Development of a High-precision Digital Display Torque Wrench

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Abstract. Thread connection is widely used in mechanical connection. Torque wrench can feedback tightening torque in real time, and can apply more accurate tightening torque, which is widely used in engineering. Some assembly lines in aerospace or military field the tightening accuracy need to reach 0.1%, comparing with the only 1% accuracy of ordinary working wrench, the high precision torque wrench is needed to apply the high accuracy torque in aerospace or military field. Two methods are introduced to improve the measurement accuracy of the torque wrench. One is to design the transducer with pure torsional transformation when it is used. The other is to apply linearity correction to the transducer by circuit software. The results shows the accuracy of the torque wrench is 0.1%, which is much higher than ordinary work wrench.

Keywords: High-precision; Digital display; Torque wrench.

1. Introduction
In order to enhance the reliability and tightness of the thread connection and prevent the gap or relative displacement of the connected parts after being loaded, the thread connection needs to be pre-tightened. When the pre-tightening force does not reach the standard pre-tightening torque of the bolt, the joint is not tight and leads to loosening, which is easy to cause accidents. When the pre-tightening force is too large, it is easy to cause the plastic deformation of the bolt, and the fatigue will be produced when the bolt is in the deformation state for a long time, which will lead to the fracture of the bolt and cause irreparable consequences. When the applied torque is greater than the yield limit of bolt material, the bolt is damaged and cannot be used, resulting in economic loss. At present, the commonly used methods to control the size of preload force are operating experience and with the help of torque wrench. the empirical approach is applied to situations where the pre-tightening force requirement is not high. in order to obtain uniform pre-tightening force, proper torque process and high precision tightening tool, the torque wrench must be used. Torque wrench is a special tool which can feedback tightening torque in real time. It can apply more accurate tightening torque and play an important role in engineering. The study of torque wrench is from the original mechanical torque wrench to electronic digital display, which has been carried out since 1975 abroad. The torque wrenches produced by French FACOM companies, American CDI companies and German GEDORE companies are the representing wrenches producers. In China, digital display torque wrench was developed by Oriental Instrument Factory and Changcheng Institute of Metrology & Measurement which are the main wrench producers[1-4]. Most working wrenches used in factory do not need high precision. The wrench with 1% measurement accuracy is enough for these applications such as shipbuilding, metallurgy, chemical engineering, bridges, machinery, especially high pressure pipes, pressure vessels, and flanges, even 5% is acceptable for these installation lines. Some assembly lines such as in aerospace or military, wrenches with high precision are needed to guarantee the precision installation. In this paper, the development process of...
high precision digital display torque wrench is introduced in detail. The digital wrench in this research using both the transducer structure and circuit software has been successfully improved the measurement.

2. Methodology

2.1. Structure of the Transducer

Figure 1 (a) shows the ordinary torque wrench, where the transducer is installed at the front part of the wrench arm but not at the front end. The structure of the transducer is shown in Fig1(b). Four strain gauges R1-R4 are attached to the upper and lower blind holes on the arm of the wrench, which form a cantilever beam transducer. Four strain gauges form a Wheatstone Bridge. When the wrench is used, it causes the unbalanced output of the bridge to obtain the force of the wrench. From the equation (1), it can be seen that the output of the Wheatstone bridge is related to where does the force applied.

\[
U_0 = \frac{F(L - l)K}{EW_z}
\]

The transducer in ordinary wrench is a shear force type transducer, which means it is sensitive to the position of the force that apply on the arm of the wrench[5]. The wrench is characterized by strict compliance with the calibration line for calibration and use, otherwise it has some influence on its torque value. This is the reason that the ordinary wrench has lower precision.

We move the transducer in high precision wrench from the arm to the front end of the wrench. The transducer is a pure torsion transformation transducer, so that its calibration and usage are not limited by the engraving line, and the torque value do not change with the force point. Pure torsion type transducers can be spoke or cylindrical. Consider the transducer used for wrench, it must be small size and light weight. After strength checking and calculation, the size of the spoke-type transducer is too large to be placed on the end. Finally, the cylindrical torque transducer is adopted. Take a 2000 N•m transducer as an example to explain the design process of transducer.

