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Analysis of the Algorithm for Changing the Output of Induction Heaters for Electric Vehicles

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Abstract
In the battery heating of the electric vehicles(EVs), existing vehicle with internal combustion engines use the heat generated by the engine to heat the cooling water. However, EVs doesn't have an engine, so additional system is needed to generate heat. Maxwell tools were used to conduct this study. Model induction heater in 2D and perform FEM analysis. Induction heaters generate heat by the AC current of the coil inducing eddy currents on the workpiece surface. A big feature of induction heaters is that they operate in the high frequency range, so heat is concentrated on the surface. We analyze this by using FEM and propose an output change design algorithm for various parameters. The characteristics of the induction heater operating in the high frequency range create a skin effect phenomenon in which eddy currents and magnetic fluxes are concentrated on the inner and outer workpiece surfaces. To take this into account, the FEM analysis tool was used to split the workpiece into units and to focus the mesh on the surface. In order to simulate the IGBT, the Maxwell-supplied devices set the external circuit and derive the output according to the duty ratio. In this paper, the magnetic flux density distribution for each output is derived. These results extend to the design of the output change. The key to this study is the effect of duty ratio on the output. Within the 50% limit, we consider the effects of the larger output and the smaller output as the duty ratio and the characteristics of the relationship between the duty ratio and output. In this paper, an algorithm for the relationship between duty ratio and output is presented. Induction heater having the advantages of weight reduction and fast heating rate can be utilized to maintain the proper temperature of the battery for the electric vehicle, it can be utilized for room heating.

Keywords: *Core loss, Workpiece, Duty ratio, Induction heater, LC resonance.*

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1. Introduction

In conjunction with finite fossil fuels and environmental regulations under energy reduction policies, the need for new environmentally friendly energy sources is growing. In many industries, the technology is continuously developed and researched. In the automotive field, various concepts such as hybrid, hydrogen fueled vehicles, and electric vehicles are emerging. But this has led to a number of issues that need to be addressed. HVAC is one of them. In the battery and room heating of the electric vehicle, the existing vehicles with internal combustion engine uses the heat generated by the engine to heat the cooling water to use the heating, but since the electric vehicle does not have an engine, an additional system is needed to generate heat. In general, the PTC heater, which was used as an auxiliary heating device of a diesel vehicle, was used as the main heating, but the battery consumption of the electric vehicle was increased, and thus, the daily charging mileage of the winter was drastically reduced[1]-[5]. In order to solve this problem, various technologies such as the addition of a heat pump or an auxiliary electric heater are currently in progress. The induction heater covered in this study is a hydrothermal type and is used for electric vehicle battery temperature maintenance and room heating. Induction heater is simple structure of coil and workpiece, so it is effective for weight reduction and has fast heating rate. Considering these advantages, it can be judged to be suitable as an electric vehicle electric vehicle[6]-[8]. The principle of operation is that AC current in the coil induces eddy currents in the inner and outer workpieces, which generate heat from the workpiece surface[9][10]. The heated workpiece boils the cooling water circulated through the inlet and outlet.

2. Basic model

Fig. 1 shows the basic architecture for Maxwell simulation of an induction heater. 2D analysis quickly derives the basic characteristics of induction heaters. 3D modeling gives an overview of the overall shape of the induction heater. This model shows simple structure consisting of work coils that generate magnetism and internal and external Workpieces (WP) that generate heat. Induction heaters consist of a work coil that generates magnetism as a current flow and a workpiece that generates heat through eddy current loss and hysteresis loss. It is a simple structure, and this advantage affects the weight savings.

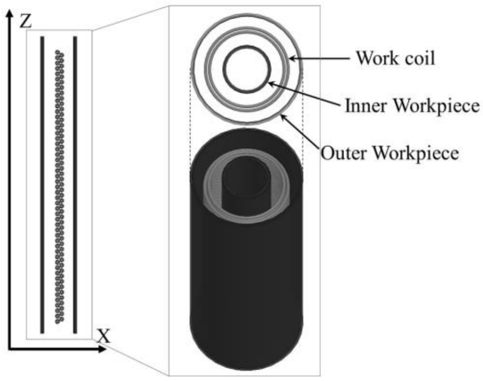

Figure 1. Equivalent 2D and 3D modeling of induction heaters for FEM

Table 1. Specification of Basic model

Parameter	Value	Parameter	Value
WP diameter(outer)	50.8mm	WP diameter (inner)	22mm
WP thickness(outer)	1.5mm	WP thickness(inner)	1.5mm
WP height(outer)	129mm	WP height(inner)	129mm
WP material (outer, inner)	SUS430F	The num. of reels	200
Coil diameter	1.414mm	The num of turns	101

• Mech Settings.

