Research on Small Size Thread Torque Coefficient with Assembly Pressure

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Abstract. Threaded connection is one of the most commonly used methods in product assembly. The stability of the joint quality has a great impact on the performance of the product. At present, research on threaded connection rarely considers the influence of assembly pressure. This paper proposes a method about small size thread torque coefficient test that takes into account the assembly pressure. The small size threaded connection test device was developed by our lab. The law of dynamic torque coefficient under different assembly pressures can be got to guide the quantitative control of small-size thread pre-tightening force.

1. Introduction

The threaded connection is one of the most widely used connection methods. It can make the connected piece obtain a large connecting force at low cost, and is easy to assemble and disassemble. When the threaded connection fails, the entire product is damaged, not just the threaded fastener itself. Taking the screw as an example, the pre-tightening force of the screw refers to the force generated in the direction of the screw axis between the screw and the connected member under the tightening torque. If the pre-tightening force is too high, the threaded connection causes stress concentration and plastic deformation of the connected part, thereby affecting the accuracy of the assembled product; if the pre-tightening force is too low, the threaded connection may be invalid or loose. Therefore, precise control of the tightening process to achieve a reasonable pre-tightening force is a core issue of the threaded connection.

Thread tightening methods generally include torque method, corner method, bolt extension method, etc. The torque method has the advantages of simple operation, flexible application and low process cost. It is the most widely used thread tightening method and the main theoretical support of this paper.

The basic principle of the torque method is to achieve indirect control of the pre-tightening force by controlling the torque during the tightening process.

\[ T = KdF \]  

where \( T \) is the torque; \( K \) is the torque coefficient; \( d \) is the nominal diameter of the screw; \( F \) is the pre-tightening force. The torque coefficient \( K \) is generally determined empirically. But during the actual tightening process, the torque coefficient \( K \) is not a constant. Even for the same batch of screws, the amount of variation in the torque coefficient may be 0.1 to 0.2 or even wider due to changes in external conditions. Therefore, it is important to study the law of torque coefficient of small-size thread and explore the quantitative control method of pre-tightening force to improve assembly quality.
At present, most of the threaded connection process research is concentrated on large-size screws. The research on small-size threaded connection with a nominal diameter of 1 to 6 is scarce, because the measurement of the small-size screw tightening process is more difficult. In engineering practice, manual assembly of small-sized screws tends to apply a screw axial assembly pressure while tightening, so as to better complete the tightening process; automated assembly screws also occur due to the fact that the speed of the electric screwdriver and the rate of descent cannot be precisely matched, resulting in additional assembly pressure. However, the existing research does not consider the influence of assembly pressure on the torque coefficient. This paper proposes a small-size thread torque coefficient test method that takes into account the assembly pressure, and develops a corresponding test device to solve the above problems.

2. Principle of the small size thread torque coefficient test
The overall structure of the test system is shown in Figure 1. The system consists of four parts: a small-sized threaded connection test device (three sensors), three amplifiers, a data acquisition card (multi-channel), and a computer. The test system can simultaneously record the tightening torque, pre-tightening force and assembly pressure of the screw in real time. Then the real-time variation law of the torque coefficient K under different experimental conditions can be get by the mathematical statistics method.

Figure 1. Schematic diagram of the overall principle of the small-size threaded connection test system
2.1 Design of the small size threaded connection test device

The threaded connection test set includes a pre-tightening test bench and a pressure-torque screwdriver that measures the screw's specification range M1-M6.

2.1.1 Design of the pressure-torque screwdriver. The pressure-torque screwdriver shown in Figure 2 is mainly composed of a torque sensor, a pressure transmitting component, a single pressure sensor, a torque transmitting component, a mounting sleeve and a screwdriver bit. The torque sensor measures the tightening torque in real time. The single pressure sensor measures the assembly pressure applied to the screw.

The internal components of the pressure-torque screwdriver are vertically arranged, which effectively avoids the influence of the self-gravity of the experimental device on the measurement result, and improves the measurement accuracy of the torque. The mounting sleeve is connected to the torque transmitting component through the pin, which minimizes the axial displacement of the screwdriver during use, and improves the accuracy and consistency of the data collected by the torque sensor and the single pressure sensor.

The pressure-torque screwdriver can be used manually or by motor. At present, the thread tightening degree of some products in aerospace industry mainly depends on the feel of the mechanic. The manual use can truly simulate and record the whole process of the mechanic's screw tightening in real time. The motor drive is used by clamping the pressure torque screwdriver on the motor shaft, setting the speed to perform constant speed tightening, simulating the automatic tightening state, and exploring the effect of the tightening speed on the torque coefficient.

![Schematic diagram of the pressure-torque screwdriver](image)

Figure 2. Schematic diagram of the pressure-torque screwdriver

2.1.2 Design of the pre-tightening test bench. The structural schematic diagram of the pre-tightening test bench is shown in Figure 3, which mainly includes the pull pressure sensor, the support surface, the connecting plate, the limiting device and the optical axis.

