Conceptual Design Study on Electromagnets of Control Rod Drive Mechanism of a 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, burnup compensation and reactor shutdown in response to demands from the plant control or protection systems.

This paper describes the design concept of primary control rod drive mechanism shortly, and performs the parametric design studies for the electromagnet device of the drive mechanism to maximize CRA gripping force.

2. Design concept of 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. 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 drive-in using the plant control system-activated shim motors.

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. Axial motion of CRA within a hexagonal duct in reactor core is produced by a gearmotor-driven ball nut acting on a lead screw of a drive shaft. The screw is restrained against rotation and the nut is restrained against axial motion. Rotation of the ball nut raises and lowers the lead screw. An electromagnet 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 attached a tension tube that extends down through the hollow drive shaft, to the uppermost end of the CRA.

The driveline passes down through a shroud tube in the upper internal structure, which provides driveline alignment, support, and coolant flow from the reactor outlet. The drive shaft below a lead screw does not carry any appreciable axial load. Its lower extremity acts as a collet ring for the CRA gripper. The tension tube carries the CRA in a multi-fingered collet-type gripper at its lower extremity. Re-gripping is accomplished by driving the gripper down to the bottom of its stroke, driving the driveline down until it re-engages the CRA header, then raising the gripper to its trigger position.

The innermost of the driveline is a position indicator rod. During power operation its lower extremity rests on top of the CRA and its upper extremity extends through the reactor head to a point above the electromagnet of a drive mechanism where its elevation can be measured.

Scram is accomplished by de-energizing an electromagnet attached in upper part of a drive shaft, the tension tube (assisted by a spring) drops down about 10 to 15mm, and releases its grip on the CRA. The CRA then drops into the core by gravity force.

In order to limit the amount of reactivity insertion due to an uncontrolled rod withdrawal event, a rod stop system (RSS), consisted of an additional motor driven ball nut, is installed on the CRDM housing.

3. Tentative design of electromagnet device

There are two feasible design options of electromagnetic coils: a solenoid coil type and a race-track type. The type and number of coils shall be determined by the safety concept. Solenoid type is selected because of its simplicity as listed in Table 1.

The device schematic concept is shown in Fig.1. It comprises of coils, electromagnet, an armature as a part of tension tube, and a protection case as a part of a drive shaft. The space for the electromagnet device is limited by 210mm in diameter. The coil protection case is made of SS316.

The two solenoid coils are located within the electromagnet cores. The power of DC 1.62V ~21.86V and 1.42A ~ 11.45A is supplied on the coils according to the stroke length (air gap). There are 960 turns of each coil, and the cross section of coil is 1 x 6 mm^2. The inner and outer diameters of the outside electromagnet core are 188 mm and 206 mm, respectively. The inner and outer diameters of inside core are 37 mm and 82 mm, respectively.

The relative permeability of the core material made of ferrite silicon is 300. The ones of SS316 and air are all about 1.

4. Calculation of electromagnet force

The electromagnetic core usually confines and guides the magnetic field. The major parameters influenced on the electromagnetic force are the geometry and arrangement of the electromagnet and armature for a given coil specification.

A typical equation calculating the electromagnetic force for a solenoid type is represented in equation (1).

$$Electromagnetic\ Force = \frac{{B_g}^2}{2\mu_0} \cdot A_g = \left(\frac{B_g}{\mu_0}\right)^2 \cdot \frac{\mu_0}{2} \cdot A_g = [AT / (l_c/\mu_r + 2l_g)]^2 \cdot ({}^{\mu_0}/_2) \cdot A_g \quad (1)$$

The first one is the increasing of the flux cross section area (A_c, A_g) in magnetic field connecting of air gap, armature and electromagnets. Secondly, the reducing of the path lengths (l_c, l_g) of the armature and electromagnet makes the magnetic flux (B) resistance to be low.

An electromagnet field analyses are performed for the initial design values of the electromagnet device. The gripping force is about 3 times of CRA weight when one coil is power on. The parametric studies on air gap, core sizes configuring of the electromagnet cores are performed to maximize the electromagnetic force. The calculated results are represented in Fig.2. It is confirmed that the electromagnetic force is inversely proportional to the square of the gap size and proportional to the air gap facing area (A_g).

Based on the parametric study results, the modified geometries to increase the force are suggested in Table 2. The gripping force for the update design of Fig.3 is increased about 17% and the lifting mass is reduced.

