Design Study on Maximizing the Electromagnetic Lifting Force of an In-Vessel CRDM

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1. Introduction

The control rod drive mechanism (CRDM) in SMART reactor is a magnetic jack type and it is immersed in cooling water inside a reactor vessel. The CRDM consists of a motor assembly (including the latch assemblies), a motor housing, an extension shaft assembly (ESA), and an electromagnetic coil assembly (including one lift and two latch coils) as shown in Fig. 1.

The motor assembly has three gaps; one gap between the stationary magnet and the movable lifting magnet is for lifting the ESA, and other two gaps are for the latch operations to engage the ESA groves.

The motor housing supports the motor assembly and the coil assembly, and forms a structural separation boundary so that they can be disassembled for the repair and maintenance.

The lifting magnet of the motor assembly is moved upward by the electromagnetic force of the lift coil assembly, and the latch magnet is held in the latched position by the electromagnetic force of the latch coil assembly, and the latches coupled to the movable latch magnet engage the grooves of the ESA when current is supplied.

The electromagnetic coils of the CRDM must be designed to produce sufficient electromagnetic attraction force between the stationary magnet and the movable lifting magnet to handle the weight of the ESA. To perform one-step withdrawal of the ESA, the upper lifting coil current is turned on to generate an electromagnetic force so that the lifting clearance gap of 12 mm could be closed. Each coil sequentially provides an electromagnetic force to withdraw or insert an ESA connected to the control rod assembly. There are some researches for the coil assembly design and electromagnetic field analyses of CRDM[1,2].

In this paper, the coil assembly designs and their electromagnetic field analyses are performed to generate an electromagnetic traction 1800 N or more for lifting the ESA under the constraint of minimizing the outer diameter of the In-Vessel CRDM within 200 mm. The motor assembly is the same as previously designed and is used as it is.

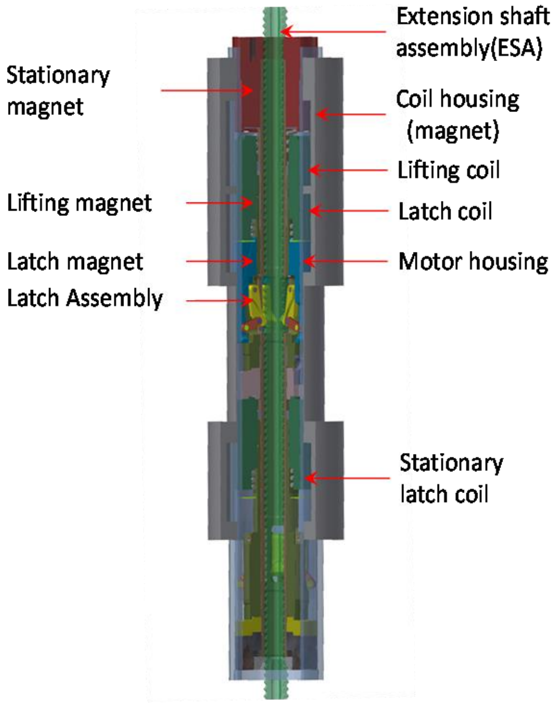

Figure 1 Components of the In-Vessel CRDM

2. Electromagnetic flux flow resistances along a closed flux circuit

Fig. 2 shows the 2-D axisymmetric section configuration of the upper portion of the CRDM. The motor magnets and the coil housing are made of AISI 410T and S420 stainless steels, respectively. The motor housing formed a physical boundary is initially assigned with a stainless steel type 304 of non-magnetic material.

The electromagnetic flux generated by the lifting coil assembly mainly passes through the lift coil housing(⑤, ⑥) and the motor magnets(①, ③) crossing the two regions(④, ⑦) of the motor housing. The electromagnetic attraction to handle the weight of an extension shaft assembly (ESA) is created at the gap (②) between the stationary and lift magnets.

The motor housing parts(④, ⑦) contacted to the lift coil housing increase the magnetic flux flow resistance because the motor housing material is assigned with a non-magnetic material. Therefore, it is suggested that the two parts of the motor housing on the magnetic flux path are locally replaced with the electromagnetic material to reduce the flux flow resistance as represented in model A to model B in Fig.3.

