Uniform Magnetic Field distribution for free-positioning wireless power transfer system

Quandi Wang, Yingcong Wang

State Key Laboratory of Power Transmission Equipment and System Security and New Technology, Chongqing University, Chongqing, 400044, China

Free-positioning magnetically-coupled resonant wireless power transfer (MCR-WPT) systems have intensively potential application such as desktop devices. The movement of receiving coil (Rx) may result in impedance mismatch of the system and decline of power transfer. This paper proposes a novel coil to generate uniform magnetic field distribution for Rx coils when transfer distance increases to several cm. Each turn of the proposed coil is composed of five circular coils and the location of each coil is properly arranged by optimization method. Using the designed parameters, the vertical magnetic field of proposed coil is simulated and compared with those of circular coil. The magnetic field generated by proposed coil is more uniform than those of circular coil on the effective charging area. A WPT prototype is implemented to verify the analysis and acceptable results are obtained.

***Index Terms*—free-positioning, wireless power transfer, vertical magnetic field, deviation.**

I. Introduction

In recent years, there has been great interest in the area of magnetic resonant wireless power transfer due to its wide application potential, such as desktop electronics. The Rx coil attached to these devices may move during charging period. Such movement may vary mutual inductance and subsequent impedance mismatch may seriously decrease power transfer [1, 2]. Therefore, research groups put forward some adaptive impedance-matching methods [3, 4], which require complex control schemes. Uniform field generation is a better solution and thus several kinds of coil structures are presented to maintain uniform mutual inductance between Tx and Rx coils [5-8]. However, the transfer distance is designed to be only several mm.

In this paper, a novel coil is presented to generate uniform magnetic field distribution on a specific rectangular area, which has a gap of 5cm. Each turn of the proposed coil is composed of five circular coils. Both the size and location of each coil is properly arranged by optimization method. Simulations are carried out to verify the proposal. The paper is structured as follows. In section II, the vertical magnetic field generated by a circular coil is deduced and analyzed. Then a novel coil structure is described in detail and characterized by superposition principle. In section III, the magnetic field generated by the proposed coil and circular coil are simulated and compared with each other. A WPT prototype is implemented to verify the analysis. Section IV concludes this paper.

II. Optimization Design of Transmitting Coil

A circular current is commonly used as energy source in WPT system. Based on the Biot-Savart law and superposition, the vertical component of magnetic field at the transfer distance (z_1) can be calculated as

$$H_z = \frac{1}{\mu_0}\frac{\mu I}{2\pi}\frac{1}{\left[(R+r)^2+z_1^2\right]^{\frac{1}{2}}}\times\left[K(k)+\frac{R^2-r^2-z_1^2}{(R-r)^2+z_1^2}E(k)\right] \quad (1)$$

where the excitation current is represented by I, $K(k)$ and $E(k)$ stand for elliptic integral of the first and second order. R represents the radius of the transmitting coil. The lateral misalignment of field point is denoted by r. The parameter k is defined as

$$k^2 = \frac{4Rr}{(R+r)^2+z_1^2} \quad (2)$$

It can be observed from (1) and (2) that the same shape of H_z-$r/R(x_1/R)$ curve is preserved under the condition of identical z_1/R, which is defined as relative axial distance. When z1/R is larger than 0.4, the magnetic fields mainly focus near the center area. Considering that the transfer separation is usually the same order of the diameter of coils in WPT system, the magnetic fields in a convex manner is of particular interest.

The structure consisting of 5 circular coils is proposed to generate uniform field on a specified square surface. The current flowing direction and locations of five coils are shown in Fig.1. It is worthy to be noted that coil 1~4 are symmetrical.

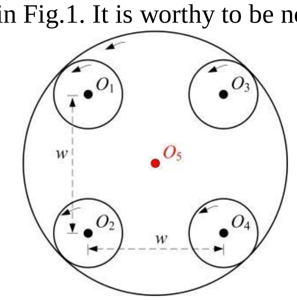


Fig. 1. The proposed structure

If the distance between O_1 and O_5 is the r_1 corresponding to the smallest H_z, the perpendicular magnetic field of four inner coils (Coil 1~4) is non-linear in a concave manner that its magnitude is smallest in the central region, as shown in Fig.2. Such concave manner exists only when w is larger than a critical value of w_0. As the magnetic field of the 5th circular coils behave in a convex manner, the superposition magnetic field of these five coils will be much more uniform than that of both cases.

