A Study on Increase of Core Loss Ratio and Inductance According to Construction of Induction Heater for Electric Vehicle

Seok-Hyun Yu[1], Jun-Kyu Kang[1] and Ki-Chan Kim[1], Member, IEEE

[1]Dept. of Electrical Engineering, Hanbat National University, Daejeon, 305-716, South Korea

Induction heater is characterized by a faster heating rate and lower cost than Positive Temperature Coefficient (PTC) devices. Therefore, it is more suitable for the air conditioning system of Electric Vehicles (EVs). However, induction heater for air conditioning system of EVs has not yet been studied. Maintaining the temperature of the battery in EVs is one of the important factors for improving the fuel efficiency of automobile. In induction heater, the ratio of core loss and inductance is related to efficiency and production cost. Increasing the inductance can reduce the capacitance of the capacitor. The increase of the core loss ratio can reduce the heat generated in the coil and increase the durability and efficiency. In this paper, the improvement of the inductance and the core loss ratio is carried out by Finite Element Method (FEM) analysis and magnetic equivalent circuit according to the structure of the induction heater. Simulation verification and inductance derivation method are also studied by comparing with measured data.

***Index Terms*— Core loss, Electric Vehicle, Inductance, Induction Heater.**

I. INTRODUCTION

IN the automotive industry, PTC devices is used as a heat source for air conditioning systems. However, PTC devices have a disadvantage of high cost and heavy weight. On the other hand, Induction heater are characterized by faster heating rates and lower cost than conventional PTC devices [1]. However, in the automotive industry, research on induction heaters has not yet been conducted. At sub-zero temperatures, EV batteries have a feature of drastically decreasing capacity. The EV starts to operate without a separate preheating time at the start [2]. Therefore, the heating time is one of the most important factors for maintaining the battery temperature in winter. Therefore, induction heaters are more suitable than PTC devices as components for maintaining battery temperature in electric vehicles [3].

Important design parameters of the induction heater are the inductance and the loss. Increasing the inductance is an element to reduce the capacitance of the capacitor connected to the circuit. The price and size of the capacitor are proportional to the capacity. Therefore, reducing the capacitance is important to reduce fabrication cost and weight. The loss is largely divided into core loss from the work piece and copper loss form the coil. The ratio of core loss to total loss is very important. If the copp er loss is large, the coil generates a lot of heat, which is not good in durability and heat transfer. Therefore, it can be seen that high loss in the work piece is the most important factor for the efficiency of the induction heater.

In this paper, we studied the improvement of the proportion of the core loss in the total loss and the inductance according to the structure of induction heater by using FEM. Analysis models are divided into three models in the paper. For comparison, the analysis models used the same turns of coil, wire diameter and used the Litz wire to reduce the skin effect and proximity effect of the coil at high frequency.

II. PROPOSED MODEL

Fig. 1 shows three proposed models. As shown in the figure, SUS430f is used as the material of the work piece. To reduce the skin effect and proximity effect of the coil, Litz wire(0.1 mm X 80reels) is used. The number of turns is 65 turns. Fig. 1-(a) shows a case where only one inner work piece and only an external coil are used. Fig.1-(b) shows a structure in which a work piece is formed inner and outer, and a coil is located therebetween. Fig. 1-(c) shows that the structure of the work piece is the same as Fig.1-(b), but the coil consists of the inner and outer parts. The three models are chosen to have the same number of turns and the size of inner work piece.

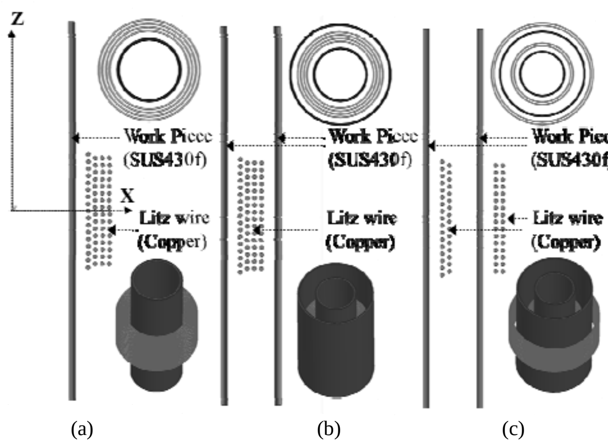
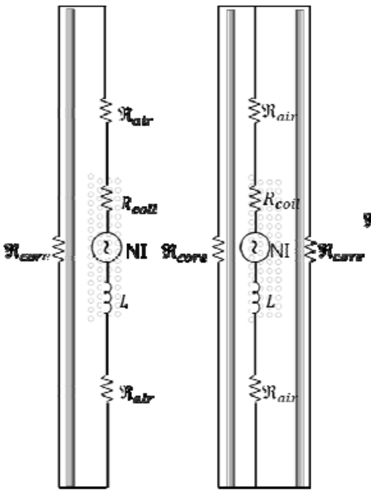


Fig. 1. Proposed model (a) Model 1 (b) Model 2 (c) Model 3

III. THE INDUCTANCE OF INDUCTION HEATER

To reduce the capacitance of the capacitors connected to the circuit, designing the induction heater to have large inductance is more advantageous for the manufacturing cost and weight. The capacitance for LC resonance can be estimated in advance by accurate inductance derivation. Therefore, it is one of the most important factors in design to accurately derive the value of inductance by simulation, magnetic equivalent circuit calculation, and actual measurement data.