The flux flow resistances by the partial electromagnetic material changes from model A to model B are greatly reduced to less than 20% from 24.9 to 4.6 at ⑦, and 10% from 11.1 to 1.0 at ④ as represented in Fig.4. The model C compared to model B is designed to get an additional reduction of flux resistance at region ⑦, the model D and E are designed to increase the magnetic flux amount at the gap ②.

As the electromagnetic materialization region gradually expands from model A to model E, the electromagnetic flux flow amount is increased at the gap region ② and then the initial attraction force through the gap is increased.

The motor housing has three bi-metal welded parts by the local material changes as shown in Fig.3.

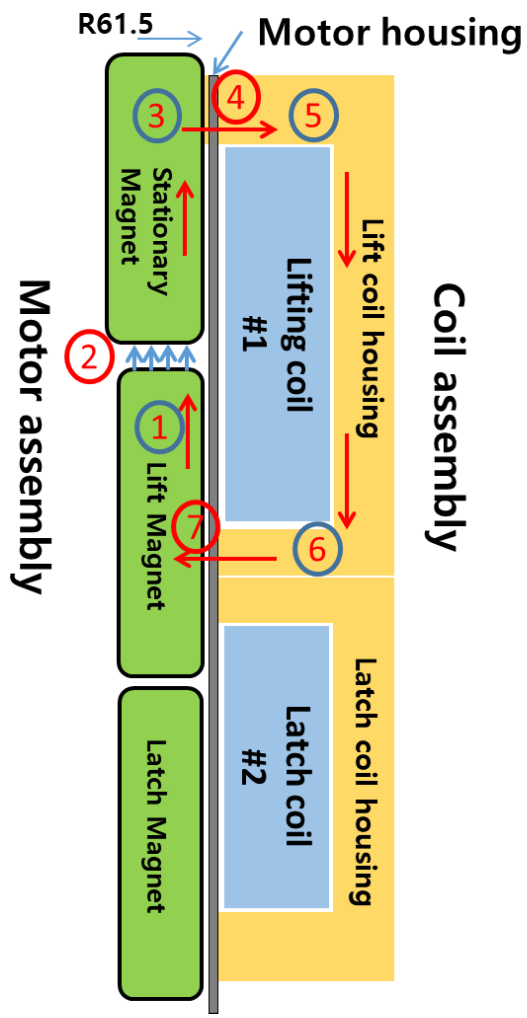

Figure 2 Axisymmetric coils & magnets configuration of CRDM

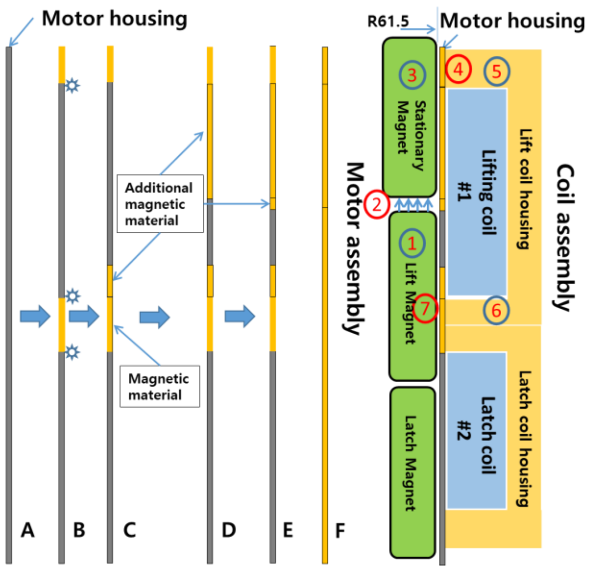

Figure 3 Magnetic-materialized parts of motor housing

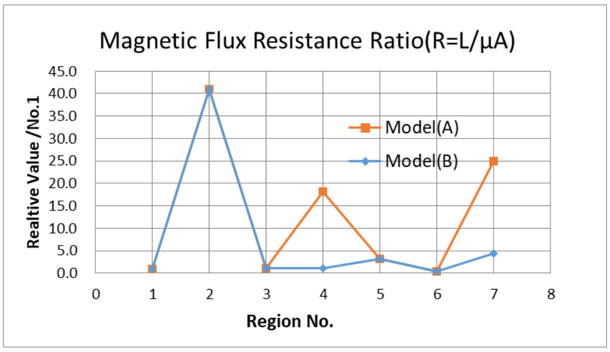

Figure 4 Electromagnetic flux flow resistance ratios (region No. 1~7 / region No.1)

3. Electromagnetic field analysis model

A 2-D axisymmetric modeling for the electromagnetic field analysis of CRDM is developed with ANSYS Emag[3]. Non-magnetic material and filled water are considered as air permeability property in the analysis. The magnetic materials of the motor assembly and the coil housing use the high temperature permeability characteristics of 400℃.

