BASIC EXPERIMENT ON 13.56 MHZ COUPLING SYSTEM OF WIRELESS POWER TRANSFER FOR ELECTRIC VEHICLE DYNAMIC CHARGING

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ABSTRACT

Wireless power transfer (WPT) is not strange to human being, since as early as 1889 Nikola Tesla had invented the famous Tesla coils which can transfer power wirelessly. Thereafter, researches on wireless power transfer began. Nowadays, WPT becomes the most convenient solution for small device charging. It can be used in mobile phone, laptop for small power transfer – about tens watt or hundreds watt. Others way, it also be used for electric vehicle (EV) charging which is kilowatts application. WPT has some undeniable advantages: contactless, more safely. But it still keeps the disadvantage: short distance which is the most difficult to eliminate. After research team of MIT proposed coupled magnetic resonance (CMR) and had a result of transferring 60 watts wirelessly over distances in excess 2 meters [1], WPT are continue in development with high power, high efficiency, long distance. There are the advantages of magnetic resonance coupling (MRC). In present, WPT with MRC – with advantages – is become the best choice for mobile power transfer, specially using for moving electric vehicle charging. In this paper, strongly coupled magnetic resonance (SCMR) antenna is investigated. The efficiency and power transfer of coupling system with electromagnetic analysis have been studied. The effect of mechanical parameters is examined in simulation. Adding that, the real coupling system is experimented. We achieve 76% efficiency at 118W transfer power and 50% efficiency at 302 W power transfer. The distance between transmitting and receiving coils is 500 mm in the experiment.

1. INTRODUCTION

In the present, energy and environment are concerned. In daily life and production, transport is very important. It also consumes a lot of energy. Gasoline and oil are used in common. They have the high energy density but they are limited. Moreover, the emissions are the major issues when fossil energy is used. Hence, the electrification for transportation has been carrying out for many years. A train can get electric power easily because it runs on a fixed rail. It's not easy for EV to get power in a similar way. Therefore, the EV has to equip a large and heavy battery pack. It is very necessary for a long trip. And people have to connect the vehicle to power source for a long time to charge the battery. It is not convenient. Dynamic charging by using WPT is a solution. It can increase the moving distance and reduce the battery capacity.

When the WPT is used in EV, the frequency is usually less than 100 kHz, and using ferrite core. It is not different from inductive power transfer (IPT) because of using non-radioactive and near-field electromagnetic. The transfer power can reach tens kW but the distance is below 200 mm [2]-[6]. In 2007, the research team from MIT published a paper in Science, in which 60W power is transferred over 2 meters. And they call the technology is strongly coupled magnetic resonance. The resonance frequency is about 10MHz. Until now, the MHz frequency operation is hard to meet the high power, long distance and high frequency. If we can solve this problem, SCMR can be one of the best solution in WPT for EV charging. In this paper, we investigate the characteristic of SCMR antenna and experiment with 300W transfer power and 500 mm distance.

2. COUPLING SYSTEM

2.1 WPT system

Wireless power transfer is transferring the electric energy over the air without conduction. The basic configuration of WPT system is shown in Fig. 1. It contents ac to dc converter (AC/DC converter), high frequency converter (DC/RF), impedance matching network (IMN), coupling system – transmitting coils and receiving coils, RF/DC rectifier and load.

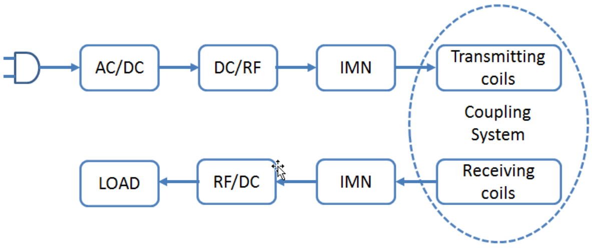

Fig. 1. Configuration of WPT system.

First, the ac power is converted to a dc power source by an AC/DC converter. Then, the DC/RF module converts the power to high-frequency ac to drive the transmitting coil through impedance matching network. The power goes from receiving coils to rectifier through other IMN. The DC power will be apply to load.

2.2 Coupling system

The coupling system which is called antenna is the importance part of WPT system because it makes power transfer system become wirelessly. It also determines the transfer distance and efficiency of system. With magnetic coupling resonance theory, coupling system can be divided into normal CMR (Fig. 2 (a)) and SCMR (Fig. 2(b)). In normal CMR, transferring side or receiving side consist of resonant coil and external capacitor in serial. The combination of capacitor and inductance of resonance coil is the resonance circuit.

