A New Inductor for Transverse Flux Induction Heating

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Abstract — A transverse flux induction heating (TFIH) device with an unique induction structure is presented in this paper. The development procedure started with theoretical analysis of the relationship between eddy current distribution and coil geometry. Then, with the help of the analysis results, new coil geometry was designed in order to get an uniform temperature distribution on the strip surface at the TFIH equipment outlet. The non-linear coupled electromagnetic-thermal problem in TFIH was solved by finite element method (FEM). Finally, a prototype was developed according to the numerical results. Test results agree with the numerical evaluations. Both numerical analysis and experimental results show that the new coil geometry can result in an uniform temperature distribution.

I. INTRODUCTION

Compared with longitudinal flux induction heating, transverse flux induction heating (TFIH) processes have considerable advantages such as much lower frequency resulting in higher electrical efficiency, more suitable for continuously heating treatment and local heating. The main disadvantage of TFIH is the resulting uneven temperature distribution on the surface of the strip cross-section at the inductor outlet, which is mainly influenced by the coil geometry and the position of the coil edges relative to the work piece width. Generally, the coil geometry used in TFIH equipment is rectangular, which is parallel to the strip[1]. Such a single inductor can't result in an uniform temperature distribution. The traditional method to solve this problem is to use two inductors each with different coil to strip width ratio [2], or to use two coil groups switched alternately [3].

In this paper a TFIH device with an unique inductor structure is presented. Test results show that the presented inductor can produce more uniform temperature distribution compared with traditional rectangular inductor structure.

II. RELATIONSHIP BETWEEN COIL GEOMETRY AND EDDY CURRENT DISTRIBUTION

To simplify the analysis of the TFIH, the inductor and the work piece is simplified to a thin metal sheet (RM) with a coil (C_1) over it as shown in Fig .1. The projection of the coil on the sheet is C_2. The distance between C_1 and C_2 is so short that magnetic flux density at the coil plane is almost equal to that at the projection plane. The magnetic fluxes penetrating through the sheet have opposite directions outside and inside C_2, which are marked with cross and point signs, respectively. The radius of C_2 is the same as that of C_1. Given a ring with the same center of C_2 in the sheet, inside radius r_2 and outside radius r_1, Let $d_r=r_1-r_2$, $a_r=(r_1+r_2)/2$ and $d_r << a_r$.

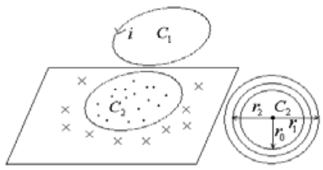

Fig. 1. The relationship between eddy current distribution and the projection of the coil geometry

when the ring is outside C_2, the eddy current can be expressed by

$$I = -\frac{\omega d_r h}{2\pi\rho} \cdot \frac{\Phi_M}{a_r} \cos(\omega t) \quad (1)$$

when the ring is inside C_2, the eddy current is

$$I = -\frac{\omega d_r h}{2\rho} B_{aM} a_r \cos(\omega t) \quad (2)$$

where, $B_{am} a_r$ increases as a_r grows.

From (1) and (2), it reveals that the eddy current mainly distributes near the projection of coil. This conclusion is helpful for coil geometry design to get an uniform temperature in TFIH.

A square coil geometry with 45º rotation is designed. One half of the physical model is shown in Fig.2. The projection area onto the strip is equal along moving direction. For compensating the heat loss at strip edges, two corners of coil should be out of strip.

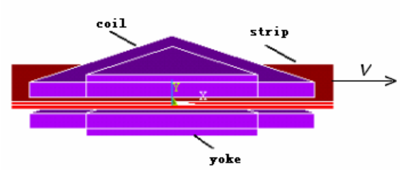

Fig. 2. One half of the TFIH inductor Structure

III. COUPLED FIELD SIMULATION PROCEDURE

The mathematical model for this sinusoidal quasi-static eddy current problem results from Maxwell equations and is described by the complex magnetic vector potential $\underline{A}$ and an electrical complex scalar potential $\underline{\phi}$ with Coulomb Gauge

$$\nabla \times \frac{1}{\mu} \nabla \times \underline{A} - \nabla (\frac{1}{\mu} \nabla \cdot \underline{A}) + \mathrm{j}\omega\sigma \left(\underline{A} + \nabla \underline{\phi}\right) = \underline{J}_S \quad (3)$$

where μ is the permeability, σ the conductivity, ω the angular frequency and $\underline{J}_S$ the excitation current density source.

