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Research Article

Study on the Characteristics of Loosely Coupled Transformer in Inductive Power Transfer System

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Abstract: A new kind of non-contact loosely coupled transformer of transmission method was proposed based on the principle of electromagnetic, thus to solve the problems of signal transmission in boring machine processing non-cylinder piston pin hole system. In this study, the factors that influence loosely coupled transformer characteristics are discussed, including coil position and air gap. Then, their influences are detailed presented by means of ANSYS simulation. Furthermore, choose appropriate coil position structure and air gap provides the reliable theory basis for non-contact power transfer system transmission.

Keywords: ANASYS, loosely coupled transformer, non-contact power transfer, transfer efficiency

INTRODUCTION

At present, the electric energy is mainly transmitted by direct contacting with wires and electrical devices such as collecting ring, brushes and spring plugs to the power supply in Giant Magnetostrictive Actuator (GMA) processing non-cylinder piston pin hole system. But this traditional power transfer mode is vulnerable to friction, erosion and so on. In consequence, not only the life span of electrical devices is decreased, but also the safety and the reliability of power supply are brought down (Zhai *et al*., 2007; Li, 2008).

A new method of non-contact signal transmission is carried out to realize power supply for GMA's drive coil which is installed internal of the high-speed rotary spindle. To transmit electrical signals by means of electromagnetic coupling, can avoid the carbon brush and collecting ring directly connected, as well as improve the transmission efficiency. The non-contact power transfer (ICPT) is based on the loosely coupled transformer. Which is able to achieve power transmission between power supply circuits and electrical equipments over a large gap, so the leakage inductance of loosely coupled transformer is relatively large and the coupling coefficient is relatively low (Zhang and Mao, 2007). The objective of the study is to choose appropriate coil position structure and air gap provides the reliable theory basis for non-contact power transfer system transmission.

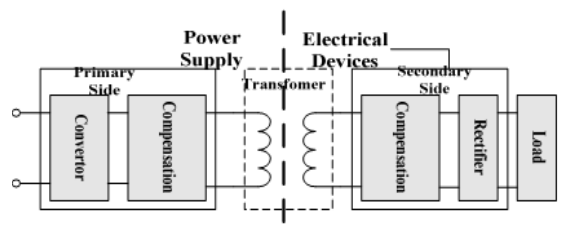

Fig. 1: The schematic diagram of CIPT system

TOPOLOGY STRUCTURE AND PRINCIPLE

As shown in Fig. 1, the loosely coupled transformer acts as an interface of primary side and secondary side and its characteristics are very critical to the performance of ICPT system. In contrast to the traditional closely coupled transformer, the loosely coupled transformer achieves power conversion from the primary side to the secondary side over a large air gap and both sides are separate. The magnetic path for loosely coupled transformer is much longer than that of conventional transformer and the magnetic motive force is mainly distributed in the air gap. So the leakage inductance of loosely coupled transformer is relatively large and the coupling coefficient is relatively low. The large gap in loosely coupled transformer brings a high stress on the switch and impacts power transfer capability, thus reduces the overall efficiency. As for the conventional transformer, the magnetic motive force is mainly distributed in the core, so the leakage inductance is much less and the coupling coefficient is high (Wu *et al*., 2003).

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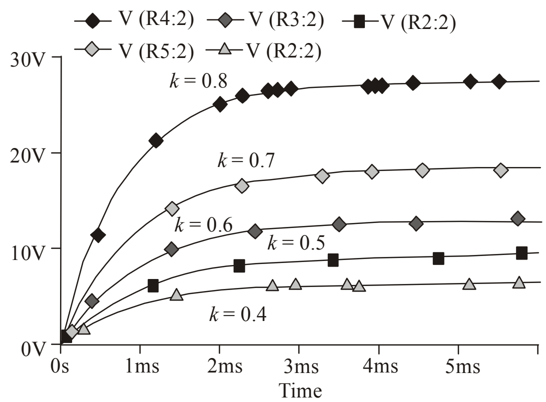
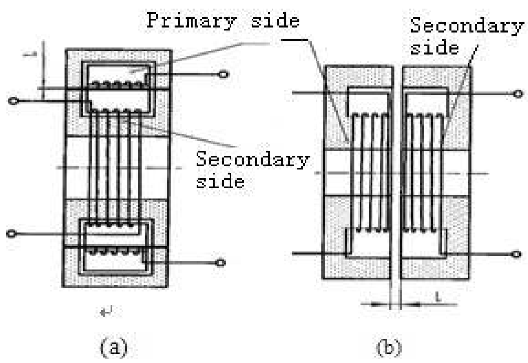


Fig. 2: Simulation of output voltage with different coupling coefficient (Zheng *et al*., 2011)



(a) Structure 1 Coil placing at the bottom
(b) Structure 2 Coil placing at the heading

Fig. 3: Two typical coil positions of transformer

As the overall efficiency of ICPT system is directly related to the coupling coefficient of loosely coupled transformer, it is necessary to improve the coupling coefficient from the design aspect.

