Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Design Improvement Study for Passive Shutdown System of the PGSFR

Lee, Jae-Han [a*] and Koo, Gyeong-Hoi [a]
[a]*Korea Atomic Energy Research Institute, Yuseong-gu, Daejeon, The Republic of Korea*
[*]*jhlee@kaeri.re.kr*

1. Introduction

There have been no experiences of implementing a passive shutdown system in operating or operated SFRs around the world. However, new SFRs are considered to adopt a self-actuated shutdown system (SASS) in the future to provide an alternate means of passively shutting down the reactor.

The Prototype Gen-IV SFR (PGSFR) also adopts this system for the same reason. This passive shutdown design concept is combined with a group of secondary control rod drive mechanisms (SCRDM). The system automatically releases the control rod assembly (CRA) around the set temperature, and then drops the CRA by gravity without any external control signals and any actuating power in an emergency of the reactor.

This paper describes the design upgrade parametric study of a passive shutdown system, which consists of a thermal expansion device, an electromagnet, a secondary control rod assembly head, etc. The conceptual design values of each component are also suggested. Parametric calculations are performed to meet the performance requirements of the thermal expansion device and electromagnets.

2. Design concept of passive shutdown system

The passive shutdown system is implemented in the SCRDM. The driver motor, stroke seal bellows, bushing and head support concepts of the SCRDM, as represented in Fig.1, are same as those of the primary control rod drive mechanism (PCRDM). The main difference is the CRA gripper type with a passive function. There is no RSS (rod stop system), drive tube, or assist spring in an SCRDM.

The passive shutdown system of SCRDM consists of a thermal expansion device, an electromagnet to hold & trigger off the CRA, a coil enclosure structure, and a flow collector. The coil enclosure structure enclosing the electromagnet coil and stator protects the components from the core exit sodium. The flow collector guides the core exit sodium to the thermal expansion device to make a sufficient contact with the sodium.

2.1 Design Requirements and Materials

The general requirements of the mechanical parts of the passive shutdown system are listed in Table 1.

When the core exit temperature of the primary sodium goes up around the set point, the thermal expansion device expands and pushes the CRA head down, the magnet flux gap between the electromagnet stator and armature of the CRA head top is then enlarged and the electromagnet force holding a CRA is weakened, and the CRA drops into the reactor core by its deadweight.

The tentatively determined materials of the SCRDM components are represented in Table 2. The drive shaft material in the region of the thermal expansion device is tentatively determined as an Inconel 718.

2.2 Thermal Expansion Device

The length of the thermal expansion device is tentatively determined to be about 4.0 m, which will be updated based on the coolant thermal transient analysis and the reactor operation bases. The diameter is limited by a control assembly duct inner space of 100 mm in diameter. The outer diameter of the thermal expansion device is determined by 90 mm taking into account a clearance of 5 mm. The key dimensions are represented in Fig.2. The inner diameter at the lower region is 86 mm. The length is about 1.181 m. The inner and outer diameters of its upper region are 64 mm and 70 mm, respectively. The region extends to below the bushing device, and the whole length is 2.86 m long.

Thermal expansion coefficients of the thermal expansion device are represented in Table 3. The total expansion difference between SS316 and Inconel 718 is expected to be about 2.4 mm - 3.6 mm when the environment fluid temperature rises up about 100 ^{o}C - 150 ^{o}C more than the normal operation temperature. The calculation results are as follows;

2.4 mm = ~ (6.0 x 10-6 /^{o}C) x (100^{o}C) x (4.0 m).
3.6 mm = ~ (6.0 x 10-6 /^{o}C) x (150^{o}C) x (4.0 m)

These values are about half of the target value of 5 mm.

2.3 Electromagnets

The electromagnet components of the passive shutdown device are located in a limited space and hot environment.

The space for the electromagnets is tentatively determined by 80 mm in diameter, and about 200 mm in length. The coil enclosure structure encloses the coil and electromagnet stators by the inside and outside steel cases made of SS316. The inner diameter and thickness of the inside coil enclosure structure are 11 mm and 2 mm, respectively. The inner diameter and thickness of the outside coil enclosure structure are 76 mm and 2 mm, respectively.

The inner and outer diameters of the outer electromagnet core are 69 mm and 75 mm, respectively. The inner and outer diameters of the inner electromagnet core are 15 mm and 27 mm, respectively.

A power of DC 2V and 17A is tentatively selected to be supplied on the coil. The 160 turn coils are allowed inside the electromagnet core, and the cross section of each coil is 2 x 6 mm^2.

