3D Modelling and Static Structural Analysis of Bottom Reflector Experimental Power Reactor (RDE) using Solidworks Software

Farisy Yogatama Sulistyob, Ari Nugrohoa and Syaiful Bakhria

a Centre for Nuclear Reactor Technology and Safety - National Nuclear Energy Agency of Indonesia, Building No. 80 PUSPIPTEK Area, Serpong, South Tangerang, 15310, Indonesia
b Centre for Nuclear Energy System - National Nuclear Energy Agency of Indonesia, Building No. 3C, Kuningan Barat, South Jakarta, 12710, Indonesia

email: farisy-yogatama@batan.go.id

Abstract. Bottom reflector design is important issue in BATAN’s Experimental Power Reactor (RDE). The Bottom reflector is a pathway out of helium gas circulation to heat exchanger. It must sustain load of pebbles and structural itself. Solidworks software was used to perform 3D design and static simulation. 3D design was made in 6 layers and show that the model similar to HTR-10. Factor of safety was obtained in static simulation using 2 simplified parts. The result show that the minimum factor of safety are 153 in parts I and 151 in parts II. This static simulation result show that the model is suitable for RDE.

Keywords: RDE, HTR-10, hot gas chamber, bottom reflector, static, factor of safety

1. Introduction

Experimental Power Reactor (RDE) has becoming a strategic planning of National Nuclear Energy Agency of Indonesia (BATAN) for 2015-2019. RDE is expected to generate 10MWe of power, which is equal to 3MWe. RDE has something in common with High Temperature Reactor (HTR-10), which is another experimental reactor that has been built in China. HTR-10, a pebble bed reactor type, is a graphite moderated, gas cooled nuclear reactor. It consists of the Reactor Pressure Vessel (RPV), internal graphite and carbon brick components (known as ceramics internals), fuel elements, control rods and their driving mechanisms, small absorber ball shut down system, fuel charging and discharging system [1].

The ceramics internals are important structure of RDE. Therefore, it should be designed to support and maintain the core structure array, ensure continued cooling by circulating helium in the coolant circuit, and ensure structural integrity of the component as well. The ceramic internal have 2 different type, graphite and carbon internal. The former is used as the neutron reflector and the latter is used as thermal insulation. The graphite consists of top, side and bottom reflectors. Each layer of graphite reflector and the carbon insulating has 20 segmental bricks, except for the bottom reflector and the inside ring of the bottom insulation which have only 10 segmental bricks [2]. The Bottom reflector is a pathway out of helium gas circulation to heat exchanger and must sustain load of pebbles. The Bottom
reflector consists of 6 layers that contain empty spaces. These empty spaces are hot plenum and hot gas chamber.

The design of HTR-10 bottom reflector in 2D high fidelity model and simplified model has been made before by William K Terry and IAEA in different technical document. This study mainly focusing on 3D design and simulation for bottom reflector to simulate and determine its safety factor by self-weight load. SOLIDWORKS software is employed to design and come up with 3D model for simulating the distribution of safety factor bottom reflector model.

2. Methodology

2.1. 3D Modelling

Bottom reflector is modelled using Solidworks software. As shown in figure 1, the model is separated into 6 layers. Each layer has 10 segmental bricks and are arranged as a full bottom reflector structure. To ensure the bottom reflector model similar to HTR-10, the layers meet the following [1] [2] [3] as figured on figure 1:

1. Layer 1
   First Layer is cone-shaped graphite with about 370 mm in height and 650 mm in long. In the middle of the object, there are 640 holes with 16 mm in diameter. In the bottom side, there are dowels to hold the graphite in place.

2. Layer 2
   Second Layer is graphite with about 133 mm in height and 650 mm in long. In the middle of the layer, there are 640 holes with 16 mm in diameter. In the top side, there are dowels holes as pair dowels from first layer. In the bottom side, there is a plenum with 50 mm in height and 440 mm in long. There are also dowels as locking movement.

3. Layer 3
   Third layer is graphite with about 280 mm in height and 650 in long. In the top side, there is a plenum with about 150 mm in 440 mm in long. In this layer, there are holes for helium separator to lead the hot helium to gas chamber downward.

4. Layer 4
   Fourth layer is graphite to continue helium gas to go to hot gas chamber. The size is about 200 mm in height and 650 mm in long.

5. Layer 5
   Fifth layer is upper half-section of hot gas chamber. The size is about 300 mm in height and 650 mm in long. Seven segments of this layer have a space as inlet of the helium gas and the other segments are solid without helium inlet. This layer have a ring-shape space with inner diameter 708 mm and outer diameter 900 mm. the ring-shaped space is space to mix helium gas.

6. Layer 6
   Sixth layer is lower half-section of hot gas chamber. The size is just as same as fifth layer.
2.2. **Static Simulation**

Bottom reflector was simulated using Solidworks Simulation feature. Solidworks simulation module is used as a guidance for its steps. The first step is drawing and assembling all 3D parts that required to be simulated. The second step is choosing the materials of 3D parts to define the material properties. The third step is setting the boundary conditions such as fixture and connection. The next step is meshing the 3D parts. Finally, computation are performed to get the factor of safety results [3].

| Table 1. Properties of unirradiated graphite |
|----|----|----|----|----|---|
| Density (g/cm³) | Modulus Elasticity (GPa) | Tensile Strength (MPa) | Compressive Strength (MPa) | Poisson ratio | Friction coefficient |
| 1.76 | 9.04 | 25.40 | 76.22 | 0.126 | 0.369 |

Static Simulation is mostly depends on its material properties. Bottom reflector in the shape of a stacks of graphite, is considered to be a brittle material. The unirradiated properties of graphite IG110 are given in Table 1 [2]. This study simulate bottom reflector using Mohr-Coloumn theory equation. To prevent failure of bottom reflector layer, the factor of safety value must more than 1. If the factor of safety value is less than 1 that means the structure is unable to withstand with the load given and may cause crack, fatigue and other failure.