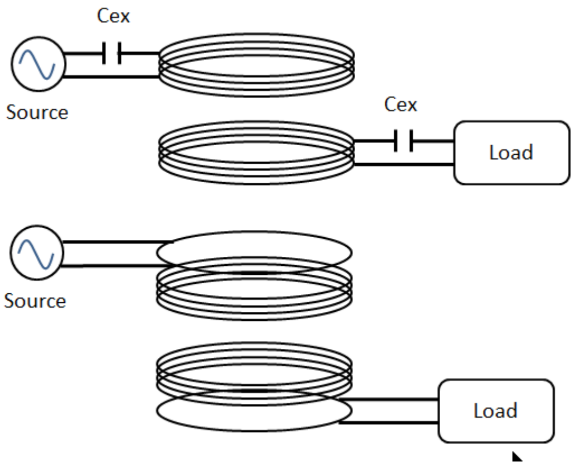

Fig. 2. Configuration of coupling system.
(a) Coupled magnetic resonance.
(b) Strongly Coupled magnetic resonance.

The structure of SCMR is much different from CMR. SCMR operates without external capacitor. There are only two coils for driver side and load side: the ring and the resonance coil. The capacitance between coils, the parasitic capacitance inside the coils and the inductance of coils make a resonance circuit. The equivalent circuit of SCMR is shown in Fig. 3. The Vs and Rs are the internal parameters of power source. R1 and L1, R2 and L2, R3 and L3, R4 and L4 are the internal resistor and inductance of transmitting ring, transmitting coil, receiving coil and receiving ring, respectively. The internal and parasitic capacitance of transmitting coil and receiving coil is C3 and C4, respectively. The resonance is occurred between coils if there private resonance frequency is matching.

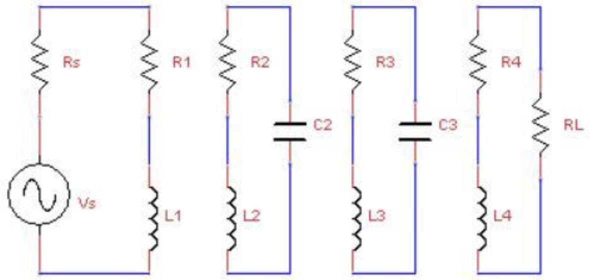

Fig. 3. Equivalent circuit of SCMR antenna

The antenna can be analyzed by s-parameter method. With this method, the antenna is replaced by state with two ports. The source side port is P1 and the load side is P2. The transmission S21 is measured by finite element analysis (FEA) or the vector network analyzer (VNA). The efficiency of coupling system is defined by equation (1).

$$\eta_{21} = S_{21}^2 \times 100 \;\; [\%] \qquad (1)$$

3. SIMULATION

In order to achieve the resonant frequency and high efficiency of the antenna, we investigate the effect of mechanical parameters by simulation. In this case, the 3D model of coupling system is built and FEA is used to get the simulation result. The 3D model is shown in Fig. 4. All parameters are in millimeter except Tr which is numbers of turns of resonance coil.

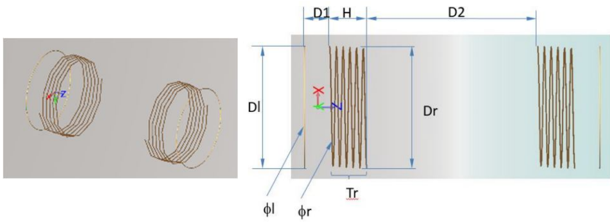

Fig. 4. 3D model of antenna.

The basic model which parameters are showed in Table 1 is firstly simulated. After that, the parameter which is investigated is changed around the first parameter. The results are shown in Fig. 5.

