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The Inductance Parameter Study ofLoose Coupled Transformer

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Abstract. We built the simulation model of loose coupled transformer in the foundation of the experimental model including the core of E-type. We analyzed the electro and magnetic relations of the loose coupled transformer, and by means of the energy method, the coupling coefficient is studied and inductances are calculated. Because of the abnormal working state of the WPT system in practical use, , we use ANSOFT to calculate both coupling coefficient and the inductances when longitudinal and lateral distance air gap is in different situation, in this way, we can study the coupling coefficient when the three factors changed, which can give a full reference for studying the coupling coefficient parameters of loose coupled transformer.

1.Introduction

As a cross subject in the field of electrical and electronic engineering, Wireless power transmission system is based on the principle of transformer in electrical engineering[1], adopting the power electronic technology such as power electronics, electromagnetic power transmission, implements the power by the original to the deputy while no electrical connection. As a brand-new electrician class discipline in resent years, WPT systems has received a lot of experimental research, its research results have been applied in all kinds of electronic products and electric power supply and charging systems.[2-4]In some special circumstances, such as mine, underwater, etc, WPT technology shows obvious advantage over traditional wired connection, especially in the avoid the switch switch, electrical, leakage of edm, and effectively prevent the security hidden danger, to curb the root cause of the accident.

We divide loose coupled transformer into three parts: including core type, resonance coupling and electromagnetic radiation. Among them, including core type core-type transmission system is more practical, relative to other two outstanding performance in the core of loose coupling transformer.[5-6]The same as the traditional transformer, there is a large permeability core in the loose coupling transformer, improved the effect of the permeability of the entire system effectively, which reduced due to the magnetic field and magnetic circuit magnetic resistance caused by the rising through the air, to a certain extent. However, due to the smaller permeability of the air, the coupling of the loose coupled transformer is still small, especially when the situation is bad, coupling coefficient will also produce great influence, the efficiency will also be affected by the corresponding.

To this end, the paper focus on the WPT system coupling coefficient of the loose coupled transformer. Considering the WPT systems working in the case of non-ideal state, through the loose coupled transformer model, using finite element software, the former vice edge analysis of the loose coupled transformer inductance parameters and coupling coefficient by air spacing, vertical lateral and horizontal lateral distance and the influence of the magnetic permeability.

2.Methodology

Loose coupling transformer basic electromagnetic relation is shown in figure 1.

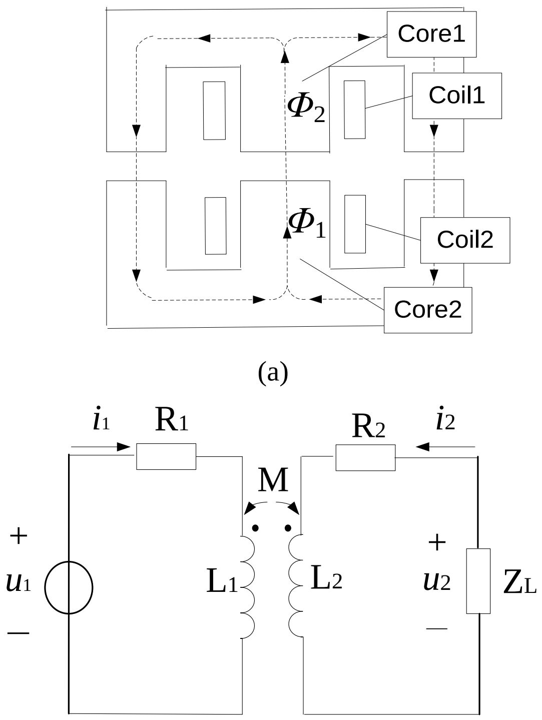

Figure.1 The Magnetic Relation and Electronic Relation of the System

Magnetic field Equations derived by maxwell's equations as follows:

$$\nabla\times\frac{1}{\mu}\nabla\times\boldsymbol{A}=\boldsymbol{J} \tag{1}$$

Current density is expressed by J, the vector magnetic potential is expressed by A, material permeability is expressed by μ. We can adopt current density J c by means of experimental measurement.

Unit interpolation as follows:

$$\boldsymbol{A}=\sum_{n=1}^{n_n}\boldsymbol{M}_n(x,y,z)A_n \tag{2}$$

A series of basis functions use the expression of n, The edge number is expressed by nn, The

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base sequence of functions is expressed by {Mn, n=1, 2, …,nn}.
The weighted residual equation is obtained by using the Green's theorem:

$$\iiint_V \frac{1}{\mu}(\nabla\times\boldsymbol{M}_m)\cdot(\nabla\times\boldsymbol{M}_n)A_n\,\mathrm{d}V=\iiint_V \boldsymbol{M}_m\cdot\boldsymbol{J}\,\mathrm{d}V \tag{3}$$

Among them, the base sequence of functions is expressed by Mm, Weight function and odd function are equivalent. Under the condition that I is known, put weight function into the plug type, available in the vector magnetic potential of the node A， we can calculate the vector magnetic potential in the fields B and H.

