Iron Loss Analysis of Turbo Generators Considering Eddy Currents in Duct Spacers and End Plates

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Abstract—**The iron loss of turbo generators is estimated by three dimensional nonlinear time-stepping finite element analysis by considering duct spacers and end plates between stator core packets. The laminated stator core is modeled by using double nodes, gap elements, and anisotropic conductivity in order to take into account the in-plane eddy currents generated at the surface of the laminated core. The eddy currents generated in the duct spacers and the end plates are also estimated. It is revealed that the duct spacers cause considerable effects on the total iron loss of turbo generators.**

Index Terms—**Eddy currents, finite element methods, hysteresis, losses, Turbo generators.**

I. Introduction

The stator cores of turbo generators are often divided into dozens of core packets in order to insert the cooling ducts [1]. In this case, the duct spacers, which are usually made from solid magnetic materials, are inserted between the core packets. As the conductivity of the duct spacers is often higher than that of the electrical steel sheets (ESSs) for the core, the eddy currents in the duct spacers are not negligible. In addition, the eddy currents flow into the core-packet end plates from the duct spacers when the insulated layers are not employed for the end plates. Furthermore, the magnetic characteristics of the duct spacers, end-plates and ESSs used for the stator core are different from each other. As a consequence, the flux also flows into the end plates and ESSs from the duct spacer due to the difference in the permeability. This flux will cause the in-plane eddy currents of the laminated stator core because it is perpendicular to the laminated stator core.

It can be stated that the electromagnetic phenomenon at the ends of the stator core packets is very complex because of the existence of several different magnetic materials. Furthermore, the considerable losses are often generated in the very small end-region as compared to the entire generator region. However, there are few papers that dealt with the loss analysis of the turbo generators by considering the eddy currents in the duct spacers and the end plates, because this analysis requires very large number of three dimensional (3-D) elements and long computational time.

From these view points, in this paper, the iron loss of the turbo generators is estimated by using the 3-D nonlinear time-stepping finite element method along with the combinations of double nodes, gap elements, and anisotropic conductivity in order to save the computer resources. The calculated total iron loss is compared with the experimental results.

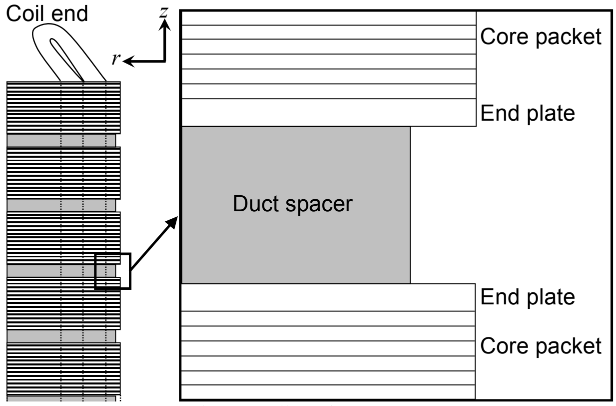

Fig. 1. Outline of stator core.

II. Modeling of Turbo Generators

The analyzed generator is a two pole 250 MVA class turbo generator. Fig. 1 shows the outline of the stator core. The duct spacer is made from the iron for general structural propose, whereas the grain oriented electrical steel sheet (GOESS) is used for the inside stator core. On the other hand, several materials are selected for the end plates, as follows:
(a) GOESS which is also used for the inside stator core
(b) Non oriented electrical steel sheet (NOESS)
(c) Structural purpose cold rolled steel sheet, type C (SPCC)
The GOESS and the NOESS have insulated layers on the surface, whereas the SPCC does not have the insulated layers. In this study, the 3-D nonlinear time-stepping finite element analysis is applied to the above-mentioned cases, respectively.