The relative permeability of the core material made of a ferrite silicon is in range of 300 - 500. Those of sodium, SS316, and air are all about 1.0.

The electromagnetic forces on a CRA head are calculated for several cases of the design parameters. The availability of the tentative sizing is checked in Section 3 by the computer simulations.

2.4 Secondary CRA Head

The CRA head has an electromagnet armature attached on the top. The size is tentatively determined to be 60 mm in diameter, and the thickness is determined to be 5 mm. The size of the extension rod is determined to be 74 mm in diameter, which is compatible with the bottom end cone shape of the thermal expansion device.

3. Parametric Calculations of Electromagnets

The electromagnet forces on the CRA head are calculated by changing the design parameters such as the number of coil turns, the size of the electromagnet core, and gap size between the electromagnet static core and the moving armature of the CRA head.

Design features of the passive shutdown device of PGSFR are represented in Table 4.

The electromagnet forces on the CRA head of the passive shutdown device under several cases are calculated for the relative permeability of core materials of 300 by the ANSYS software, and the summary results are listed in Table 5 and Table 6. The electromagnet forces are existed in the range of 48 N to 530 N, which is much smaller than the target value of 800 N. An improved conceptual design and a typical electromagnetic field are represented in Fig.3.

4. Summary

The maximum thermal expansion difference length of 3.6 mm is less than the target value of 5 mm, and the calculated electromagnet forces on the CRA are smaller than the target value of 800 N. An additional design improvement to increase the thermal expansion difference length of a thermal expansion device are necessary to meet the target value, and the electromagnetic force should be increased by an adjustment of the electromagnet design values such as supplied current, material permeability, etc. The design feasibility of the thermal expansion device as a passive concept will be verified based on these results.

ACKNOWLEDGEMENT

This study was supported by the MSIP through its National Nuclear Technology Program.

REFERENCES

[1] Lee, Jae-Han, Preliminary conceptual design of control rod drive mechanism of a Sodium-cooled Fast Reactor,(Revision.00),SFR-MS124-WR-01-2011 Rev.0, 2011.12

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

[3] Lee, Jae-Han, and G.H. Koo, “Conceptual Design Study on Passive Shutdown Rod Drive Mechanism of a SFR,"KNS Spring meeting, 2012.05.

[4] Lee, Jae-Han, “PGSFR mechanical structure design of passive shutdown system," SFR-DM-302-008, 2014.8.11.

Table 1 Tentative design requirements of passive shutdown device

Parameters	Requirements
Installation space limit	< 100 mm in diameter
Gripper off mechanism	Bimetal thermal expansion difference : ~ 5 mm (operating temperature:600°C~650°C)
CRA mass	~ 40 kg
Gripper type	Electromagnet with solenoid coil

Table 2 Materials of CRDM passive shutdown device

No.	Components	Materials
1	Electromagnet coil	Cu
2	Electromagnets & armature	SS410
3	Drive shaft corresponding to the thermal expansion region	Inconel 718
4	Thermal expansion device	SS316
5	Coil enclosure structure and flow collector	SS316

Table 3 Thermal expansion coefficients of thermal expansion device

	SS316		Mod.9Cr-1Mo (Inconel718)	
Temp [°C]	Thermal Expansion [E-6 mm/mm/°C]	Thermal Conductivity [W/(m°C)]	Thermal Expansion [E-6 mm/mm/°C]	Thermal Conductivity [W/(m°C)]
425	19.6	20.1	13.4(14.13)	27.9(17.7)
450	19.8	20.5	13.6	27.9
475	20	20.8	13.7	27.9
500	20.2	21.2	13.8	27.9
525	20.4	21.5	14.0(14.4)	27.9(19.4)
550	20.6	21.9	14.2	27.8
575	20.9	22.2	14.4	27.7
600	21.1	22.6	14.6	27.6
625	21.4	22.9	14.9(14.9)	27.5(21.2)

Table 4 Design parameters of passive shutdown device

Design Data	PRISM (one of kind, USA)	EFR (France)	CFBR (India)	PGSFR (KAERI)
Design holding force (N)	-	1000	1177	~ 800 N
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	~ 5 mm (Thermal expansion)
Length of thermal expansion device	20 ft (316SS/ Mo-Re alloy)	6 m ~ 7 m	Curie Magnet	~ 4.0 m (TBD)
Weight of shutdown rod assembly	-	630 N	393 N	~ 40 Kg_f
CRA drop time	< 1.0	< 1.0	< 1.0	< 1.0

Table 5 Electromagnet forces induced by design parameter variations of electromagnets

