ISSN: 2472-3703 DOI: 10.6911/WSRJ.202103_7(3).0051

Research on the Influence of the Structural Parameters of the Contactless Power Transmission Device on the Coupling Coefficient in Rotary Ultrasonic Machining

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Abstract

Aiming at the phenomenon of contact power transmission in rotary ultrasonic machining that is not conducive to tool change, severe carbon brush wear, carbon deposits and ignition, a partially coupled contactless power transmission model was established. According to the theoretical model, the magnetic core structure and coil parameters are designed, and the electromagnetic simulation software Maxwell is used to simulate the transient electromagnetic field of the model, and the coupling coefficient and the maximum magnetic flux density change law under different structural parameters are analyzed. The simulation results show that as the central angle of the primary core increases, the coupling degree gradually increases, and the maximum magnetic flux density does not change significantly; with the increase of the air gap, the coupling degree gradually decreases, and the maximum magnetic flux density decays rapidly; As the depth of the window increases, the degree of coupling gradually decreases, on the contrary, the maximum magnetic flux density gradually increases. The effect of structural parameter changes on the device performance is obtained through simulation, which provides a reference for the optimal design of contactless power transmission devices.

Keywords

Rotary ultrasonic machining; Contactless power transmission; Coupling coefficient; Maximum magnetic flux density.

1. INTRODUCTION

Hard brittle materials (such as aluminum silicon carbide, engineering ceramics and optical glass) with excellent mechanical and physical performance, in aviation aerospace, defense, military, medical equipment and other fields play an important role. At present, rotary ultrasonic machining is the most important processing method for hard and brittle materials [1]. Compared with traditional processing methods, rotary ultrasonic machining can effectively increase cutting efficiency, reduce cutting force, and improve the surface machining accuracy of parts.

The rotating ultrasonic machining system is mainly composed of ultrasonic generator, power transmission device, transducer and luffing rod. The ultrasonic generator provides power for the transducer through the power transmission device. The power supply mode is mainly divided into contact carbon brush slip ring transmission and contactless induction power transmission. In the long working process, contact carbon brush slip ring transmission device will produce the phenomenon of carbon deposition and ignition, and is not conducive to tool

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change [2, 3] of the machine tool, so it is difficult to be applied in high-speed cutting. In order to solve the above problems, the application of the principle of loosely coupled transformer scholars both at home and abroad to the rotary ultrasonic machining system, developed a contactless power transmission system[4, 5], its structure is mainly composed of the original, magnetic core and the original, deputy vice side coil, the original side core fixed on the machine tool, vice side core fixed on the handle, the handle with the spindle rotation at a high speed.

Abroad earlier research on contactless power transmission way, Germany in 2007 DMG/Sauer company successfully developed a series ULTRASONIC machine, and using the local coupling type contactless power transfer system (the original side core as part of the circle, deputy side core for the entire circle), the local coupling structure than the fully coupled structure is more advantageous to machine tool change, but the two on the transmission efficiency of electricity power transmission way is different. Since there is an air gap between the primary and secondary sides of the contactless power transmission device, the coupling coefficient is low, and the coupling coefficient and transfer efficiency of the device are related to its own material and structure, so it is necessary to study the device with different structural parameters. This paper proposes a finite element simulation analysis method to study the influence of the core Angle (hereinafter referred to as the core Angle), the air gap (hereinafter referred to as the air gap) and the window depth on the coupling coefficient of different original magnetic cores.

2. DESIGN OF CONTACTLESS POWER TRANSMISSION DEVICE

To design the magnetic core of contactless power transmission device, the effective area A_c of the magnetic core passing through the magnetic sensing line should be calculated first. According to Faraday's Law, the effective area of the magnetic core passing through the magnetic sensing line is [5]:

$$A_c = \frac{U_p}{K_f f B_{\max} N_p}. \tag{1}$$

Type: U_p is the original voltage; K_f is the waveform coefficient, for square wave, $K_f = 4.0$,for sine waves, $K_f = 4.44$, f is the operating frequency; B_{max} is the working maximum flux density, in order to make the high frequency alternating current work within the range of material B-H curve, generally take $B_{max} = B_s / 2$, Bs is the saturation magnetic flux density of material; N_p is the number of turns of the original side coil.

