Reduction in eddy current loss for a power coupler in an electrodeless discharged lamp

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We investigated reduction in an eddy current loss for a power coupler in an electrodeless discharged lamp with our previously proposed analysis method for plasma in the lamp. We confirmed that a large eddy current flow was observed at the top of an Al stage in the power coupler and the loss was reduced by a decrease in the height of the Al stage. This result suggests that a decrease in the height is effective to reduce wasted power losses and implies the possibility of an improvement in the lamp efficiency. We also confirmed that upward-moving and moderate-elongation of the ferrite core in the power coupler is effective to reduce the wasted loss. In order to verify the result, we evaluated the lamp efficiency of a lamp with a modified power coupler. Resultantly, the lamp efficiency was increased by approximately 3 lm/W (lumen per Watt). Therefore, we can conclude that reducing the eddy current loss in the power coupler is one of the important factors to obtain high lamp efficiency.

Key words: electrodeless discharged lamp, inductively-coupled plasma, high frequency excitation

1. Introduction

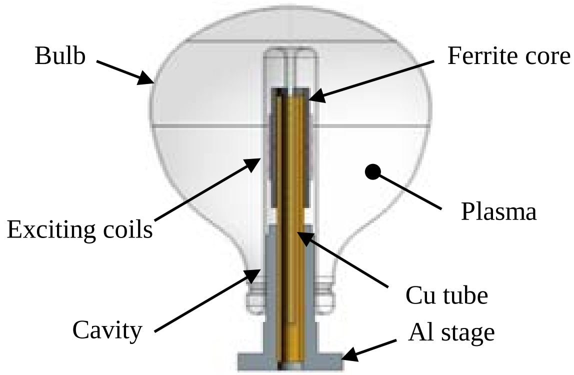
Recently, electrodeless discharged lamps are widely used for light sources with high luminous flux such as street lamps and high ceiling ones since they have some industrial advantages including long life time and low maintenance cost[1-3]. Although the electrodeless discharged lamps are hopeful candidates for new light sources, their lamp efficiency of approximately 90 lm/W is smaller than those for conventional lamps such as high-pressure sodium ones (110～130 lm/W) and metal halide ones (70～130 lm/W), which situation prevents them from further spreading. Therefore, an improvement in their lamp efficiency is strongly required.

The emission of the light originates from Inductively-Coupled Plasma (ICP), and the state of the plasma strongly influences the lamp efficiency. As the electric power is transmitted to the plasma through the magnetic coupling for ICP, magnetic designs such as the shapes and positions of exciting coil and magnetic core strongly influence the plasma state. Thus, we need to pay attention to a suitable magnetic design to obtain the high lamp efficiency.

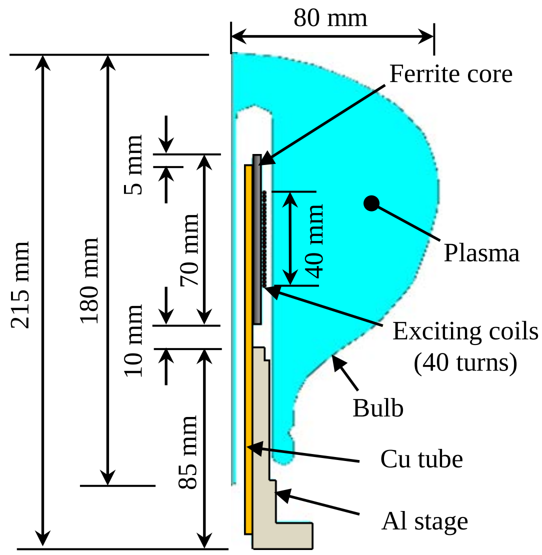
Since a high frequency magnetic field is needed for maintaining the plasma in this type of lamp, eddy currents flow in electrically-conductive components of the lamp. In this study, we focus on a reduction in the eddy current loss of a power coupler and investigate a design of the power coupler with low eddy current loss.

