CRDM Magnetic Force Analysis

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1. Introduction

A Control Rod Drive Mechanism (CRDM) is an electromechanical device that drives a control rod assembly vertically using electromagnetic force. A CRDM withdraws/inserts a control rod assembly from/to a reactor core when the electrical current is supplied to the coils to control the core reactivity. SMART is a System-integrated Modular Advanced ReacTor with 365 MW thermal powers. The SMART CRDM is magnetic jack type with three large capacity direct current electromagnetic coils [1]. The CRDM coils produce magnetic fields around a motor assembly and generate the attraction force between magnetic components that makes the latches engage with or lift up a drive shaft coupled with the control rod assembly. The drive shaft and the control rod assembly drop by gravity. As a result of the reduced core height in SMART, control rod assembly weight is less than the conventional reactor control rod assembly weight. The configuration of SMART CRDM is shown in Fig. 1 [2].

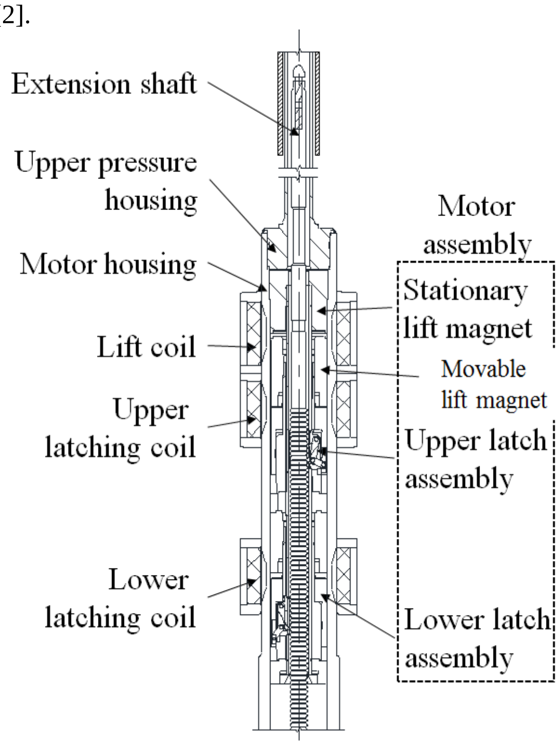

Fig. 1 SMART CRDM Configuration

The coil assembly is designed to produce an electromagnetic field which generates the adequate attraction force between the stationary lift magnet, the movable lift magnet, and the upper latch magnet.

Analyses of the SMART CRDM magnetic force are required to evaluate the optimum electric current which generates sufficient electromagnetic attraction force at varying conditions. In this paper, the numerical analysis for the latching force estimation before and during the engagement with and lift up the drive shaft were performed.

2. Modeling Approach

Finite element electromagnetic analyses are conducted for the magnetic force estimation of SMART CRDM at various conditions, each condition has its own boundary conditions and electrical current to evaluate the appropriate force that makes the latch engage with or lift up the drive shaft with control rod assembly. B-H characteristics of the motor housing, magnet assembly, and coil housing were obtained from a test result considering the nonlinear magnet characteristics of the material, as shown in Figure 2. The latching forces are evaluated at three stages; the initial latching movement, latching without engagement, and engagement and lift up of the drive shaft.