The influencing factors of coupling coefficient: Figure 2 shows simulation of output voltage with different coupling coefficient when any other circuit parameters are the same except the coupling coefficient K. Moreover, under the condition of same load, the coupling coefficient K is bigger, the output voltage is higher. There are many factors associated with the characteristics of loosely coupled transformer and we mainly focus on the coil position and air gap and discuss their relationship with the characteristics.

The factor of coil position: Figure 3 shows the models for two typical coil positions of transformer.

Structure 1: In Fig. 3a, the coils are placed at the bottom of the transformer core, Primary winding is on the outside and the secondary winding is on the inside. Primary winding and housing constitute the stator. The rotor is made of secondary winding that fixedly connected with spindle. There is a certain gap L in the circular radial direction between primary and secondary side.

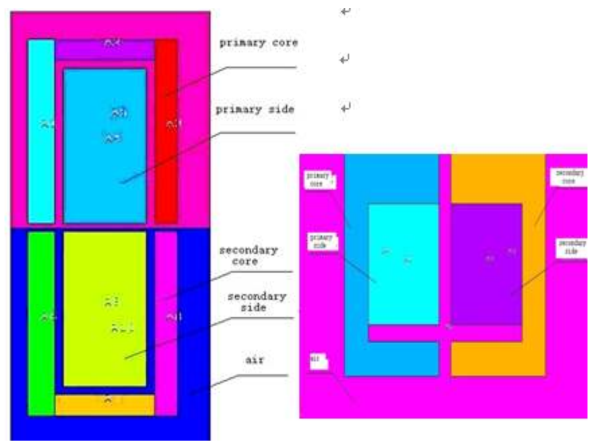


Fig. 4: (a) Structure 1 (b) Structure 2

Table 1: The properties of materials

Material	Properties
Transformer core	μr = 2500(MURX)
Current-carrying coil	μr = 1(MURX), ρ = 1.75e-8
Air	μr = 1 (MURX)

Table 2: Constants of the coils

The cross-sectional area of core (CARE)	0.105e-4m2
The turns of the coils	100
Current direction vector	ESYS,1(1,0,1)
Air gap(mm)	0.5
Symmetric coefficient	1
Fill factor(FILL)	0.00698

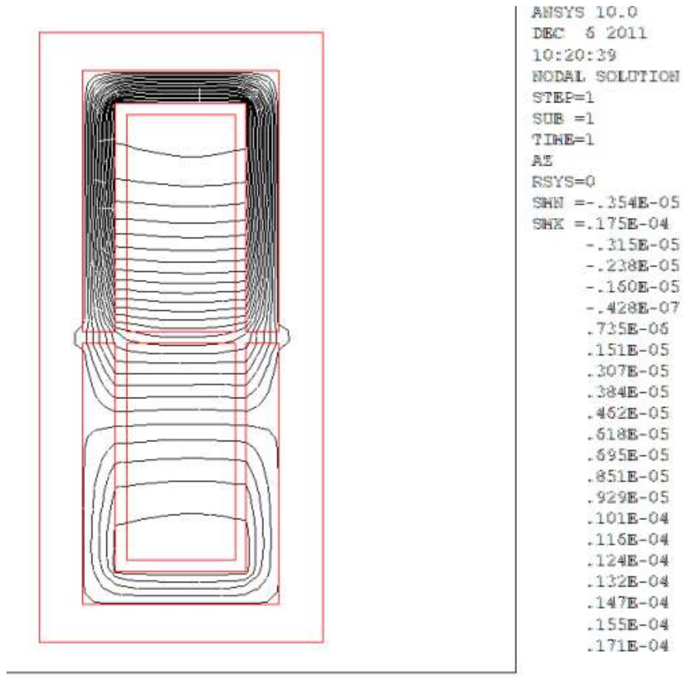
Structure 2: In Fig. 3b the coils are divided in halves and placed at the headings of the core. There is also an axial gap L .The analyses are given based on ANSYS simulation.

Choose Mn-Zn ferrite as material for transformer, two kinds of structures of the two-dimensional physical model are shown in Fig. 4a and b.

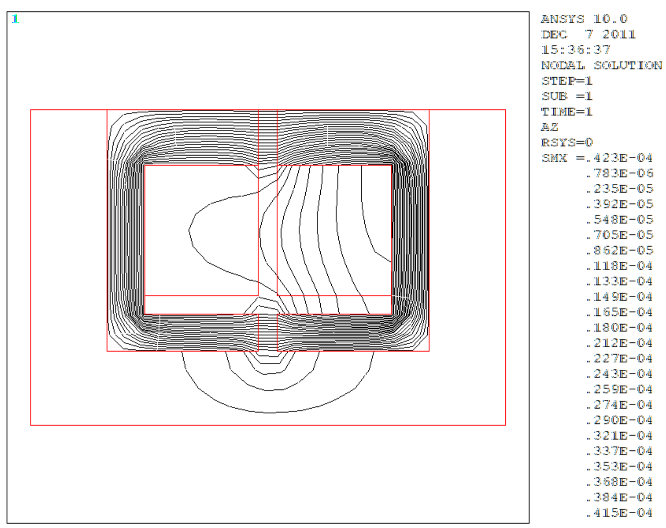
Since the modeling of structure 2 is more complex, only analyse half of the model, according to the principle of magnetic field symmetry. Moreover, the workload will be reduced. The material properties and constants of the coils are defined in Table 1 and 2.