2. Analysis Procedures

We analyze the eddy current losses in a commercial electrodeless discharge lamp (150 W type) produced by Panasonic, Ltd. as shown in Fig. 1. The lamp is composed of two separable parts, which are a bulb and a power coupler. Ar



(a) Analysis object



(b) Modeled lamp

Fig. 1 Analysis objects and modeling of a lamp. A spherical electrodeless discharge lamp (150 W type) produced by Panasonic Ltd. is used as reference model in this study.

gas and amalgam (Hg-metal compound) are enclosed in the bulb, and the gas pressures under lighting are 23.2 Pa and 0.93 Pa for Ar and Hg, respectively. Phosphor materials, which are applied with inner surface of the bulb, convert ultraviolet rays in the plasma into visible light. The power coupler is consisted of a ferrite core and exciting coils, a Cu tube and an Al stage. The roles of them are a generator of high frequency magnetic field, a radiator for the core and a stage for the lamp, respectively.

In order to calculate the eddy current loss, we use our proposed analysis method for the plasma in the lamp. Details of the analysis model and method are described in Reference 4. The input power and the excitation frequency are set at 150 W and 135 kHz, respectively.

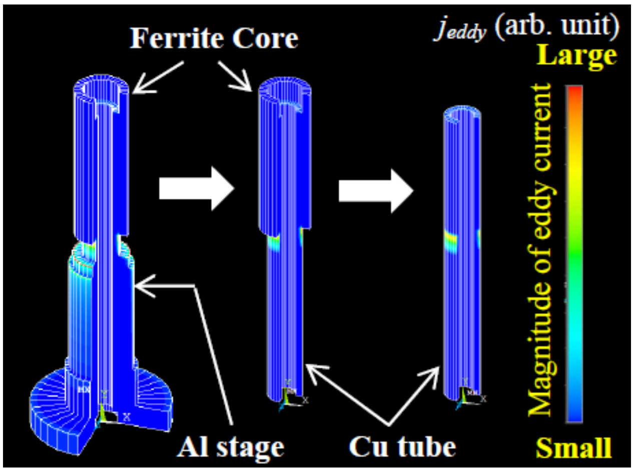


Fig. 2 Eddy current per unit volume in the power coupler of the commercial lamp.

3. Results and Discussion

3.1 Eddy current in the power coupler

Figure 2 shows eddy current per unit volume in the power coupler. As you can see, large eddy currents flow in the areas around the top in the Al stage and around the bottom of the core in the Cu tube. The eddy current loss in the coupler is one of wasted power losses and doesn't contribute to the lamp emission. Thus, we need to reduce the eddy current loss in the power coupler for developing the lamp with high lamp efficiency.

3.2 Suitable design of the power coupler

Figure 3 shows overall results for the eddy current losses of the Al stage and the Cu tube. In Fig. 3, the eddy current losses in the coils and the core are not apparent since both losses are very small compared with those for large volume and electrically-conductive components of Al stage and the Cu tube. The schematic representations of the power coupler indicate the