Use the pressure-torque screwdriver to tighten the screw through the optical hole of the support plate into the test piece with the screw hole. At this time, the connecting plate and the four optical axes pass through the limiting device to prevent the screw-shaped test piece from rotating, which reduces the error value of the pre-tightening test. The tightening force is transmitted to the tension pressure sensor through the connecting plate.

There is a square groove on the end surface of the support surface, and a specific square plate can be placed in the groove to simulate the state of the contact surface under different working conditions of the screw. The installation method with the screw hole test piece and the connecting plate is the shaft hole connection to quickly complete the test piece replacement and improve the test efficiency. In order to adapt to the test screws of different lengths, the limit device can adjust the position.
2.2 The step of small size thread torque coefficient test

In the first step, a certain type of screw is randomly selected as a test piece;

In the second step, after determining the lubrication conditions and the materials of the two connected parts, the screw is tightened by the pressure torque screwdriver. The tightening process is as follows: the test piece with the screw hole is mounted on the connecting plate at the top of the pull pressure sensor, and the screw passes through the light hole of the supporting surface, and the screw is driven into the test piece by hand for pre-connection without generating the pre-tightening force.

In the third step, after the screwdriver bit is in contact with the screw, the assembly pressure is applied and the screwdriver is rotated, and the screw connects the support surface of the pre-tightening test bench with the screw-hole test piece. The single pressure sensor is used to measure the assembly pressure of the screw. The screwdriver is pressed to bring the assembly pressure of the screw to the set value \( F_N \), and the assembly pressure is maintained during the tightening of the screw. The torque sensor measures the torque received by the screw. The pull pressure sensor measures the pre-tightening force of the screw. When the torque or pre-tightening force reaches the set value, the tightening of the screw is completed, and the dynamic curve of the torque, pre-tightening force and assembly pressure of the screw can be get.

In the fourth step, the invalid value in the torque and pre-tightening force data is removed, and the torque coefficient curve of the screw is calculated according to the formula \( T = K_d F \).

In the fifth step, the above steps are repeated to complete the multiple tightening of a single screw or the tightening comparison test of multiple screws.

In the sixth step, a mathematical model of the relationship between the pre-tightening force \( F \) and the torque \( T \) of the screw is established under the assembly pressure \( F_N \), the lubrication condition and the material of the connected piece.

3. Analysis of the influence of assembly pressure on torque coefficient

In order to explore the specific influence of assembly pressure on the torque coefficient, this paper uses the small-size threaded connection test device designed by our lab to carry out physical experiments on the M5 screw commonly used in aerospace products. As shown in the figure 4, screws used in the experiment were 4.8 grade with the standard of GB/T 70.1-2000, coarse teeth, and the surface of the screws was not coated. The material of the test piece with screw hole is 45 steel, and the contact surface square plate material is 304 stainless steel. In order to remove the effects of dust, impurities and oil on the experiment, it is necessary to clean the test piece with the screw hole, the contact surface square plate and the test screw. The cleaning agent in this experiment is anhydrous ethanol, which can remove impurities well and does not damage the surface of the test piece. After the cleaning was completed, the anhydrous ethanol remaining on the surface of the test piece was quickly volatilized using a blower.
The experiment was carried out in two groups. The first group was subjected to the tightening test without assembly pressure, and the second group was controlled to maintain the assembly pressure at 80N for the tightening test. In both sets of experiments, it was ensured that the tightening was stopped when the pre-tightening force reached 1550N and the conditions other than the assembly pressure were kept the same.

Experimental results can be seen in the figure 5. When the pre-tightening force is in the range of 100N-1550N, the torque coefficient under the screw tightening assembly pressure of 80N is greater than the torque coefficient without assembly pressure. When the assembly pressure is 80N, the torque coefficient first decreases and then increases with the increase of the pre-tightening force, and the final torque coefficient is smaller than the initial torque coefficient. When there is no assembly pressure, the torque coefficient exhibits a gradually increasing variation law with the increase of the pre-tightening force, and the final torque coefficient is more than the initial torque coefficient. When the pre-tightening force is in the range of 100N-300N, the torque coefficient difference under different assembly pressures is more obvious, but as the pre-tightening force continues to increase, the torque coefficients of the two sets of experiments gradually approach.
Based on the above experimental results, it is recommended to introduce the influence of assembly pressure on the torque coefficient when designing the threaded joint process.

4. Conclusion
Threaded connection is one of the most commonly used methods in various product assembly. For the current threaded connection research, the problem of assembly pressure is not introduced. The author proposes a threaded connection tightening method based on the influence of assembly pressure. Before using the torque method for the small-size threaded connection assembly, it is necessary to collect the actual assembly pressure generated in the manual/automatic tightening. Under this actual assembly pressure, the thread connection test of the customized working condition is performed, the torque curve is got, and the torque coefficient corresponding to the target pre-tightening force is intercepted, thereby realizing more precise quantitative control of the pre-tightening force. It provides an effective and innovative evaluation method for the tightening process of small-sized screws.

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