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Heating Performance Improvement and Field Study of the Induction Cooker

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Abstract—Magnetic induction heating is a common technique exploiting high frequency eddy current losses on metallic objects. In the past one to two decades, induction heating has been extended to the catering industry as induction cooker. Currently, the induction cooker draws more and more attentions as one of the popular kitchen appliances. This paper mainly investigates the magnetic field of induction cooker for improving its heating performance. Firstly, the magnetic field and heating performance of conventional induction cooker are analyzed. Furthermore, the problems associated with conventional induction cooker are identified. In order to overcome those disadvantages of traditional induction cooker, a novel coil format is proposed. Meanwhile, Finite Element Method is used to simulate and further analyze the behavior of the induction cooker. Finally, a prototype of the proposed induction cooker is built. The experimental results of conventional and the novel induction cooker are presented and compared. Both the simulation and experimental results indicate that the proposed solution can efficaciously improve the heating performance of conventional induction cooker.

Keywords–Induction cooker, magnetic field, heating performance, coil

I. INTRODUCTION

In recent years, due to the inherent benefits of the induction cooker, such as high heating efficiency, quiet, clean etc., it has been widely used in families and catering instead of ordinary stove plates. Traditional induction cooker basically consists of one metal wok and one magnetic coil. The coil is usually excited by a medium-frequency (20 kHz ~ 100 kHz) power source and producing alternating magnetic field, which causes eddy currents and hysteresis to heat up the wok[1].

In the past, many research efforts have been devoted to continuously improve the operation performance of induction cookers. Reference [2] analyzed the inductance and ac resistance of the heat-coil, the changing of the magnetic field intensity influences the coil inductance and ac resistance to a large extent was illustrated. Reference [3] presented a design of induction heating coil and focused on the transient temperature distribution and power densities of the workpiece during an induction heating process. Reference [4] analyzed the heating performance of induction cooker with and without a ferrite plane. It was proved that the application of an additional ferrite plane is beneficial to the induction cooker heating performance. Reference [5] studied the application of half-bridge series resonant inverter in the induction cooker. However, it is found that few efforts try to improve the heating performance of induction cooker from the point of magnetic field analysis and coil format.

This paper investigates the structure and associated problems of heating performance for conventional induction cooker from the perspective of the magnetic field distribution as it can reflect the heating distribution of induction cooker. Based on the study, a novel coil design is proposed to address those problems. The FEM (Finite Element Method) is applied to the simulation of both the conventional and proposed induction cookers to compare their experimental results.

II. CONVENTIONAL INDUCTION COOKER

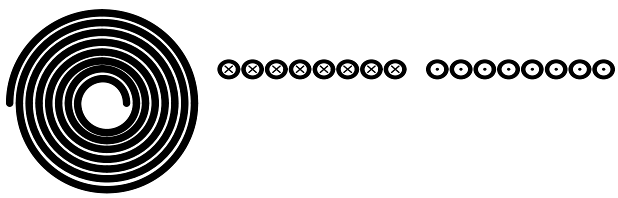
1. Structure of conventional induction cooker

The conventional induction cooker mainly comprises wok, coil and driving circuit as simplified in Fig. 1. A flat pancake coil is placed underneath the conductive cooking wok with a thermal insulator between them. A medium-frequency current (20 kHz ~ 100 kHz) in the coil induces eddy currents in the wok, causing it to heat up.

Driving Circuit
Wok
Insulator
Coil

Fig. 1: Simplified structure of conventional induction cooker

The conventional coil is a single coil with even distribution as shown in Fig. 2 (a). If there is current in the coil, the direction of the current at one moment would be like Fig. 2 (b).



(a) Planform of coil (b) Cutaway view of coil
Fig. 2: Format of conventional coil

2. FEM simulation of conventional induction cooker

For further study of the conventional induction cooker, a 3D FEM model as shown in Fig. 3 is built for simulation. The insulator is omitted because of its low relative permeability and low conductivity material. The model consists two parts: the wok and the coil. The coil is modeled according to the conventional coil which is single coil and its current is even distributed.