3. Size Calculation of the Transducer

The maximum torque is 2000 N•m and the material of the transducer is 40CrMoMiA. The relationship between the output of the bridge and the strain of the transducer are shown in the following equation (2)[6]:

\[
u_i = \frac{u_i KE(1 + \mu)}{EW_n} M
\]

where the elastic modulus E is 210 GPa, bridge supply voltage is 10V and the strain gauge sensitivity coefficient is 2.11. The value of \( D \) can be calculated by the following equation with the output of the bridge voltage set to 2mv/V.

\[
0.002 = \frac{2.11 \times (1 + 0.29) \times 2000}{2.1 \times 10^9 \times \left(\frac{\pi \cdot D^3}{16}\right)}
\]
The value of D is 39.7mm after calculation. Considering that the wrench should be easily calibrated on the standard torque machine, the design of the joint is also considered in the structural design. The specific size and shape of the transducer are shown in Fig.2.

4. Strain Gauge Compensation Method
In practical use, there exists bending moment, axial force and even the lateral force on the transducer. In order to eliminate the influence of these stresses, the layout of the strain gages is shown in the Fig.3. Such layout of the gages can only check the torsional stress and ignore the other stress caused by the bending and lateral forces. The transducer can accurately measure the torque of the wrench.

5. Micro-circuit Design
The main part of the micro-circuit is the single chip microcomputer. The working principle is shown in Fig.4. The output of the bridge is analog voltage signal. The Microcontroller unit will deal with the signal by filtering, amplifying and A/D conversing, then the analog signal is changed into digital signal. The Microcontroller unit controls the reset circuit, power circuit, clock circuit, LCD circuit, acousto-optic alarm, serial port module, key and memory module and display the torque value on the LCD screen. The ordinary wrench only has two-point linearity correction, which is also a reason for the low accuracy. The circuit software for high precision torque wrench is designed to provide at least 4 points, up to 8 points of linearity correction[7-8], so that the wrench accuracy can be improved.

6. Test Verification
Through a large number of tests, the wrench with intermediate range is easy to meet the accuracy requirements, while the measurement accuracy at both ends, such as the small range(50 Nm) and the large range(2000Nm), is not easy to achieve the required measurement accuracy. We use the torque wrenches with a range of 50 Nm and 2000Nm to verify the measurement accuracy. Install the digital display on the standard torque machines by a self-made clamps. One standard torque machine with 0.03% measurement accuracy ranged from 10-1000 Nm is used for calibration the wrenches with the 50 Nm maximum measure value. Another standard torque machine with 0.03% measurement accuracy ranged from 50-5000 Nm is used for calibration the wrenches with the 5000 Nm maximum measure value. The calibration tests carried out is in accordance with the JJG797-1992[9]. The results are shown in Table 1-2.
Figure 4. The diagram of high precision digital torque wrench

Table 1. The calibration results of the 50N•m torque wrench

| Direction | Point (N•m) | 1    | 2    | 3    | Average | Relative error (%) | Repeatability (%) |
|-----------|-------------|------|------|------|---------|-------------------|-------------------|
| Clockwise | 10.000      | 10.004 | 10.005 | 10.003 | 10.004 | -0.04             | 0.02              |
|           | 30.000      | 30.001 | 30.006 | 30.007 | 30.005 | -0.02             | 0.02              |
|           | 50.000      | 49.975 | 49.969 | 50.000 | 49.981 | 0.04              | 0.06              |
| Anticlockwise | 10.000     | 10.002 | 10.004 | 10.002 | 10.003 | -0.03             | 0.02              |
|           | 30.000      | 30.002 | 30.004 | 30.005 | 30.004 | -0.01             | 0.01              |
|           | 50.000      | 49.984 | 49.979 | 49.980 | 49.981 | 0.04              | 0.06              |

7. Conclusion
According to the results of calibration on standard torque machine, the measurement accuracy of the wrench can reach 0.1%, which shows that the accuracy of the wrench can be improved to 0.1 by changing the structure of transducer and apply linearity correction by software.

Table 2. The calibration results of the 2000Nm torque wrench

| Direction | Point (N•m) | 1    | 2    | 3    | Average | Relative error (%) | Repeatability (%) |
|-----------|-------------|------|------|------|---------|-------------------|-------------------|
| Clockwise | 500         | 499.5 | 499.6 | 499.5 | 499.5   | 0.09              | 0.02              |
|           | 1000        | 999.5 | 999.5 | 999.6 | 999.5   | 0.05              | 0.01              |
|           | 2000        | 1999.9 | 1999.9 | 1999.9 | 1999.9 | 0.01              | 0                 |
| Anticlockwise | 500        | 499.6 | 499.6 | 499.6 | 499.6   | 0.08              | 0                 |
|           | 1000        | 999.8 | 999.8 | 999.8 | 999.8   | 0.02              | 0                 |
|           | 2000        | 1999.9 | 1999.9 | 1999.9 | 1999.9 | 0.01              | 0                 |

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