

A Torque Sensor with a Unified Coupling Interface for Wireless Power and Data Transmission

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Abstract – This paper presents a single-coil technical solution for a strain-type torque sensor based on magnetic coupling resonance, enabling simultaneous wireless power and data transmission. The power and data sharing a common set of coupling coils, the system leverages frequency-division multiplexing (FDM) and carrier modulation technologies to independently control distinct operating frequencies, directly modulate data onto the power carrier via amplitude-shift keying (ASK), and perform data pickup and demodulation. A prototype torque sensor was developed, achieving an output power of 5 W and a data transmission rate of 20 Kb/s.

Keywords: wireless power and data transfer, torque sensor, frequency-division multiplexing

I. INTRODUCTION

In high-precision measurements, strain torque sensors are the most mature and reliable. The torque sensor is installed on the rotating shaft system, and torque measurement is relatively difficult. The torque sensor needs to be divided into two parts, the rotor and the stator, to solve the matching problem between rotating and stationary components. Due to its two independent parts, there are problems with power supply and communication between the two parts. Currently, the mainstream technical solutions for strain sensors are: conductive slip ring type for contact, and wireless power supply plus wireless communication or battery power supply plus wireless communication for non-contact. However, the above technical solutions cannot meet the requirements of high reliability and easy maintenance. Therefore, how to design a strain torque sensor that is easy to install, easy to use, and has high reliability is a technical problem that urgently needs to be solved.

In recent years, the proposal of the magnetic coupling resonance concept [1-2] has achieved medium-distance wireless power transfer (WPT). Subsequently, after ten

years of development based on this, magnetic-coupled wireless power transfer (MC - WPT) has gradually matured, and a wireless power and signal synchronous transmission system has also been developed based on this technical foundation.

The basic principle of wireless power and signal synchronous transmission is to use wireless power transfer technology and, on this basis, add a signal transmission topological structure to achieve the synchronous transmission of wireless power and signals. Compared with traditional wired power transmission, wireless power transfer technology has advantages such as non-contact, flexibility, safety, and reliability, and has been widely applied in various fields, such as electric vehicle charging, medical equipment, lighting, and electronic products.

Currently, wireless power transfer (WPT) technology can be transmitted through various media, including electric and magnetic fields. According to different transmission mechanisms, it can be divided into three methods: inductive, resonant, and radiative. At present, the mainstream wireless power transfer (WPT) technologies mainly include electromagnetic wave radiative, electromagnetic inductive, and magnetic-coupled resonant types.

A. Electromagnetic Wave Radiative Wireless Power Transfer Technology

The electromagnetic wave radiative wireless power transfer technology adopts the principle of microwave power transmission, that is, it converts electrical energy into microwaves through a highly directive transmitting antenna, and then uses a receiving antenna to collect the microwaves and convert them into direct current for subsequent circuits. This technology has the ability of long-distance transmission. For example, in the 20th century, the United States proposed the Space Solar Power Station (SSPS) plan [3]. By deploying satellites in outer space, the solar energy in outer space is converted into electrical energy and transmitted to the ground through microwaves.

B. Electromagnetic Inductive Wireless Power Transfer Technology

The electromagnetic inductive wireless power transfer technology is an electric energy transmission method based on the electromagnetic induction phenomenon. This technology is similar to the principle of a transformer and has high requirements for the coupling coefficient between coils. When there is a position offset, it will have a great impact on the power and efficiency of wireless power transfer, and the transmission distance is relatively short, only a few centimeters, so its application is limited.

C. Magnetic-Coupled Resonant Wireless Power Transfer Technology

The magnetic-coupled resonant wireless power transfer technology uses a high-frequency power supply to form a resonant circuit through the coil inductance and capacitance, generating a strong high-frequency alternating current, thus generating a high-frequency electromagnetic field through the coil. The receiving coil is also in a resonant state, receiving the electromagnetic signal from a distance and converting it into a high-frequency alternating current. Through the mutual coupling of the two coils, wireless power transfer is achieved. This technology has advantages such as high transmission power, high transmission efficiency, and strong anti-interference ability.

This technology was first proposed in a paper published in the journal "Science" by the Massachusetts Institute of Technology in the United States [1-2]. In 2007, it demonstrated its results to the outside world: at a frequency of 9.9 MHz, a 60W light bulb was successfully lit with an efficiency of 40% at a distance of 2m. The release of this research result has elevated the practical application of wireless power transfer to a new level. Subsequently, scholars from various countries have invested in research in this field.

Zhang [4] first applied this technology to medical equipment to charge implantable devices, verifying its feasibility in the medical field. Takehiro [5] proposed applying this technology to the field of wireless charging for electric vehicles and explored the precise frequency and efficiency required to achieve electromagnetic coupling based on antenna theory, circuit theory, experimental observations, and electromagnetic calculations [6]. Subsequently, Cannon B.L [7] explored the possibility of supplying power to multiple receivers, expanding the application scenarios of magnetic-coupled wireless power, enabling power supply to multiple receivers, as shown in Figure 1.2.

