Design, Fabrication, and Characteristic Experiment of a Hybrid Electromagnet for Bottom-mounted Control Rod Drive Mechanism

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1. Introduction

A control rod drive mechanism (CRDM) is located in the reactor pool top (Top-mounted) or a reactivity control mechanism room under the reactor pool bottom (Bottom-mounted). The function of the CRDM is to insert, withdraw, or maintain neutron absorbing material at any required position in the reactor core in order to keep reactivity control of the core. There are so many kinds of CRDMs, such as magnetic-jack type, hydraulic type, rack and pinion type, chain type, and linear or rotary step motor and so on[1]. As a part of a new project, we have completed the design, fabrication, and characteristic experiment of the prototype bottom-mounted CRDM (BMCRDM). A BMCRDM in a research reactor is composed of a hybrid electromagnet, stepping motor, ball screw, guide tube, armature and extension shaft assembly, damping mechanism, and electromagnetic rigidity measuring device as shown in Fig. 1[2]. A hybrid electromagnet is newly proposed for BMCRDM. Compared with other electromagnet, a hybrid electromagnet has a permanent magnet connected with electromagnet serially in order to further increase the carrying capacity of BMCRDM as shown in Fig 2. The 3D parametric-magneto-static analysis for the optimal design for a hybrid electromagnet is performed using ANSYS tool[3,4].

It is important that the temperature of hybrid electromagnet windings be maintained within the allowable limit of the coil insulation as well, since a hybrid electromagnet is always supplied with current during the reactor operation. So the thermal analysis of the coil insulation which is composed of polyimide, epoxy, and air were performed by Maxwell 3D Magneto-static and ANSYS Mechanical Steady –state Thermal Coupling Method.

Finally, in view of the optimal results mentioned above, the design experimental verification has been successfully completed.

This paper presents the representative comparison results between the model calculations and the experimental results of proto-type hybrid electromagnet for BMCRDM.

2. Methods and Results

In this section the numerical magnetic field calculation with FEM for the optimal design of a hybrid electromagnet is described and compared with the carrying capacity characteristics of fabricated proto-type hybrid electromagnet.

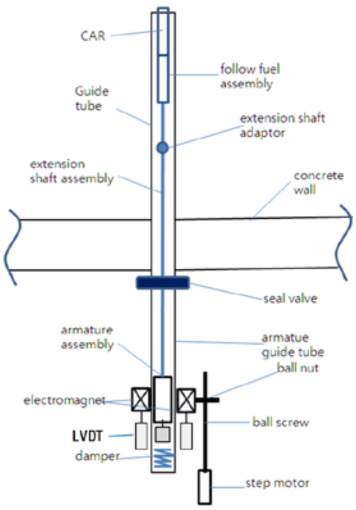

Fig. 1. Schematic of a hybrid BMCRDM.

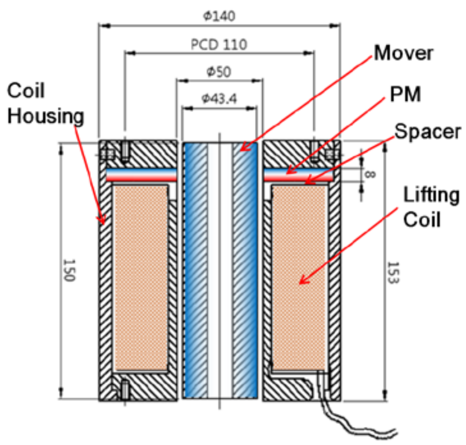

Fig. 2. A dimension of newly proposed hybrid electromagnet.

2.1 Magneto-static FEM Analysis and Results

In recent year, the FEM has become widely accepted by the engineering professions as an extremely valuable method of analysis. Its application has enabled satisfactory solutions to be obtained for many problems which had been regarded as insoluble, and the amount of research effort currently being devoted to the FEM ensures a rapidly widening field of application.

Table 1 shows the input data for a hybrid electromagnet magneto-static FEM analysis.

Table 1: A design specification of a hybrid electromagnet model

Component	Material	Remark
Lifting coil (mm)	Copper	33x111
Coil housing	STS416	
Mover	STS416	
Guided tube	STS316	
Permanent magnet	Neodymium	N35EH
Spacer	STS316	
Air-gap (mm)	Air	3.3
Current (A)	2.0	
Coil diameter (mm)	Copper	ϕ1.1
Coil turn	2,800	
Space factor	0.65	

A proposed model for such a computation is given in Fig. 3, where the exact course of the B vector and magnitude B of a hybrid electromagnet is shown.