In modeling, the coil spaces (width x length) are allocated by 20 mm x 157 mm for the lift coil and 20 mm x 117 mm for two latch coils. The coil spaces can accommodate the required 331 and 245 coil turns respectively, which are achieved by winding a mineral insulated(MI) coil with a diameter of 3 mm. Up to 20 A is allowed on the lift coil while the latch coil current of 10 A is supplied.

Fig. 5 shows the meshed shape of the electromagnetic field analysis model.

4. Electromagnetic Force Analysis Result

Design studies are carried out to partially change only the motor housing material while all other variables are constant so that the outer diameter of CRDM is fixed by 194 mm.

Six electromagnetic traction force calculations are performed with different magnetic materialization models (from A to F) of the motor housing in Fig.3. The motor housing thickness (T2) of 5 mm is fixed so that it could withstand the operation loads and support the weight of both the motor assembly and coil assembly. And the coil housing thickness(9.45 mm) is set so that the outer diameter of CRDM is by 194 mm.

Fig. 6 shows the analysis results when the coil current (19A) is supplied. As the electromagnetic materialization area changes in the order of A→B→C→D→E, the attraction forces are increased more and more. Fig. 7 presents the electromagnetic flux contour of the model C and D of the motor housing. The resulting force of the motor housing model E satisfies the electromagnetic traction force requirement of 1,800 N or more. Fig.8 and Fig.9 represent the electromagnetic flux concentrated in region ② for the model E.

The model F is the whole electromagnetic materialization condition of the motor housing. A quite low attraction force is generated in the gap of region ② compared to other models(A to E) because a part of electromagnetic flux is directly transmitted to the motor housing without passing through the gap ②.

5. Conclusions

The local electromagnetic material adoption for the motor housing could reduce the electromagnetic flux resistance in the magnetic flow path, then the electromagnetic traction force of CRDM is increased above design requirement of 1,800N and the design margin is secured.

Based on the design studies for the magnetic materialization models of the motor housing, further minimization of the outer diameter of the CRDM even in the new design environments could be feasible by various combinations of design parameters such as the motor housing thickness, the coil housing thickness, and enforced coil current.

