Design and Analysis of Multi-Coils Induction Cooker for Thermal Performance Improvement

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Abstract — This paper investigates induction cookers with multiple coils to improve their thermal performances. Two multi-coils solutions are proposed to replace the traditional single coil design. The eddy currents and power losses distributions of the systems are analyzed by utilizing finite element method (FEM). Furthermore, thermal fields on the induction pan are computed to evaluate the thermal performances of the proposed multi-coils systems. By comparing the uniformity factor (UF) of the multi-coils designs against the conventional single coil system, the proposed multi-coils are validated to be capable of providing more uniform and better thermal distribution, as well as potentially more flexible and sound functions.

I. INTRODUCTION

Nowadays, investigations of induction cooker mainly focus on improving its thermal performance and providing innovative functions. One tendency is the development of multi-coils that are adaptive to desired shapes and power capabilities, to replace the traditional single coil [1].

Thermal distribution of an induction cooker is generally determined by its induction coil geometry [2]. Traditional single coil system commonly suffers from localized heating distribution which leads to fast aging of the pan. In addition, it is technically challenging to realize many flexible and sound functions, such as heating up specific areas on the pan. Design of several distributed coils is expected to improve the thermal performance as well as to provide flexible functions. However, there are few studies on the design and analysis of multi-coils for induction cookers.

This paper proposes and investigates two multi-coils systems. Considering the proximity effects among the distributed coils [3], a switched exciting manner for the multi-coils is adopted. The eddy currents and power losses distributions are studied by conducting finite element method (FEM) analysis. The thermal performances of the two multi-coils systems are further evaluated, considering temperature dependence of thermal properties.

II. DESIGN OF MULTI-COILS SYSTEMS

Considering the pan shape, two novel formats of multi-coils are proposed, as shown in Fig. 1.

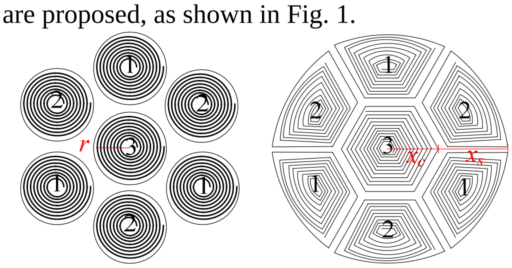

Fig. 1. Proposed multi-coils, (a) 7-circle coils, (b) hexagon like 7-coils.

Due to the proximity effects among the distributed coils, the relative phase differences among the exciting currents play a crucial role in determining the magnetic flux and eddy currents distribution. As reported in [3], out of phase exciting currents for nearby coils can enhance the eddy currents density in the boundary area, indicating enhancement of the heating source. Hence, a switched exciting manner for multi-coils is applied in this research.

The switched exciting manner is defined as follows: each of the coil sets 1 and 2 consists of three coils, as shown in Fig. 1. The center coil (coil 3) is excited in phase with set 1 while anti-phase with set 2 for N cycles. Then coil 3 is switched to anti-phase with set 1 and in phase with set 2 for the other N cycles. N is usually selected as 10-20, which will not affect the thermal stability.

III. FEM COMPUTATION AND ANALYSIS

The induction cookers implementing the proposed multi-coils are investigated by conducting FEM analysis. The technical parameters are given in Table I. The exciting current is 10A RMS at 20 kHz for each coil set.

TABLE I
PARAMETERS OF THE PROPOSED INDUCTION COOKERS

Induction pan (Iron material)	Radius	0.25 m
	Thickness	0.002 m
7-circle coils system	Total surface radius	0.16 m
	Inner radius (each)	0.01 m
	Outer radius (each)	0.05 m
	Number of turns (each)	14
Hexagon like 7-coils system	Total surface radius	0.16 m
	Length x_c (center)	0.05 m
	Length x_s (side coils)	0.11 m
	Number of turns (each)	14
Distance between coils and pan	Thickness of insulator	0.007m

A. Heating Source Distribution Analysis

The eddy currents J and power losses distributions on the pan are particularly studied. Fig. 2 shows the eddy currents distributions on the pan obtained by FEM analysis. The low eddy currents areas around the center coils are remedied by applying the switched exciting manner.

The eddy currents results facilitate calculation of power losses as the heating source Q_e by

$$Q_e = \frac{|J|^2}{\sigma}, \tag{1}$$

where σ denotes the electrical conductivity. Fig. 3 shows the average power losses in an operating period along the midline of the pan for the proposed multi-coils systems, as well as a conventional single coil system (inner radius: 0.01 m, outer radius: 0.15 m, 30 turns). It is found that there is single peak in each side of the center for the single coil, which indicates the problem of uneven and localized heating source. Both of the multi-coils systems outperform the single coil by offering larger area and better uniformity of high power losses.

