Design and Analysis of Cubical Compact Coils for Wireless Power Transfer

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I. INTRODUCTION

As an emerging technology, wireless power transfer (WPT) has attracted substantial attention in many applications, such as electric vehicles, portable electric devices and medical instruments [1]. Generally, the WPT system possesses the advantages of safety, high reliability, low maintenance, and electrical isolation [2]. As one of the most prominent technologies, the WPT is changing the conventional usage of energy in daily life for human being. The key element in the WPT system is a pair of magnetically coupled coils [3-5]. When delivering power in a large area, multiple coils can be adopted to form a single uniform magnetic field. Also, in the multifrequency WPT system, a single transmitter can be used to feed multiple receiver coils with different resonant frequencies [6]. Usually, the coreless planar coil is preferable to achieve better ability of tolerance to misalignment than that with ferrite core. Since the circular coil has the problem of limited coverage, the rectangular coil is preferable in the multiple-receiver WPT system. However, in order to provide the desired power transfer capability, the size of this kind of system is usually very large and thus the system flexibility is reduced. Normally, a single-layer planar coil is used for both the transmitter and receiver, which will significantly increase the system complexity and occupied volume.

This paper focuses on the design and analysis of multilayer rectangular coil structures, dubbed as cubical compact coils, for those multiple-receiver WPT systems desiring compact size and good power transfer capability. In order to make sure that the mutual inductances of the multiple receivers are the same, the magnetic field distribution over the transmitter should be uniform enough. This paper proposes three different types of cubical compact coils, namely the spiral type, concentrated type, and uneven compound type. Their designs and analyses are elaborated. Apart from assessing their magnetic field distributions, the corresponding electric potential distributions are analyzed at different currents to provide the guidance for selection and arrangement.

II. METHODOLOGY

The proposed cubical compact coil structures are shown in Fig. 1, which are the spiral type, the concentrated type and the uneven compound type. These three coil types can be applied to both the transmitter and receiver. For exemplification, the peripheral dimensions are 200 mm and 140 mm. The Litz wire with 165×0.1 mm is adopted to make up all coils. For the spiral type, all turns of the coil are distributed evenly with two layers. Meanwhile, for the concentrated type, all turns of the coil are bundled together with two layers. By combining the advantageous features of both the spiral type and concentrated type, the uneven compound type is proposed where five turns form one bundle with two layers and the pitch distances between every two bundles are not the same, namely, S_1=3 mm, S_2=5 mm, and S_3=7 mm. Once the system parameters are predefined, the mutual inductance between the transmitter and receiver becomes the major determinant of the system performance such as power transfer capability and efficiency. Generally, the uniform magnetic flux density makes the mutual inductance keep constant, thus improving the ability of misalignment tolerance. Therefore, the magnetic field distribution can be utilized to analyze the system performance. Based on the same peripheral dimensions, the magnetic field distributions and electric potential distributions of all three types of coils are analyzed by using the finite element method based software JMAG.

As a result, the spiral type of coil essentially provides the magnetic field distribution in a conical-like shape as shown in Fig. 2(a), whereas the concentrated type of coil presents a rectangular concave-top distribution as shown in Fig. 2(b). Meanwhile, the uneven compound type can provide much more uniform magnetic field distribution than both the spiral and concentrated types. Focusing on the magnetic flux densities at the middle plane as shown in Fig. 2(c), it can be found that along the horizontal displacement, the uneven compound type can exhibit much more uniform field and hence achieve better tolerance for the misalignment. Moreover, for this kind of multilayer structures, the proximity effect should be analyzed. As shown in Fig. 2(d), the maximum electric potential of the concentrated type of coil is simulated, which is well below the breakdown voltage of 1400 V of the Litz wire. Finally, an experimental prototype has been constructed and tested to verify the feasibility of the proposed system. More experimental results including the power transfer capability and misalignment tolerance will be given in the full paper.

III. CONCLUSION

In this paper, three cubical compact coil types of transmitter and receiver for WPT have been proposed and implemented. They are particularly suitable for those multiple-receiver WPT systems desiring compact size and good power transfer capability. By newly combining the spiral coil type and concentrated coil type, the uneven compound coil type can provide more uniform magnetic field distribution, hence minimizing the difference of magnetic flux densities that can be picked up by multiple receivers. Moreover, the electric potential distribution is analyzed to ensure that the maximum electric potential is well below the breakdown voltage of the Litz wire. This work was supported by a grant (Project No. 17204317) from the Hong Kong Research Grants Council, HKSAR, China.

