

Magnetic-Jack Type CRDM Coil and Pressure Housing Design

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1. Introduction

A control rod drive mechanism (CRDM) is an electromechanical device which provides linear movement to control rods to control reactivity in a nuclear reactor. A driving part of a magnetic jack type CRDM consists of a motor assembly and a coil assembly. The coils provide electromagnetic fields to magnetize the magnetic parts of a motor assembly through a motor housing which forms a pressure boundary. To improve the cooling efficiency of the coil assembly, a new cooling structure may be introduced; however, the current design is limited by a constraint that prevents any increase in the coil's outer diameter.

Therefore, this study aims to identify design parameters that can reduce the coil outer diameter while maintaining the sufficient lifting force, thereby enabling the integration of a cooling structure into the CRDM coil. Furthermore, the feasibility of this reduced-size design is evaluated.

2. Design Methods

The drive unit of the CRDM comprises a motor assembly, which facilitates the vertical displacement of the drive shaft via latch engagement, and a coil assembly, which generates the required electromagnetic driving force. These assemblies are separated by a motor housing that serves as the reactor pressure boundary [1]. In domestic pressurized light water reactors and the SMART (System-integrated Modular Advanced Reactor by KAERI), this housing is constructed from magnetic material, which inherently introduces electromagnetic field losses. To maximize lifting force, the CRDM is engineered to allow diagonally adjacent coil assemblies to be in close proximity.

Currently, the CRDM coil assemblies rely on a forced-air cooling system that transfers directly outside the reactor containment. While enhancing drive unit efficiency could theoretically enable natural circulation cooling within the containment, such a transition necessitates a significant improvement in the heat dissipation efficiency of the coil housing, typically through the addition of cooling fins. However, strict constraints on the coil outer diameter currently preclude the integration of such external cooling mechanisms.

As initial research, this study evaluates whether a redesigned coil can generate sufficient lifting force by optimizing the motor housing thickness. Given that the housing minimum thickness is governed by the structural

safety requirements of the primary coolant pressure boundary, it must be maintained at the minimum value necessary to ensure integrity. Consequently, this study develops an analytical model based on a simplified cylindrical motor housing, featuring a coil inner diameter reduced by 21.1 mm compared to the existing design. While the structural integrity implications of potential material changes will be addressed in future work, this research builds upon previous research [2], which focused on optimizing housing design while maintaining the coil outer diameter to explore the feasibility of reducing the coil outer diameter itself.

3. Analysis Results

A 2-D axisymmetric model for the CRDM is developed using Ansys Electronics Desktop [3]. The magnetomotive forces (MMFs) on the lift and latching coils are assumed to be the same as the previous research (on the lift coil, 15,000 A·turn, and on the latching 5,100 A·turn for this study) [2]. It is assumed that the coil and the coil housing width and height remained identical to the present design, with only the inner and outer diameters varying. First, the results of utilizing the same magnetic material as the present design for the motor housing were compared with those of employing a non-magnetic motor housing. These comparisons are presented in Table I and Fig. 1.

As illustrated in Fig. 1, when a magnetic motor housing is used, it occupies a significant portion of the magnetic path that should otherwise be directed to the motor assembly, thereby resulting in a loss of lifting force. Consequently, it is confirmed that the non-magnetic motor housing yields a relatively higher driving efficiency, despite the losses incurred by the motor housing space acting as an air gap.

To partially compensate for the loss of electromagnetic force across the air gap, a flux ring can be utilized. In this study, the effects of applying pure iron, which possesses excellent soft magnetic properties, at thicknesses of 3 mm and 5 mm are analyzed. The corresponding analytical results are summarized in Table II and Fig. 2.

Table I: Lifting force [kN]

Material	Lifting Force
Magnetic	1.95
Nonmagnetic	3.16

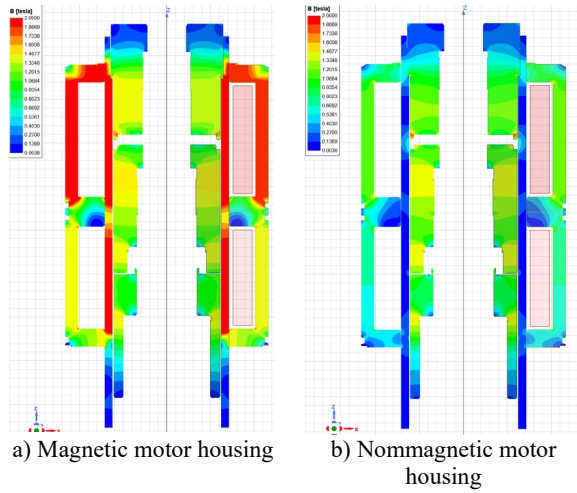


Fig. 1. Flux Density Distribution

Table II: Lifting force with flux ring [kN]

Flux ring thickness [mm]	Lifting Force [kN]	Increment [%]
3	3.24	2.5%
5	3.25	2.8%

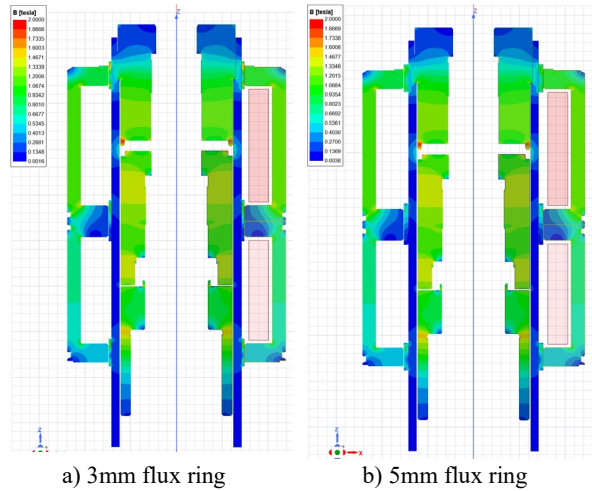


Fig. 2. Flux Density Distribution with Flux Ring

The increments presented in Table II are based on a comparison with the analytical results that consider only the non-magnetic motor housing. Although the introduction of a flux ring is expected to yield a slight increase in lifting force, it consequently enlarges the outer diameter of the coil, thereby adversely affecting space allocation.

Based on these results, applying a non-magnetic motor housing is deemed appropriate to secure sufficient space for installing cooling channels and cooling mechanisms within the coil assembly. Furthermore, these findings are expected to serve as foundational data for the optimal design of the coil, coil housing, and flux ring to minimize heat generation in future iterations.

4. Conclusions

To evaluate the feasibility of securing installation space for cooling channels and mechanisms for the CRDM coil assembly, the potential for generating adequate lifting force by modifying the shape and material of the motor housing was investigated. It was confirmed that a viable lifting force is generated despite a partial loss of magnetic force caused by the miniaturization of the coil housing. Consequently, this study demonstrates that an improved design of the CRDM can be achieved through subsequent design optimization.

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