Electromagnetic Induction Wireless Power Transmission Efficiency Research

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Keywords: Wireless Charging, Transmission Efficiency, Simulation.

Abstract: Using the theory of mutual inductance coupling theory and establish mathematical model for the coupling coil wireless charging, is obtained by analyzing the key factors influencing the electromagnetic induction wireless power transmission efficiency: two coil radius relative position and relative size, coil, coil number of turns, working frequency and load, etc. Then by using Maxwell's software control variable method is used to simulation analysis was carried out on the key factors. According to the simulation results, summed up the method of improve the efficiency of the wireless charging equipment transmission.

1 INTRODUCTION

In recent years, along with the advance of science and technology, the traditional way of charging already can't satisfy people's needs, under the background of the wireless charging technology. The existing wireless charging technology there are four main ways: electromagnetic induction method, magnetic resonance (NMR) method, to electric field coupling mode and radio reception mode. Electromagnetic induction technology products on the production cost is lower than other techniques. Due to the wireless charging technology based on electromagnetic induction transmission efficiency is influenced by many factors, so the wireless charging technology based on electromagnetic induction study transmission efficiency is particularly important.

Maxwell is a powerful, accurate and easy to use 2D / 3D electromagnetic field finite element analysis software, Maxwell has a wizard style user interface, high accuracy of the adaptive split technology and powerful postprocessing features, 3D Maxwell for high performance 3D electromagnetic design software, Maxwell can analyze the eddy current, displacement current, set skin effect and proximity effect, the motor, bus, transformer, coil and other components of the overall characteristics, power loss, coil loss, a certain frequency of impedance, torque, inductance, energy storage and other parameters can be automatically calculated. At the same time can be given the whole phase lines, B/H distribution, energy density, temperature distribution and other graphic results. The software allows engineers to simulate complex electromagnetic fields.

2 ELECTROMAGNETIC INDUCTION PRINCIPLE OF WIRELESS CHARGING

Electromagnetic induction wireless charging through energy to realize the energy transfer coupling coil, the basic principle is in the sender and the receiver have a coil, send the coil connected high-frequency alternating power supply cable, and generate electromagnetic signal, the receiver coil receives the change of the electromagnetic signal, namely the induced electromotive force, through the rectifier filter circuit as dc voltage regulator, supply wireless charging equipment batteries, the charging process is completed.

Wireless charging system equivalent diagram is shown in figure 1 (Junyong et al., 2012). Assuming that AC power supply voltage for Us, circuit resonance frequency for ω; The transmitter coil current i_1, the impedance of the transmitter coil for z_1, transmitter coil equivalent resistance of R_1, the transmitter coil inductance for L_1, transmitter coil on the capacitor C_1, accept coil current i_2, accept the

Jiang T. and Cheng J.
500
Speech De-noising based on Wavelet Transform and Genetic Algorithm.
DOI: 10.5220/0006029505040509
In *Proceedings of the Information Science and Management Engineering III (ISME 2015)*, pages 504-509
ISBN: 978-989-758-163-2

impedance of the coil as the z_2, accept coil equivalent resistance R_2, accept coil inductance of L_2, accept the capacitance on the coil for C_2, launch mutual inductance between coils and receive coil for M; The impedance of the load for R_L.

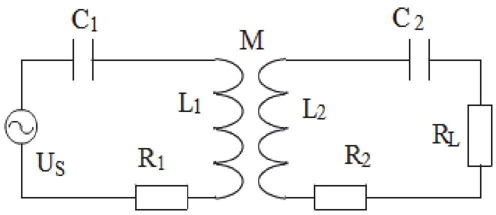

Figure 1: Schematic diagram of electromagnetic induction of WPT.

According to the circuit system diagram can get circuit impedance equation:

$$\begin{cases} Z_1 = R_1 + j\omega L_1 + 1/j\omega C_1 \\ Z_2 = R_2 + R_L + j\omega L_2 + 1/j\omega C_2 \end{cases} \quad (1)$$

By using kirchhoff's voltage law is available:

$$\begin{bmatrix} U_S \\ 0 \end{bmatrix} = \begin{bmatrix} Z_1 & j\omega M \\ j\omega M & Z_2 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} \quad (2)$$

By (1) (2) available for current equation:

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \frac{U_s}{Z_1 Z_2 + (\omega M)^2} \begin{bmatrix} Z_2 \\ -j\omega M \end{bmatrix} \quad (3)$$