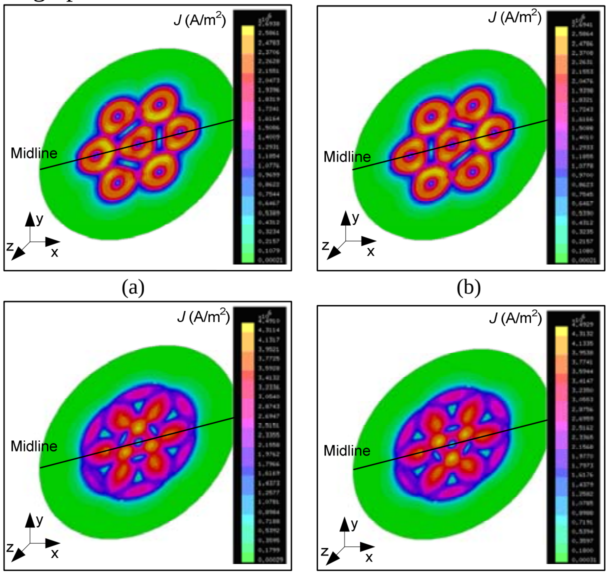

Fig. 2. FEM results of eddy currents on the pan, (a) half period of 7-circle coils, (b) the other half period of 7-circle coils, (c) half period of hexagon like 7-coils, (d) the other half period of hexagon like 7-coils.

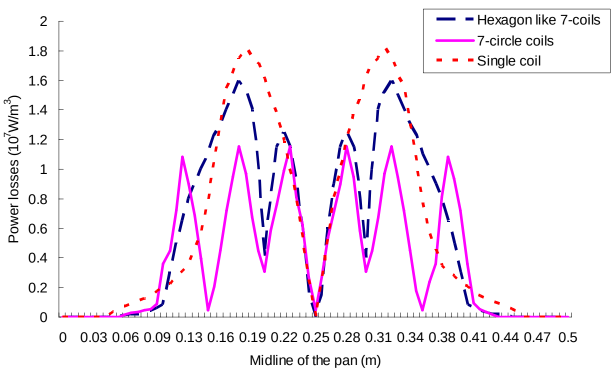

Fig. 3. Power losses distribution.

B. Thermal Analysis

The temperature T on the pan of the induction cooker is generally lower than 500 °C, which is below the Curie temperature (around 770 °C) [4]-[5]. Transient diffusion equation in (2) is applied for thermal field calculation.

$$\nabla\cdot(\lambda\nabla T)-c\rho\frac{\partial T}{\partial t}=-Q_e\,, \tag{2}$$

where λ denotes thermal conductivity, c stands for specific heat, and ρ represents mass density. In order to improve computing accuracy, temperature dependence of thermal properties is also included. Thermal properties of the pan in temperature regions below Curie temperature are regarded as linear functions as

$$\lambda=-0.0738T+82.1926\,, \tag{3}$$

$$c=0.42T+435.2\,. \tag{4}$$

Fig. 4 shows the temperature distribution along the midline of the pan after operating for 50 seconds. The resulting thermal distribution of each system is similar to its power losses distribution. This phenomenon would be invariable until the pan temperature higher than its Curie temperature.

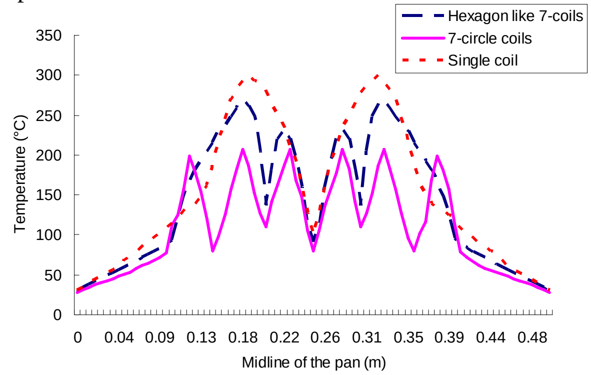

Fig. 4. Thermal distribution at 50 seconds.

The uniformity factor (UF) is utilized for assessing the three cookers' uniformity performance, as defined in (5).

$$\mathrm{UF}=\frac{S_{ah}}{S_t}\,, \tag{5}$$

where S_{ah} stands for the area above half of the maximum value, and S_t is the total thermal area. Hence UF of each system is computed and compared in Table II. The 7-circle coils system offers the best thermal uniformity with relatively lower temperature. Actually, the relatively low temperature can be enhanced by increasing the number of turns of each coil, while increasing the total power capability. The hexagon like 7-coils system provides medium performances in both uniformity and temperature intensity. In general, the proposed multi-coils systems can effectively address the localized thermal problem of single coil system, while providing better uniform thermal distribution and diverse heating functions.

TABLE II
UF of Induction Cooking Systems

	Single coil	Hexagon like 7-coils	7-circle coils
Power losses UF	0.412	0.534	0.583
Temperature UF	0.526	0.673	0.750

IV. Acknowledgment

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V. References

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