Table 1. Parameters of basic model

ϕl	ϕr	Tr	Hr	Pitch	D1	D2
(mm)	(mm)		(mm)	(mm)	(mm)	(mm)
3	3	5	100	20	50	500

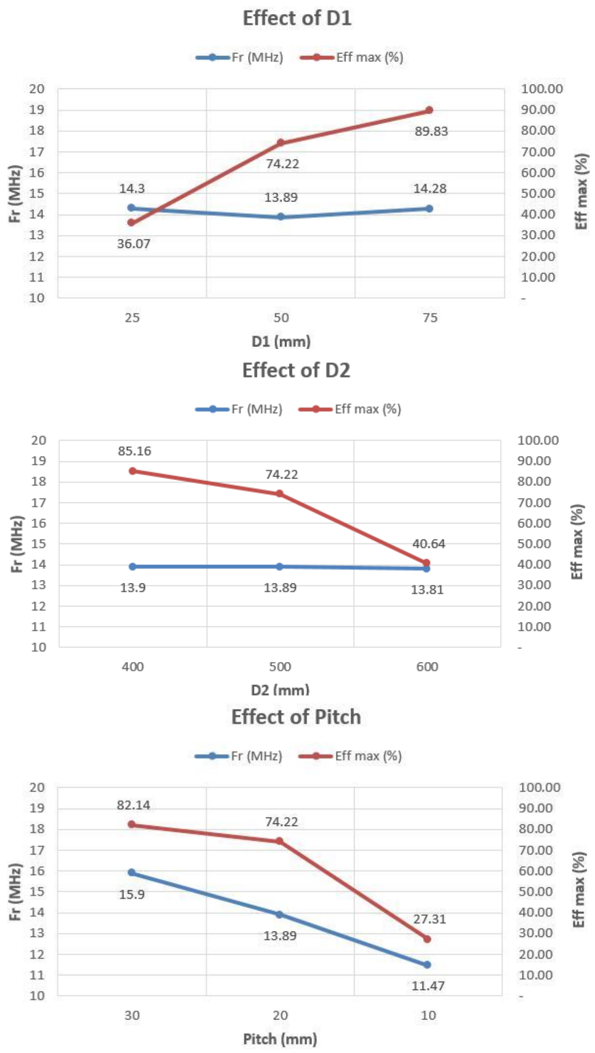

Fig. 5. The effect of antenna parameters to resonance frequency and maximum efficiency.

4. EXPERIMENT

The parameters of antenna are optimized by simulation and experiment to achieve 13.56 MHz resonant frequency at 500 mm distance. The picture of antenna is shown in Fig. 6. The parameters are in Table. 2.

Fig. 6. The picture of antenna

The antenna is supplied by an amplifier which can set the output power and frequency. On the load side, the antenna is connected to the resistor which is changed to several values. All of the coupling system and load are put inside the shield.

Table 2. Parameters of experiment antenna

ϕl (mm)	ϕr (mm)	Tr	Hr (mm)	Pitch (mm)	D1 (mm)	D2 (mm)
2.6	2.6	5.5	110	20	50	500

At first, the value of load is set at some value: 20Ω, 50Ω, 75Ω, 100Ω and the frequency is changed from 13.5 MHz to 13.6 MHz and the input power is about 120 W. The results are shown in Fig. 7. The highest efficiency is 76% with 20Ω resistor and 13.5 MHz frequency. But with other load, the highest efficiency is achieved at 13.56 MHz frequency.

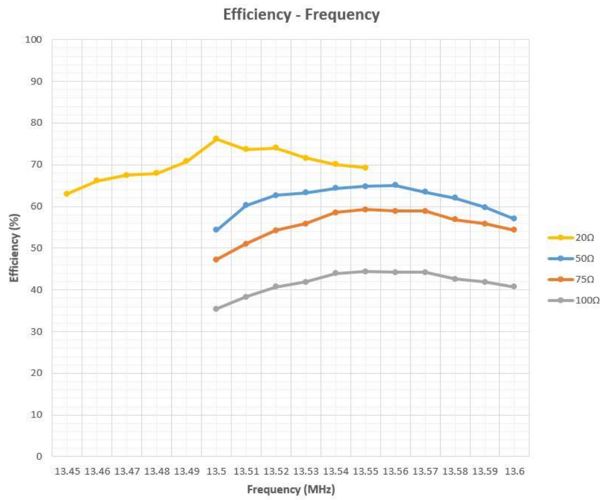

Fig. 7. The result of experiment when change the value of load

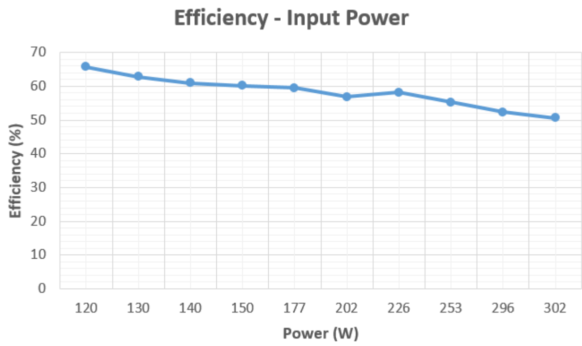

Fig. 8. The result of experiment when change the input power from 120 W to 302 W

In experiment with 50Ω resistor, the input power is increased from 120 W to 302 W at 13.56 MHz frequency. The efficiency reduces from 65.7% to 50% (Fig. 8). The antenna which is at higher input power is warmer than at lower input power. So the reduction of efficiency can be explained by the dissipation in the form of heat, as a result of eddy current and skin effect etc.

CONCLUSION

We have studied the effect of SCMR antenna parameters to resonant frequency and efficiency by finite element analysis. The antenna is hand-created and experiment was done. The maximum transferred power is about 150 W which can light a bulb or charging mobile phone etc. In order to charge an electric vehicle, the transferred power must be much larger. But the distance between transmitting coil and receiving coil is 500 mm. It is suitable for electric vehicle charging. Therefore, if we can optimize the design of antenna and reduce the power loss, an SCMR antenna can be applied to the midrange WPT application.

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