Development of a CEDM Thermal Analysis Model for Coil Temperature Estimation

Jin Seok Park, Myoung Goo Lee, In Yong Kim, Taek Sang Choi
KEPCO Engineering & Construction, Inc.
150 Deokjin-dong, Yuseong-gu, Daejeon, 305-353, Korea
Email: jsbach77@kepco-enc.com

1. Introduction

The Control Element Drive Mechanism (CEDM) is an electro-mechanical device to provide a controlled linear motion for the control element assembly. Reliable operation of the CEDM is very important because its failure directly causes shutdown of a nuclear power plant. As far as the reliability of the CEDM is concerned, the CEDM coil has been an important issue as its failure has been reported several times. The main cause of the CEDM coil failure is the thermal degradation of the coil insulation due to the thermal load generated by reactor coolant and coil current.

Design improvement has been desired to lower the coil temperature. It can be approached in two ways. One is reducing the power consumption while the magnetic force is maintained by improving the CEDM design in electro-magnetic point of view. The other one is improving the heat transfer efficiency to remove the heat effectively.

There have been efforts to improve the CEDM performance in electro-magnetic point of view. Finite element model for CEDM was developed to perform an electro-magnetic analysis [1]. A research was done to develop a low power consuming CEDM by optimizing a CEDM design parameter [2]. However research on the heat transfer of the CEDM has hardly been tried.

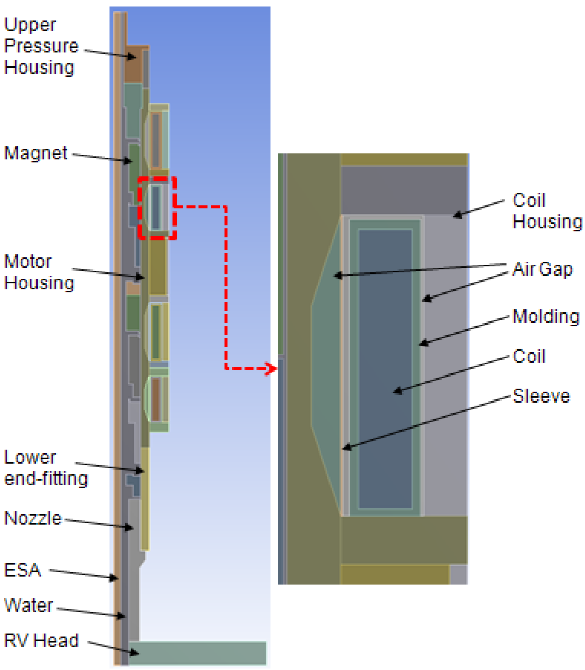

Fig. 1. Analysis model of the CEDM

Although thermal analyses of the CEDM have been carried out during the design and evaluation process for the commercial plant, those analyses have focused on thermal stress calculation and structural integrity evaluation of the pressure boundary component. Those analyses have been done in a relatively simple manner just to calculate the thermal stresses conservatively, which means its thermal analysis model is not appropriate for precise estimation of the coil temperature.

In this paper, a new thermal analysis model is built so that it can be used for future works such as investigation on the CEDM coil temperature escalation mechanism and CEDM design improvement.

2. Modeling

An initial model of the CEDM was developed using ANSYS Workbench [3] as shown in Fig. 1. The geometry and dimensions of the CEDM for OPR1000 were used. The model includes the extension shaft assembly, reactor vessel head nozzle and reactor coolant water as well as the CEDM. Upper part of the pressure housing is excluded in the model assuming the axial temperature gradient is ignorable in the upper pressure housing.

For precise calculation of the coil temperature, the coil assembly was modeled in more detail. The coil assembly model consists of coil, molding, coil housing, sleeve and air gap between the molding and coil housing. However copper wire and its coating material were modeled as one coil area. Otherwise the analysis model becomes too large and complicated. Air gap between the coil stack assembly and the motor housing was also included.

Non-linear thermal properties such as thermal conductivity and specific heat were considered. Equivalent thermal conductivity of the coil was calculated to consider the thermal conductivity of the copper wire and its coating material.