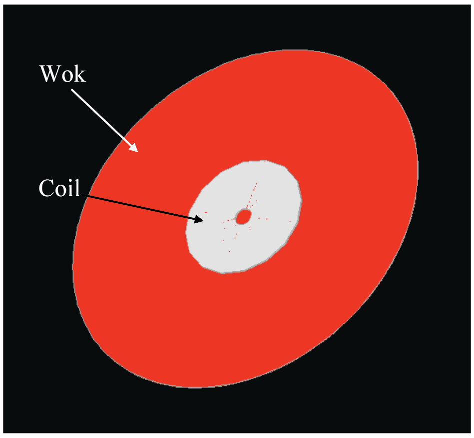


Fig. 3: 3D FEM model of conventional induction cooker

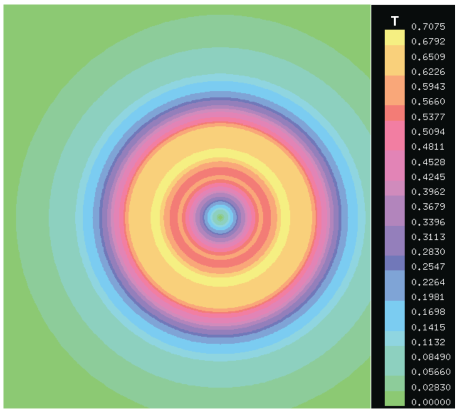
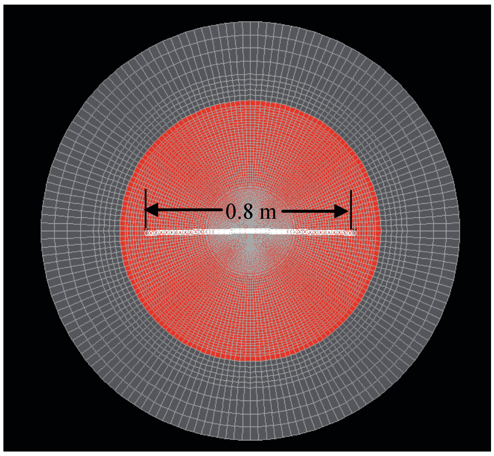
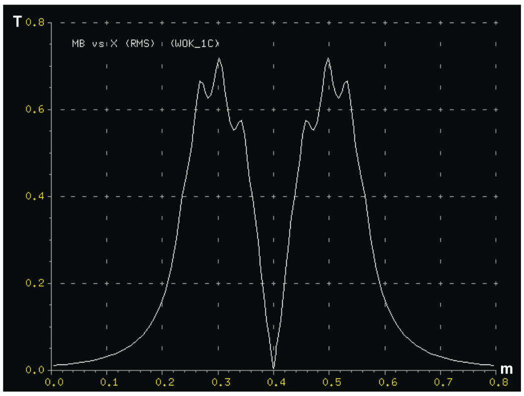


Fig. 5: Magnetic field distribution of the conventional induction cooker

Fig. 4 shows the flux density *B* amplitude curve versus the midline of the wok. It is easily found that the magnetic field is uneven and the cross-sectional view as shown in Fig 4b only has single peak in each side of the center which presents small area of high magnetic field.



(a) Planform of the model



(b) Magnetic field vs. midline of wok

Fig. 4: Planform and magnetic field vs. midline of conventional induction cooker

The simulation result of the magnetic field distribution on the conventional induction cooker model is presented in Fig. 5. The magnetic field concentrates in a small ring area with a single peak which indicates the same problem in Fig. 4. The size of the ring is less than 20% for field density higher than 0.6T.

All of the simulation results show that the magnetic field of conventional induction cooker is uneven and localized which will lead to local hot spots and poor heating performance, together with the fast aging of the heating surface and inefficient heat transferring of induction cookers.

III. Proposed Induction Cooker

1. Novel coil proposed

To overcome the drawbacks and improve the heating performance of the conventional induction cooker, a novel format of coil is proposed.

According to Ampere's law,

$$\oint_{l_m} H \cdot dl = N \cdot I \qquad (1)$$

where H is magnetic field, l_m is a closed circumference length, I is the current through the coil, *and* N is the turns of the current.

The magnetic field strength and magnetomotive force F can be found by application of (1). The MMF F(x) across the coil of the conventional induction cooker, as a function of the distance x from the edge is sketched in Fig. 6.

