Development and verification of wireless torque sensor node for rotating shaft

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Abstract. There are many torque measurement technologies at present, because the rotating shafting torque monitoring is very important. However, compared with the cost-effective strain measurement technology, there are signal transmission and power supply technology bottlenecks in the long-term monitoring of large shafting torque. In view of these technical bottlenecks, this paper designs a strain torque monitoring system based on wireless signal transmission technology and wireless inductive power supply technology. In this paper, the current torque measurement technology is analyzed. The design principle and technical characteristics of wireless torque sensor and wireless induction power supply device are developed. This paper is a complete long-term monitoring solution for shafting torque, which has a good referent value for relevant engineers and technicians.

1. Introduction
The shafting is the most fundamental structure of all machines, and most shafting systems are used to transmit torque especially for the rotating shaft. The dynamic torque of the shafting is one of the main factors affecting the reliability and service life of the machine. The transmission shafting of various mechanical equipments may experience short-term or continuous torque fluctuations due to mechanical, electrical, power or load during operation, and may damage the shaft and its connecting members in severe cases.

With the rapid development of modern science and technology, torque measurement technology has become a new branch of test technology. Torque measurement applications are becoming more and more extensive, ranging from aircraft, ships, drilling, power generation equipment and metallurgical mining equipment to micro-motors, household appliances and clock springs. The measurement and analysis of the shafting torque can obtain important information such as the working performance of the machine and the stress of the shafting. As the evaluation basis and the mechanical design basis, it can also detect the running state of the machine and become an important means of fault diagnosis.

Accurate torque measurement plays an important role in shortening the development cycle of modern ship equipment, improving the performance of weapons and equipment, and reducing the cost of use and support. With the substantial improvement of China’s economic strength and technology level, in the civil and defence fields, on the one hand, the demand for automobiles, ships, aircraft,
drilling and other equipment has increased significantly, on the other hand, the level of demand for these equipment (including speed, tonnage, dynamic characteristics, safety, etc.) have also undergone great changes, which also put forward more and higher requirements for torque measurement. The development of high-accuracy torque sensors is one of the key technologies to improve the accuracy of torque measurement. Considering the above torque testing methods and current situation, strain sensor is selected in this paper because of its simplicity and easy utilization.

2. Wireless torque sensor design

2.1. Overall design scheme
During the design process, the torque sensor in this paper has the rotate speed measurement in order to gain the shaft mechanical power. Through the tested torque and rotate speed, the shaft power can be calculated indirectly. The wireless torque-speed sensor mainly comprises a strain measuring circuit, a data processing unit, a rotational speed measuring unit, a wireless communication unit and an inductive power unit, as shown in Fig.1. The solid line frame is the component of the sensor, the strain gauge in the dotted line frame is a sensitive component, and they are connected by the lead wire and the strain measurement circuit of the wireless torque-speed sensor. The magnetic stripe in the dotted line frame is placed in the relative fixed position to wireless torque-speed sensor, and the position is close to the rotation revolution measuring unit.

![Fig.1 Torque sensor node configuration](image)

2.2. Strain gauge measurement circuit
The strain gauge and the wireless torque-speed sensor are fixed together on the rotating shaft, and a specific torque measuring gauge is attached to the transmission shaft to form a strain bridge, which is a basic torque sensor. The stabilized power supply is provided to the strain bridge, and as the excitation source, when the shaft rotates, the resistance value of the strain bridge changes, which will cause the voltage of the test terminal to change, and the data acquisition circuit collects the voltage signal of the test terminal.

The sensor node has built-in independent high-precision bridge resistance and amplification modulation circuit. At the same time, it can realize automatic switching of 1/4 bridge, 1/2 bridge and full bridge measurement mode through the host computer software, and is compatible with various types of bridge sensor.