Assumes that the transmitter coil and accept coil at the same resonance frequency, so $\omega L_1 = \omega L_2 = 1/\omega C_1 = 1/\omega C_2$ So the impedance of the circuit equation:

$$\begin{cases} Z_1 = R_1 \\ Z_2 = R_2 + R_L \end{cases} \quad (4)$$

So the output power of the load of PL and power supply output power for Ps equation:

$$P_L = i_2^2 R_L = \frac{(\omega M)^2 U_S^2}{\left[Z_1 Z_2 + (\omega M)^2\right]^2} R_L \quad (5)$$

$$P_S = U_S i_1 = \frac{Z_2 U_S^2}{Z_1 Z_2 + (\omega M)^2} \quad (6)$$

Charging efficiency can be represented as (Ying et al., 2003):

$$\eta = \frac{P_L}{P_S} = \frac{(\omega M)^2 R_L}{Z_2\left[Z_1 Z_2 + (\omega M)^2\right]} = \frac{(\omega M)^2 R_L}{(R_2 + R_L)\left[R_1(R_2 + R_L) + (\omega M)^2\right]} \quad (7)$$

As you can see, the transmission efficiency and M, ω, R_1, R_2, R_L, including mutual inductance L, M and coil axial spacing coil radial dislocation S, receiving coil diameter D, transmitter coil diameter D, closely related to the coil number of turns N (Huiping and Xueguan, 2007).

3 MAXWELL MODEL ESTABLISHMENT

The simulation steps of the 3D Maxwell model include: select the type of solver, establish the 3D model, set up the material properties, set the boundary conditions, set the excitation, the grid partition, the finite element calculation and the result processing.

Firstly analyzed the influence of the ferrite of coil, ferrite in wireless charging coil design has two main functions: 1) enhance the magnetic field intensity, reduce the magnetic flux leakage, for flux 1 the low impedance path; Isolation of metal material to the absorption of the magnetic field; 2) increase the induction distance, improve the coil inductance and quality factor (Na et al., 2012). Different ferrite materials because of the different permeability, frequency characteristics, has a great influence on the coil inductor, ferrite loss. Using Maxwell software model, transmitter coil with TDK PE22 ferrite materials, the receiver coil choose Fair Rite Material 44 ferrite materials of the company. The coil with ferrite shielding and coil without ferrite shielding are compared, and the simulation can be seen from the simulation results in table 1 compare, with ferrite shielding winding capacitance value increased significantly, coupling coefficient between coil was improved, too.

Table 1: Results comparision µH.

Project	Inductance simulation
Accept the coil D1 No ferrite	19
Accept the coil D1 Have a ferrite	29.3
Receiving coil D2 No ferrite	10.2
Receiving coil D2 Have ferrite	21.10

Using software Maxwell model, give a transmitter coil plus the sine voltage of 12 V, set the transmitter coil pure impedance is 0.03 Ω, transmitter coil inductance for 30μH, pure impedance of receiver coil is 0.3 Ω receiving coil inductance for 20μH.To analyze the impact of various factors on the transmission efficiency, software simulation using the control variable method. Constant when the choice, according to the actual application situation, first determine the receiving coil diameter D is 60 mm, after many experiments, the other parameters constant finally selected as shown in table 2.

Table 2: Model parameters.

project	Constant value	range
Accept coil D1	60 mm	-
Transmitter coil D2	60 mm	30mm-90 mm
Coil radial dislocation S	0	-10 mm -10 mm
Coil axial spacing L	0	0-15 mm
The coil number of turns N	30T	25T-35T
The input voltage frequency f	150kHz	50 kHz -300 kHz
Load RL	10Ω	1Ω-70Ω

4 THE EXPERIMENTAL RESULTS

The experimental results are shown in figure 2 ~ 7

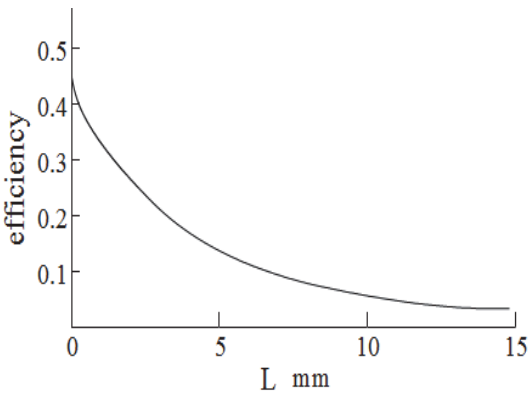

Figure 2: Efficiency - coil spacing L.

Coil can be seen from the figure 2 power transmission efficiency increases with coil distance L fell quickly, when the spacing of 5 mm, only coil joint efficiency of 30%.

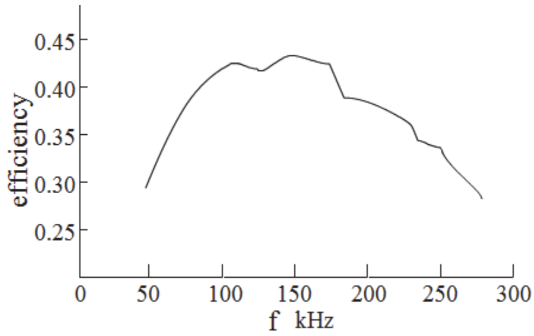

Figure 3: Efficiency - coil spacing L.