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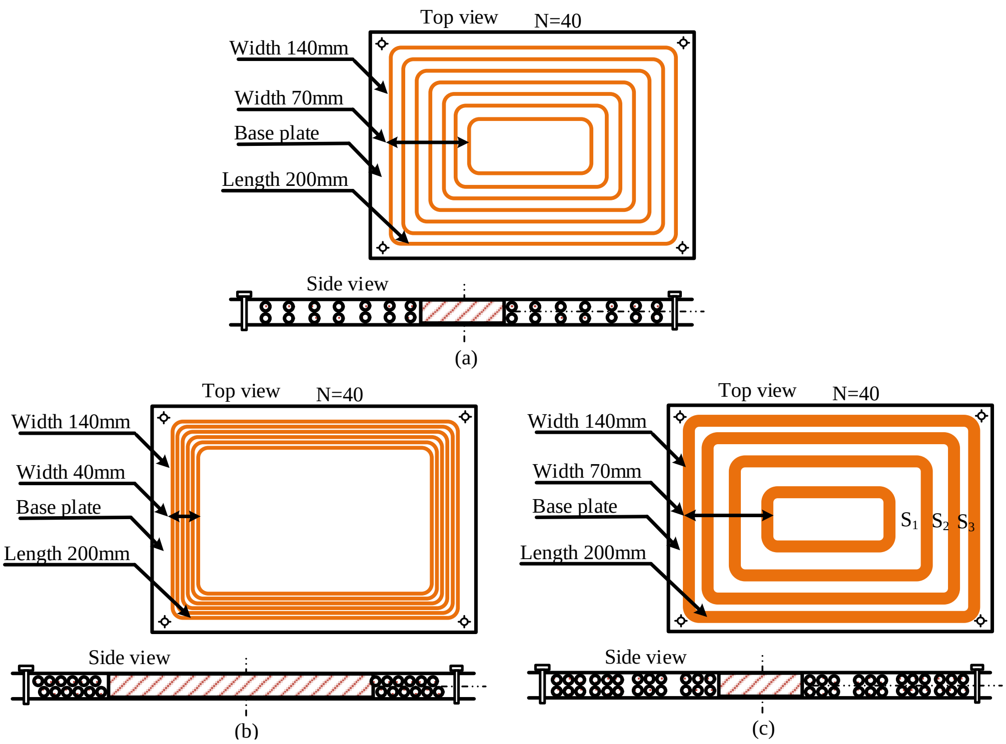

Fig. 1 Proposed cubical compact coil structures: (a) Spiral type. (b) Concentrated type. (c) Uneven compound type.

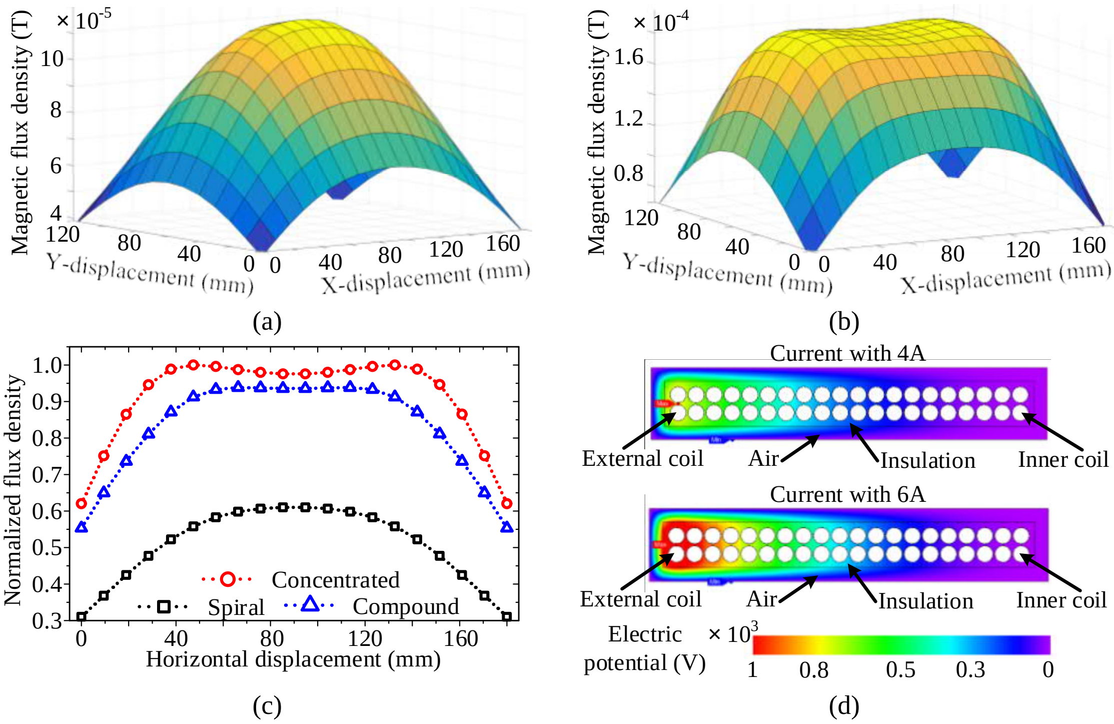

Fig. 2 Simulation results: (a) Magnetic field distribution of spiral type. (b) Magnetic field distribution of concentrated type. (c). Magnetic flux densities at middle plane. (d). Electric potential distributions of concentrated type.