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# Design of the spacer for the multi-layer pressure vessel installed in the reactor pool

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## 1. Introduction

In the case of the multi-layer pressure boundary assembly, the cooling of the outmost layer can be covered by the convection of the pool water. However, the cooling of the inner layers should be considered also to avoid overheating the layer due to nuclear heating.

Cooling by forced convection, e.g. the cooling of the outmost layer by pool water circulation, would be a conventional method. However, if the structure of the multiple-layer pressure vessel restricts the circulation, the inner layer would be cooled by natural convection rather than forced convection; the cooling efficiency of natural convection is hard to predict and it is much smaller than that of the forced convection.

Thus, the conduction through the spacer between the layers would be one of the possible approaches for sufficient cooling of the vacuum chamber as the inner layer. In this case, the trade-off between stress and temperature should be considered in the design stage because the stiffer spacer, the lower the thermal resistance. In this study, stiffness and the thermal resistance of the spacer between the two cylinder is investigated and reviewed whether the spacer can be contributed to the thermal conduction meaningfully. The material of the spacer is SB-209 [1].

## 2. Methods and Results

The main objective of the spacer is an alignment of two cylinders and to prevent excessive stress due to the misalignment during the assembly procedure, e.g. welding contraction. In addition, the spacer should cool down the inner cylinder by conduction.

Thus, the basic concept of the spacer is properly distributed plate spring and its shape and installed shape are illustrated in Fig. 1.

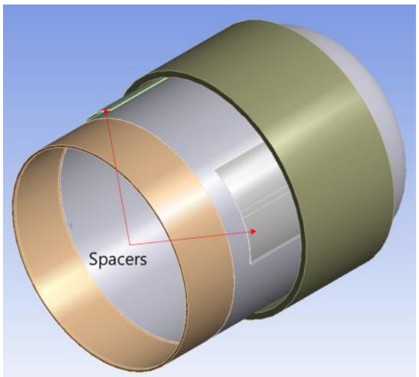


Fig. 1. The basic concept of the spacer

### *2.1 Design parameters*

Design parameters for the spacer are four and those parameters are summarized in Table 1 and illustrated in Fig. 2. (Diameter of the outer surface of the inner cylinder is 226 mm and diameter of the inner surface of the outer cylinder is 235 mm)

Table I: Design parameters for the spacer

| Parameters | Description |
|---|---|
| t | Thickness: 0.41 mm and 0.508 mm. |
| θ1 | Half-angle for the contact region with outer cylinder |
| θ2 | Angle for the transient region inner and outer cylinder |
| θ3 | Angle for the contact region with inner cylinder |

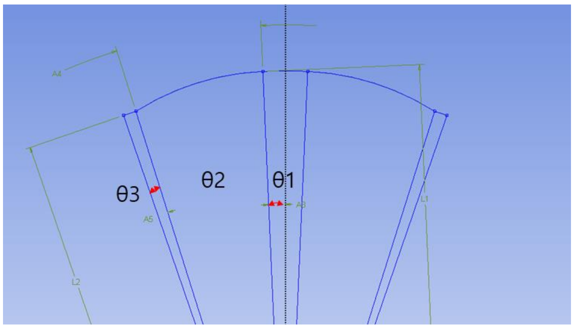


Fig. 2. Design parameters of the spacer for angles

The parameters t and θ2 are factors for the trade-off between stiffness and thermal resistance. The parameters θ1 and θ3 are factors to investigate the sensitivity of the contact surfaces area, which are uncertain factors in the manufacturing stage.

### *2.2 Boundary conditions for structural analysis*

The boundary conditions for the structural analysis are illustrated in Fig. 3.

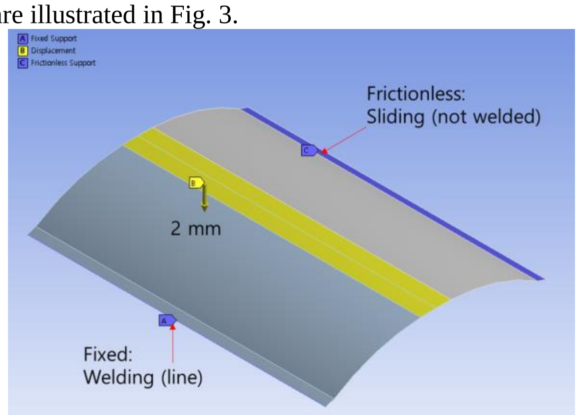


Fig. 3. Boundary conditions for the structural analysis

The objective is absorbing uncertainty due to the misalignment or welding contraction without excessive stress, i.e. stress of the spacer should be within the allowable range; membrane stress + bending stress should be less than 1.5 times of the allowable stress. In this sense, only one edge is fixed and the other edge is slide freely along the inner cylinder surface to prevent excessive stress.

