Test Bench Construction and Verification for Static Magnetic Coupling Wireless Power Transfer Systems

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Abstract. In this paper, a test bench construction and verification scheme for static magnetic coupling wireless power transfer (WPT) systems is introduced, including test indices, test bench construction, test procedure, a test bench prototype and a specific test case. Firstly, a brief introduction to the working principle of the static magnetic coupling WPT systems is presented. Secondly, by interpreting the existing WPT systems test standards, the indices and test methods of the performance for WPT systems are given. Finally, the test procedure developed above is demonstrated by construction of an automatic test bench for WPT systems and a specific test case. In a word, the test bench shown in this paper can better complete the testing of various important indices of WPT systems, and it has certain guidance and reference significance for the construction and improvement of the subsequent bench.

1. Introduction
As the vehicles around the world are developing towards intelligence and networking continuously, consumers are increasingly demanding convenience in charging, hence wireless power transfer (WPT) technology would become an important development trend of energy supply for electric vehicles (EVs) in the future. WPT is a kind of technology based on non-conductor contact, which realizes the transmission of electric energy from the power side to the load side by means of electromagnetic conversion, microwave or other physical space energy carriers. In recent years, WPT technology has received a large amount of research and development (R & D) investment from relevant institutions.

According to the different transmission mechanism, WPT technology is mainly divided into electric field coupling, magnetic field coupling and microwave radiation [1]. Among them, the magnetic field coupling WPT technology is the most popular radio energy transmission technology, which has the ability of long transmission distance, high transmission efficiency and high transmission power.

In 2007, Professor Marin of MIT published a paper on WPT technology in science [2], which caused a research boom in the field of wireless charging. On one hand, the academic institutions mainly carry out theoretical research on wireless charging technology, including system modeling and control, magnetic coupling mechanism, etc. On the other hand, major companies and enterprises have also invested in accelerating the application and industrialization of wireless charging technology. Among
them, witricity’s drive 11 systems can provide an output power of 11kW, with an efficiency up to 93%. And it cooperated with BMW to launch the world’s first EV equipped with wireless charging power-BMW 530e in 2018. Zhongxing New Energy Corporation has realized the maximum output power of 60kW in 2014, with an efficiency of 90%. Zonecharge Wireless Power Technology Co., Ltd has also developed and completed the wireless charging equipment of 3-30kW electric vehicle, with an energy conversion efficiency of 95%. However, most of the enterprises are still in the stage of R & D and have not yet carried out large-scale commercial services. It can be predicted that the electric vehicle wireless charging industry will develop rapidly. Therefore, a set of standard and automatic test equipment and method flow is urgently needed to verify the wireless charging equipment.

On this basis, combining with the existing standards and regulations, this paper builds an test bench, and carries out the test verification of wireless charging system cases, striving to provide technical support for the industry to carry out the test and verification, so as to promote the technical progress of the industry.

2. Principle of static magnetic coupling WPT systems

Figure 1 shows the static magnetic coupling WPT system that adopts series-series topology. According to the Kirchoff’s voltage law, the voltage equation can be expressed as follows [3]:

\[
\begin{align*}
(R_1 + j\omega L_1 - j\frac{1}{\omega C_1})I_1 + j\omega M I_2 &= U_s, \\
j\omega M I_1 + (R_2 + j\omega L_2 - j\frac{1}{\omega C_2} + R_L) I_2 &= 0
\end{align*}
\]

(1)

where \(R_1\) and \(R_2\) are the internal resistances of the Ground Assembly (GA) coils and the Vehicle Assembly (VA) coils, respectively. \(R_L\) is the load resistance, \(L_1\) and \(L_2\) are the inductance of the GA and the VA coils, respectively. \(C_1\) and \(C_2\) are the compensation capacitors of the GA and the VA coils, respectively, and \(\omega\) is the resonance frequency.

![Figure 1. Schematic view of WPT systems.](image)

According to (1), the corresponding input and output impedance can be calculated as:

\[
\begin{align*}
Z_1 &= R_1 + j\omega L_1 - j\frac{1}{\omega C_1} \\
Z_2 &= R_2 + j\omega L_2 - j\frac{1}{\omega C_2} + R_L
\end{align*}
\]

(2)

Simplified from (1) and (2), The real power transfer efficiency can be calculated by:
where $M$ is the mutual inductance.

3. Test indices and method of the WPT systems performance

In the SAE J2954TM April 2019 version [4] and the GB/T 38775.1-2020 standard [5], the general requirements of WPT systems for EV are given. Through the interpretation of the standard, this paper determines three important test indices of WPT systems, including transmission efficiency, component surface temperature and magnetic field radiation intensity.

![Figure 2](image_url)  
**Figure 2.** Test items for WPT systems.

The main test items of WPT system for EV are shown in Figure 2. Among them, the main measurement information includes: voltage value and current value at the AC input side, voltage value and current value at the DC output side, relative coordinate position between the VA coils and the GA coils, relative deviation angle between the VA and the GA, sample surface temperature, electromagnetic radiation intensity around the sample, etc.

### 3.1. Efficiency

The efficiency shall be determined by measuring the power from the AC grid to the GA electronics and measuring the DC power in the VA. Efficiency is the ratio of output power to input power, expressed as a percentage.