Figure 5a and b give the distribution of magnetic field lines via ANSYS. Figure 6 gives the curves between magnetic flux density and air gap under two kinds of coil positions. When the air gap is set to be 0.5 mm, the magnetic flux density of bottom coil position structure is less than that of heading coil position. It shows that the leakage is larger when using the structure in Fig. 3a than that in Fig. 3b. In Fig. 3b, the connection between both sides is tight which allows magnetic field lines go through coils vertically. As a consequence, the leakage becomes small which improves the coupling coefficient (Mao *et al*., 2010).

The factor of air gap: Through the analysis in the previous section, choose structure 2 as the loosely



(a) Structure 1



(b) Structure 2

Fig. 5: The distribution diagram of magnetic field lines

coupled transformer structure. In order to research the influence of the air gap on the power transmission efficiency, the simulation of the transformer with heading coil position is performed and a model of air gap sizes range from 0 to 1 mm based on the ANSYS simulation is built. After coupling, gain the data from the area which the magnetic flux density is most concentrated to graph. As shown in Fig. 6.

Contrast Fig. 7a and b, the magnetic field magnetic flux density will be very large, only if no air gap exists. However, it's impossible. Consequently, it would be better to plot the graph (b) in order to observe the relationship between air gap and magnetic flux density.

As can be seen, the magnetic flux density in the loosely coupled transformer can be reduced exponentially with increasing gap size. Magnetic field intensity with the air gap size that ranges from 0.5 mm to 1 mm changes indistinctively. It is concluded that one key factor in loosely coupled transformer design is to let the air gap in a certain changing range. So, as long

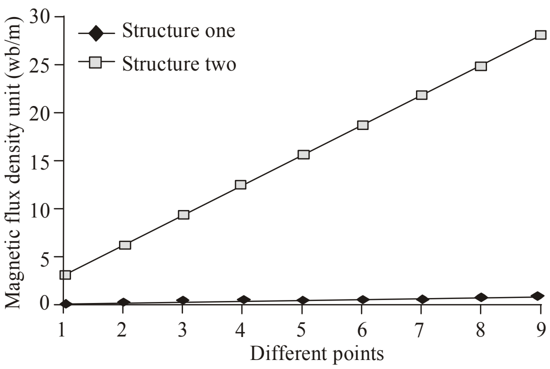
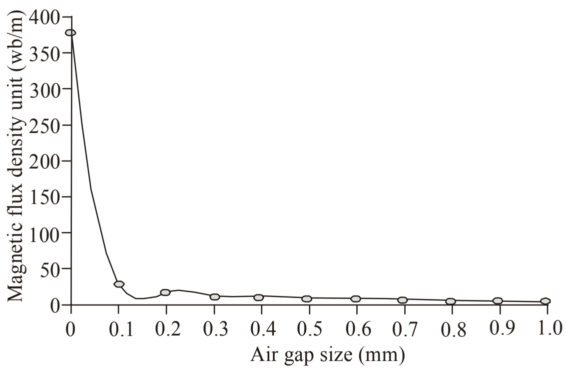
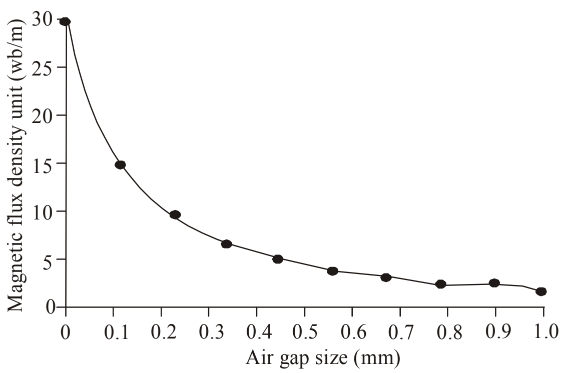


Fig. 6: Curves between magnetic flux density and air gap under two kinds of coil positions



(a) 0 ~ 1 mm



(b) 0.1~ 1 mm

Fig. 7: Magnetic flux density and the air gap width relation curves

as we control air gap range in 0.5 to 1 millimeter, it can ensure transformer coupling coefficient changes little, for the optimization design of the converter and transmission efficiency increase. And, that is also an advantage of optimization design and high efficient transmission for loosely coupled transformer (Albach and Rossmanith, 2001).

CONCLUSION

In this study, the characteristics of the loosely coupled transformer in ICPT system are mainly discussed. The influencing factors on the transformer are analyzed. Through simulated test, We may safely conclude that, in a certain range of air gap, the coupling coefficient of heading coil position method is larger than that of bottom coil position. The former method is relatively reasonable in the transformer design. According to this reliable conclusion, loosely coupled transformer in ICPT system ensures high electrical energy efficiency transmission for GMA processing non-cylinder piston pin hole system.

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