In finite element analysis, the mesh setting is a very important factor. The energy density of the induction heater is concentrated on the surface. Fig. 2 shows the meshes of the induction heater. Finite element meshes are an important element. FEM divides the whole area into smaller areas called meshes. Induction heaters operate at high frequencies. Eddy currents are induced on the surface of the magnetic material. Because the frequency is very high, the phenomenon is not distributed throughout the magnetic material and is concentrated on the surface. The permeable depth is derived numerically as shown in equation (1). The higher the frequency, the higher the specific permeability, and the smaller the specific resistance, the more concentrated the surface. Since the induction heater of this study operates in the high frequency band of 30kHz, it should be simulated by setting up a lot of mesh on the workpiece surface for accurate analysis.

$$\delta = 503\sqrt{\frac{\rho}{\mu_r f}} \tag{1}$$

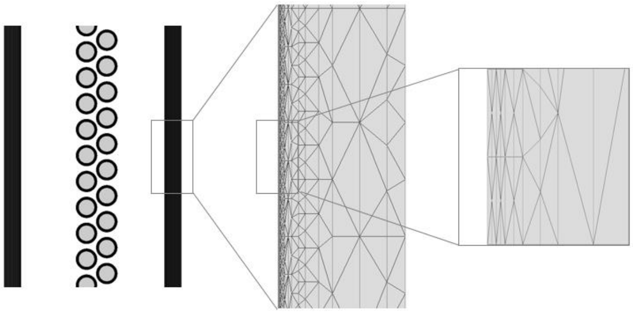

Figure 2. Concentrated mesh on the workpiece surface.

• **External circuit**.

Fig. 3 shows a full bridge circuit structure for LC resonance of the induction heater. A capacitor is added for LC resonance. The IGBT's fast switching adjusts the output voltage. The resistor portion is for considering the copper loss of the coil, the inductor portion is for interlocking the induction heater and the capacitor is for resonating.

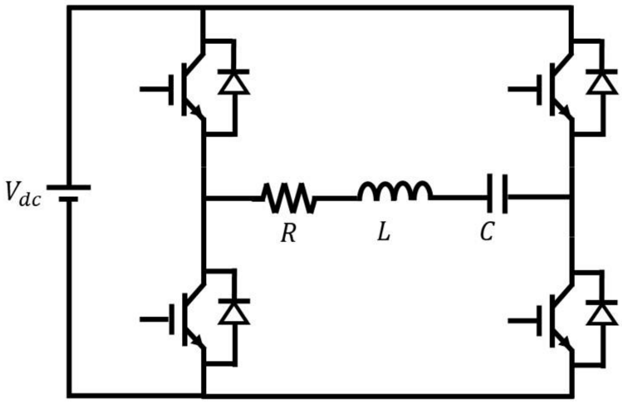

Figure 3. LC resonance external circuit for operating induction heater

3. External circuit interlocking analysis and result

Fig. 4 shows the external circuitry associated with the FEM tool. The switching frequency is 30 [kHz]. In order to simulate the IGBT, a switch and diode were connected. In addition, capacitors are added for LC resonance to minimize impedance. The internal resistance of the inductor on the external circuit is 17 [ohm] and the added capacitance is 0.432[uF]. The inductance of the induction heater of the basic model is about 65[uH]. At this time, the capacitance resonating at 30 [kHz] is 0.432[uF] by Equation (2).

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad (2)$$

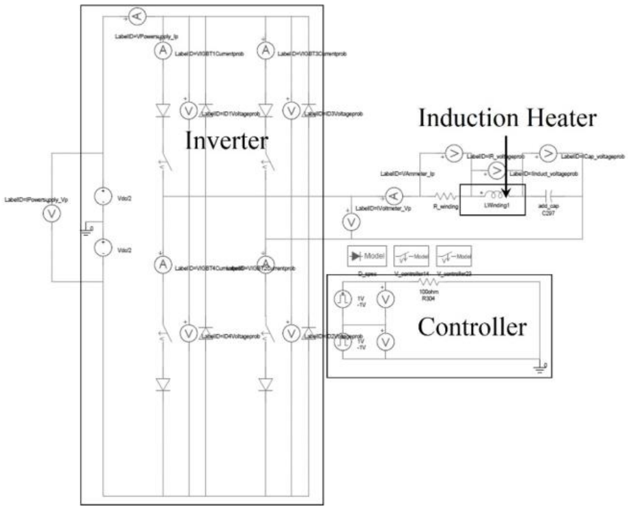

Figure 4. Interlocked LC resonant external circuit for simulation.

Fig.5 shows the current and voltage waveforms according to the duty ratio in the switching circuit. The simulation was performed by setting the duty ratio having a 30[kHz] switching frequency as a variable. Duty ratio means the whole time zone on time. 18% duty ratio is based on 1[kW] output of the basic induction heater. The 42% duty ratio is based on the 6[kW] output of the basic induction heater. The design specifications remain the same, only the duty ratio is modulated. The switch simulated in the interlocked LC resonance circuit modulates the duty ratio through the controller. In the first cycle, switching is performed to apply a forward voltage to the induction heater, and current starts to flow in the forward direction. To avoid dark shorts, set some delay time before applying reverse voltage. In the delay time, current flows through the diode. At this time, the current fluctuates noticeably, and the residual voltage is still applied to the capacitor. After the delay time, voltage starts to be applied in the reverse direction. Fig. 6 shows the magnetic flux density distribution of each induction heater. In common, we can see that a lot of magnetic flux flows on the top and bottom edges of the workpiece. It can be seen that the greater the output, the greater the loss on the workpiece.

