Asymmetrical Arrangement of Coils in an Induction Cooker to Improve Heat Distribution

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I. INTRODUCTION

Induction cooker with coils arranged evenly along radial direction has a significant deficiency that the heat distribution in the vessel is uneven. The area with high temperature only limits in a ring-zone in the vessel. This ring-zone endures high temperature and often breaks the vessel (pan or wok) into two parts along the ring zone. Furthermore the evenly arranged coils will cause a cold spot in the center area of vessel. This is not often the expectation. Fig. 1 shows the phenomena of fiery ring-zone and cold spot.

To overcome the problem of uneven heat distribution, one feasible method is to arrange more coils at the different area beneath the vessel to produce more even heat distribution. But this method needs to add more power electronics driver, which will complicate the drive system and increase the cost. Another feasible method is to use single planar coil with a number of turns arranged unevenly. The density of turns of the single planar coil is arranged to fulfill specified requirements. Through elaborate design this kind of asymmetrical coils can make the heat distribution more even in a wide range and the cold spot at the center shrink greatly.

Fig. 1. Ring red zone and cold spot

To find out the optimum arrangement of the coil, analytical solutions of the eddy current in the vessel is necessary. This paper presents the equation for eddy current distribution. Methods to optimize the coil arrangement under specified requirements are also presented.

Results of FEM simulation proved the methods of optimization. A 20kW induction cooker with unevenly arranged coil is built. Experimental results also proved the efficacy of the coil arrangement methods.

II. ANALYTICAL SOLUTIONS FOR EDDY CURRENT

Assume the metal plate above the coils is circular plane with infinite radius and the metal is isotropic, linear and homogeneous. Reference [4] discussed the skin effect and proximity effect of coils in the induction cooker system. Delta coils without cross section are used to obtain analysis solution of eddy current.

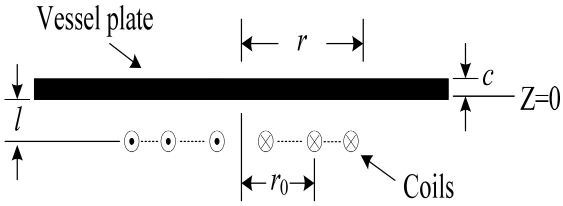


Fig. 2 simplified model of the system of induction cooker

A is the θ component of **A**. r is the distance from the calculated point to the center. z is the height from the calculated point to the bottom of the metal plane. r_0 is the radius of the coil, z_0 is the negative height from the bottom of the metal to the coil. μ_0 is the permeability of vacuum. And μ_r is the relative permeability of the metal plate. I is the magnitude of the AC current through the coil.

The analytical solution of this vector potential can be acquired as equation (8) by using the method in reference [1,5].

$$A = \mu I r_0 \int_0^{\infty} J_1(\alpha r_0) J_1(\alpha r) e^{-\alpha l} \alpha \left[\frac{e^{2\alpha_1 c - \alpha_1 z} + e^{+\alpha_1 z}}{(\mu_r \alpha - \alpha_1) + (\mu_r \alpha + \alpha_1) e^{2\alpha_1 c}} \right] d\alpha \quad (8)$$

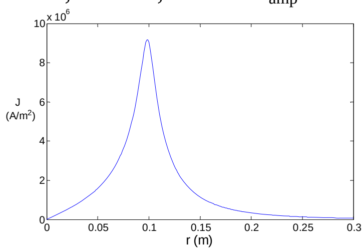
After vector potential **A**(r,z) is obtained, the eddy current can be derived from equation (9).

$$J = \sigma E = -\sigma \partial A / \partial t = -j\omega\sigma A \quad (9)$$

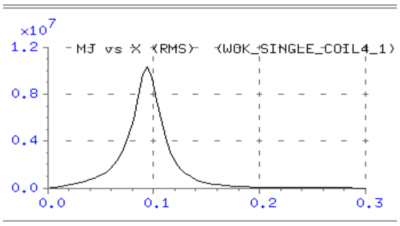
III. METHOD FOR OPTIMIZATION

A. Analysis of theoretical results

For the case of a single delta coil, according to equations (8) and (9), the distribution of magnitude of eddy current density along the radius is illustrated in Fig. 3 (a). The model for calculation is illustrated in Fig. 2. The parameters are r0=98.8mm, l=6mm, c=2mm, z=0 and I_{amp}=10A.



