Experimental Study on pot core transformer for contactless power supply

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Abstract:

Detailed study on coupling and power transfer characteristics of pot core transformer for contactless power supply has been done experimentally. Experimental results have been compared with the calculated results. Good concordance has been achieved. Due to the large leakage inductances that result, compensation is usually necessary to achieve the required power transfer capability. Further study has been done on the performance improvements by primary and secondary compensation.

Keywords:

contactless power supply, pot core transformer, primary and secondary compensation

1. Introduction

New contactless power supply system realizes contactless power transmission with high security and reliability [1]. Such systems can be used for non-contact battery charging, robotic applications, contactless energy transfer in wet or hazardous environments, and so on [1]. Theoretical analysis has been done about the power transmission characteristics of the system [5]. Performance improvements with primary and secondary compensation have been analyzed. The magnetic structure is the core of the system and pot core transformer is often used in this system due to its simple structure and good coupling characteristics. To validate the analysis results and further deepen the related research, with the pot core transformer as the primary concern, detailed experiments have been done about the coupling with air gap, frequency, horizontal displacements and power transfer characteristics with frequency and load resistance. Power and efficiency change ratio are introduced to study the applicability of different secondary compensation topologies. The power supply characteristics before and after primary compensation have been compared.

2. Experimental prototype

The geometrical parameters of the experimental prototype are as shown in fig. 1. The prototype adopts ferrite core with an initial magnetic conductivity of 2000. The turns for primary and secondary windings are respectively 116, 15. To minimize the skin effect, litz wires are used for both windings. The high frequency power source is composed of a signal generator and a power amplifier. The maximum output voltage is 50V and frequency range is 0-1MHz.

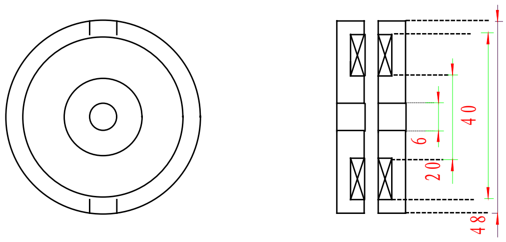


Fig.1 Geometrical parameters for the prototype

3. Coupling Characteristics of pot core transformer

Three experiments have been done about the coupling characteristics of the prototype: (1) coupling coefficient with operational frequency, (2) coupling coefficient with air gap, (3) coupling coefficient with horizontal displacement.

Fig.2 shows the curves of coupling coefficient with different frequency and air gap. The frequency varies from 5kHz to 100kHz. Due to the fact that the frequency has little effect on the magnetization curves of the ferrite core material [4], the coupling coefficient varies little with increasing frequency. It drops with air gap increased.

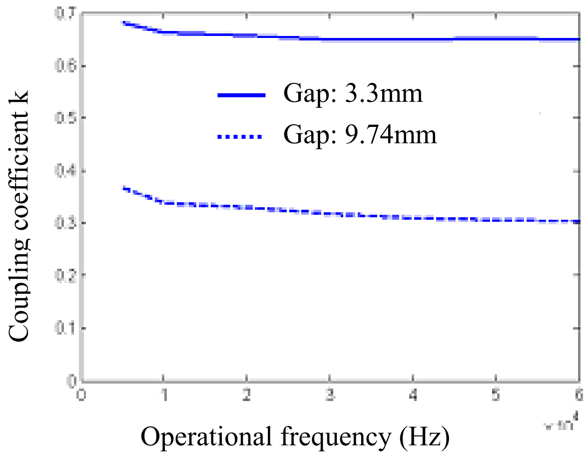
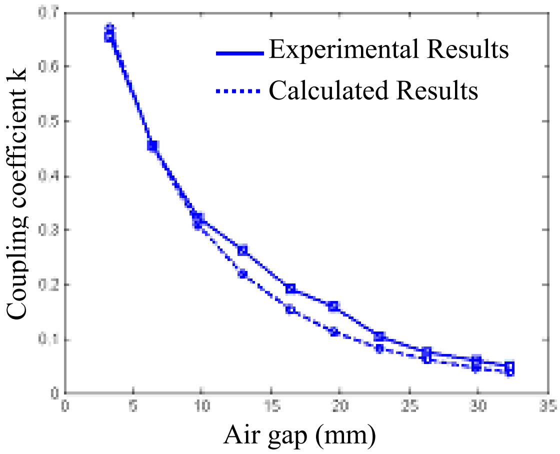


