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Conceptual Design of a Helical Steam Generator with 750 MWt for an SFR

Ho-Yun Nam, Jong-Bum Kim, Yong-Bum Lee, and Ji-Young Jeong

Korea Atomic Energy Research Institute
E-mail: hynam@kaeri.re.kr

1. Introduction

A reliable steam generator (SG) design is one critical issue in developing a sodium-cooled fast reactor (SFR). To date, various types of SG have been developed in many countries, but the specifications of the SGs are very different in each country. Although many countries already developed their own SG concept, actually it has not been used in SFR systems. This is because the current techniques adopted for SFRs have yet to be stabilized in selecting the proper SG [1]. The conceptual design of a Korean sodium-cooled fast reactor has been progressed by KAERI. In this system, a total of two SGs with the capacity of 750 MWt are to be installed. The SG has been conceptually designed and its three-dimensional drawings were obtained to evaluate the feasibility of its fabrication.

2. Review of the Design Specifications

2.1 Important design parameters

Reactors such as PFR, FERMI, BN-350 and BN-600 [2] have experienced a severe sodium-water reaction (SWR) accident. In particular, the Phenix reactor experienced a total of four times of an SWR during its lifetime [3]. Therefore, an SWR has been considered one of the most important issues for an SG design. In EFR [4] design, the design target of the probability of a potential SWR is defined as 10^{-4}/ry. Experts who met on the maintenance and repair of LMFBR steam generators [5], the capability of rapid restart just after a leak detection being necessary was agreed upon.

Various types of steam generators have been developed to overcome thermal expansion of structural materials. A U-type SG has been used only in PFR because of the complexity of the sodium flow in the shell-side. A J-type SG was selected in the CRBR design, but it has not yet been applied in actual operation. A straight-tube type SG is easy to fabricate and the size is relatively small when compared to its power capacity. However, bellows, which are under development for actual operating conditions, are needed to remove the thermal stress between shell and tube bundle. The helical-tube type SG was developed to resolve the thermal stress. But it is difficult to use a non-destructive testing and to fabricate long tubes ranging from 65 to 100m. For the Superphenix, the heat transfer tubes were made by seven welded-tubes [5].

A heat transfer tube can be generally classified into two categories, which are a single-wall and a double-wall tube. Although a double-wall tube can reduce the possibility of an SWR by forming a two-layered barrier between sodium and water, most fast reactors except for some cases including EBR-II employ a single-wall tube due to low heat transfer capability and high fabrication cost of a double-wall tube.

A large thermal-rated SG is preferred in Japan, and two SGs with the capacity of 1765 MWt are to be installed in JSFR. France also prefers a large thermal-rated SG. Recently, however, they proposed that 18 small thermal-rated SGs with the capacity of 200 MWt are to be installed in an SFR with the capacity of 1500 MWe [6]. Thus, in Russia, small thermal-rated SGs with a capacity of less than 70 MWt were mainly used, but recently large thermal-rated SG with the capacity of 600 MWt was selected in BN-1800. In India, small thermal-rated SG with the capacity of 200 MWt will be employed for CFBR design.

2.2 Important design specifications

When the water mass flux is high for the tubes, flow-induced vibration becomes an important problem and an erosion problem arises in the two phase flow regime of the helical tube. When the mass flux is low, the SG size becomes large and the risk of flow instability increases. In order to reduce the size of the SG, the mass flux needs to be increased to 1600kg/m^2-s., but recently, it decreases to 1100kg/m^2-s considering the tube vibration.

The design pressure of the SG shell-side was low at the early design stage and then gradually increases. According to the JAEA's research in regard to the MONJU SWR event, it was reported that the shock wave pressures affecting the SG and IHX are 2.2 and 1.1 MPa, respectively [7]. After that report, most design pressure of the SG shell-side was set to be about 2.3MPa. The ratio of the design to the operating pressure of the steam side is about 1.1.

Although the design temperature of SFRs increases slightly around of 550°C, the allowable stress of a material decreases considerably. The ratio of the design to the operating temperature in the SG design was set to be high at the early stage, but recently the ratio is about 1.05.

In SFRs, the tube thickness of the SG is quite thick compared with that of light water reactors due to an SWR accident. At the early stage, the ratio of the tube thickness to its diameter ranged 0.05 to 0.25 with respect to the designs, but in recent designs the ratio ranges from 0.134 to 0.156. As the tube thickness becomes thick, the thermal stress caused by thermal expansion becomes an important parameter to be considered in a tube design.

One of the most important design parameters in the helical-type SG is the bending radius of helical tubes. It affects the stress distribution and heat transport in the tubes. The ratio of the bending radius to the outer diameter of helically-coiled tubes was about 14, but has recently gradually increased to more than 20.

Maximum free distances between two supports in a helical coil region were about 1400mm in PRISMs, 1100mm in the Superphenix, and 1000mm in MONJU.

3. Design of the Steam Generator

3.1 Conceptual design

The conceptual design of a helical coil SG with the capacity of 750MWth has been completed for the 600MWe SFR developed at KAERI. The specifications of the SG are shown in Table 1. The heat transfer tube is made with the single-wall tube, and Benson steam cycle is employed. There are four feed water headers at the bottom part of the shell and four steam headers at the top part of the steam generator. Sodium enters into the SG unit from two nozzles at the upper part of the unit and flows out through one nozzle at the bottom center of the unit. All tube positions were precisely calculated by the computer program developed in this study.

3.2 Three dimensional drawing

Table 1 Design specifications of the steam generator

Parameters	Values
SG type	Helical
Power (MWt)	750
Tube type	SWT
Inlet/outlet sodium temperature (℃)	502/305
Inlet/outlet water temperature (℃)	215/471
Sodium mass flow rate (kg/s)	3073
Water mass flow rate (kg/s)	344.65
Tube OD/ID (mm)	26/20
Tube inclination(deg)	7.1415
Transverse pitch (mm)	47
Bundle height (m)	10.99
Longitudinal pitch (mm)	37
Diameter of first row (mm)	1316
Number of tube in first row	14
Number of tube increase	1
Number of row	29
Total number of tube	812
SG height (m)	22
SG outer diameter (m)	4.2
Tube length (m)	102
Number of radial support	8
Upper–top steam header	4
Lower-side water header	4
Diameter of water/steam header(mm)	880
Thickness of water tubesheet (mm)	150
Thickness of steam tubesheet (mm)	180
Thickness of shell (mm)	70

The steam generator developed in this study was three dimensionally drawn with NX Ver. 8 software to evaluate the feasibility of its fabrication. As shown in Figure 1, it is a vertically oriented helical coil, sodium-to-water counter-cross flow, and shell-and-tube type heat exchanger. In the figure, only 29 tubes were drawn without supports to simplify the figure, which are the first tubes in each row.

Fig. 1 A 750MW helical steam generator

4. Conclusions

The conceptual design of Korean sodium-cooled fast reactor has been progressed by KAERI. In this system, total two SGs with the capacity of 750 MWt are to be installed. The steam generator employs helical-coiled and single-wall heat transfer tubes. The design specifications have been reviewed, and a steam generator was conceptually designed. A three dimensional drawing was also developed to evaluate the feasibility of its fabrication.

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