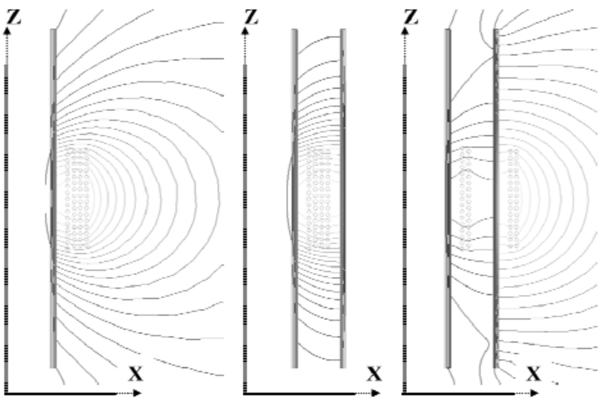
Fig. 2 shows the magnetic equivalent circuits of proposed models. As shown in the figure, the inductance value calculated by using the the magnetic equivalent circuit.



(a) (b) (c)

Fig. 2. Magnetic Equivalent Circuit of Proposed models (a) Model 1 (b) Model 2 (c) Model 3

Fig. 3 shows the magnetic flux distribution in the FEM simulation. As shown in Fig.3-(a), the magnetic flux leaks into the air. Thus, it can be seen that the inductance decreases due to leakage flux. On the other hand, Fig.3-(b) shows that the outer work piece blocks magnetic flux leaking into the air. Therefore, it can be seen that inductance is higher than model 1. Fig.3-(c) shows the magnetic flux leaking from outer to the air.



(a) (b) (c)

Fig. 3. Flux Line Distribution (a) Model 1 (b) Model 2 (c) Model 3

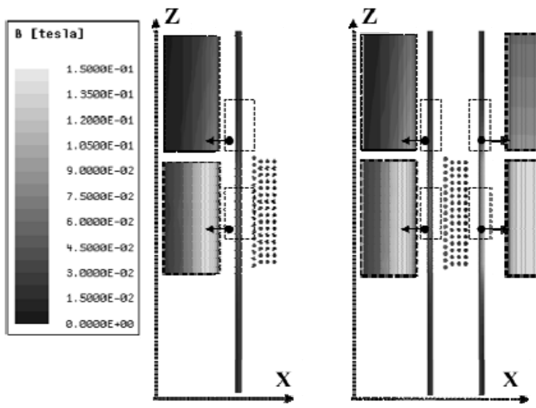
Based on the above results, inductance analysis for three proposed models is conducted. As a result, we intend to derive a structure favorable to inductance among the three model structures.

IV. THE CORE LOSS RATIO IN TOTAL LOSS

Equation (1) shows the core loss equation. Where K_h, K_c and K_e are the hysteresis loss constant, eddu current loss constant, and access loss constant, respectively. As can be seen from the equation, the core loss is caused by a material characteristic such as a hysteresis loop of a material and a variation in magnetic flux density with time.

$$CoreLoss = K_h \frac{1}{\pi}\frac{\partial B}{\partial t} + K_c \frac{1}{2\pi^2}\left(\frac{\partial B}{\partial t}\right)^2 + K_e \frac{1}{C_e}\left[\left(\frac{\partial B}{\partial t}\right)_{\max}\right]^{-0.5}\frac{\partial B}{\partial t}. \quad (1)$$

Fig. 4 shows the magnetic flux density distribution. As shown in the figure, model 2 has a small amount of magnetic flux leaking into the air and most of the flux flows through the work piece. Therefore, core loss is higher than model 1. Thus, when the number of turns and diameters of the coils are the same and the input power is the same, the copper loss of both models is the same, but the core loss ratio changes.



(a) (b)

Fig. 4. Flux Density Distribution (a) Model 1 (b) Model 2

As mentioned above, the output of the induction heater is divided into core loss and copper loss. Therefore the ratio of these losses is important to the design. If the copper loss ratio is high, the coil generates a lot of heat. However, coils are coated for insulation purposes. Therefore, when a large amount of heat is generated in the coil, the efficiency is low due to the durability of the coil and the low heat transfer rate. Therefore, FEM simulation has been carried to increase the ratio of core loss to tatal loss.

REFERENCES

[1] Boadi, A, Tsuchida, Y, Todaka, T, and Enokizono, M, “Designing of suitable construction of high-frequency induction heating coil by using finite-element method,” IEEE Trans. Magn., vol. 41, pp.4048-4050, Oct. 2005.

[2] Acero, J, Carretero, C, Alonso, R and Burdio, J.M, “Quantitative Evaluation of Induction Efficiency in Domestic Induction Heating Applications”, IEEE Transactions on Magnetics, vol. 45, pp.1382-1389, Apr. 2013.

[3] M. Messadi, L. Hadjout, Y. Ouazir, H. Bensaidane, T. Lubin, S. Mezani, A. Rezzoug, N. Takorabet, “Eddy Current Computation in Translational Motion Conductive Plate of an Induction Heatre With Consideration of Finite Length Extremity Effects”, IEEE Transactions on Magnetics, vol. 52, no. 3, pp. article 6300304, Mar. 2016.