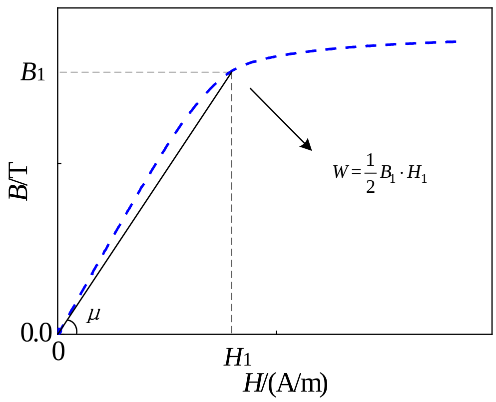

Figure.2 Energy Calculation Method

According to the energy method to adopt the magnetization curve by calculating the parameter. Figure 2 shows that B, H value can get from above can calculate magnetic energy value:

$$W=\frac{1}{2}\int_\Omega \boldsymbol{B}\cdot\boldsymbol{H}\mathrm{d}\Omega \tag{4}$$

At the same time, the transformer magnetic energy and inductance parameters and excitation current has the following relationship:

$$W=\frac{1}{2}L_{\mathrm{ab}}I_aI_b,(a,b=1,2) \tag{5}$$

Among them, on the condition that a=b, self inductance of the former and vice edge L11 and L22 can be calculated; on the condition that a≠b, mutual inductance of the former and vice edge M12 equals to L12.

Equation (4) energy result equals to equation (5), L1, L2, M12 can be obtained the same. This loose coupling transformer coupling coefficient can be obtained： $k=\frac{M_{12}}{\sqrt{L_{11}L_{22}}}$

3.The Study of Coupling Coefficient related Factors

Because of the loose coupled transformer on both sides of the coil winding on the two different core respectively, and an air gap exist between them. At the same time, the former and vice edge of lateral core may exist certain Angle, there may some errors spacing on two sides of the coil, which related to the efficiency, the inductance parameters and coupling coefficient. The paper researched on the former and vice edge coupling coefficient under different relative position.

At present, the commonly used core is U-U type, C-I type, E-E type, etc., we adopt the type of E as an example. The former and vice edge under different relative position of the loose coupled transformer coupling coefficient for simulation analysis.

3.1 The Study of Air Gap Thickness influencing the Coupling Coefficient. As shown in figure 3, the loose coupled transformer model is built, analyzing coupling coefficient when the air gap changed.

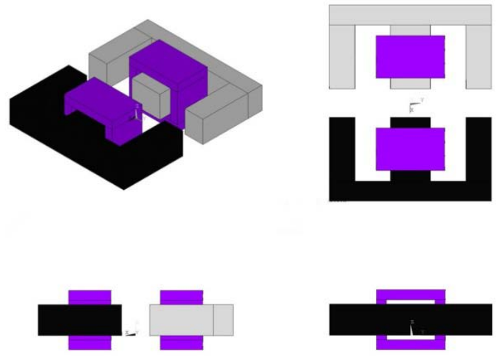

Figure.3 The 3D Model When the Air Gap is d

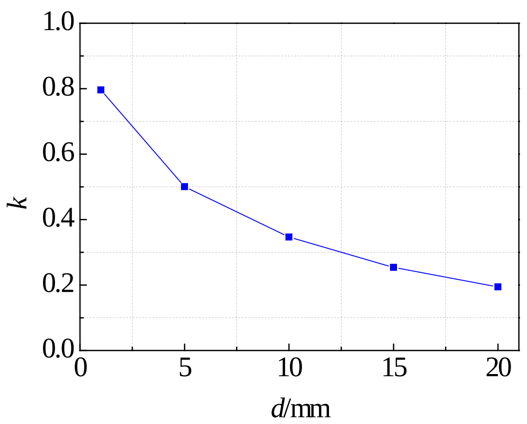

Figure.4 The relation between Coupling Coefficient and the Air Gap

The transformer core material is 30 q130 type silicon steel sheet, calculating finite element under 1 mm, 5 mm, 10 mm, 15 mm, 20 mm air-gaps. As is shown in figure 3, the coupling coefficient shows close to the air gap thickness, thickness of air gap increases in rapid attenuation of the inductance parameters and coupling coefficient greatly reduced.

3.2 Core Transverse Lateral Influence on Inductance Parameters. The figure 5 shows that loose coupled system model is built, studying when the air-gap is 10 mm, when the transverse lateral distance changed, coupling coefficient changes. The former and vice edge set core coaxial horizontal lateral distance is y = 0 mm.

