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Conceptual Design Study on Passive Shutdown 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 is currently under consideration adopting a self-actuated shutdown system (SASS) to provide an alternate means of a passive shutdown of the reactor, which corresponds with the core exit temperature of primary sodium in reactor vessel.

This paper attempts to describe the design concept of the reactor shutdown rod drive mechanism shortly and to perform the parametric design studies of the passive shutdown device. Its design feasibility is investigated for a given design installation space constraint.

2. Design concept of passive shutdown system

The system automatically activates above a certain pool temperature, for example 650°C, and releases the control rod assembly [CRA] by gravity without any external control signals and any actuating power. This concept is going to be implemented in a group of the secondary CRA in prototype SFR [1].

There are several kinds of passive shutdown devices releasing the on-off gripping force of a CRA of SFR. One is a bimetal device by a thermal expansion difference[2]. The other is a method utilizing an inherent feature of an electromagnet core material, which loses its magnetic physical feature above a curie temperature[3].

The tentative passive shutdown system of a prototype SFR uses a combination of both the thermal expansion device and the electromagnet device in order to trigger off a CRA[2]. When the temperature of the primary sodium rises up to the limiting value, the thermal expansion jacket expands and pushes the CRA down a little, then the magnet flux resistance is increased by the wider gap between the armature and the CRA head, and then the CRA drops into the active core by its deadweight, which becomes greater than the electromagnet force holding a CRA. The holding force also can be lost when the DC power supply on coil is off by an operator.

The shutdown device schematic is shown in Fig.1. It comprises of an electromagnet coil, armature, a coil protective jacket, flow collector, and thermal expansion device. The coil protective jacket encloses the electromagnet coil and armature, which protects the components from liquid sodium. The flow collector of a skirt type guides the core exit sodium flow such that the thermal expansion device can be quickly contacted with the core exit hot sodium.

3. Tentative design of electromagnet device

The electromagnet device of a shutdown system is located in limited space and hot liquid sodium environment. The overall 3D configuration is shown in Fig.2. The allowed space for the electromagnet device is limited by 120mm in diameter, and 200mm in length. The coil protective jacket has inside and outside cases made of SS316. The outer and inner diameters of the outside case are 120mm and 116mm, respectively. The inner diameter and thickness of the inside case is 30mm and 2mm, respectively.

The power of DC 2V and 17A is chosen to be supplied on the coil, which is corresponded with 160 turns of coils around inside magnetic core, and the rectangular coil cross section of 2 x 6 mm^2. The inner and outer diameters of the outside electromagnet core are 103 mm and 115 mm, respectively. The inner and outer diameters of inside core are 35 mm and 61 mm, respectively.

The relative permeability of the core material made of a ferrite silicon is in range of 300 ~ 500. The ones of sodium, SS316 and air are all about 1.

4. Calculation of electromagnet force

An electromagnet field analysis is performed for the tentative design values of the electromagnet device. The ANSYS meshed model is represented in Fig.3. The electromagnetic force is calculated by 380N for the tentative design values with a structural gap of 2.0 mm, and the core material of relative permeability of 300. The calculated force is much less than the target value of 800N as listed in Table 1.

The three changeable parameters influenced on the electromagnetic force are chosen as the permeability of core material, coil turns, and the gap (thickness) of case structural material[4].

There are some ways in order to increase the electromagnetic force as shown in equation (1). At first, the increase of the current on coil and the number of coil turns [AT, Ampere-Turns], which is limited by the device installation space; secondly, the increase of the core material relative permeability (μ_r), which should be compatible with the high temperature environment; thirdly, the reduction of the structural gap size(l_g) between the armature and the top of CRA, which makes the magnetic flux (B) resistance to be low, and the structural integrity to be resisted.

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

To investigate the available design of closing to the target electromagnetic force, the parametric studies are performed for these design parameters. The electromagnetic forces, holding the CRA by the device, are calculated. The calculated results are represented in Fig. 4. As shown in Fig.4, it is confirmed that the electromagnetic force is inversely proportional to the square of the gap size and proportional to the coil turns.