Fig. 2 Coupling coefficient vs. frequency

Fig.3 and Fig.4 respectively show the curves of coupling coefficient with air gap and horizontal displacements. These experiments have been done at 20kHz. Calculated results by finite element method have also been shown in the figures for comparison. Good concordance has been achieved. The air gap is increased from 3.3mm to 32.2mm. The air gap is controlled by add insulation board with a thickness of 1.1mm. With increasing air gap, the coupling coefficient drops sharply and then slows down. It will be gradually less insensitive to the air gap. With horizontal displacement increased, the coupling coefficient first drops rapidly, then rises, and finally drops again. The reason for this phenomenon is due to the reverse magnetic flux density in the secondary core when the edge of the secondary core is at the mid core of the primary. So pot core transformer is more appropriate for power supply for still apparatus.



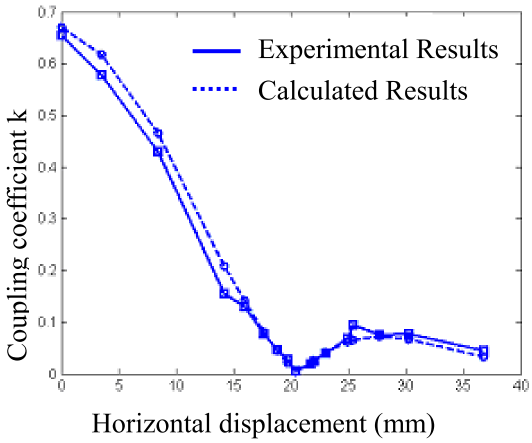


Fig.3 Coupling coefficient vs. air gap **Fig. 4 Coupling coefficient vs. horizontal Displacement**

4. Power transfer characteristics

The power transfer characteristic is mainly considered from three respects: voltage ratio V_o/U_p, output power P and transmission efficiency η.According to the mutual inductance model [5], the expressions for them are as follows:

$$V_o / U_p = \frac{MR_L / L_p}{\sqrt{R_L^{\,2} + (\omega L_s - \omega M^2 / L_p)^2}} \tag{1}$$

$$P = \frac{U_p^{\,2} M^2}{L_p^{\,2} R_L + \omega^2 (L_s L_p - M^2)^2 / R_L} \tag{2}$$

$$\eta = \frac{P}{P_1} = \frac{P}{P + p_{fe} + p_{cu}} \tag{3}$$

To validate the above expressions, related experiments have been done. During the experiments the air gap of the prototype is fixed at 3.3mm and the output voltage of the power source is 50V. The curve of voltage ratio with load resistance at 20kHz is shown in fig.5. The voltage ratio rises gradually with load resistance increased. So for small load the power transfer capability will be restricted badly. The curves of output power and efficiency with load resistance and frequency are respectively shown in fig.6-7. Both the output power and efficiency have a maximum value with load resistance in variation. The output power gets to the maximum when the load resistance is equal to the reactance in the equivalent secondary circuit and decreases with increasing frequency. Generally the efficiency will be improved with higher frequency, but it also be influenced by the core loss characteristic. The calculated results according to (1)-(3) are also shown in the figures for comparison. They've agreed well with the experimental results.

