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Electromagnet Tests on Primary Control Rod Drive Mechanism of a Prototype Gen-IV SFR

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1. Introduction

The conceptual design of a prototype SFR (sodium-cooled Fast Reactor) of 150MWe capacity was began in 2012 through the Korea national long term R&D project by KAERI. The prototype SFR has six primary control rod assemblies (CRAs) and three secondary shutdown assemblies [1]. The primary control system is used for power control, burn-up compensation and reactor shutdown in response to demands from the plant control or protection systems.

This paper describes the lifting and holding force tests of the electromagnetic equipment of a primary control rod drive mechanism (CRDM).

2. Design concept of primary CRDM

The CRDM system consists of the drive motor assembly, the driveline, and its housing. The driveline consists of three concentric members of a drive shaft, a tension tube, and a position indicator rod, and it connects the drive motor assembly to the CRA. Each CRDM has two means of rod insertion [2].

The first is by un-gripping the CRA from the driveline allowing it to drop into the core due to gravity. The second is by the control shim motor or the fast drive-in motor activated by the plant control or protection system. The general design requirements are listed in Table 1.

The drive mechanism as shown in Fig.1 is mounted on top of the rotatable plug and controls axial motion of the CRA. It affects insertion, withdrawal, scram release.

Table 1 Tentative design requirements of CRDM

Parameters	Prototype
Housing diameter limit	250mm
Maximum motor force	8,000 N
Maximum motor stroke	1,100 mm
Rapid rod insertion time by fast drive-in motor	24 seconds
Gripping on-off stroke	10 ~15mm
CRA weight	~ 40 kg
Gripper type	Collet or Finger
Coil type (number)	Solenoids (dual)
Sealing from sodium	Bellows

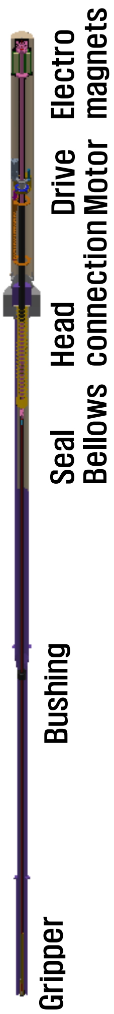
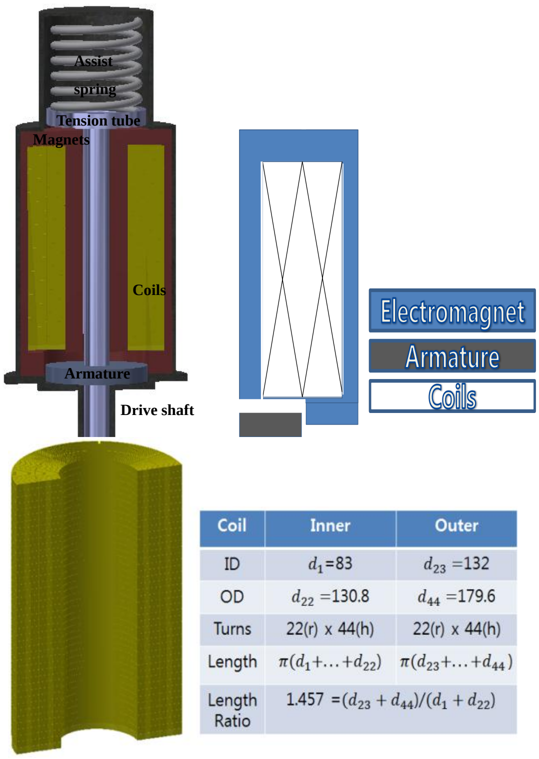


Figure 1 Conceptual design of primary CRDM

An electromagnet component as shown in Fig.2 is attached to the upper part of the drive shaft, which is supported on the lead screw motor-driven nut mounted on CRDM housing. The electromagnet holds an armature to which is jointed with a tension tube that extends down through the hollow drive shaft, to the uppermost end of the CRA. Dual coil system is adopted to allow the test and maintaining of the reactor protection system (RPS) circuits without dropping the control rod [3].

The driveline passes down through a shroud tube in the upper internal structure, which provides driveline alignment, support, and coolant flow from the reactor core outlet flow. It is a long structure and its length is about 12.8 m. The tension tube with a multi-fingered or collet-type gripper at its lower extremity carries the CRA. Re-gripping is accomplished by driving the gripper down to the bottom of its stroke, and then by raising the gripper to its trigger position.