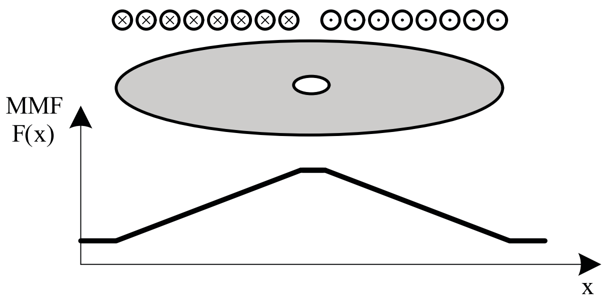


Fig. 6: MMF of conventional coil

The analysis of conventional induction cooker indicates that the magnetic field of the inner and outer position of the wok needs to be increased. From (1), when the current is keeping the same, the magnetic field can be adjusted by changing N and l_m. The low magnetic field can be enhanced by increasing the number of coil turns in corresponding area. One example of the novel coil format is illustrated in Fig. 7. It can be named as variable turn pitch coil. Although this coil is still single coil, it changes the turn density at different area of the coil which can affect the magnetic field at different area.

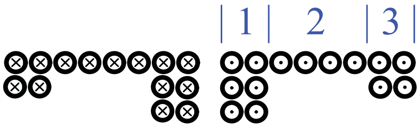


Fig. 7: Variable turn pitch coil

Take half side of the coil to compare conventional coil in Fig. 2 and the proposed coil in Fig. 7. Table 1 shows the differences of these two coil formats.

Table 1: Comparison of conventional and proposed coil s

Coil	Turns			
	Area 1	Area 2	Area 3	Total
Conventional	2	4	2	8
Proposed	6	4	4	14

The MMF F(x) across the proposed coil of the induction cooker, as a function of the distance x from the edge is sketched in Fig. 8. It can be observed that the MMF of the inner and outer position of the coil has been increased.

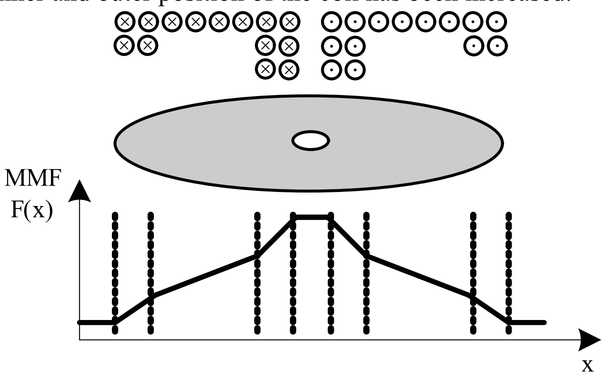


Fig. 8: MMF of proposed coil

2. FEM simulation of proposed induction cooker

A 3D FEM simulation model is built for the proposed induction cooker as shown in Fig. 9. All the parameters are the same as the model of conventional induction cooker except the coil which is variable turn pitch coil.

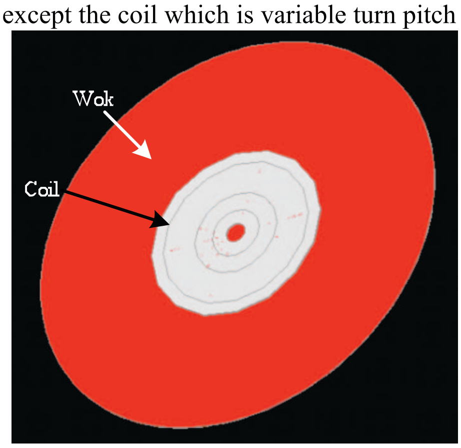
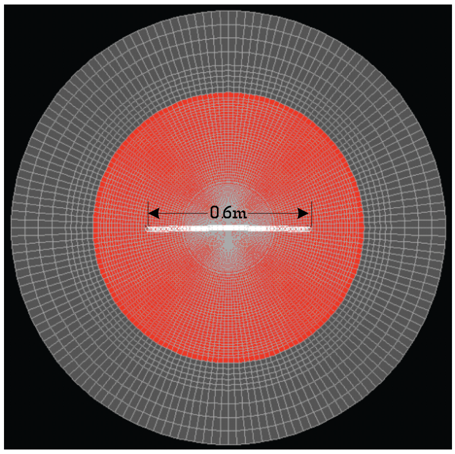
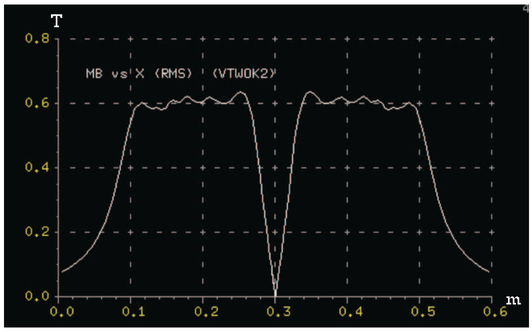