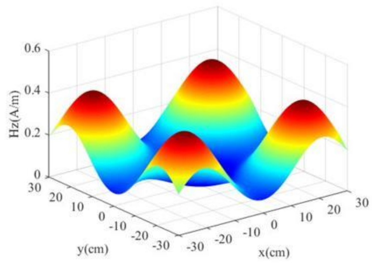


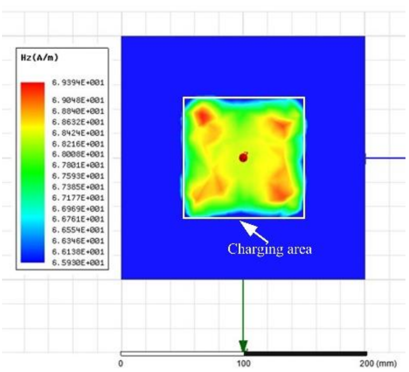
Fig. 2. The perpendicular magnetic field generated by four outside coils

To keep the same current in each coil, these five coils should be connected in series to form a closed loop. When the charging area is 10cm×10cm with a 5cm gap, the radius of coil 1~5 and positions of coil 1~4 are optimized by using MATLAB. Then the designed parameters are

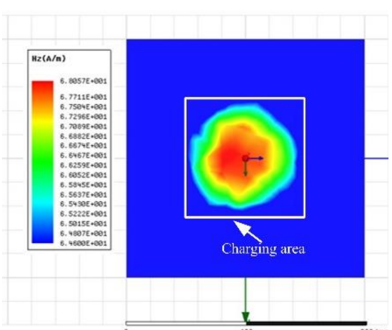
R_0=9.62cm, w=11.6cm

III. Verification and Discussion

Using the designed parameters, simulation models of two-turn coils are established in Ansys Maxwell software package and the perpendicular magnetic field H_z is plotted in Fig.3. Note that the deviation of Hz exceeds 5% on the blue area. Compare with circular coil, the perpendicular magnetic field of the proposed coil is much more uniform than those of conventional coil.



(a)The proposed coil



(b)Circular coil

Fig. 3. Simulated magnetic field on charging surface

Fig.4 explains the setup for measuring received power and results are plotted in Fig.5. Note that resonant frequency of our system is 6.78MHz. The test region is set from x =−5cm to +5cm. The curve of received power is not perfectly symmetric because small error of coil position is inevitable. The load demand is 3W and deviation of output power is 0.12W, which occupies only 4% of load power. Therefore, WPT system with the proposed coil shows a stable output power according to the Rx coil's position.

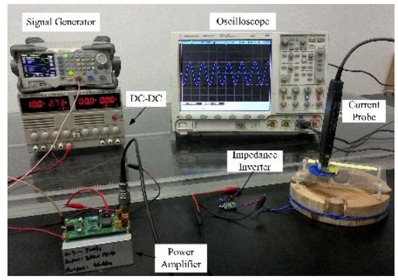


Fig. 4. The perpendicular magnetic field generated by four outside coils

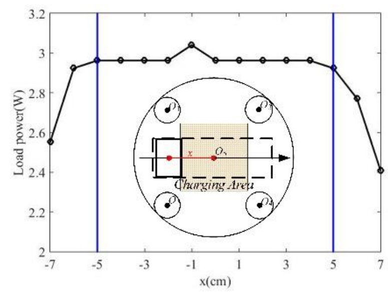


Fig. 5. Load power versus the lateral position of the Rx when gap is 5cm

IV. Conclusion

In order to prevent significant drops in power transfer, this paper proposes a novel Tx coil structure. When transfer distance is 5cm, simulated magnetic field shows that the uniformity of a novel coil is much better than those of circular structure on the effective charging area. Finally, measurements reveal that the deviation of output power is only 4%.

References

[1] Lee, S.G., Hoang, H., Choi, Y.H., and Bien, F.:'Efficiency improvement for magnetic resonance based wireless power transfer with axial misalignment', Electron. Lett., 2012, 48, (6), pp. 339–340

[2] Koizumi, M., Komurasaki, K., Komaru, T., Mizuno, Y., Shibata, T., and Kano, K.:'Mid-range wireless power transmission in space'. 8th Annual Int. Energy Conversion Engineering Conf., Nashville, TN, USA, July 2010, pp. 2010–6918

[3] Lee, W.-S., Lee, H.L., Oh, K.-S., and Yu, J.-W.:'Switchable distance based impedance matching networks for a tunable HF system', Prog. Electromagn. Res., 2012, 128, pp. 19–34

[4] Park, J., Tak, Y., Kim, Y., Kim, Y., and Nam, S.:'Investigation of adaptive matching methods for near-field wireless power transfer', IEEE Trans. Antennas Propag.,2011,59, pp. 1769–1773

[5] J. Kim, H.-C. Son and Y.-J. Park.:'Multi-loop coil supporting uniform mutual inductances for free-positioning WPT', Electronics Letters.,2013,49, pp. 417–419

[6] Xun Liu, S. Y. Hui. :'Optimal design of a hybrid winding structure for planar contactless battery charging platform', IEEE Transactions on Power Electronics.,2008,23, pp. 455 - 463

[7] L Shen，W Tang，H Xiang，W Zhuang. 'Uniform magnetic field by changing the current distribution on the planer coil for displacement-insensitive wireless power transfer/near field communication', Microwave & Optical Technology Letters, 2015, 57, pp. 424-427

[8] WS Lee，H Lim Lee，KS Oh，JW Yu. 'Uniform magnetic field distribution of a spatially structured resonant coil for wireless power transfer', Applied Physics Letters, 2012, 100, pp. 1-5