Development of SMART CRDM Coil Design

Jaeseon Lee [a*], Taewan Kim [a], Suhn Choi [a], Heejune Park [b]
[a] *Korea Atomic Energy Research Institute, SMART Development Division, Daedeok-daero 989-111, Yuseong-gu, Daejeon*
[b] *Woojin Inc.,NPP Instruments Production Team, 292 Osan, Dongtan, Hwasung, Gyeonggi*
[*] *Corresponding author: leejs@kaeri.re.kr*

1. Introduction

A control rod drive mechanism (CRDM) is an electromagnetic device which drives a control rod assembly linearly to regulate reactivity of a nuclear core. Driving force is electromagnetic force generated from coils installed outside of a motor housing. The magnetic parts of a motor assembly installed inside of a motor housing are magnetized when a coil is activated, and adhere to each other to produce latching or driving force as a result. A coil assembly consists of a lifting coil, a movable latch coil and a stationary latch coil as shown in Fig. 1. The latch coils make a drive shaft engaged with or released from latches, and the lift coil makes a drive shaft and a control rod assembly move up or drop. A CRDM control system supplies controlled electric current to a specified coil in order, and then a control rod assembly moves up or down.

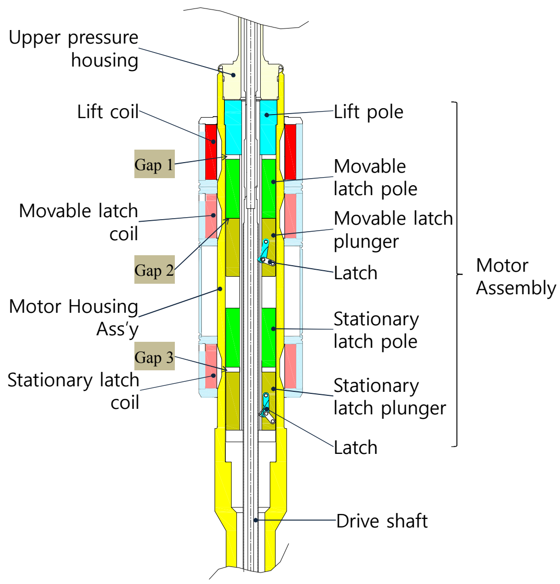

Fig. 1. Configuration of the coil assemblies for SMART CRDM

The coil assembly for SMART CRDM has been developed based on the design concept of a coil assembly for control element drive mechanism (CEDM) of the OPR1000, and modified to satisfy dedicated design requirements for SMART reactor. Some of representative design requirements are the lifting capacity of 3200N which is greater, the lifting step of 15.875mm which is longer than that for CEDM, and one step driving instead of two step driving. Design process through an electromagnetic analysis for a lift coil is described herein as a representative example, and representative results of the analysis are presented.

2. Analysis Methods and Results

The electromagnetic analysis was performed to develop the lift coil. The electromagnetic analysis model includes coils, coil housings, a motor housing assembly, and a motor assembly. The design of latch coils is fixed in this analysis. MAXWELL is used as an electromagnetic analysis tool [1].

2.1 Analysis Steps

The analysis is performed under the lifting condition as shown in Table 1. Positions of the gaps are shown in Fig. 1. Gap 1 means air gap between a lift pole and movable latch pole, and it is 15.875 mm. A control rod assembly is lifted up when this gap is changed into closed status and dropped when changed into open status. Gap between a movable latch pole and a movable latch plunger (Gap 2 in Table 1) remains closed so that the movable latches can engage a drive shaft, and gap between a stationary latch pole and a stationary latch plunger (Gap 3 in Table 1) remains open so that the stationary latches cannot engage.

Table 1. Operating gap and coil status

	Part	Status
Gap Condition	Gap 1	Open
	Gap 2	Closed
	Gap 3	Open
Coil input Status	Lift coil	Energizing
	Movable latch coil	Energizing
	Stationary latch coil	Not energized

Coil housings, a motor housing assembly, a lift pole, latch poles and latch plungers are magnetic. Other non-magnetic materials like latches are considers as voids in the analysis.