Fig. 9: 3D finite element model of proposed induction cooker

Fig. 10 shows the flux density *B* amplitude curve versus the midline of the wok. The magnetic field has been improved a lot and there are larger areas of high and even magnetic field.



(a) Planform of the model



(b) Magnetic field vs. midline of wok

Fig.10: Planform and Magnetic field vs. midline of proposed induction cooker

The simulation results of the magnetic field distribution on the proposed induction cooker model with variable turn pitch coil are presented in Fig. 11. Instead of concentrating in a small ring area, the magnetic field covers wider area of the induction wok which would improve the heating performance of the induction cooker significantly.

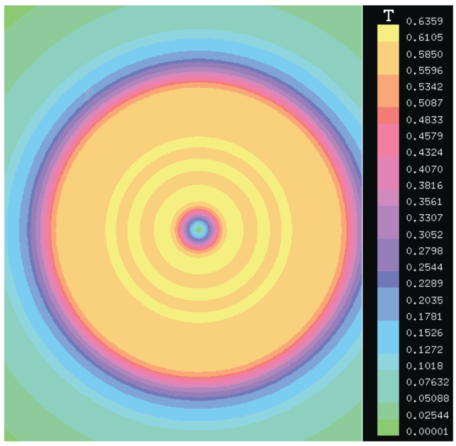


Fig. 11: Magnetic field distribution of the proposed induction cooker

The simulation results indicate that the application of proposed variable turn pitch coil in the induction cooker can improve the heating area size and thermal evenness visibly. The problem associated with the conventional induction cooker could be solved availably by the proposed coil format.

IV. Experimental Verification

In order to validate the performance of the proposed method, an induction cooker with variable turn pitch coil is built as shown in Fig. 12. The construction of the windings based on the proposed variable turn pitch. Stranded wire is used to reduce proximity and skin effects.

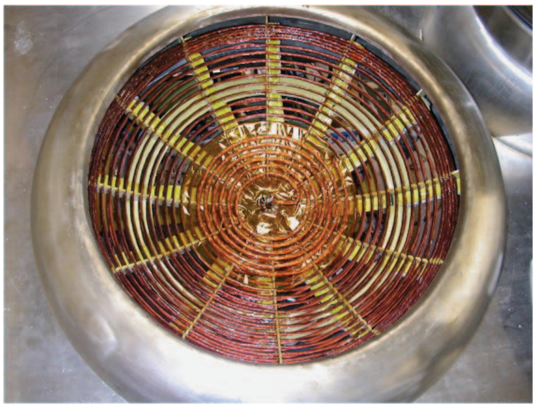
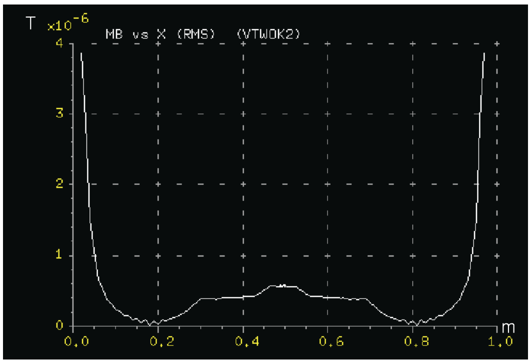
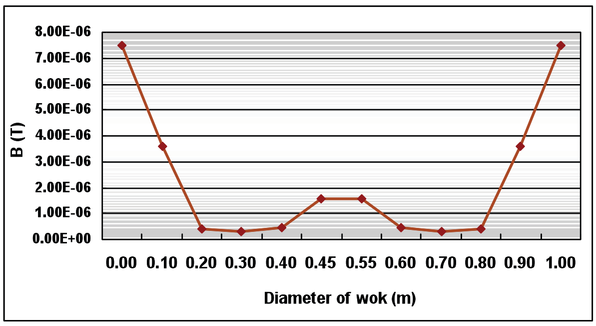


Fig. 12: Induction cooker with variable turn pitch coil

Prior to the performance testing, the magnetic field of wok outside surface is observed in simulation model and the induction cooker prototype to verify the accuracy of the simulation results. Fig. 13 shows the comparison of simulation and experimental results. It indicates that the *B* field shape of the simulation result is similar to the experimental result. As it is at the outer surface of the wok, which is actually in the air, *B* is quite smaller compared to *B* value of the wok inside.