From these results, the increase of core relative permeability from 300 to 500, the increase of the coil turns by adapting a long device and the reduction about 30% of the gap size between the core material and the head of CRA are the available design modification range for meeting the target electromagnetic force.

ACKNOWLEDGEMENT

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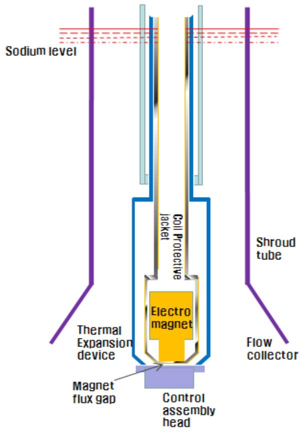

Fig.1 Schematic concepts of passive shutdown device

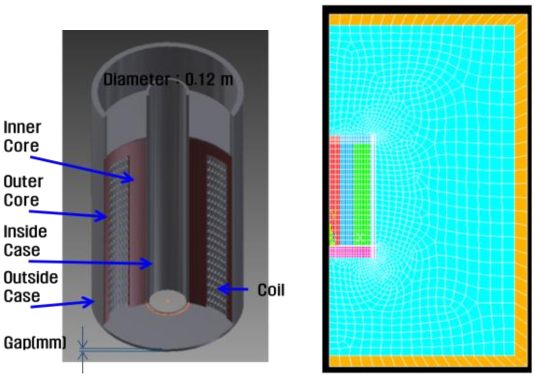

Fig.2 Tentative design concept and analysis model of electromagnet

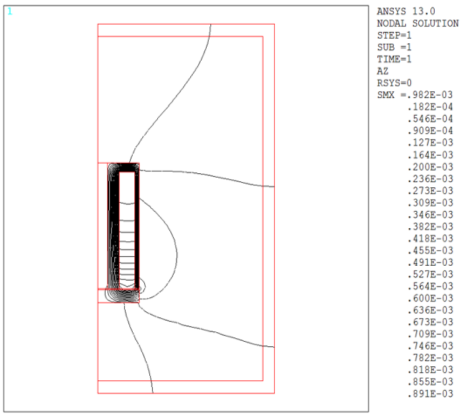

Fig.3 Analysis results of electromagnet flux field around the shutdown device

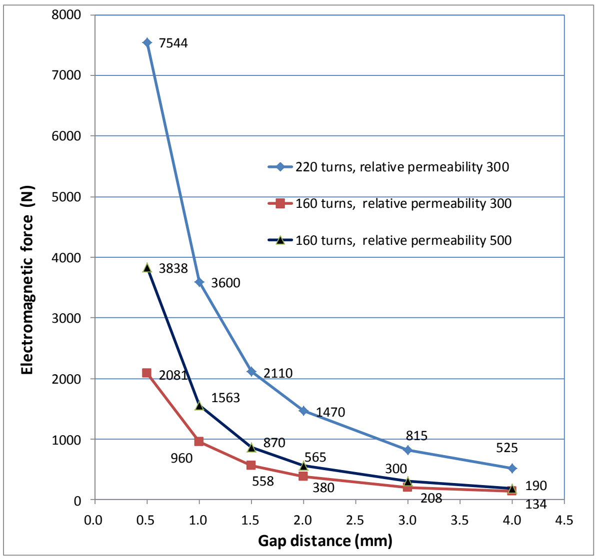

Fig. 4 Electromagnet force variations interacting between core materials and CRA head

Table 1 Design parameters of passive shutdown device

Design Data	**PRISM (one of several)**	**EFR**	**CFBR**	**Prototype (KAERI)**
Design holding force (N)		1000	1177	800 (TBD)
Operation temperature	538°C (1000°F)	600°C	600°C	650°C
Gripper opening action length	1/2" (Collet type latch)	7.5mm (Thermal expansion)	NA	~5mm (Thermal expansion)
Length of thermal expansion device	20 ft (316SS/ Mo-Re alloy)	~1.5 m	Curie Magnet	~1.5m
Weight of shutdown rod assembly		630N	393N	TBD