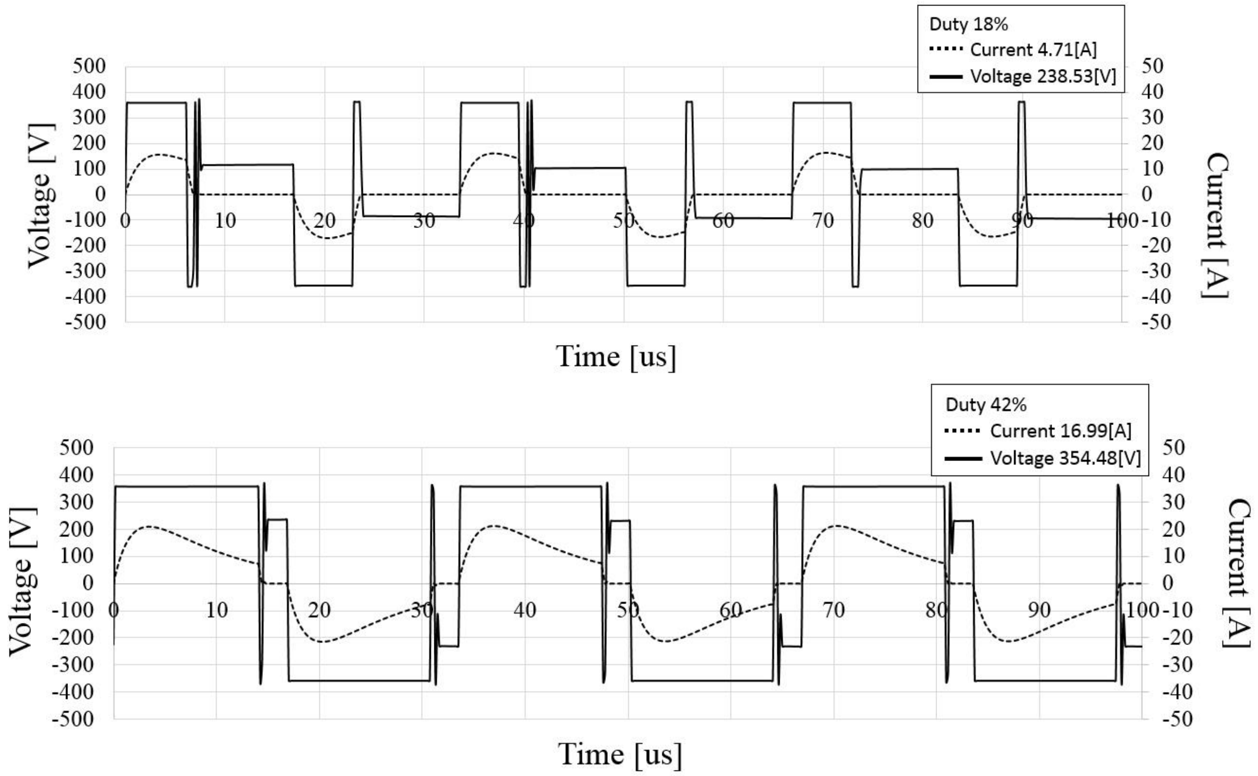

Figure 5. Output waveform of induction heater according to duty ratio

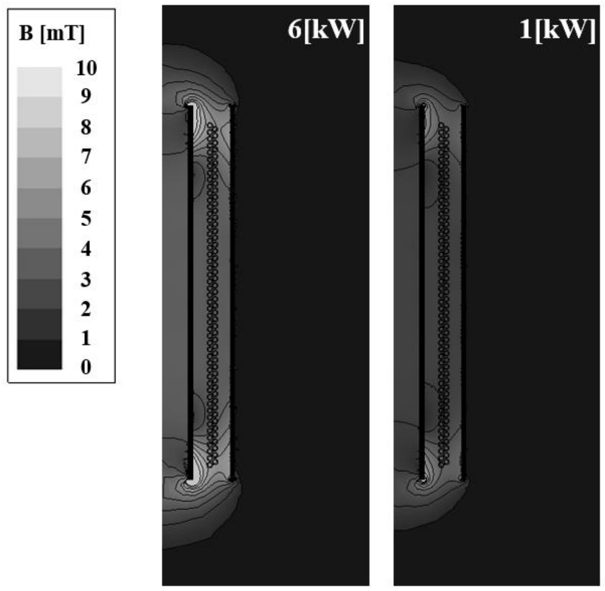

Figure 6. Magnetic flux density distribution by output

3. Conclusion

In this paper, the output waveform according to the duty ratio for the switch is identified. The derived output allows us to characterize the induction heater. In application systems with high external temperature changes, induction heaters for rapid temperature rises are needed for thermal management to improve battery life and maintain battery energy density. The nonlinear mathematical model of the heater makes it possible to construct an induction heater design model suitable for various battery capacities. Also, from the technical point of view, it can be extended to other fields through the establishment of electromagnetic characteristic analysis technique.

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