In order to make the coil reasonably wound in the magnetic core, the window area (Aw) of the magnetic core should meet [5]:

$$A_w = \frac{2N_p I_p}{K_0 J}. \tag{2}$$

Type: N_p is the number of turns of the original side coil; I_p is the original edge current; K_0 is the use coefficient of the window, which is generally taken $K_0 = 0.4$; J for current density, the current density of copper conductor 6 A/mm^2. Diagram of effective area A_c and window area A_w of magnetic core is shown in Figure 1.

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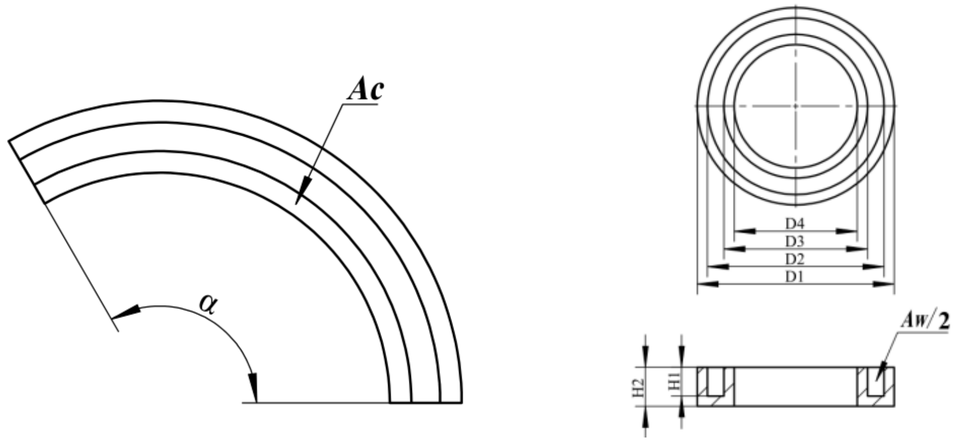

(a) Original side core structure (b) Secondary side core structure

Figure 1. The effective area and window area of the core

At the same time, choosing the right core material is also a key step in the design. Manganese zinc ferrite has high permeability and resistivity and is widely used in high frequency transformers. In this design, the magnetic core material is PC40 manganese zinc ferrite, its relative permeability μ_i is 2300, saturation magnetic flux density B_s is 500mT, coercer H_c is -13A/m.

3. SIMULATION OF TRANSIEN ELECTROMAGNETIC FIELD

3.1. Before Processing

A 3D electromagnetic simulation platform was established based on electromagnetic simulation software Ansoft Maxwell. Transient magnetic field analysis was selected from the solution type, and then a 3D model of the device was established according to the design results. Eddy current effects of coils and magnetic cores were ignored in the transient solver. The working frequency of the rotating ultrasonic processing system is set. The magnetic core material is PC40 manganese zinc ferrite and the coil material is copper. Original input voltage U_p=220V and adopt the external circuit excitation way. Due to the speed basic had no effect on the coupling coefficient and the transmission efficiency, so select deputy side rotation of the magnetic core is not here. According to the design formula (1) and (2), take the central Angle of the original edge magnetic core α = 90°, Take the outer diameter of magnetic core D_1 = 41.5 mm, Take the inner diameter D_4 = 33.5 mm, The number of turns of the coil is 50. The calculation can be approximated, D_2 = 39 mm, D_3 = 36 mm, Coil window depth H_1 = 9 mm, The core height is taken H_2 = 12 mm. Examine the difficulty of assembling the primary and secondary magnetic cores into machine tools, the minimum value of air gap g is defined as 0.4 mm.