In order to reduce the required computer resources, several GOESSs in the inside stator core are modeled to be one layer of 3-D finite elements by using the anisotropic conductivity (σ_z = 0). In addition, the double nodes and equivalent gap elements are inserted between the finite element layers in order to take into account the insulation and the magnetic resistance of the insulated layers, respectively. The anisotropic conductivity, double nodes, and gap elements are also applied for the modeling of the end plates in the cases of (a) and (b), whereas they are not applied to the end plates in the case of (c) because SPCC does not have the insulated layers.

Fig. 2 shows the 3-D finite element mesh. Half the stator core packet is discretized by using the tetrahedral edge finite elements. The unknowns are the magnetic vector and electric scalar potentials. The number of finite elements is 5233833. The computational time is 435 h by using Core i7 3.4 GHz PC.

III. Results and Discussion

Fig. 3 shows the eddy current distributions in the duct spacer, end plate and inside core in the case of (b). Considerable eddy currents are generated at the duct spacer. The in-plane eddy currents are also generated at the end plates, as well as the inside core due to the perpendicular flux.

Fig. 4 shows the calculated and measured no-load iron losses. In the calculated results, all the end plates in the generator are assumed to be one material described in section II as case (a)-(c). The losses generated in the end core packets are obtained by the other analysis [1]. On the other hand, the measured result is obtained by the generator, in which both the NOESS and the SPCC are alternately applied for the end-plates on each core packet. The calculated results imply that the electrical contact between the duct spacers and the SPCC end plates causes considerable loss increase. However, the calculated loss still underestimates the total loss. The neglect of the segmental gap of the stator core is one of the reasons.

IV. Conclusion

The iron loss of turbo generators are investigated by considering the complex stator core structure including duct spacers and end plates. It is revealed that the duct spacers cause considerable effect on the total iron loss of the generator.

References

[1] K. Yamazaki, et. al. "Eddy current analysis considering lamination for stator core ends of turbine generators," *IEEE Trans. on Magn.*, vol. 44, no. 6, pp. 1502-1505, 2008.

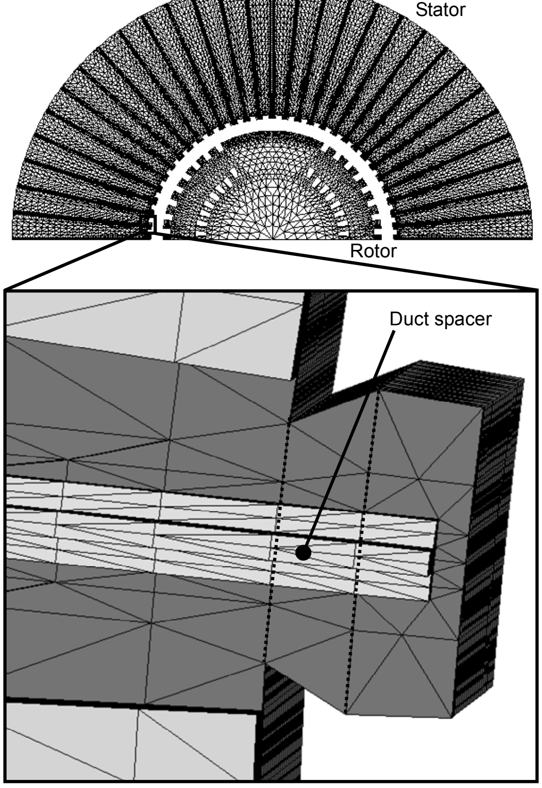

Fig. 2. 3-D finite element mesh

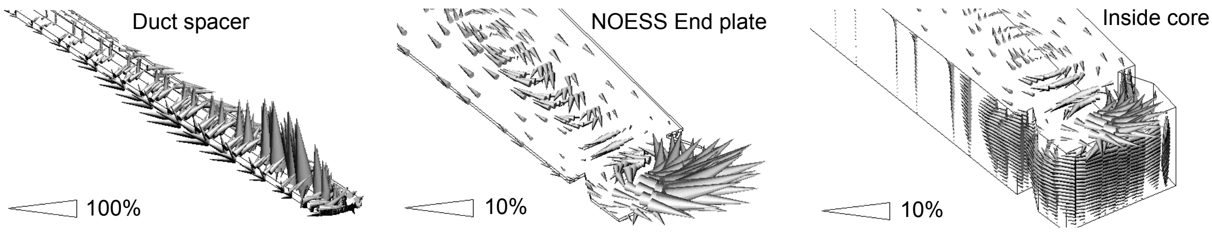

Fig. 3. Eddy current distributions.