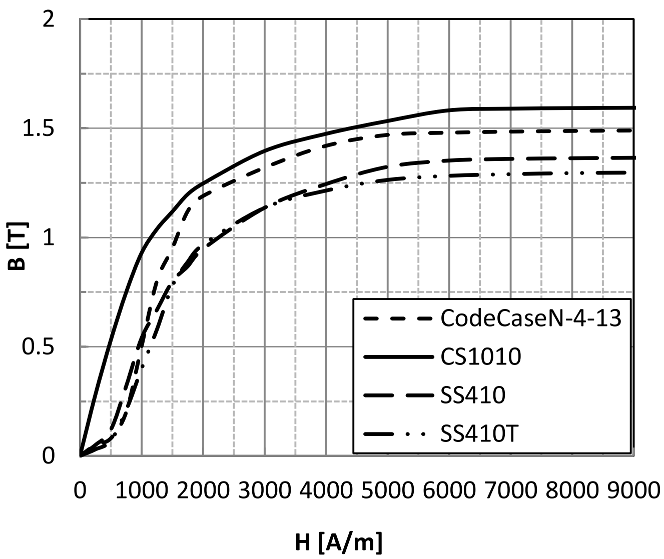

Fig. 2. Material B-H Curve

2.1 Material properties

Material types of SMART CRDM are summarized in the Table I.

Table I: CRDM Material

Part	Material
Motor housing	ASME Code case N-4-13
Movable lift magnet	Type 410
Upper latch magnet	Type 410T
Coil	Copper

2.2 Design review

The CRDM magnetic forces are analyzed using ANSYS Electronics Desktop version 19 [3] by adapting a 2-D axisymmetric model as shown in Fig. 3. The electric current is supplied only to the movable latch coil for this analysis while the other coils are off. The function of the movable latch coil is to produce sufficient magnetic force that makes the movable latches engage with the drive shaft and then lift it up a little. As the movable latch coil is activated and the movable lift magnet and upper latch magnet are energized, the attraction force would lift up the upper latch magnet until the latches engage with the drive shaft and lift it up a little. Latches are connected in a trinodal link that would engage with the drive shaft grooves and hold it during the lift up process. Analyses are performed for three stages:

- The initial stage represents the rest condition of the upper latch magnet where the gap between the movable lift magnet and the movable upper match magnet is maximum, as shown in Fig. 4.
- At the second stage, the magnetic force is active and lifts the movable upper latch assembly up to the fully-shrunk status without contacting the drive shaft.
- At the last stage, the latches are fully engaged with the drive shaft grooves and the gap between the movable lift upper magnet and upper latch magnet is equal to non-magnetic spacer thickness. The following step is the lift of the drive shaft a little as designed.