The coupling coefficient is an important parameter to describe the performance of contactless power transmission device. Its value is mainly related to the material and structure of the magnetic core and the relative position of the primary and secondary side coils. Since the primary and secondary side are coupled through the air gap, the magnetic flux leakage is large and the coupling coefficient is low, so it is necessary to verify the change rule of the coupling coefficient through simulation. Based on Maxwell's simulation of transient electromagnetic field, the self-inductance L^p of the primary coil, the self-inductance Ls of the secondary coil, and the mutual inductance M can be obtained. The coupling coefficient can be obtained by formula (3):

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$$k = \frac{M}{\sqrt{L_p L_s}}. \tag{3}$$

Table 1. Factor level table

Factors	Level	Step length
Central Angle α[°]	60~150	30
The air gap g [mm]	0.4~1	0.2
The depth of the window H1 [mm]	6~15	3

Table 1 is the factor level table of model transient magnetic field simulation, and the above parameters are put into Maxwell for solution.

According to the simulation results, the self-inductance and mutual inductance of the primary and secondary coils can be obtained, and the coupling coefficient can be calculated by substituting into Equation (3). In order to prevent the phenomenon of magnetic saturation during the operation of the device, the magnetic flux density variation of the magnetic core under different parameters was studied. Sinusoidal alternating current with the peak current of 1A was applied to the coil. The longitudinal section of the model was selected, and the distribution cloud map of magnetic flux density B was drawn in the post-processing, and the maximum magnetic flux density B_{max} was obtained.

3.2. Effect of Center Angle on Coupling Coefficient and Maximum Flux Density

Draw the coupling coefficient, maximum flux density changing with central Angle curve, as shown in figure 2, it can be seen that with the rising of central Angle, coupling coefficient also gradually rise, that increasing the core through the effective area of Ac magnetic induction line can effectively increase the efficiency in power transmission, but too much of the original side core central Angle will be more conducive to machine tools to replace the handle; With the increase of the central Angle, the B_{max} curve is basically horizontal. Therefore, the change of the central Angle has basically no influence on the maximum flux density.

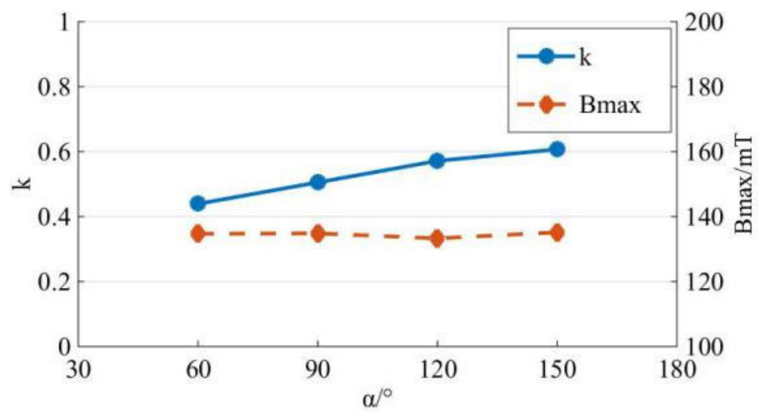

Figure 2. The change curve of coupling coefficient and maximum magnetic density with center Angle

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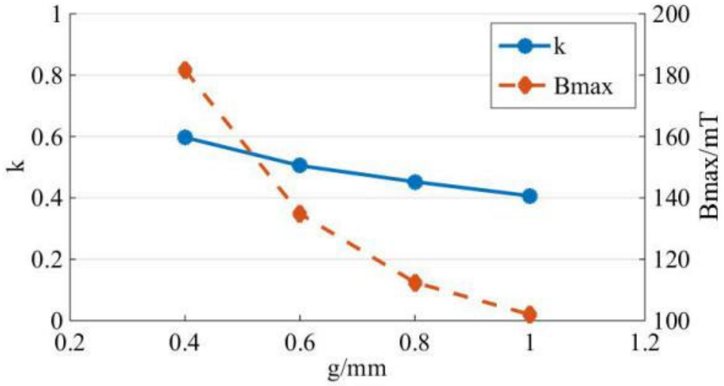

Figure 3. The curve of coupling coefficient and maximum flux density with air gap g

3.3. Effect of Air Gap on Coupling Coefficient and Maximum Flux Density

Figure 3 shows the curves of the coupling coefficient and the maximum flux density changing with the air gap. It can be seen from the figure that the coupling coefficient and the maximum flux density are negatively correlated with the gap, and B_{max} rapidly attenuates with the increase of the air gap, so the air gap value has a great influence on the maximum flux density.