### *2.3 Boundary conditions for thermal analysis*

The boundary conditions for thermal analysis are illustrated in Fig. 4.

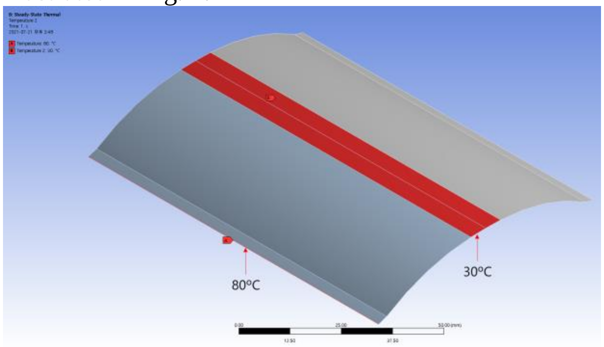


Fig. 4. Boundary conditions for thermal analysis

To investigate the approximate heat transfer rate, and the thermal resistance simple boundary conditions are applied; the temperature of the fixed edge is 80ºC, and the temperature of the contact surface with the outer cylinder surface is 30ºC.

The heat transfer rate through reference spacer, ring shape with slots, as shown in Fig. 5 is 3419W. The heat transfer rate of a reference spacer is used as a reference value.

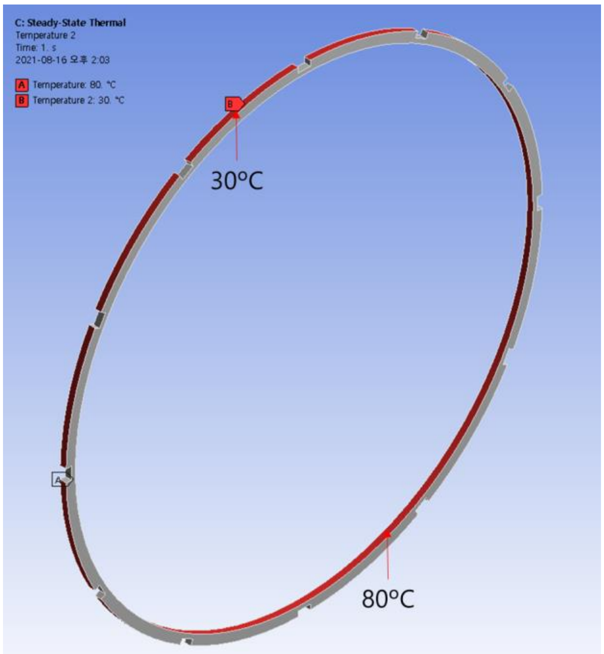


Fig. 5. Design and thermal boundary condition of the another spacer design

### *2.4 The results of the parametric study*

The results of the parametric is summarized in Table II.

Table II: The results of the parametric study

| θ1(º) | θ2(º) | θ3(º) | t | $\sigma_m+\sigma_b$ (MPa) | W |
|---|---|---|---|---|---|
| 2.5 | 15 | 1.5 | 0.500 | 335.0 | 11.52 |
| 2.5 | 7 | 1.5 | 0.500 | 1329.3 | 21.71 |
| 2.5 | 15 | 1.5 | 0.410 | 277.7 | 9.45 |
| 2.5 | 7 | 1.5 | 0.410 | 1111.4 | -17.77 |
| 2.5 | 20 | 1.5 | 0.410 | 162.4 | -7.28 |
| 2.5 | 25 | 1.5 | 0.410 | 110.9 | -5.92 |
| 1.5 | 25 | 1 | 0.410 | 114.3 | -6.03 |
| 2.5 | 15 | 1.5 | 0.508 | 227.8 | 11.71 |
| 2.5 | 20 | 1.5 | 0.508 | 132.7 | 9.02 |
| 2.5 | 25 | 1.5 | 0.508 | 90.8 | 7.33 |
| 2.5 | 22.5 | 1.5 | 0.508 | 108.6 | 8.09 |
| 1.5 | 22.5 | 1 | 0.508 | 112.5 | 8.26 |

The results clearly show that θ2 is the major factors for the trade-off between stiffness and thermal resistance, and heat transfer rate is not sensitive to the change of the contact surface area (θ1 and θ3). The heat transfer rate of the spacer is about 10 W if it satisfies the structural requirement. which is much smaller than that of the reference spacer design, 3419 W.

## 3. Conclusions

The parametric study shows the spacer can absorb uncertainty due to the misalignment or welding contraction without excessive stress and the contact surface area is not a critical factor for the heat transfer. However, additional heat transfer mechanism, such as aluminum mesh, could be introduced additionally, because heat transfer rate through the spacer is too small comparing with the reference spacer.

## REFERECES

[1] ASME Bolier and Pressure Vessel Code, Section II Part D, Material, American Society of Mechanical Engineers, 2013