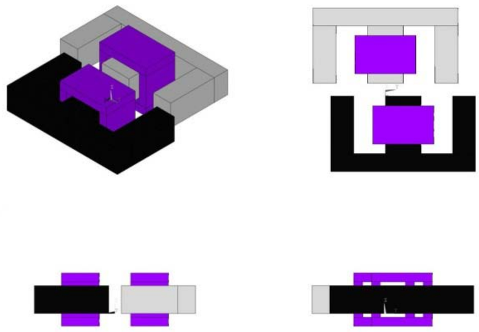

Figure.5 The 3D Model When the Transverse Lateral Distance is y

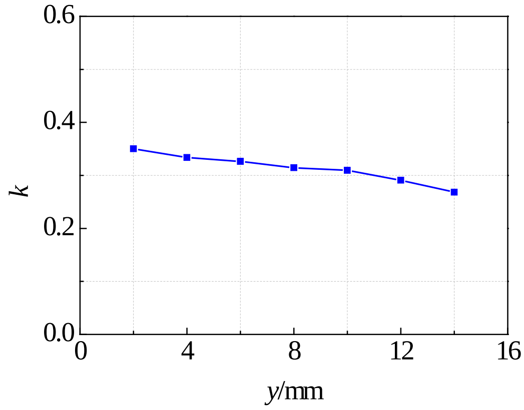

Figure.6 The relation between Coefficient and Transverse Lateral Distance

Calculating finite element under 2 mm, 4 mm and 6 mm, 8 mm, 10 mm, 12 mm, 14 mm lateral distance. The results shows that the loose coupled transformer air-gap thickness of certain circumstances, lateral distance show little influence on self-inductance, and mutual inductance reduced. Obviousely, the former and vice edge transverse lateral distance shows slight relation to the mutual inductance, coupling coefficient, lateral sway in the practical application of smaller cases, loose coupling transformer coupling coefficient of impact is small.

3.3 The Study of Longitudinal Lateral Influencing the Inductance Parameters. The figure 7 shows that loose coupled transformer model is built, studying when the thickness is 10 mm, when different longitudinal lateral distance coupling coefficient changes. The former and vice edge set core coaxial horizontal lateral distance is z = 0 mm, 2 mm, 4 mm and 6 mm, 8 mm, 10 mm five groups of longitudinal coupling coefficient under lateral distance value.

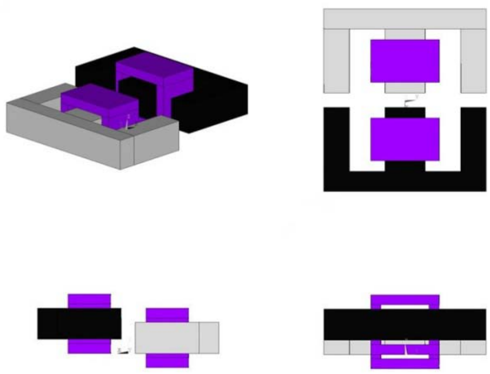

Figure.7 The 3D Model When the Longitudinal Lateral is z

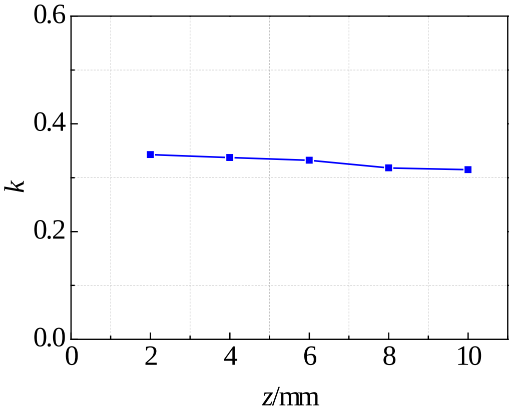

Figure.8 The relation between Coupling Coefficient and Longitudinal Lateral Distance

As shown in figure 6, when air-gap thickness of the loose coupled transformer is secure, coupling coefficient reduced when horizontal lateral distance increased, while it is slight, therefore, coupling coefficient shows some relation to the longitudinal lateral, but it’s small.

4.Conclusion

This paper studies the impact of coupling coefficient in loose coupled transformer in Wireless power transmission system when the former and vice edge in different relative positions, the conclusions are as follows:

Using ANSOFT, the finite element method, to analyze the coupling coefficient of loose coupled transformer when the system work abnormal. Coupling coefficient shows great changed when the air gap changed. While it changed slowly when horizontal and vertical lateral distance increased, the coupling coefficient decrease slowly. The inductance shows little relate to the lateral change, in the case of small lateral situation, coupling coefficient error cannot ignore; because of the coupling coefficient shows great relation to the air gap , to reducing the air gap size or percentage of air gap in the magnetic field transmission circuit, such as increasing size of the core, improve its nominal capacity, etc, can effectively make up for the thickness of air gap caused by the coupling coefficient of attenuation.

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