3. Analysis and Tuning

Boundary conditions were applied as the same as the test conditions as follows. 625°F was applied on the RV head and the bottom of the Extension Shaft Assembly (ESA) and the water. Film coefficient and ambient temperature for the test result of 700 SCFM with 120°F inlet air temperature were applied on the surfaces exposed to the cooling air such as outer surfaces of the coil housing and the motor housing. Heat generated by the 45V voltage source and the coil resistance corresponding to the coil temperature was calculated and applied to the upper gripper coil to describe the holding mode.

Table I and Fig. 2 show the analysis results of the initial model which have big deviations from the test result. The deviation occurs because of the water's state inside the pressure housing.

The analysis result of Table I is the one for steady state in holding mode ignoring any convection effect of the water. But the test result was measured 30 minutes after a stepping mode, which is more severe condition than the complete steady state of the holding mode.

The water temperature is high at the bottom and low at the top. The hot water and the cool water inside the CEDM pressure housing are mixed during stepping mode because the ESA and the magnets keep moving up and down and stirring the water. Since the heat capacity of the whole system is large, 30 minutes may not be enough to cool down the mixed water. Even if the forced convection effect disappears in 30 minutes, there is also natural convection due to the axial temperature gradient of the water. So the convection of the water has to be considered in the analysis for more reasonable calculation of the temperature distribution. However it is very difficult to consider the convection as it is in the analysis because the geometry and the motion of the magnets are too complicated to be implemented.

As an alternative, a simple method is suggested to consider the convection effect of the water. The convection of the water was considered by adjusting the conduction coefficient of the water so that its result of the coil temperature matched well with the test results. Since the gripper coil is the most vulnerable and mainly concerned, the tuning was performed to minimize the temperature difference between test and analysis result of the gripper coil.

Table II and Fig. 3 show that the analysis results of the tuned model matches well with the test results.

Table I: Temperature Ratio of the Initial Model Analysis Result to Test Result

Upper Lift Coil	0.85
Upper Gripper Coil	0.97
Lower Lift Coil	0.70
Lower Gripper Coil	0.66

Table II: Temperature Ratio of the Tuned Model Analysis Result to Test Result

Upper Lift Coil	0.94
Upper Gripper Coil	1.00
Lower Lift Coil	0.97
Lower Gripper Coil	1.00

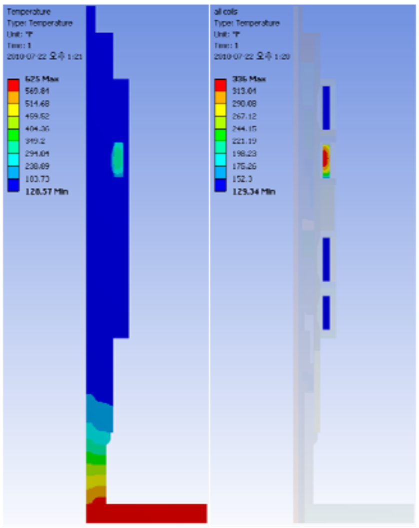

Fig. 2. Analysis result of the Initial model

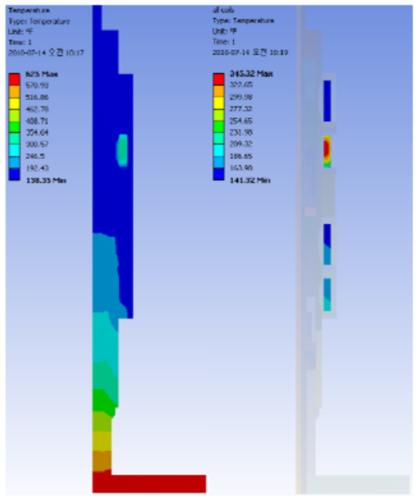

Fig. 3. Analysis result of the Tuned model

4. Conclusion

Finite element model for CEDM thermal analysis was developed. Heat generations from the water and the coil current were considered. Forced convection due to the cooling air was also considered. The model was tuned by adjusting the conductivity of the water to consider its convection effects. Final result of the tuned model matched well with the test result. The model is expected to be used for future works to improve the CEDM design.

REFERENCES

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