The Mohr-Coulomb stress criterion is based on the Mohr-Coulomb theory also known as the Internal Friction theory. This criterion is used for brittle materials with different tensile and compressive properties. Because brittle materials do not have a specific yield point, therefore it is not recommended to use the yield strength to define the limit stress for this criterion. As a result, the theory predicts failure will be occur when the combination of the maximum and minimum principal stress exceeds their respective stress limits [10].

For the principal stresses $\sigma_1$, $\sigma_2$, and $\sigma_3$ ordered such as $|\sigma_1| > |\sigma_2| > |\sigma_3|$, the Mohr-Coulomb theory predicts failure to occur in the following cases [5]:

| Table 2. Mohr-Coloumb Theory |
|----|----|---|
| State of Principal stresses | Failure Criterion | FOS |
| Both principal stresses in tension: $\sigma_1 > 0$ and $\sigma_3 > 0$ | $\sigma_1 > \sigma_{Tensile limit}$ | $\left(\frac{\sigma_1}{\sigma_{Tensile limit}}\right)^{-1}$ |
Both principal stresses in compression:

\[ |\sigma_1| > \sigma_{\text{CompressiveLimit}} \]
\[ \frac{|\sigma_1|}{\sigma_{\text{TensileLimit}}} + \frac{|\sigma_2|}{\sigma_{\text{CompressiveLimit}}} > 1 \]
\[ \frac{|\sigma_1|}{\sigma_{\text{CompressiveLimit}}} + \frac{|\sigma_3|}{\sigma_{\text{TensileLimit}}} > 1 \]

As shown in table 2, in Solidworks simulation, Mohr-Coloumb criteria is able to determine a factor of safety material by using finite element method (FEA). Meshing is created by using solid mesh type, curvature base mesh method and have 20-100mm element size. Bottom reflector was given external load by gravitation force (9.81m/s\(^2\)), weight of upper layer give force to lower layer. In this study, bottom reflector are separated into two big segment to simplify the simulation. First segment is for hot gas chamber parts, and the other is for 3 segment that do not have hot gas chamber.

3. Results and Discussion
Design and simulation using Solidworks software are performed as described above. Model will be shown in side, top and isometric view.

3.1. 3D Model Assembly

![Assembly model view; (A) top view, (B) side view, and (C) isometric view.](image)

3.2. Simulation
3.2.1. Simplified models. The bottom reflector is simplified into two different parts. As shown in figure 3, parts I contain hot gas chamber as represented by 7 segments with same size while parts II contain the 3 segment block that do not have hot gas chamber. Each part represents the bottom reflector.
Figure 3. Bottom reflector parts separation; (A) parts I model and (B) parts II model.

3.2.2. Meshing. A typical mesh in model, figure 4, has been made. If the percentage of elements with aspect ratio less than 3 is higher than 50% that means the meshing is successfully created. As shown in table 3, the component has a high quality and will provide an accurate result.

Table 3. Model meshing parameter

| Parts   |  I    |  II   |
|---------|-------|-------|
| Total Nodes | 127710 | 413523 |
| Total Elements | 78129  | 254335 |
| Maximum Aspect Ratio | 14.408   | 28.443   |
| % of elements with Aspect Ratio < 3 | 75.7 | 73.3 |
| % of elements with Aspect Ratio > 10 | 0.0218 | 0.0409 |

Figure 4. Meshed model; (A) meshing on parts I and (B) meshing on parts II.

3.2.3. Factor of safety (FOS). The resultant force of entire model is about 4154 Newton for parts 1 and 13210 N for parts II. As shown in figure 5, the minimum factor of safety of parts I and parts II is 153 and 151 respectively. If the minimum factor of safety is more than 1, it means the model can sustain the load given because the load by the mohr-coloumb stress criteria is less than the stress limit and compressive stress limit of the model. As shown on figure 6, the side edge of the dowel have
factor of safety minimum value, it means the dowel have local stress concentration. This local stress concentration is mostly due to endure the graphite movement.

**Figure 5.** Factor of Safety (FOS) of bottom reflector; (A) result of parts I and (B) result of parts II.

**Figure 6.** Layer 5 Factor of Safety (FOS) detail; (A) parts I and (B) parts II.

4. **Conclusion**  
3D models and simulation by self-weight have been performed using Solidworks software. The result show that the minimum factor of safety of parts I and parts II are 153 and 151, inform that the bottom reflector is able to withstand the load given. The minimum factor of safety locate on the dowel edge. The dowel contribute as the local stress concentration to endure graphite movement.

The 3D modelling and simulation result is possible to be applied as RDE design. Further researches related to another parameter such as pebbles load, temperature effect and radiation effect are necessary to be carried out to have holistic analysis of RDE design. The dowel parameter must be investigated to obtain optimum load configuration for full-scale design.

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