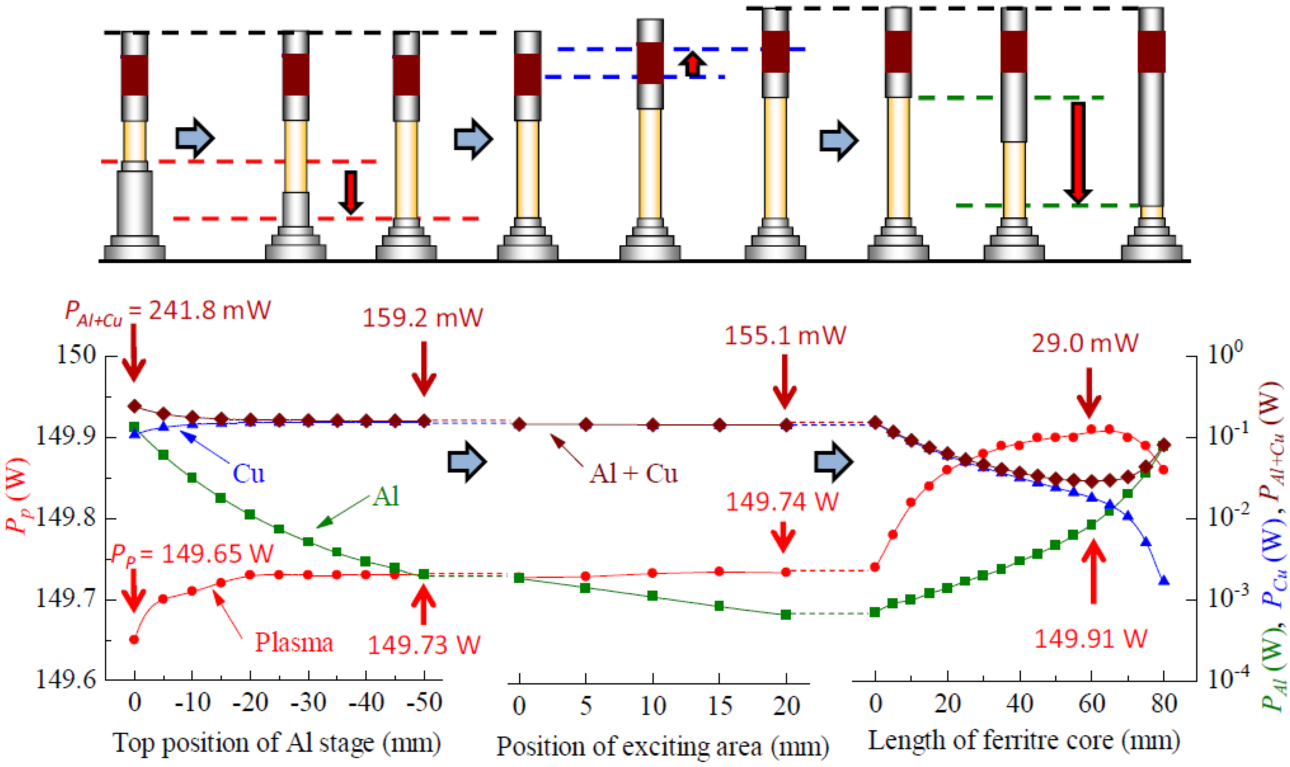


Fig. 3 Eddy current losses of the Al stage P_{Al} and the Cu tube P_{Cu} calculated with various simulation models. The simulation models are shown in the same figure schematically. Calculated eddy current loss of the plasma P_p is also shown as a reference.

simulation models. In this paper, the losses of the Al stage and the Cu tube describe P_{Al} and P_{Cu}, respectively. We deal with a summation of P_{Al} and P_{Cu} as the eddy current loss in the power coupler. As we have already confirmed a good correlation between calculated eddy current loss in plasma P_p and measured luminous flux in an electrodeless discharged lamp, P_p is also shown in the Fig. 3 as a reference.

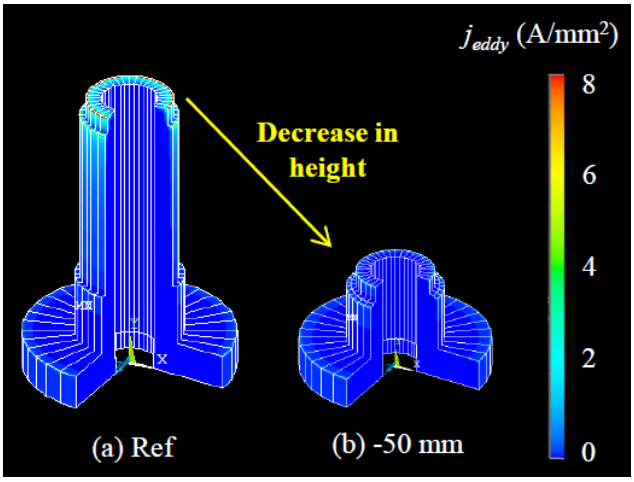


Fig. 4 Contour figure for eddy current per unit volume in the Al stage before and after reducing the height.