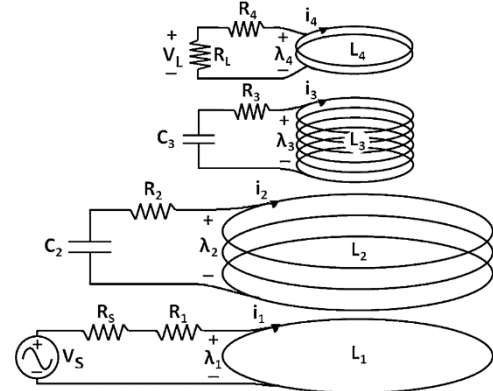


Fig. 1. Schematic diagram of one to many magnetic coupled radio energy transmission

The Korea Advanced Institute of Science and Technology (KAIST) has carried out a large amount of research in the field of electric vehicles, mainly focusing on detailed research in aspects such as dynamic power supply [8], electromagnetic relay [9], and coil structure [10].

Based on the above research foundation, this paper proposes a technical solution for a single - coil strain torque sensor based on magnetic - coupled resonant wireless power and data synchronous transmission. This solution solves the two functions of power transmission and signal transmission of the torque sensor simultaneously through a single system. The advantage of this technical solution is that it greatly improves the convenience of use and maintenance of the torque sensor, thus effectively enhancing the competitiveness of related products.

II. CONTRIBUTION

This paper designs a wireless power and data synchronous transmission system according to the measurement dimensions of the torque sensor. The system block diagram is shown in Fig.2. Based on this, a torque sensor experimental prototype is developed, The influence of rotational speed and metal media on the system was explored, and the reliability of the system is verified through experiments.

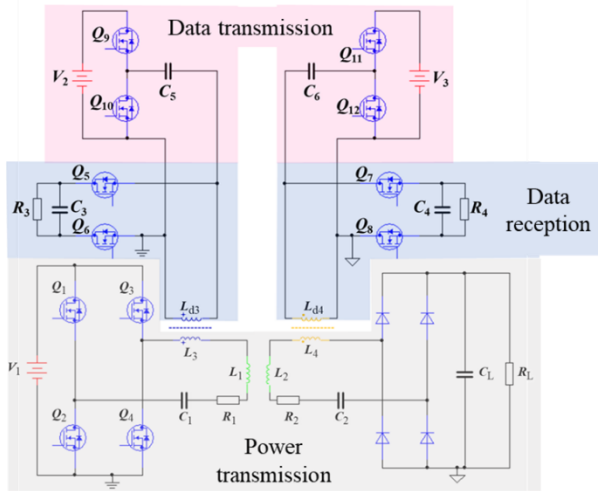


Fig. 2. wireless power and data synchronous transmission circuit block diagram

III. RESULTS

Based on the above mentioned system, this paper subsequently manufactures the 2000 Nm torque sensor, including the mechanical structure processing of the rotor and stator, the pasting of strain gauges, the production and debugging of the circuit board, as shown in Fig.3. Subsequently, the wireless power and data synchronous transmission system is tested. The waveforms are shown in Fig.4. Point 1 is the waveform at the data loading end; Point 2 is the waveform at the data receiving end; Point 3 is the waveform after envelope filtering of the data; Point 4 is the data output waveform. It can be seen from Figure 4 that the demodulation effect of the data transmission waveform signal is good, and the bit-error rate is low.



Fig. 4. Physical diagram of the 2000 Nm torque sensor

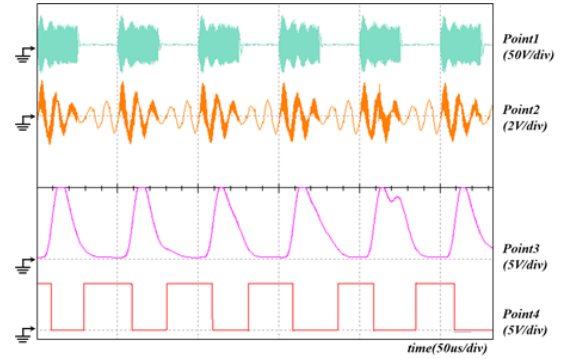


Fig. 4. the wireless power and data synchronous transmission system waveform diagram

IV. CONCLUSIONS

This paper proposes a technical solution for a single - coil strain - type torque sensor based on magnetic - coupled resonant wireless power and data synchronous transmission. Based on a 2000 Nm torque sensor, a system experimental prototype is designed. The influence of rotational speed and metal media on the system is explored, and the reliability of the system is verified through experiments.

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