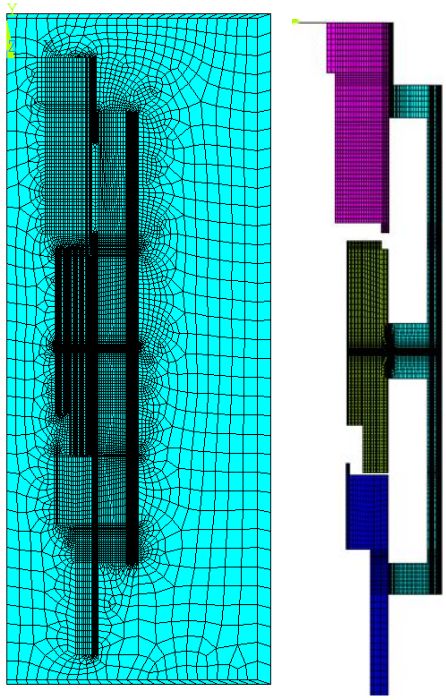

Figure 5 Mesh configuration of the electromagnetic analysis model

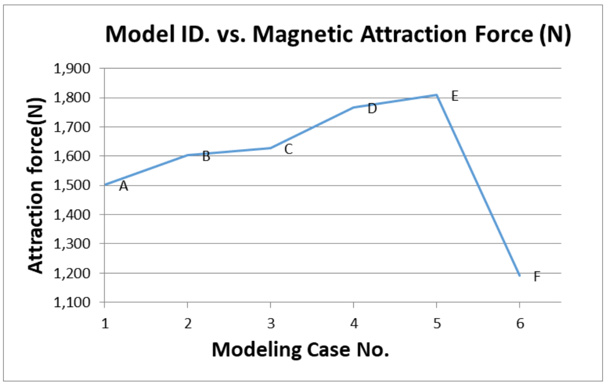

Figure 6 Attraction forces vs. modeling cases (A to F) of the motor housing

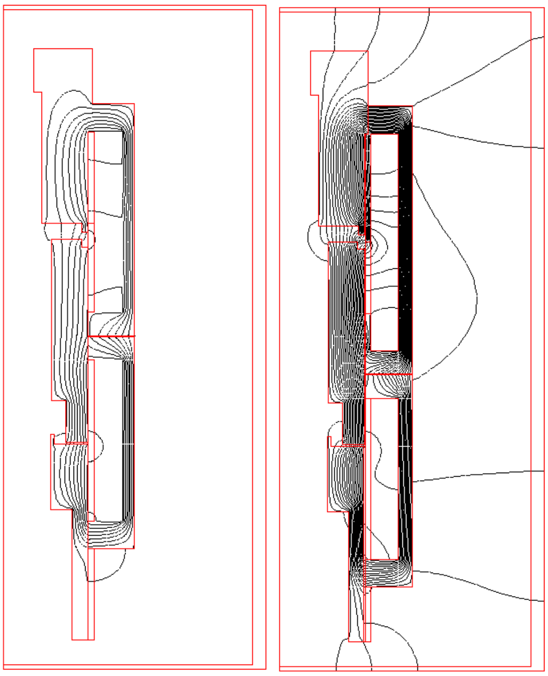

Figure 7 Electromagnetic flux Flow distributions for the motor housing model C and D

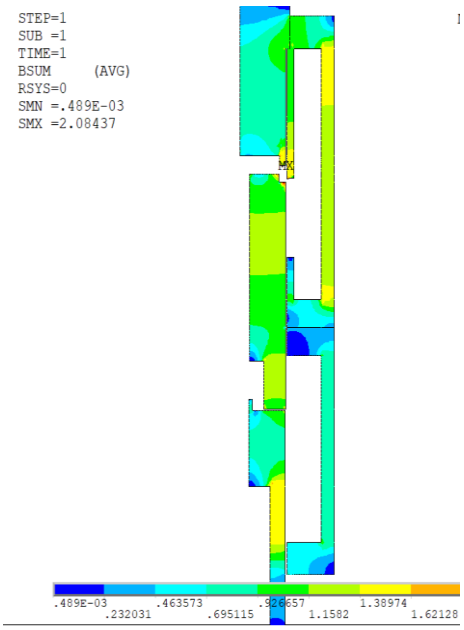

Figure 8 Electromagnetic flux contour of ID 9 of model E

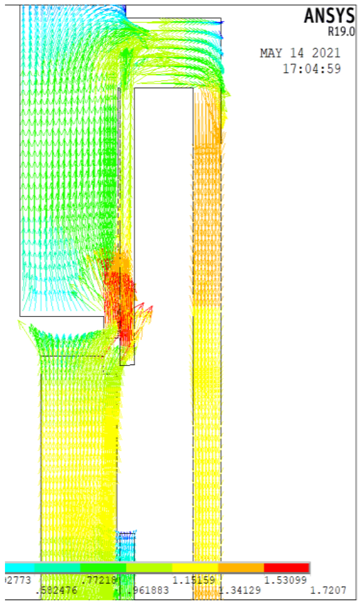

Figure 9 Electromagnetic flux concentration of the motor housing model E

ACKNOWLEDGEMENT

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REFERENCES

[1] JaeSeon Lee, Experimental Study of an Electromagnetic Actuator for a Control Element Drive Mechanism, IEEE Transactions on Magnetics, Vol. 50, No. 11, November 2014.
[2] Park Jinseok, 2015, "Conceptual Design of a Magnetic Jack Type In-Vessel Control Element Drive Mechanism," Trans. Korean Soc. Mech. Eng. C, Vol. 3, No.3, pp.225~232.
[3] ANSYS Emag. V19. ANSYS Inc. 2020.