Lifting force(Fz) of a coil is proportional to the square of magnetic flux density(B) and magnetized area(S).

$$F_z \propto B^2 \cdot S \qquad (1)$$

And magnetic flux density is proportional to permeability(μ) and magnetic field(H) as follows.

$$B = \mu H \qquad (2)$$

Magnetic field from a solenoid is proportional to the number of coil turns per unit length(N) and the electric current(i).

$$H = Ni \quad (3)$$

It can be known from above relation that the more coils are wound or the higher current is supplied, the greater lifting force is produced. Inner and outer diameters of the coils are not to be modified as a design restriction. So it is possible to modify a coil design by adding the number of wound wires in height direction. The height of the core increases as multiplication of added turns by the wire outside diameter including insulation thickness.

FEM models were analyzed by MAXWELL for three cases as summarized in Table 2. Case 1 is for initial design. For the case 2, 200 turns are added in the height direction with the same wire that is for the case 1. It is no use increasing the height of the coil over a certain range because magnetic field affects barely lifting force. The limitation is not analyzed in this research. For this reason, the thinner wire is used for the case 3 to increase windings within the similar coil height to that for the case 2.

Table 2. Design data of the coils

	Case 1	Case 2	Case 3
Wire Nominal Diameter [mm]	1.613	1.613	1.450
No. of turns	850	1050	1350
Height [mm]	126	155	155.3
Resistance at 20℃ [Ω]	4.28	5.28	8.58
Inner Dia. [mm]	176.2		
Outer Dia. [mm]	212.4		

2.3 Analysis results

Lifting forces for each case are calculated with varying electric current from 11.5 A to 21.5 A, and the results are shown in Fig. 2.

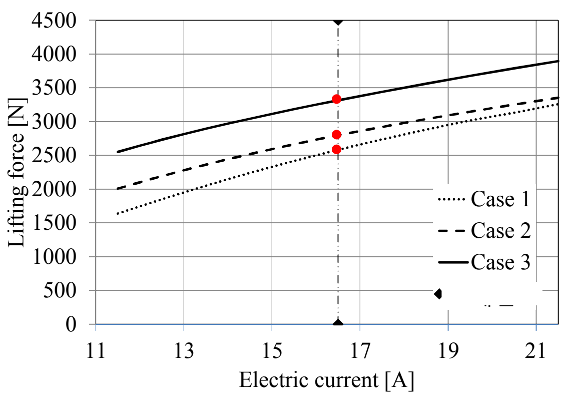

Fig. 2. Analysis results of the lifting force of the lift coil

It is proved that lifting force increases when electric current increases. The design requirement on lifting force of a lift coil is 3200N at a nominal electric current of 16.5A. Thus required lifting force is investigated at the nominal electric current (a phantom line in Fig 2). Calculated lifting forces for each case are 2582 N, 2800 N and 3315 N, respectively. It can be concluded that the coil design of the Case 3 satisfies the lifting force requirement.

Fig. 3 shows coil resistance and temperature correlation. Resistance is high and increases rapidly for the case 3 compared to the case 1 or 2 because of the thinner wire. An anticipated problem with increased resistance is excessive heat generation. However lift coil operates in a short time and remains inactivated during a cycle, so the problem may not be serious in this case.

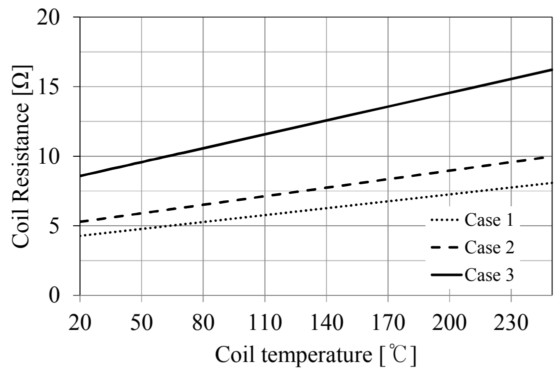

Fig. 3. Coil resistance and temperature correlation

3. Conclusions

An electromagnetic analysis for a lift coil of SMART CRDM is performed and the lift coil design is developed. It is confirmed that higher electric current and more wound wire produce greater lifting force. With spatial restriction of the coil, thinner wire is recommended to increase lifting capacity.

REFERENCES

[1] MAXWELL Version 4.1.208

ACKNOWLEDGEMENTS

This study has been performed under a contract with the Korean Ministry of Educational Science and Technology.