Scram is accomplished by de-energizing an electromagnet so that the tension tube (assisted by a compressed spring) drops down about 10 mm, and releases its gripping force on the CRA. The CRA then drops into the core by gravity force.



Coil	Inner	Outer
ID	d_1=83	d_{23} =132
OD	d_{22} =130.8	d_{44} =179.6
Turns	22(r) x 44(h)	22(r) x 44(h)
Length	$\pi(d_1+\ldots+d_{22})$	$\pi(d_{23}+\ldots+d_{44})$
Length Ratio	1.457 $=(d_{23}+d_{44})/(d_1+d_{22})$	

Figure 2 Electromagnet and coils

3. Electromagnet test facility

The test facility consists of dual electromagnetic coils, fixed electromagnet, a moving armature, a dummy mass, an assist spring, a tension bar, and a support fixture frame as shown in Fig.3. The whole mass of the test facility is about 178kg as represented in Table 2.

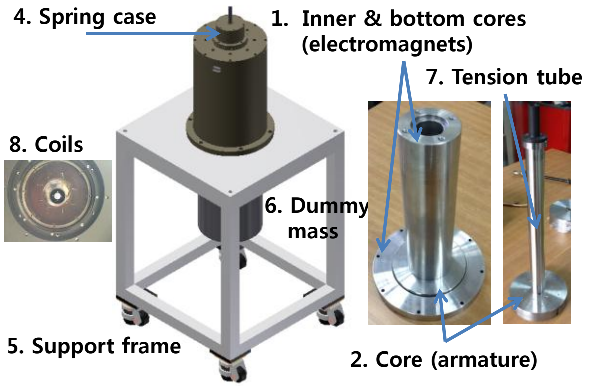


Figure 3 Test facility of electromagnet [4]

Table 2 Specification and material of electromagnet equipment

Components	Specifications	Materials	Mass
1.Core (electromagnet)	Solid Structure	S10C SS410	29.0
2.Core (armature)	Disk drum (25 mm, thickness)	S10C SS410	2.9
3.Spring (4 type)	14 KN/m (40,45) 34 KN/m (40,45)		
4.Spring case	Cylinder box	Al6061	
5.Support frame & Core case	Beam & plate structure	Al6061	35.3
6.Dummy mass	Cylinder drum	SS41	70.0
7.Tension tube	Hollow cylinder	SS304	0.8
8.Coils	Solenoids (dual) w/ 960 turns and section of 1 x 6 mm^2	Cu	40
9.Power supply	~15A, DC ~ 30 V		

4. Test results

The several tests are performed by changing the parameters such as lifting dummy mass, assist spring force, energized inner or outer coil, and electro-magnetic core material. Test values of electromagnet equipment are listed in Table 3. The current resistances of the coils are measured as 1.0 ohms and 1.4 ohms, respectively.

Table 3 Test parameters of electromagnet

Parameters	Test values
Holding and lifting distances	0.5mm, 1mm, 10mm
Dummy mass of CRA	5.2 ~ 75.2 kg (6kinds)
Stiffness of assist springs	14KN/m, 34KN/m w/ pre-compression of 5mm & w/ free spring length
Core materials	S10C and SS410
Energized coil	Inner / outer coils

4.1 Lifting and holding tests

Lifting and holding tests are performed to find the threshold coil current values according to the several dummy masses in range of 5.2 kg to 75.2 kg.

The minimum current to lift the tension tube less than 15.2kg is 2.5A. The minimum holding current is 0.7A. The tension tube does not drop quickly for the light dummy mass less than 20kg. For the dummy mass above 30kg, the lifting and holding currents are linearly increased as shown in Fig.4. It is also observed that the contribution of residual electromagnetic force is relatively small for the heavy mass.

4.2 Assist spring force effects

Lifting and holding tests with an assist spring inducing a downward force on tension tube are performed to find the threshold current values according to the several dummy masses in range of 5.2 kg to 75.2 kg. The minimum current for lifting the maximum weight of the tension tube is 15A and the minimum current for holding it is 1.42A.

The minimum currents to lift and hold the tension tube are increased about 10% ~ 20% due to the spring reaction force as shown in Fig.4.