![Figure 3](image_url)  
**Figure 3.** Efficiency measurement point (1) and (2) in a WPT system.
3.2. Surface temperature
During the test, the surface temperature of the functional components shall be monitored to ensure that they meet the temperature limit requirements of SAE J2954TM April 2019 version and the GB/T 38775.1-2020 standard. During the test, the thermal camera is used to detect the surface temperature of the sample shell and other components, as shown in Figure 4.

![Figure 4. Schematic diagram of the thermal camera measuring temperature.](image)

3.3. Magnetic field intensity
The test bench is equipped with a magnetic field tester, which is used to monitor the magnetic field around the WPT sample in real time during the whole test process, and record the real-time change value.

4. Test bench construction and test verification for WPT systems

4.1. Construction of Test bench

4.1.1. Test stand requirement. The equipment for power transmission performance test is preset and specified in SAE J2954TM April 2019 version standard, as shown in Figure 5. The test bench can be used for matching and interoperability test, and is compatible with component level and vehicle level test of complete configuration.
The test equipment shall be able to meet the following requirements:
a) It enables X and Y offsets and Z-gap variation, and the automatic control accuracy is within ± 0.1 mm, meeting the accuracy requirements; b) It can meet the requirements of rotation angle test, and the accuracy of rotation angle can reach ± 1 °; c) It can measure the input and output power of the system and calculate the system efficiency in real time; d) It is able to monitor the temperature.

4.1.2. Test bench configuration. The whole test bench is controlled by the automatic program. Each equipment communicates with the bench in various forms such as RS232 / 485 / WLAN, feeding back current information in real time and changing the state according to the test requirements, as shown in Figure 6. The automatic operation bench controls the progress of the whole test, and presets certain protection for the power supply / load to prevent accidents.
4.1.3. Test bench prototype. An experimental prototype as shown in Figure 7 is established to confirm the practicality of the test bench for WPT systems, including integrated programmable Isolated AC power supply (adjusting input voltage amplitude and frequency), programmable electronic load (adjusting output voltage, current and power), power analyzer (testing input harmonic current and power factor, input and output power, system efficiency), six axis movable stand (to adjust the position and angle rotation of the GA coils and the VA coils) and magnetic field tester (magnetic field test).

![Test bench prototype for WPT systems.](image)

**Figure 7.** Test bench prototype for WPT systems.

4.2. Verification test of WPT systems

4.2.1. Test Scheme. After completing the initial setting and safety protection setting of the test bench, we can run the automatic calibration program, and start the test after the calibration is correct.

a) Place the VA coil and the GA coil on the fixed six-axis stand and mobile support stand, respectively, align the initial position, and adjust the initial nominal z-axis air gap; b) Start the AC power supply and electronic load to make the WPT system work normally; c) Adjust the position of the GA coil by industrial computer, such as offset, rotation, tilt, etc., and record the system efficiency, power factor and other parameters under different positions by power analyzer; d) Analyze test data and get test results.

4.2.2. Verification test. We select the WPT system composed of the GA sample from manufacturer A and the VA sample from manufacturer B for performance test, respectively. The power level is WPT2, and the transmission distance level is Z1, Z2 and Z3. The three-phase rated input voltage of the GA is 380V, and the rated current is 16A. Figure 8 shows the effect of offset and rotation on efficiency and output power under different z-axis gaps, as well as the change of sample surface temperature and radiation intensity of surrounding magnetic field during the test.
(a) The effect of Z-axis gaps on efficiency and output power.

(b) The effect of Z-axis gaps on efficiency and output power.

(c) The effect of Z-axis rotation on efficiency and output power with different Z-axis gaps.
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(d) Equipment surface temperature time-varying curve.

(e) Intensity time-varying curve of surrounding magnetic field.

Figure 8. Partial measurement data of test bench for the WPT system

It can be seen from the Figure 8 that the test bench can measure the performance indicators of the WPT system mentioned in this paper comprehensively.

5. Conclusion
The main contributions of this paper are as follows:

Three important test indices and specific test methods of the WPT system performance for EV are proposed.

A test bench prototype for a WPT system of EV is proposed, and the performance of the prototype is verified through specific sample test.

The work of this paper has certain guidance and reference significance for the construction and improvement of the follow-up bench, and provide technical support for the industry to carry out the test and verification, so as to promote the technical progress of the industry.

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References
[1] X. Zhang, X. Chen, and Z. Liu, A new design of wireless power transfer using cubic magnetically-coupled resonant, in Proc. Prog. Electromagn. Res. Symp., (2016) 5176-5178.

[2] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, Wireless power transfer via strongly coupled magnetic resonances, Science, 317 (2007) 83-86.
[3] A. Ahmad, M. S. Alam, and R. Chabaan, A comprehensive review of wireless charging technologies for electric vehicles, IEEE Trans. Transport. Electrific., 4 (2018) 38-63.

[4] Wireless Power Transfer for Light-Duty Plug-In/Electric Vehicles and Alignment Methodology, document SAE J2954TM, 2017.

[5] Electric vehicle wireless power transfer-Part 1: General requirements, document GB/T 38775.1, 2020.