Case	Gap size between fixed and armature	Magnet (fixed)			Coil		Force
		Thickness (inner) outer 3mm	ID (OD 27mm)	Bottom armature thickness	Length	Ampere turns	
	mm	mm	mm	mm	mm	AT	N
A	1	6	15	20	185	17x 160	177
B	1	8	11	20	185	17x 160	217
C	1	9	9	20	185	17x 160	231
D	1	11	5	20	185	17x 160	251
E	1	11	5	10	385	17x 320	290
F	1	11	5	10	185	17x 160	245
G	1	11	5	10	185	17x 220	463
H	2	11	5	20	185	17x 160	86
I	3	11	5	20	185	17x 160	48
J	0.5	11	5	20	185	17x 160	490

Table 6 Electromagnet forces for several enlarged electromagnet sizes

Case	Gap size between fixed and armature	Electromagnet core (fixed)			Coil		Force
		Inner core thickness	Outer core thickness	Coil space	Layer no	Ampere turns	
	mm	mm	mm	mm		AT	N
A	1	12	4	19.5	4	20x150	253
B	1	14	5	16.5	4	20x125	310
C	1	17.5	5.5	12.5	4	20x100	384
D	1	17.5	5.5	12.5	4	20x125	456
E	1	17.5	5.5	12.5	4	25x125	532
	Fixed	Inner hole diameter : 5 mm			Coil turns 160 ➔ 150/125/100		

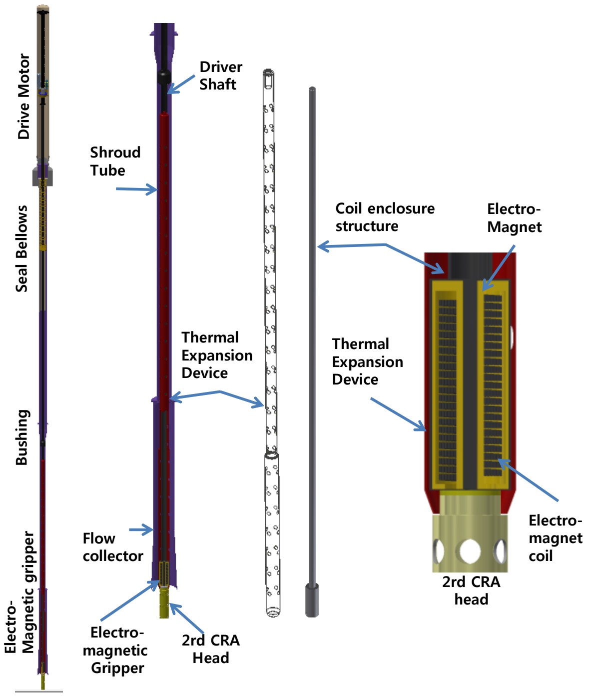

Fig.1 Schematic concepts of passive shutdown device

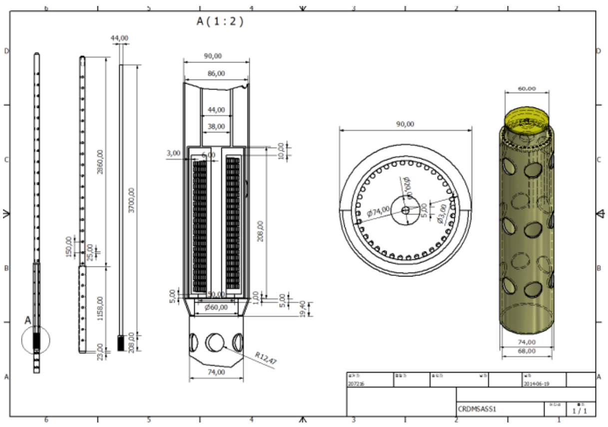

Fig.2 Conceptual design drawing of passive shutdown device

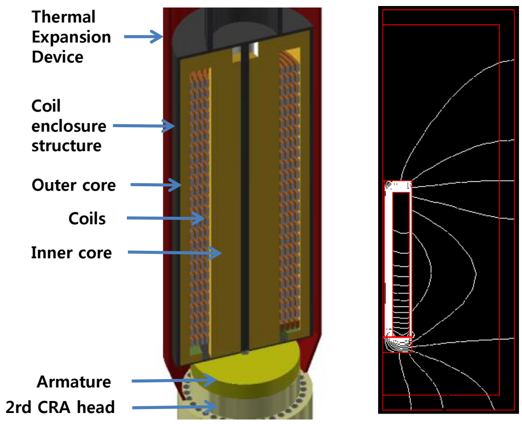

Fig.3 Improved conceptual design and an analysis example of a passive shutdown electromagnets