2.3. Rotation revolution measurement unit
The speed measuring circuit composed of the Hall element and the peripheral device converts the motor speed into a pulse signal, and sends it to the counter of the data processing unit for counting, and the actual speed of the motor is measured by timing. Fix a permanent magnet to the transmission shaft, fix the torque-speed sensor on the transmission shaft, and bring one end of the Hall element close to the permanent magnet end.
When the shaft rotates, the Hall element is subjected to the Hall sensor position, then it will be influenced by the magnetic field of the magnet, thus, the sensor can generate a pulse voltage which has the peak value of 20mV. The voltage is amplified by the operational amplifier to drive the semiconductor transistor to complete the break-over and cut-off process. The data processing unit is connected to the output end of the semiconductor transistor for counting.

2.4. Wireless transmission & reactivation unit
The wireless communication unit uses the 802.15.4 protocol for wireless data transmission, and transmits the measured strain and rotate speed values to the host computer data test system in wireless. The module can be configured according to the commands and parameters issued by the host.

2.5. Wireless power supply unit
The unit is based on the resonant coupled power wireless transmission technology, and can provide power for devices that are inconveniently to use the power line for short distances (in the range of 1 to 5 cm). And it plays very important role during the development of the toque node, especially for the rotational shafting torque testing. Its development detail is expatiated in chart 4.

3. Wireless inductive power supply unit

3.1. Inductive power working principle
The unit comprises two parts of a radio energy transmitter and a receiving end, and the transmitter power transmits the electric energy to the receiving end through resonant coupling, and its working principle is shown in Fig.2.

![Fig.2 Working principle of the inductive power supply](image)

Firstly, the power source drives the transmitting coil resonance through the inductive power transmitting module to convert the power energy into electric and magnetic field energy in the resonant transmitting coil.

Secondly, the magnetic field energy generated by the transmitting coil is converted into electric field energy in the resonant coil by magnetic field coupling, the resonant coil resonates, and the electric field energy and the magnetic field energy are exchanged between the booster capacitor and the inductance.

Finally, the magnetic field in the resonant coil can be coupled to the receiving coil through the magnetic field, the receiving coil resonates, the energy is finally transmitted from the transmitting coil to the receiving coil, and the electric energy is continuously output through the receiving module processing.

Since the coil of the resonant coupling energy wireless transmission resonates, that is, the high frequency equivalent circuit of the coil itself resonates; the coil loop impedance reaches a minimum value, so that more energy is collected by the receiving coil, which improves the energy transmission efficiency.
3.2. Main parameters
In order to meet the power requirement of torque node sensor, the main parameters are measured, and its result is shown in table 1.

**Table 1 Main parameters of the power supply unit**

| Input characteristics | Voltage range | 90-264 VAC |
|-----------------------|---------------|------------|
| Frequency range       | 47-440 Hz     |            |
| Input power           | < 8W          |            |
| Efficiency            | < 35%         |            |
| Leakage current       | < 0.5mA @ 50/60 Hz;264 VAC | |

| Output characteristics | DC voltage | 8V |
|------------------------|------------|----|
| Voltage regulation accuracy | ±3% | |
| Rated current          | 125mA      | |
| Rated power            | 1W         | |
| Ripple and noise       | 60mVp-p    | |

| Environment characteristics | Operating temperature | -40--+80°C |
|-----------------------------|-----------------------|------------|
| Storage temperature         | -40--+85°C            | |
| Relative humidity           | 10%~95%RH             | |

3.3. Installation and fixation
The magnetic coupling resonant wireless energy transmission technology is different from the inductive wireless energy transmission technology in that the technology combines resonance technology, which not only improves the energy transmission distance, but also improves the energy transmission efficiency.

During the stalling the inductive power supply transmitting module, removing the gasket at the mounting screw hole of the base and fixing the mounting base, and M4 countersunk screws is used for the fixing the inductive power transmitting module with. The transmitting coil can be made of a PCB board, a copper tube, etc. according to the actual use environment, and the coil of the required size is fixed outside the rotating shaft.