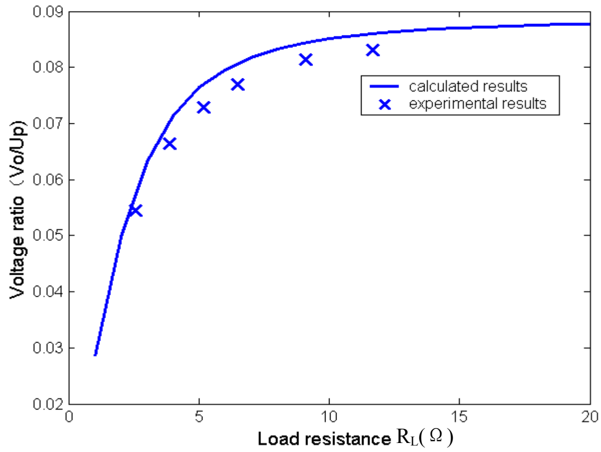


Fig.5 Voltage ratio vs. load resistance

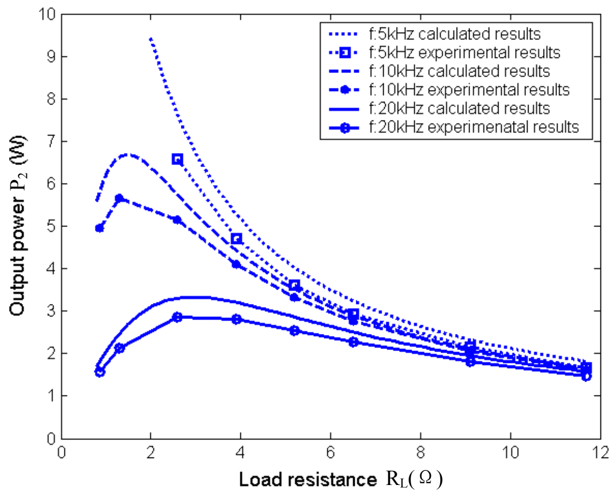


Fig. 6 Output power characteristics

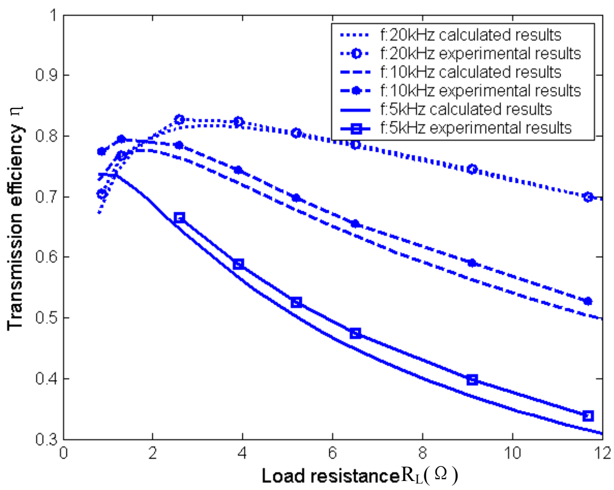


Fig.7 Efficiency characteristics

5. Primary and Secondary compensation

5.1 Primary compensation

Primary compensation is used to improve the power supply characteristics of the primary power source. Table I shows the input parameters of the system before and after compensation with load resistance being 9.1Ω. The output power is 1.8W. The input voltage and input current have been reduced greatly respectively by series compensation and parallel compensation. The power factor is 0.2463 before compensation and is highly reactive. It becomes close to 1 either by series or by parallel compensation.

Table I Comparison between input parameters before and after primary compensation

Input	Without compensation	Series compensation	Parallel Compensation
Input voltage（V）	50	12.92	49.8
Input current（A）	0.1913	0.1907	0.0512
Power factor $\cos\varphi$	0.2463	0.9984	0.9617
Visual power（VA）	9.565	2.464	2.55