(a)



(b)

Fig. 3 eddy current distribution excited by single coil

(a) Theoretical result

(b) FEM simulation result

Fig. 3 (b) is the simulation results by FEM software MEGA From Fig. 3 it can be found that the peak value of eddy current appeared at the position exactly above the coil. And at the center of the metal plate is zero.

The case of concentric coils arranged along radial line can be regarded as the sum of single coils. Fig. 4 illustrates the case of 10 coils

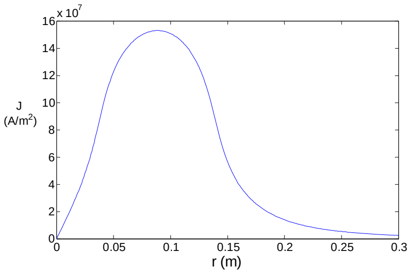


Fig. 4 eddy current distribution excited by multi-coil

The eddy current at the center is still zero. This explains the formation of the cold spot at the center of vessel.

B. Methods of optimization

The guidelines of optimized arrangement of coils can be concluded (will be presented in the full paper).

C. Verified by FEM simulation

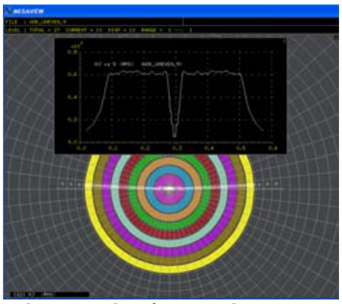


Fig. 5. Simulation results of proposed uneven arranged coil

Simulation has been done by the FEM software MEGA. Fig. 5 illustrates the distribution of eddy current with the optimized coil arrangement. From Fig. 5 it can be found that the eddy current distribution is quite even.

IV. Experimental Results

A 20kW prototype of induction cooker has been built for Chinese rolling wok. This prototype includes drive circuit and uneven arranged coil. The drive circuit adopts full-bridge load resonant converter [5].

Fig. 7 is the result of dry-heat test at the time of 30s. The temperature of the whole wok is measured by infrared camera. Nine testing points are arranged evenly along the radius of the rolling wok. Fig. 8 shows the temperature along radius of the wok.

From Fig. 7 and Fig. 8 it can be found that the cold spot is quite small and the distribution of temperature is even in a wide range of the wok. Experimental results proved the efficacy of the method of optimization.

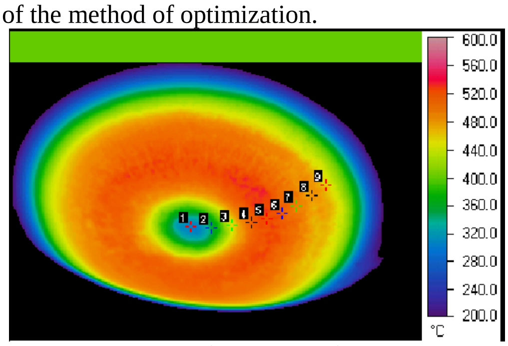


Fig. 7. The pattern of temperature of rolling wok

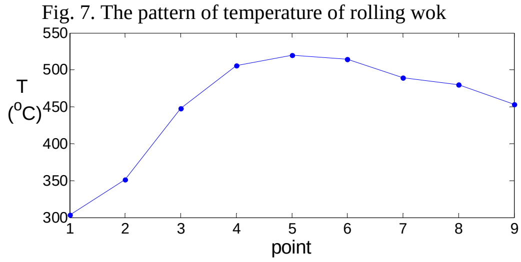


Fig. 8. Distribution of temperature along radius

V. Conclusion

The evenly arranged coils of induction cooker will cause cold spot and uneven distribution of eddy current. They are not often the expectation. The heat distribution of vessel can be improved by the uneven arrangement of coils. Coils near the center should be arranged with more turns to reduce the cold spot.

Acknowledgment

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