It is observed that the tension tube quickly drops compared to the ones without a spring for the light dummy mass less than 20kg.

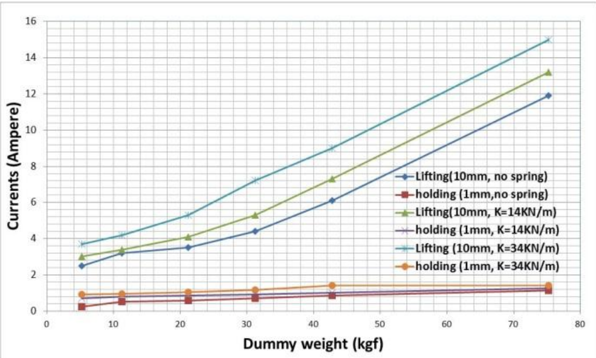


Figure 4 Coil currents to hold and lift the weight loads

4.3 Electromagnetic core material effects

Lifting and holding tests for the dummy mass of 75.2 kg are performed to find the effects of the replaced SS410 core material. The minimum currents for lifting the tension tube are increased to about 30% as shown in Fig.5. However, the change of the holding currents is not large to the lifting ones because of several uncertainties such as a residual electromagnetic force and a friction, et al.

4.4 Other effects

Holding force tests are performed to find the minimum currents for the dummy mass of 75.2 kg by changing the holding gap sizes (0.5mm, 1mm). The required currents can be reduced by shortening the gap size as shown in Fig.6.

The holding currents for SS410 core material, which has a higher permeability than SS410, are smaller than S10C core material. The reason is not clear, but it is guessed that a residual electromagnetic force just after a strong lifting current gives an influence on them.

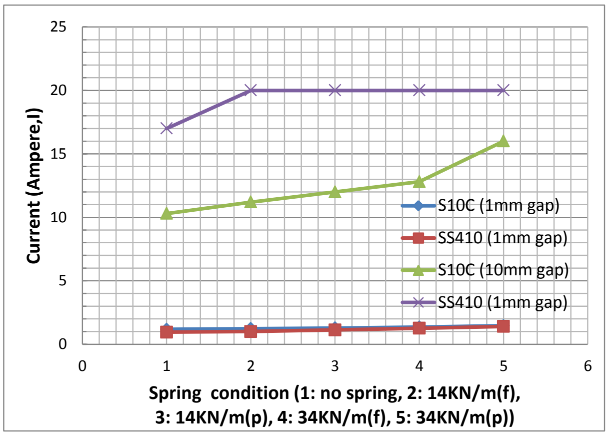


Figure 5 Lifting and holding currents for core materials

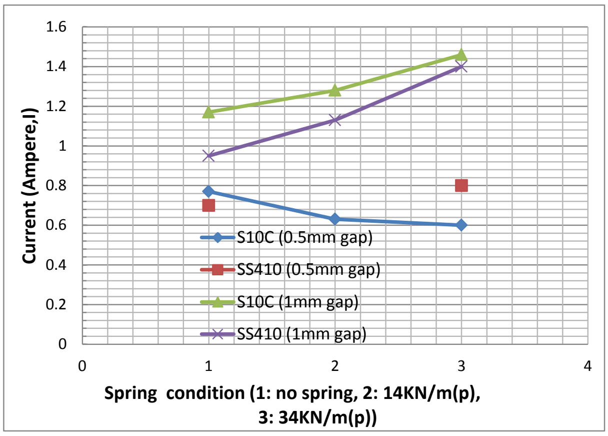


Figure 6 Holding currents for the gap sizes

5. Conclusions

The supply currents above 1.5 A and 15A on coil are required for holding the CRA with a 1mm gap, and lifting the CRA with 10mm gap, respectively. The currents cover all the loads to be expected in driveline.

The S10C carbon steel can be replaced with the SS410 stainless steel by increasing the supply current about 30%.

The assist spring, pushing down the tension tube with a compressed force, plays an important role when the operation load is smaller than 20kgf. The spring force can cease a time delay on the free drop of the tension tube carrying a light driving mass because a residual electromagnetic force may exist for a while even though the supply power is cut off.

The holding current can be reduced by closing the gap size of 1mm between inner core and armature.

ACKNOWLEDGEMENT

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