3.4. Effect of Window Depth on Coupling Coefficient and Maximum Flux Density

Figure 4 shows the variation curve of the coupling coefficient with the depth of the window. When the number of turns of the coil remains unchanged, the coupling coefficient decreases as the depth of the window increases. In order to study the reason for this change, a two-dimensional transient electromagnetic simulation model with window depth H_1=6mm and H_1=15mm was established. Under the same simulation conditions, by observing the distribution of flux linkage at 8.25 μs, it can be seen that the primary side A part of the magnetic core does not flow into the secondary side magnetic core, but forms a closed loop with the other side of the magnetic core. These leakage magnetic fluxes are stored in the primary side magnetic core without participating in energy transfer, and the window depth is 15mm (The magnetic core of Figure 5 (right) has more leakage flux than the window depth of 6mm (Figure 5 left), so the coupling coefficient decreases with the increase of the window depth; on the contrary, the maximum magnetic flux density increases with the window depth Increase and increase.

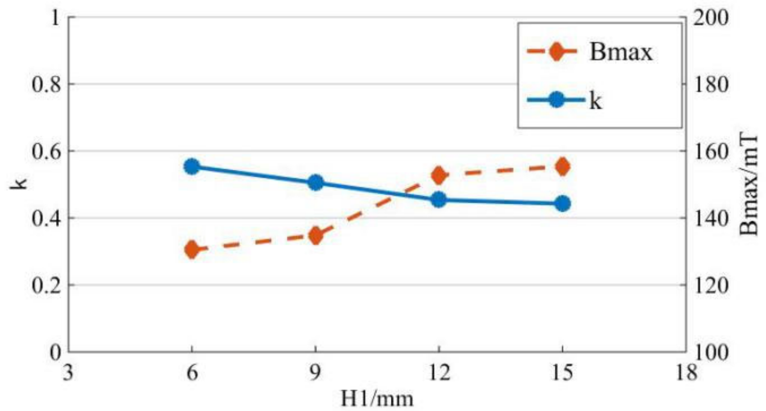

Figure 4. The curve of coupling coefficient and maximum flux density with window depth H_1

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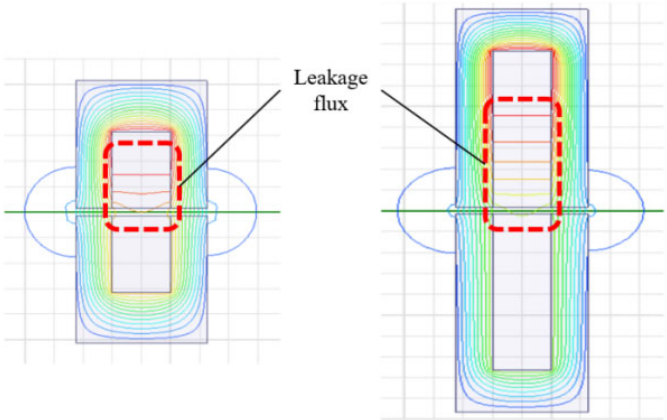

Figure 5. Distribution of two-dimensional magnetic field at 8.25 s

4. CONCLUSION

In this paper, under different structural parameters, through finite element analysis, the coupling coefficient and maximum magnetic flux density of the contactless power transmission device are obtained. The conclusions are as follows:

As the central angle increases, the coupling degree gradually increases, and the maximum magnetic flux density does not change significantly. On the premise of not hindering the automatic tool change of the machine tool, increasing the central angle is an important way to improve the coupling coefficient.

As the air gap increases, the coupling degree gradually decreases, and the maximum magnetic flux density is greatly affected by the air gap. Reducing the gap between the primary and secondary side is an important way to improve the coupling coefficient, so it is particularly important to design a stable and reliable primary side magnetic core fixing device.

As the depth of the window increases, the degree of coupling gradually decreases and the maximum magnetic flux density increases. Through the simulation in a two-dimensional magnetic field, it can be known that the deeper the groove, the greater the magnetic leakage, and the coupling coefficient will naturally decrease.

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