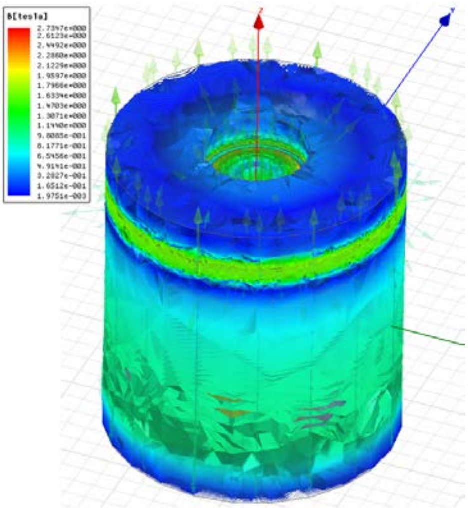

Fig. 3. Magnetic flux density vector and magnitude distribution outputs from magneto-static FEM analysis for a hybrid electromagnet.

2.2 Experimental Results of Proto-type Hybrid Electromagnet

Fig. 4.Experimental setup of a hybrid electromagnet.

Fig. 4 shows the experimental setup for measuring the carrying capacity of fabricated proto-type hybrid electromagnet which is designed by FEM analysis result.

Fig. 5 is the outputs of the measured and the calculated carrying capacity of proto-type hybrid electromagnet. As a result, the measured carrying capacity of a hybrid electromagnet is approximately 2.8 (kgf) larger than the calculated carrying capacity using FEM analysis.

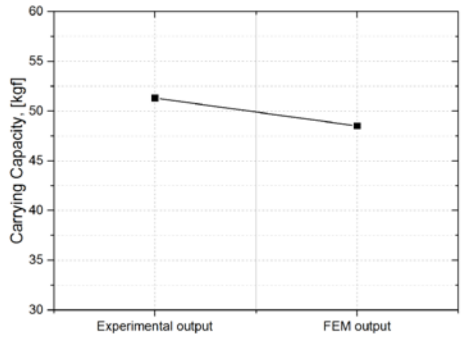

Fig. 5. Comparison of measured and calculated carrying capacity of a hybrid electromagnet.

2.3 Steady-state Thermal Analysis and Results

The thermal analysis of the coil insulation which is composed of polyimide, epoxy, and air were performed by Maxwell 3D Magneto-static and ANSYS Mechanical Steady –state Thermal Coupling Method. The surface of the conductor is covered with insulated Polyimide and finally impregnated with Epoxy. However, Polyimide cannot adhere to Epoxy, so a very thin air-gap exists between them. Therefore, creating a model for analysis that consists of the whole model, considering complex and dense parts, is difficult.

The maximum temperature of winding measured at the center point as shown in Fig. 6 is 111^{o}C.

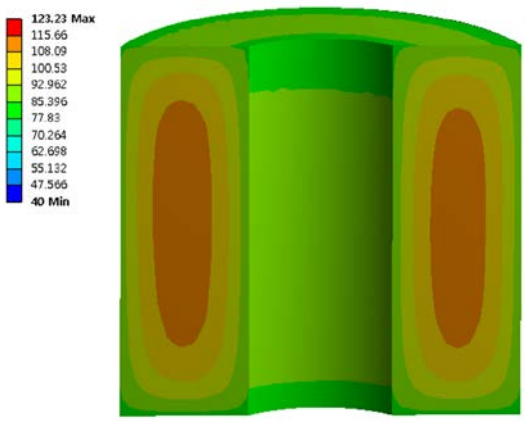

Fig. 6. Steady-state thermal analysis result of a hybrid electromagnet.

2.4 Experimental Thermal Analysis Results of Proto-type Hybrid Electromagnet

Fig. 4 shows the integrated experimental setup of the proto-type hybrid electromagnet as well and Fig. 7 shows the comparison of measured and calculated maximum temperature at the center of the winding for a hybrid electromagnet. The experimental measured temperature of winding, 106°C, appeared to be 5°C higher than the analytical result.

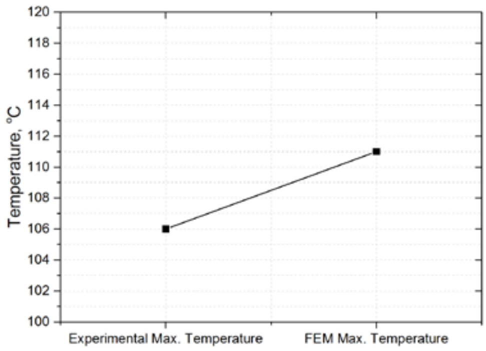

Fig. 7. Comparison of measured and calculated maximum temperature at the center of the winding for a hybrid electromagnet.

4. Conclusion

The Results of FEM and the experiment in this work lead to the following conclusions:

(1) The measured carrying capacity of proto-type hybrid electromagnet is approximately 2.8 (kgf) larger than that of 3D-FEM result. The major reasons of the disagreement between the measured and calculated results are as follows.
   A. B-H Curve differences of ferromagnetic materials
   B. Fabrication tolerance

(2) The measured maximum temperature at the center of winding for proto-type hybrid electromagnet, 106°C, appeared to be 5°C higher than the analytical result. The major reasons of the disagreement between the measured and calculated results are as follows.
   A. Difficult for exact modeling of winding including impregnated epoxy, coil insulator, and isolator.

REFERENCES

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