4. The technical parameters and verification results
The wireless inductive power supply unit and torque node is shown in Fig.3. In order to verify the reliability and precision, the node was sent to Changcheng Institute of Metrology & Measurement. The main result is shown in Table.2 (the unit in this table is με), and its test report No. is GFJGJL1001170310949. From this report, the zero drift and measurement stability value is 1με/4h and 0.01%με/4h respectively.
Table 2 Main test report results

| Standard Value | Display Value | Uncertainty U(k=2) | Standard Value | Display Value | Uncertainty U(k=2) |
|----------------|--------------|-------------------|----------------|--------------|-------------------|
|                | +           | -                 |                | +           | -                 |
| 0              | 0           | 0                 | 1              | 600         | 601               |
| 10             | 10          | 10                | 1              | 700         | 701               |
| 20             | 20          | 20                | 1              | 800         | 801               |
| 30             | 30          | 30                | 1              | 900         | 900               |
| 40             | 40          | 40                | 1              | 1000        | 1000              |
| 50             | 50          | 50                | 1              | 2000        | 2001              |
| 60             | 60          | 60                | 1              | 3000        | 3002              |
| 70             | 70          | 70                | 1              | 4000        | 4002              |
| 80             | 80          | 80                | 1              | 5000        | 5003              |
| 90             | 90          | 90                | 1              | 6000        | 6004              |
| 100            | 100         | 100               | 1              | 7000        | 7004              |
| 200            | 200         | 200               | 1              | 8000        | 8005              |
| 300            | 300         | 300               | 1              | 9000        | 9006              |
| 400            | 400         | 400               | 1              | 10000       | 10007             |
| 500            | 500         | 500               | 1              | 15000       | 15010             |

5. Conclusions
At present, most contact measurement systems transmit signals through a collecting ring. The collecting ring method is a common method of transmitting signals between static and dynamic components. Due to the instability of the contact resistance between the static and dynamic parts of the collecting ring, and the frictional electrostatic interference, this transmission mode will greatly reduce the signal-to-noise ratio, which is not suitable for being long-term monitoring system power source.

The advantage of torque node sensor includes: high sensitivity and accuracy of measuring strain; small size and light weight of the strain gauge, which has no effect on the working state and stress distribution of the tested part; large measurement range, which can measure elastic deformation and plastic deformation; inductive power supply, which can resolve the rotating shafting torque testing.

References
[1] Duan Guofang and Miao Yansong 1997 The review on torque measurement technique home and aboard Journal of test and measurement technique pp 44-47
[2] Ville N 2011 Implementing clamp on wireless torque measurement system for rotating shaft application 14th European conference on power electronics and applications pp 1-10
[3] D. R. Myers 2007 Design and evaluation of a torque testing apparatus for strain gauges University of California, Berkeley, department of mechanical engineering
[4] Lotfi Baghli, Jean Francois Pautex and Smail Mezani 2010 Wireless instantaneous torque measurement application to induction motors International conference on electrical machines(ICEM)
[5] R. Wolfenbuttel and J. Foerster 1990 Non-contact capacitive torque sensor for use on a rotating axle IEEE transactions on instrumentation and measurement pp 1008-1013
[6] W.J. Fleming 2008 New automotive sensors: a review IEEE sensors journal pp1900-1921
[7] M. Ferri, F. Mancarell, L. Belsito, A. Roncaglia, J. Yan, A.A. Seshia, K. Soga and J. Zalesky 2010 Strain sensing on steel surfaces using vacuum packaged MEMS resonators, Proceeding Engineering pp 1426-1429
[8] NRF2401 single chip 2.4GHz radio transceiver datasheet 2016 Nordic VLSI ASA
[9] Pietron G M, Fuji Y and Kucharski J 2013 Development of magneto-elastic torque sensor for automatic transmission applications SAE international journal of passenger cars mechanical systems pp 529-534