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Bellows Design of IHX in PGSFR

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1. Introduction

Sodium cooled fast reactors are designed to work at temperature levels up to 600 ^{o}C. The components and piping systems are submitted to changing temperature varying between room temperature and temperatures in operational, incidental or accidental conditions. Bellows are generally used to introduce a high flexibility of piping systems and for the leak tight connection of components with relative displacement. In PGSFR a bellows is used in an IHX to absorb the difference of thermal expansion between the inner pipe and the thermal shield cylinder.

In this paper, the shape design of IHX bellows by the ASME Sec. VIII Division 1 Appendix 26 [1] is described and the result of its structural integrity by ASME BPV Code Cases: N-290-1 [2] is also addressed.

2. Shape Design of Bellows

In this section the shape design of IHX bellows is described. The results include the necessary stroke distance of IHX bellows and its shape design such as a number of convolutions, convolution height, convolution pitch, thickness of bellows and so on.

2.1 Calculation of Absorbing Distance

In order to design the IHX bellows, the absorbing distance should be determined in advance. Basically the IHX bellows is designed for taking extension and contraction forces alternatively when the heat-up (normal operation) and cool-down (refueling stage), because if the only extension or contraction force is applied, then an excessive primary stress might occur in the bellows.

Before the determination of bellows stroke distance, the calculation of relative distance at two points which the IHX bellows will be installed is performed. Table 1 shows the results of thermal expansion distance at two positions.

Table 1. Relative Thermal Expansion Distance

Operation Condition	Position #1	Position #2	Relative Distance
Normal Operation	15.2 mm	-17.7 mm	32.9 mm
Refueling	49.4 mm	45.1 mm	4.3 mm

On the basis of results in Table 1, the stroke distance of IHX bellows is obtained as follows:

Stroke distance of IHX bellows
= Relative thermal expansion difference (32.9≈ 33) × 1.5(design margin)=49.5≈ 50 mm →±25 mm.

Fig. 1 shows the IHX bellows locations at manufacturing, installation, refueling, and normal operation. Actual stroke distance of IHX bellows between the normal condition and refueling stage are like these:

32.9 mm (normal operation) – 4.3 (refueling stage) = 28.6 mm →±14.3 mm.

For having the same stroke distance (±14.3 mm) in the normal operation and refueling stage, the IHX bellows should be installed with the 18.6 mm initial deformation (compression).

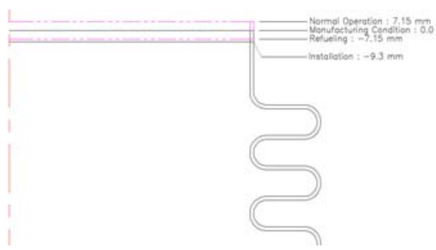

Fig. 1. Bellows locations at manufacturing, installation, refueling, and normal operation.

2.2 Shape Design of IHX Bellows

In order to determine the shape of IHX bellows by ASME BPV Sec. VIII Division I Appendix 26 the various input data shown in Fig. 2 are necessary. These data are changed until all design requirements in ASME BPV Sec. VIII Division I Appendix 26 are satisfied. Based on the design input data, the dimensions of IHX bellows shape as shown in Table 2 are determined.

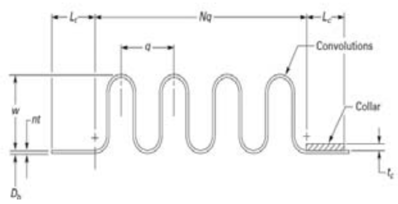

Fig. 2. General bellows shape.

Table 2 IHX bellows design values

Design Parameters		Values
Total displacement range	S_t	50 mm
Inner diameter of bellows	D_b	428.7 mm
Convolution height	w	60 mm
Nominal thickness of bellows	t	3.3 mm
Convolution pitch	q	50 mm
End tangent length	L_t	50 mm
Number of convolution	N	8 EA
Number of cycles	C	570 cycles

3. Structural Integrity Evaluations

The structural integrities of the IHX bellows designed by ASME BPV Sec. VIII Division 1 have been evaluated by ASME BPV Code Cases: N-290-1 procedure.

3.1 Loading Conditions

Table 3 shows the load combinations for each service level. The primary load (equals to mechanical loads) subjected to the IHX bellows during the normal operation is set to 0.6 MPa. The design pressure in the IHX bellows is set to 2.5 MPa by virtue of a sodium-water reaction pressure.

Table 3. Load Combinations for Each Service Level.

Event Name	Load Combinations	Service Time (year)	No. of cycle	Temp. (°C)
Design Condition	- Design pressure	60	-	565
Normal operation (Level A&B)	-Normal operation pressure	60	180	332.3
Sodium-water reaction (Level C)	- Sodium-water reaction pressure	60	25	332.3

3.2 Evaluation Section

In order to evaluate the structural integrity of IHX bellows an evaluation section is chosen as shown in Fig. 3.