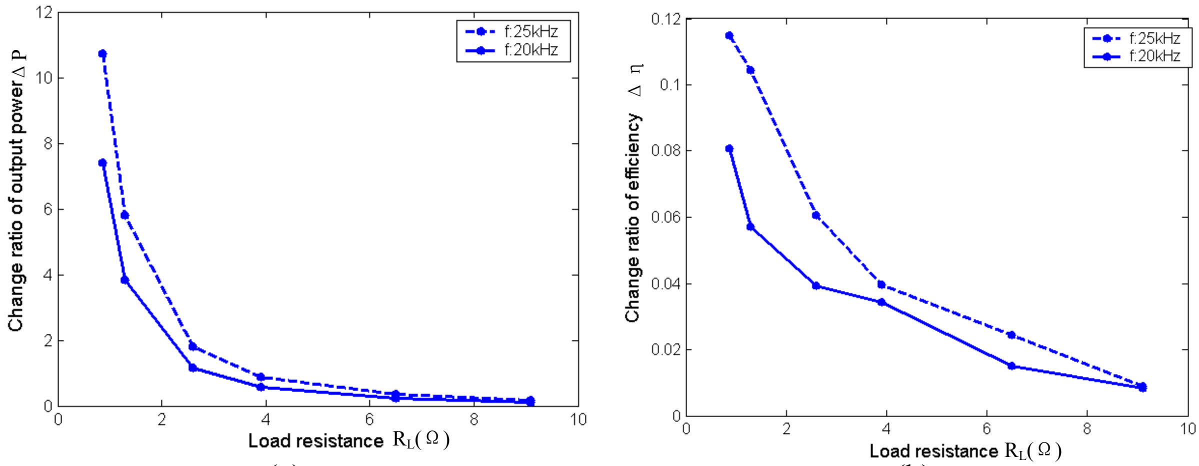
5.2 Secondary compensation

The power and efficiency change ratio after compensation can be given as:

$$\Delta P = \frac{P_c - P}{P} \tag{4}$$

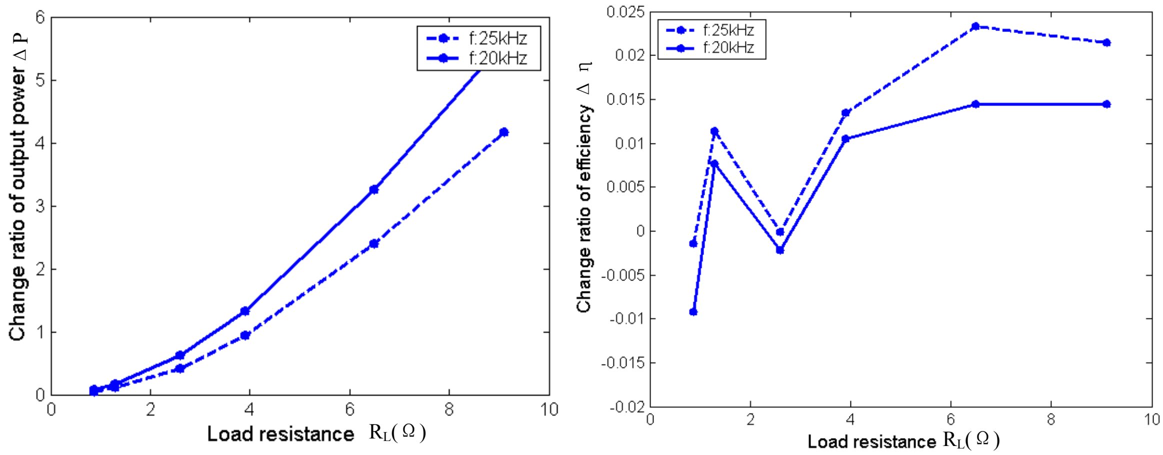
$$\Delta \eta = \frac{\eta_c - \eta}{\eta} \tag{5}$$

The power and efficiency change ratio curves with frequency and load resistance by series and parallel compensation are respectively shown in Fig.8-9. For series compensation, the smaller the load resistance, the more the output power and efficiency are improved. The change ratios are improved with higher frequency. But for parallel compensation, it’s just the reverse. It can be seen that series compensation is more appropriate for small load resistance, while parallel compensation is more fit for large load resistance.



(a) (b)

Fig.8 Change ratio of output power and efficiency by series compensation



(a) (b)

Fig.9 Change ratio of output power and efficiency by parallel compensation

6. Conclusion

Detailed experimental study on pot core transformer for contactless power supply has been done in this paper. The experimental results have validated the analysis results. The coupling coefficient of the ferrite core transformer is very sensitive to the air gap and horizontal displacement. The power transfer capability of the system can be improved greatly by secondary compensation. Series compensation is more fit for small load resistance. For large load resistance parallel compensation is more favorable. The power supply characteristics of the power source have been improved greatly by primary compensation. The power factor is close to 1 after compensation.

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