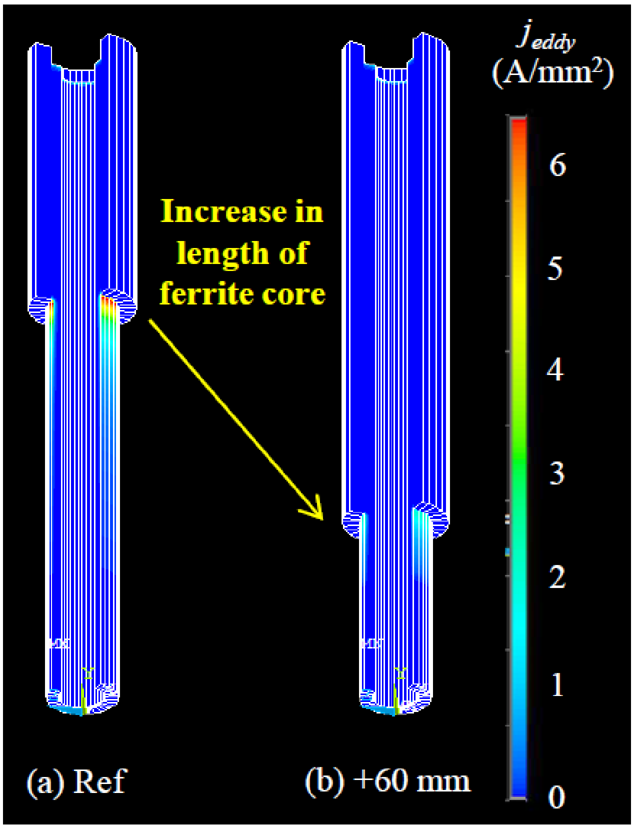


Fig. 5 Contour figure for eddy current per unit volume in the Cu tube before and after elongation of the core.

Firstly, we changed a height of the Al stage. As shown in Fig. 3, the P_{Al} shows a dramatic decrease with a decrease in the height of the Al stage from the commercial coupler dimension. In order to clarify the reason for the dramatic decrease, we confirm the eddy current flow. Figure 4 shows contour figures for the eddy current in the Al stage before and after reducing the height. In the decreased-height model, the eddy current flow around the top of the Al stage is remarkably small as compared with the reference one. The decrease in the height causes an increase in the distance between the bottom of the core and the top of the Al stage. As the increased distance leads to a decrease in the interlinkage magnetic fluxes, the eddy current in the Al stage decreases. Therefore, an increase in the distance between the core's bottom and the Al stage is one of effective design approaches to reduce the wasted power loss.

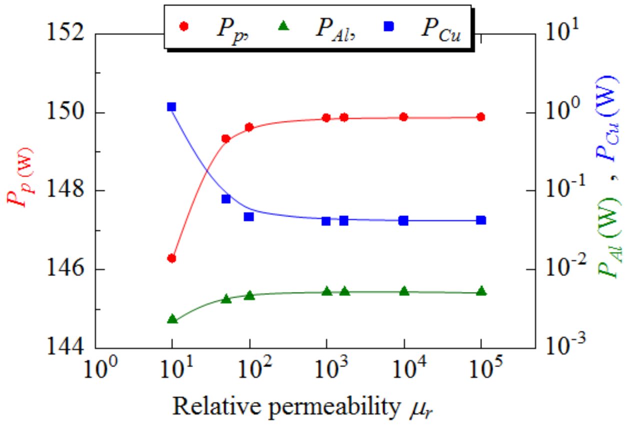


Fig. 6 Change in eddy current loss in plasma P_p, Cu tube P_{Cu} and Al stage P_{Al} as a function of the relative permeability of the ferrite core. The relative permeability for a commercial lamp is 1700.