ACKNOWLEDGEMENT

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REFERENCES

[1] Lee, Jae-Han, Conceptual study of reactor control and shutdown rod drive mechanism of a SFR, KAERI /TR-4712/2012.
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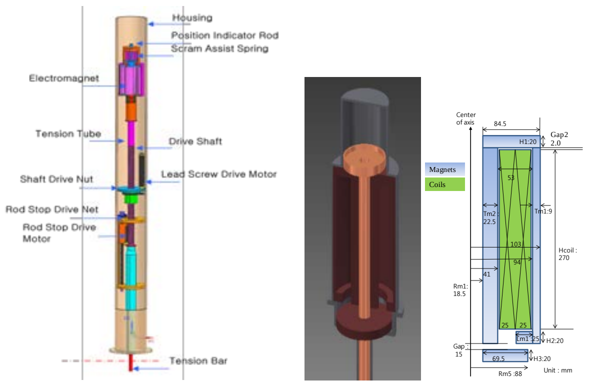


Fig.1 Initial concept of electromagnetic device

Table 1 Design parameters of electromagnet system

Parameters	PRISM	EFR	PFBR	Prototype
Coil type (number)	Solenoid (1, 2, 4)		Solenoid (1)	Solenoid (2)
Gripping stroke	1", 1/2", 1/4"		6.5 cm	1.0 ~1.5cm
CRA weight		630N		~ 400N
Gripper type	Collet type	Bayonet type	3 fingers type	Collet type
Sealing from sodium	Bellows & gas pressure	Bellows & gas pressure	V-ring & gas pressure	TBD

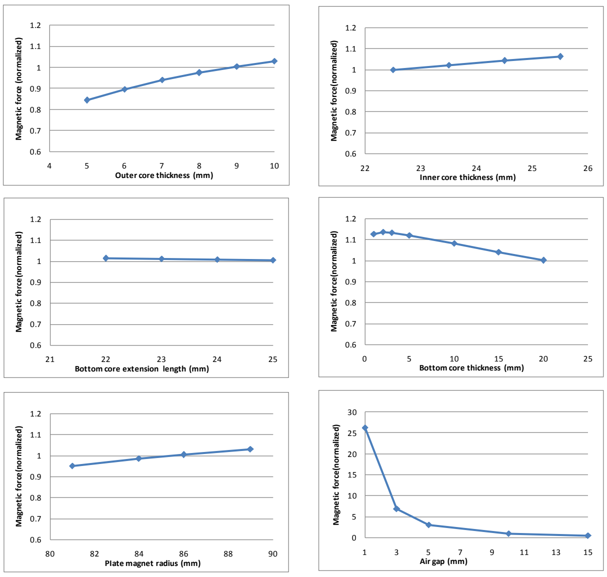
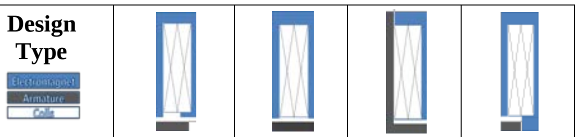
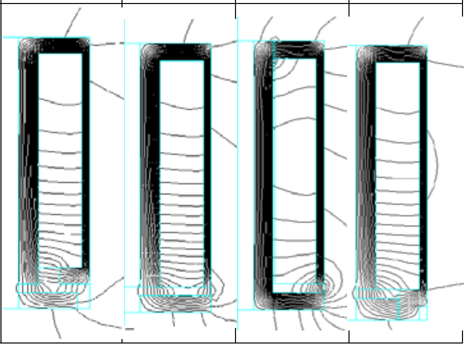


Fig. 2 Electromagnet forces between electromagnet and armature (drive shaft and tension tube)

Table 2 Electromagnet design shape and griping forces

Design Type				
Armature mass (kg)	3.7	5.2	15.3	2
Griping force ratio	1.0	1.05	1.08	1.17
Electro-magnetic flux fields				

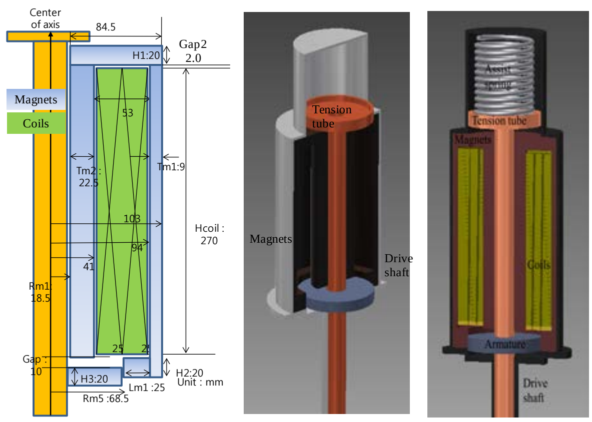


Fig.3 An update design concept of electromagnet core