The requirement of a zero divergence condition of current density must be fulfilled

$$\nabla \cdot \left(\sigma \underline{A} + \sigma \nabla \underline{\phi} \right) = 0 \quad (4)$$

The temperature field ϑ is computed based on the Fourier's thermal conduction equation

$$\frac{\partial \left(c \rho \vartheta \right)}{\partial t} = \nabla \cdot \left(\lambda \nabla \vartheta \right) + p_V \quad (5)$$

where c is the specific heat, λ the thermal conductivity coefficient, and ρ the mass density.

In the coupled problem iteration process, the material characteristic is updated [4], [5].

IV. SIMULATION AND EXPERIMENTAL RESULTS

The steel strip width is 0.2m, thickness 0.5mm, the exciting current 100A, and the working frequency about 0.7KHz. The calculated eddy current distribution on the strip surface is shown in Fig. 3, which demonstrates that the eddy current distribution concentrates on the coil projection onto strip surface. The corresponding temperature distribution is shown in Fig. 4, which indicates that the temperature at the inductor outlet is nearly uniform. The transverse flux induction heating equipment is developed as shown in Fig.5. The temperature distribution on the strip surface was obtained by a thermal imaging camera, shown in Fig.6. Test results agree with the numerical simulation results as shown in Fig. 7.

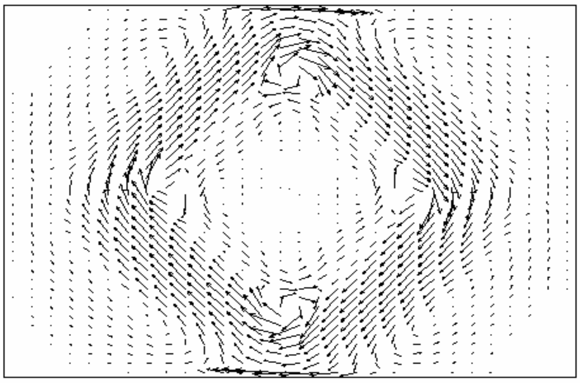

Fig. 3. Eddy current distribution on strip surface.

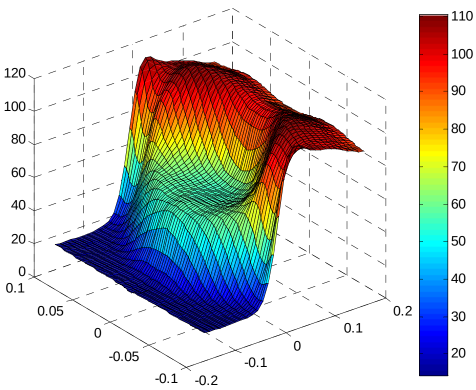

Fig. 4. Temperature distribution on strip surface (in ℃)

Fig. 5. Transverse flux induction heating equipment.

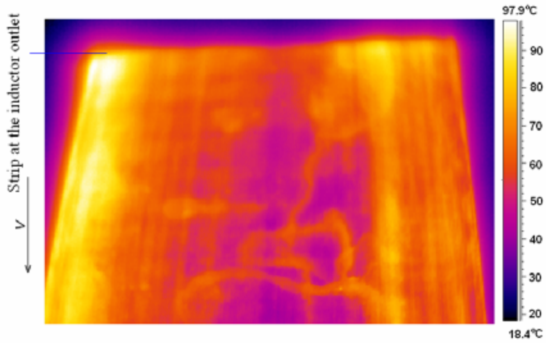

Fig. 6. Temperature test results

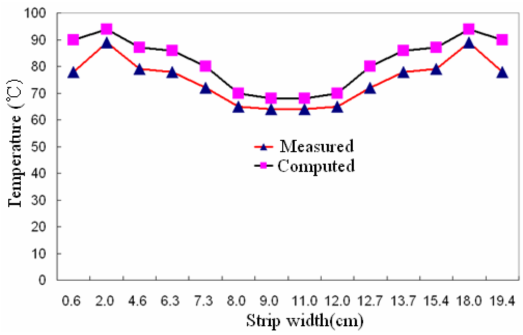

Fig. 7. Comparison of computed temperature with the measured

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