clear indication of the mechanical coordination and component status that are not visible inside the test bench. Since the device has good mobility and can be calibrated off-site, with the rapid development of my country's nuclear power industry and the gradual increase in the number of operating nuclear power plants, the application of the device has broad market prospects.

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