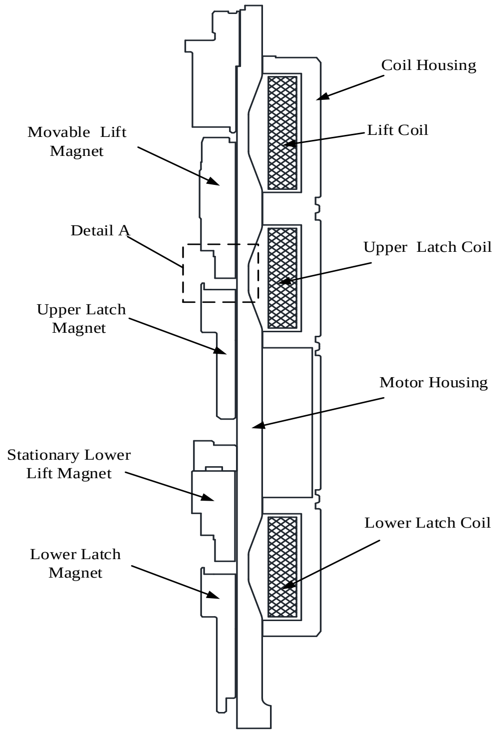

Fig. 3. 2-D Axisymmetric Model

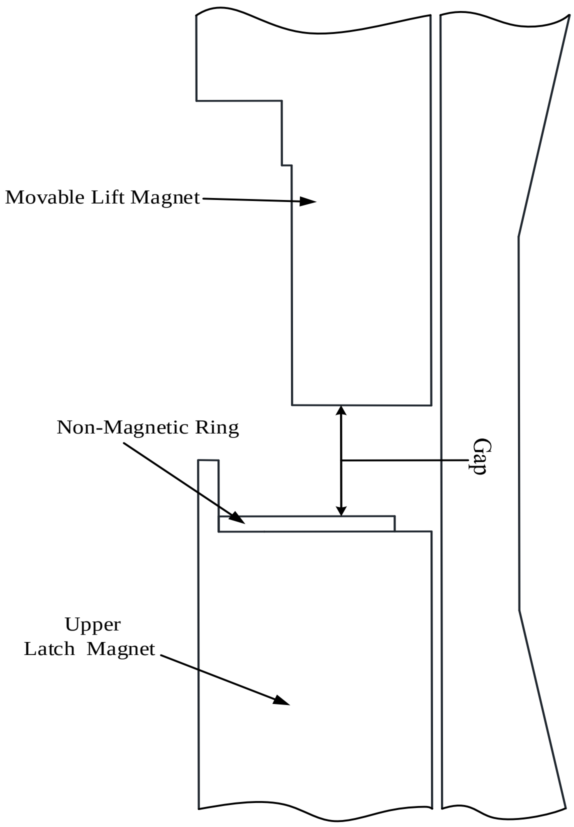

Fig. 4. View of Detail A

2.3 Design requirement

1) At the first two stages, the electromagnetic force should overcome the spring restoration force between the movable lift magnet and upper latch magnet.
2) At the last stage, the electromagnetic force should overcome the weight of the drive shaft, control rod assembly, and spring restoration force.

2.4 Analysis results

Analysis result shows the estimated lifting force according to the supply current at three different conditions. It is confirmed that the lifting force according to the supplied current is sufficient to lift the control rod assembly and the drive shaft. At the initial stage, the lift magnet is only subjected to the spring restoration force. As a result, low current could produce adequate force to move latches up to the fully-shrunk status. As the latches engage with the drive shaft and initiate lifting up, the magnet force should overcome the weight of the control rod assembly and the drive shaft. The analysis result shows that the magnetic force increases when the gap between the movable upper latches magnet and the upper movable lift magnet decrease and reach the maximum when the gap is equal to the non-magnetic spacer. So the CRDM coil design is verified by finite element electromagnetic analysis to be suitable. The results show that the magnetic force increases almost linearly with an increase of the supply current as shown in Fig. 5. From the analysis results, the appropriate supplied current to the moveable latch coil produces a force that is almost double the weight of the drive shaft and the control rod assembly. This force may be enough to lift up the weight. A further verification is going to be performed during the experimental test.

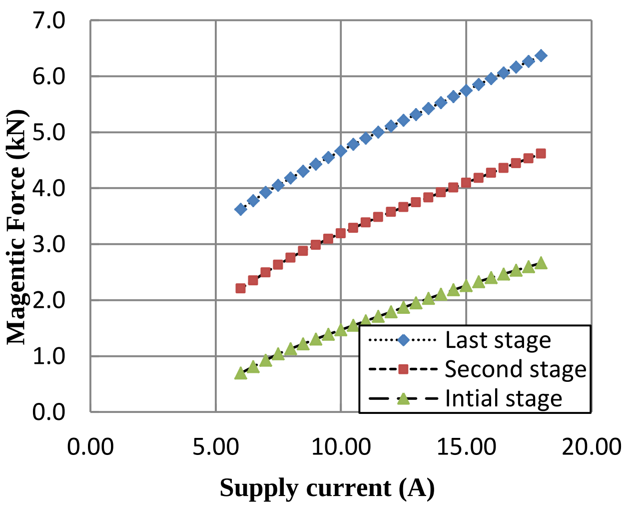

Fig. 5. Lifting force estimation at each stage

3. Conclusion

Electromagnet analyses for the latching force estimation of the movable upper lift magnet and the upper latch magnet were performed at three stages, the initial latching movement, latching without engagement, and lift up of the drive shaft. The latching force confirmed to overcome the design requirement of each stage as per the Finite element electromagnetic analysis. Further verification is going to be performed during the experimental test.

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