(a) Simulation results



(b) Experimental results

Fig. 13: Magnetic field at wok outer surface comparison between simulation and experimental results

Fig. 14 is experimental result of the magnetic field distribution and heating patterns of conventional induction cooker. The heating performance is poor and localized as analyzed before.

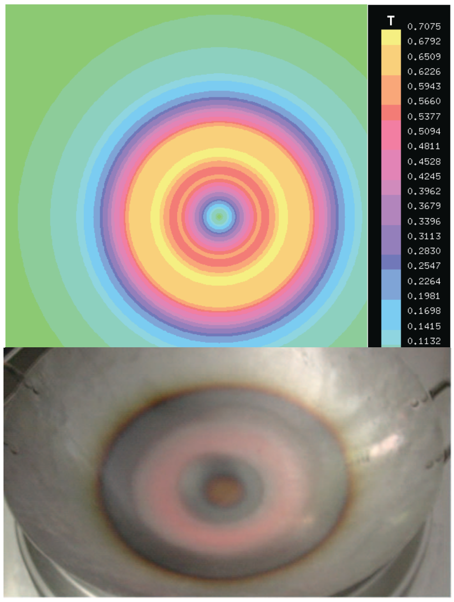


Fig. 14: Comparison of conventional induction cooker magnetic field distribution and heating patterns

Meanwhile, Fig. 15 shows the experimental result of the magnetic field distribution and heating patterns of proposed induction cooker. The heating performance is obviously improved and the heating area is larger than the conventional one. It proves that the variable turn pitch coil method can effectively improve the poor heating performance of conventional induction cooker.

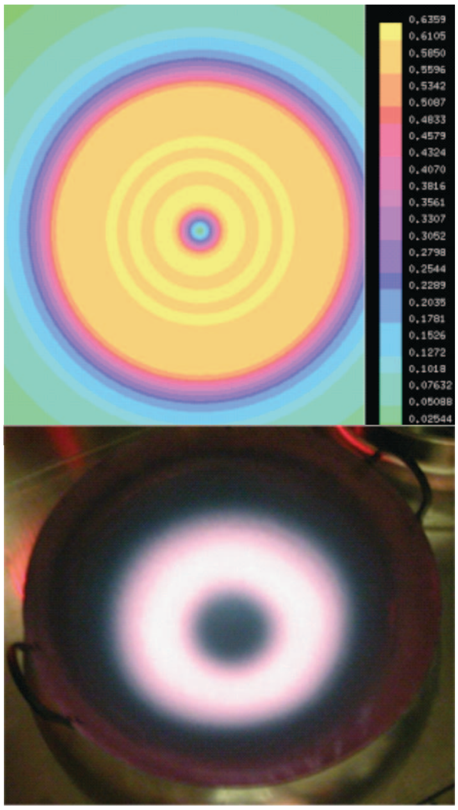


Fig. 15: Comparison of proposed induction cooker magnetic field distribution and heating patterns

V. Conclusion

This paper analyzes the heating performance and existing limitations of the traditional induction cooker. As poor thermal distribution and localized heating area are commonly found in the traditional induction cookers, by using FEM simulation, its magnetic field distribution is studied. To address the problem of the conventional induction cooker, a variable turn pitch coil format is proposed. FEM simulation is applied to observe the magnetic field distribution of the induction cooker with the proposed coil. Experiments are then carried out to verify the correctness of the FEM simulation results as well as the validity of the novel coil format. The benefits of the proposed induction cooker are identified and clarified as follows.

- Better heating performance than conventional induction cooker with less cost induced.
- Straightforward modification of conventional coil leads to convenient implementation of the proposed coil without any additional components.
- No need to change driving circuit, control and any other elements of the conventional induction cooker except the coil.

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