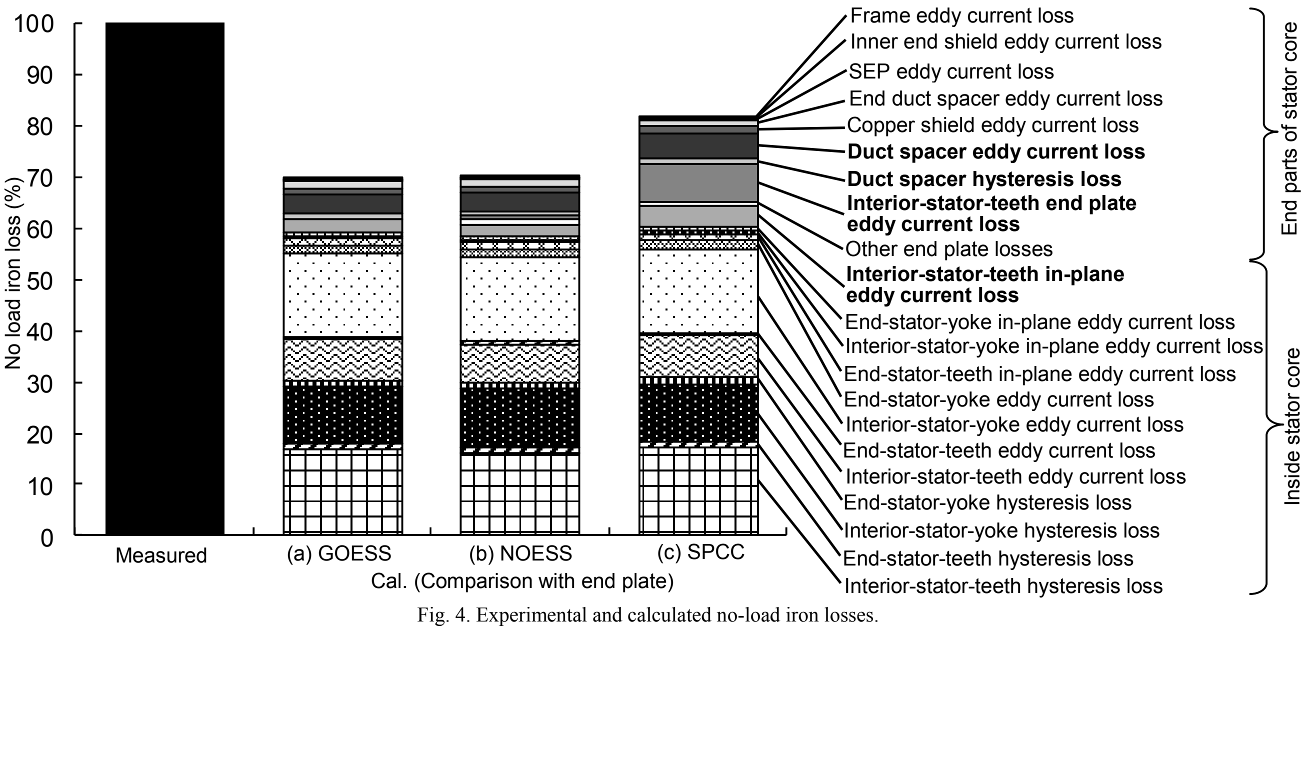

Fig. 4. Experimental and calculated no-load iron losses.