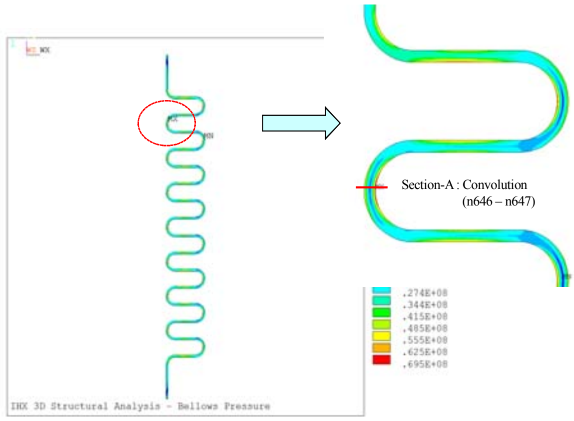

Fig. 3. Sections for structural integrity evaluations

3.2.1 Design Condition

According to the ASME BPV Code Case N-290-1, the primary membrane stress (Pm) should be satisfied with the allowable stress (So) in the design condition. The Pm should be calculated by following formulation:

$$Pm = p\bar{A}/A_c + 0.5p \quad (1)$$

where p is the pressure and definitions of $\bar{A}$ and A_c are shown in Fig. 4. Therefore Pm is

$$Pm = p\bar{A}/A_c + 0.5p = 88.4 \text{ MPa} < 89.4 \text{ MPa (So)}.$$

The result reveals that the primary stress in the section is satisfied with the design criteria for the design condition.

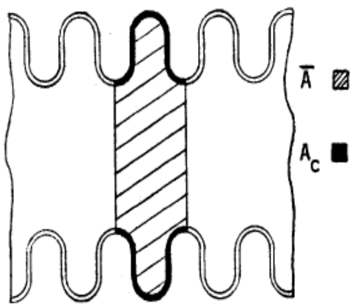

Fig. 4. Definition of area $\bar{A}$ and A_c

3.2.2 Normal Operation (Service Level A&B)

In service level A&B, following criteria should be satisfied.

$$Pm \le S_{mt} \quad (2)$$
$$PL + Pb \le 1.5KS_m \quad (3)$$

The allowable stress (S_{mt}) at metal temperature 332.3 °C is 189.3 MPa[3] and Pm can be calculated by Eq(1).

As applying normal operating pressure 0.6 MPa in Eq(1), Pm yields to 15.2 MPa. Thus Eq(2) is satisfied.

PL+Pb values in Eq(3) for the evaluation section are calculated as shown in Table 4. The results show that all PL+Pb stresses in the section are satisfied with the design criteria for the service level A&B load combinations.

Table 4. Evaluation Result of Structural Integrity under Service Level A&B.

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress	Margin	Temperature (°C)	C&S
Section-A	Inner(646)	Pm	15.20	Smt=189.32	11.46	332.3	Nulcear Code Case N-290-1
		PL+Pb	58.40	1.5KSm=425.97	6.29		
	Outer(647)	Pm	15.20	Smt=189.32	11.46	332.3	Nulcear Code Case N-290-1
		PL+Pb	64.90	1.5KSm=425.97	5.56		

3.2.3 Sodium-Water Reaction (Service Level C)

In service level C, following criteria should also be satisfied.

$$Pm \leq 1.2S_m \quad (4)$$

$$PL+Pb \leq 1.8KS_m \quad (5)$$

The allowable stress ($1.2S_m$) at metal temperature 332.3 °C is 225 MPa[3] and Pm can be calculated by Eq(1). Applying normal operating pressure plus sodium-water reaction pressure 4.1 MPa in Eq(1), Pm yields to 103.5 MPa. Thus, Eq(4) is satisfied. PL+Pb in Eq(5) for the evaluation section is calculated as shown in Table 5. The results show that all PL+Pb stresses in the section are satisfied with the design criteria for the service level C load.

Table 5. Evaluation Results of Structural Integrity under Service Level C.

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress	Margin	Temperature (°C)	C&S
Section-A	Inner(646)	Pm	83.20	1.2Sm=227.18	1.73	332.3	Nulcear Code Case N-290-1
		PL+Pb	399.00	1.8KSm=511.20	0.28		
	Outer(647)	Pm	83.20	1.2Sm=227.18	1.73	332.3	Nulcear Code Case N-290-1
		PL+Pb	443.80	1.8KSm=511.20	0.15		

4. Conclusions

The bellows for absorbing thermal expansion difference in IHX has been designed and its structural integrities under the design condition, typical service level A&B, and service level C load combinations have been reviewed. As a result, it was confirmed that the structural integrity of IHX bellows is satisfied with ASME BPV Code Case N-290-1 under a steady state condition. In the future, the fatigue test of the designed bellows will be conducted.

Acknowledgement

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REFERENCES

[1] ASME BPV Sec. VIII Division I, Appendix 26, Pressure Vessel and Heat Exchanger Expansion Joints, 2013.
[2] ASME BPV Code Cases: Nuclear Components, N-290-1, Bellows Expansion Joint, 2013.
[3] ASME BPV Sec. II Part D, Properties(Metric) Materials, 2013