As you can see from figure 3, when fi is less than 100 KHZ, efficiency as the fi and improve, when fi is greater than 150 KHZ, basic as fi lower and lower efficiency.

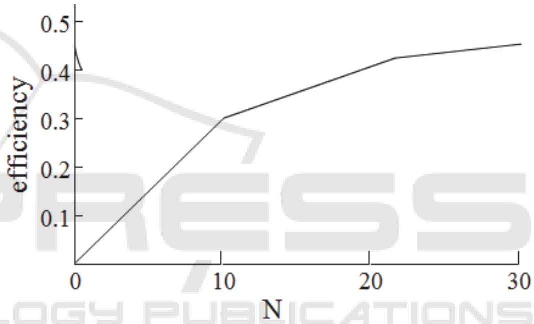

Figure 4: Efficiency - coil spacing L.

You can see from figure 4 efficiency as the coil number of turns N increases.

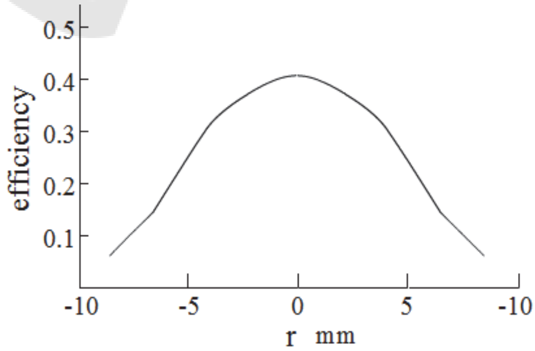

Figure 5: Efficiency - coil spacing L.

Can see from figure 5, when the offset r coil diameter of 0, the receiver and the transmitter coil equal size, maximum efficiency.

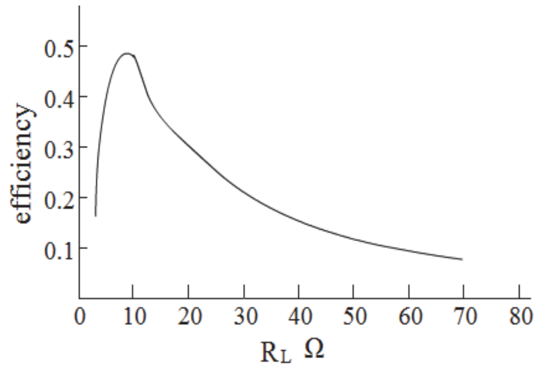

Figure 6: Efficiency - coil spacing L.

Can see from figure 6, when the load RL is 10 Ω reach maximum efficiency.

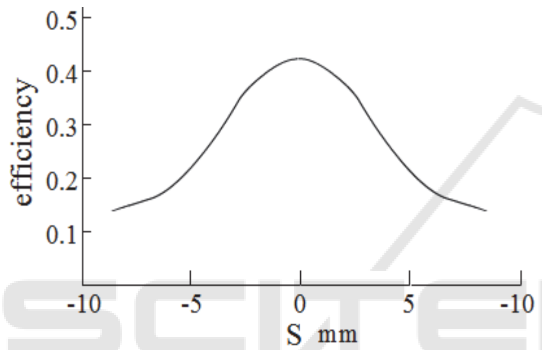

Figure 7: Efficiency - coil spacing L

From figure 7, you can see that the transfer efficiency is very sensitive to the radial dislocation, the efficiency of the radial dislocation is 5 mm is no radial position only mistake efficiency 47%.

5 CONCLUSIONS

According to above the results of simulation analysis, to improve the efficiency of wireless charging device, should try to shorten the transmitter coil and the receiving coil axial spacing, the coil as close to as possible, to control the equipment at the same time, the working frequency of frequency range between 100 KHZ to 150 KHZ. In the conditions allow, as far as possible increase the coil number of turns; Receiving coil and the transmitter coil diameter should be equal or close, under the condition of the simulation, the applicable load for 6 Ω~15Ω, can only meet the demand of small wireless charging devices; Because the efficiency is sensitive to the radial dislocation, all must be fixing the transmitter coil and the location of the receiver coil.

Since the establishment of wireless charging Union (WPC), wireless charging technology has been paid more and more attention, how to improve the efficiency of wireless charging, especially to improve the efficiency of large power wireless charging is still a very difficult task (Zhang Bao Qun, Li Xiang Long, 2015). In this paper, some suggestions are put forward to improve the transmission efficiency from the angle of the electromagnetic induction coil coupling. The research on the large power promotion will be the next research direction.

ACKNOWLEDGEMENTS

The authors acknowledge the financial Supported by a project grant from Huaian technology bureau (Grand No.HAG2014007).

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