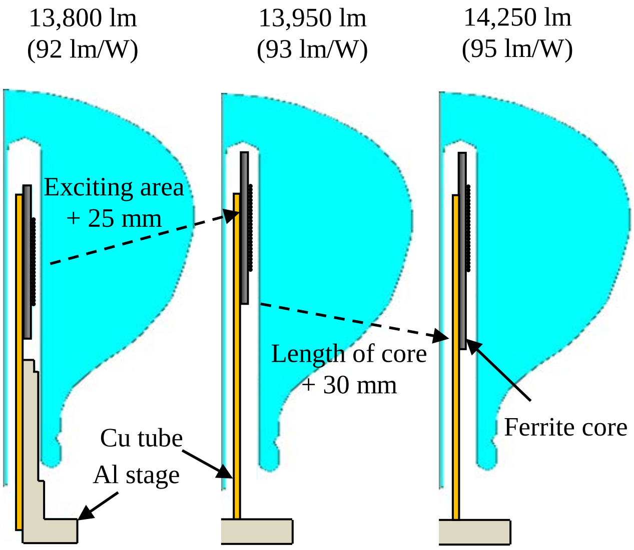


Fig. 7 Schematic representation of the coupler in the measured lamp. Measured values of the luminous flux and the lamp efficiency are also shown in the top of each lamp.

Considering the result for the decrease in the eddy current loss due to the separation between the core and the Al stage, we change a position of the exciting area and investigate the effect of the position on the eddy currents. In this investigation, drastic changes in the eddy current losses are not observed, and the loss for the Al stage slightly decreases with upward-moving of the position.

Finally, we evaluate the effect of the core length on the eddy current loss. As shown in the Fig. 3, the eddy current loss in the power coupler P_{Al+Cu} shows a decrease with increasing the bottom-length of the core and shows a minimum at +60 mm, followed by an increase in the longer length region. The increasing P_{Al+Cu} in the longer length region could be attributed to decreasing the distance between the core and the Al stage. P_{Cu} shows a decrease with increasing the bottom-length of the core. Figure 5 shows contour figures for the eddy current in the Cu tube without or with the elongation of the core. As shown in Fig. 5, the eddy current flow around the bottom of the core is reduced by an elongation of the core. Since an effective permeability of the core changes with the core length, the change in the effective permeability influences the P_{Cu}. In order to investigate the reduction in the eddy current for the Cu tube, we evaluate the effect of permeability of the core. Figure 6 shows the changes in P_{Al}, P_{Cu}, and P_p as a function of relative permeability of the core.

It is difficult to determine the effective permeability of the core since the core does not have the special shapes such as a sphere or a spheroid. Therefore, we change the relative permeability of the core. As you can see, P_{Cu} shows a dramatic increase with decrease the permeability. Since the effective permeability of the core increases with increasing the core length, we expect the effective permeability for the model of Fig. 5 (b) is higher than that for Fig. 5 (a). Therefore, increase in effective permeability due to the elongation of the core enables us to reduce P_{Cu}. From above-mentioned result, an adequate elongation of the core is one of hopeful design to improve the lamp efficiency.

3.3 Verification of analyzed results

In order to verify the analyzed results, we measure luminous flux of an electrodeless discharge lamp with a modified power coupler. Figure 7 shows schematic representation of the coupler for the measurement of luminous flux. Resultantly, the luminous flux is increased from 13,800 lm to 14,250 lm and the lamp efficiency is improved by approximately 3 lm/W. Therefore, we can conclude that reduction in the eddy current loss in the power coupler is one of important factors to obtain high lamp efficiency.

4. Conclusion

We investigated the reduction in the wasted power loss for improving in the lamp efficiency and focus on the eddy current loss of the power coupler. In a commercial electrodeless discharged lamp, large eddy current is observed in the Al stage and the Cu tube. For the Al stage, we can reduce the eddy current loss with separating from the bottom of the core. For the Cu tube, an elongation of the core reduces in the eddy current loss. We have confirmed the improvement in the lamp efficiency for a lamp with a modified power coupler, and conclude that a lamp design with low eddy current loss is effective to obtain a high efficiency lamp.

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Received October 26, 2012; Revised January 31, 2013;
Accepted February 06, 2013