Basic Design of Structural Components of a Dual Cooled Fuel for OPR-1000

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1. Introduction

One of the peculiar features of a dual cooled fuel is an additional coolant flow passage formed inside a fuel rod to increase the surface area of heat transfer. This makes the outer diameter of a fuel rod considerably larger compared with that of a conventional fuel rod, which draws a lot of technical issues. Mechanical issues of the structural components have been presented previously [1]. Those have been resolved by changing the shape and dimension of the conventional fuel's components. One of the constraints in the design change was that the components should comply not only with the design criteria and functional requirements but also with the current internal structures of the OPR-1000. Finally, basic design of the components was completed with fabricating mockups of each component as well as a dual cooled fuel rod. In turn, those were assembled to compose a fuel assembly of a half length. The structural compatibility between the components was then verified. This paper presents the basic design results.

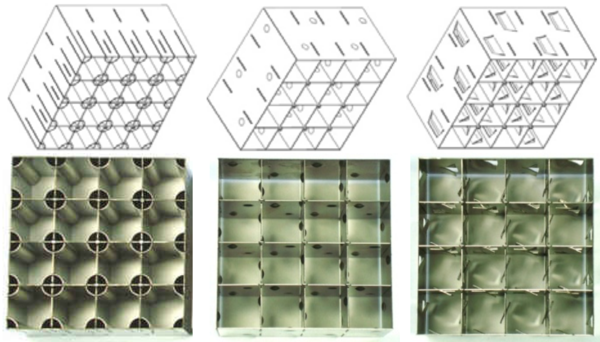
2. Key Results of the Basic Design

2.1 Fuel Rod Supporting Structure

In general, the fuel rod supports locate at the center of the grid cell width. However, it is almost impossible for a current dual cooled fuel of 12X12 array since there remains a very narrow gap between the fuel rod and grid surfaces. It is only 0.38 mm for the currently designed dual cooled fuel due to 15.9 and 0.46 mm for the fuel rod diameter and grid strap thickness, respectively. An alternative way is to move the location of the supports to the edges of the grid cell. Such a tough condition of the supports' formation could presumably make the fuel rod supporting structure differ considerably from a conventional spacer grid.

Candidate designs of the supporting structure are shown schematically in Fig. 1 together with the fabricated mockups, made of stainless steel. Those resembled the conventional concept of a spacer grid, i.e. vertically oriented intersecting straps. The stiffness was measured as 1806.4, 1327.1 and 68.9 N/mm for the cylinder insertion, hemisphere protrusion and cantilever spring types in order [2]. It was also found that the supporting forces of all types were larger than the minimum required force, 7 N, when a dual cooled fuel rod was inserted.

Besides, a completely new concept of supporting structure was also developed. It was composed of two (upper and lower) *horizontally* oriented straps with holes for fuel rod clamping and a truss of thin wires between them as illustrated in Fig. 2. It is called a "*perforated plat support with truss structure*" It may be used as a mid grid for segmented fuel rods specifically. Therefore, it cannot be used presently. However, in the mean time, it can also be used as a debris filtering grid attached just above a bottom end piece. Its mechanical characteristics can be consulted in [3].



(a) (b) (c)

Fig. 1. Schematic and mockup view (4X4) of the candidates of fuel rod supporting structure: (a) cylinder insertion (b) hemisphere protrusion (c) cantilever spring types.

Fig. 2. Schematic and mockup view of the perforated plate structure for segmented fuel rods.

2.2 Top and Bottom End Pieces

It is conventional that the flow holes of the top and bottom end pieces locate between the fuel rods. However, the holes at the fuel rod locations should also be necessary for a dual cooled fuel since a sufficient coolant flow through the internal flow passage of a dual cooled fuel rod is highly required. Two different candidates were designed for each top and bottom end piece. As for the top end piece, a diamond and an "X" like pattern (termed "type D and X", respectively) were designed while the unit hole shapes of a circle and a rounded square (termed "type C and S", respectively) were designed for the bottom end piece.

Due to the additional flow hole at the fuel rod locations, total flow area was increased relative to conventional top and bottom end pieces. The increase ratios were 5.7(Type D) and 6.6(Type X)% for the top end piece, and 2.6(Type S) and 9.4(Type C)% for the bottom end piece. Another associated concern was the reduction of mechanical strength, even though the pressure drop decreased positively. Finite element analysis was conducted with using the ABAQUS. The most severe load exerted to the top and bottom end pieces was 22.24 kN in the case of fuel assembly handling (lift-up load). The Tresca stress in the high stress region was evaluated by using a stress linearization process according to the ASME NB-3200.

The results are given in Table I. It should be noted that the Tresca stress is far below the stress intensity limits. So it is soundly concluded that the newly designed top and bottom end pieces sufficiently satisfy the strength criteria as well.

Table I: Tresca stresses and stress intensity limits, S_m

Compo-nent	Type	Classifi-cation	Tresca stress (MPa)	S_m (MPa)
TEP	D	P_m	5.02~10.15	for P_m: 215
		$P_m + P_b$	3.53~16.60	
	X	P_m	5.02~10.17	
		$P_m + P_b$	2.59~15.08	
BEP	C	P_m	16.04~61.46	for $(P_m + P_b)$: 322.5
		$P_m + P_b$	13.56~127.38	
	S	P_m	15.63~61.44	
		$P_m + P_b$	13.69~128.78	

Notes: TEP: Top End Piece, BEP: Bottom End Piece,
P_m: Primary membrane stress, P_b: Primary bending stress

2.3 Guide Tubes

If a conventional guide tube is to be used for a dual cooled fuel, maldistribution of the coolant flow occurs in the cross section of a fuel assembly due to considerable difference between the fuel rods' gap and the gap between the fuel rod and guide tube. Therefore, it was attempted to apply an additional tube of larger diameter outside the conventional one (i.e., coaxial dual tubes). As a result, the outer diameter of the outer tube was determined as 33.50 mm with the thickness of 1.0 mm to have a hydraulic diameter of 9.0 mm.

The criterion of the control rod drop time was satisfied automatically since a conventional guide tube was used for guiding the control rods. Other strength criteria have also been investigated analytically. As a result, the bending stiffness and buckling strength were increased by 2.87 and 3.47 times compared with those of a conventional guide tube. This was attributed to the increased area moment of inertia. On the other hand, a joint and connection method between the current dual guide tubes and top/bottom end pieces, and that between the inner and outer tubes were also developed.

3. Feasibility Check of Composing a Fuel Assembly

After the component design was completed, a partial fuel assembly of half length was fabricated with the mockups of the structural components as shown in Fig. 2. Two regions of 4X4 array were constituted diagonally in the partial assembly. Each region had supporting structures of different types. Dual tubes for the fuel rods as well as the guide tubes, dummy pellets of annular shape and plenum springs were also fabricated. Consequently, it has been validated that the current component design could constitute a dual cooled fuel assembly for OPR-1000.

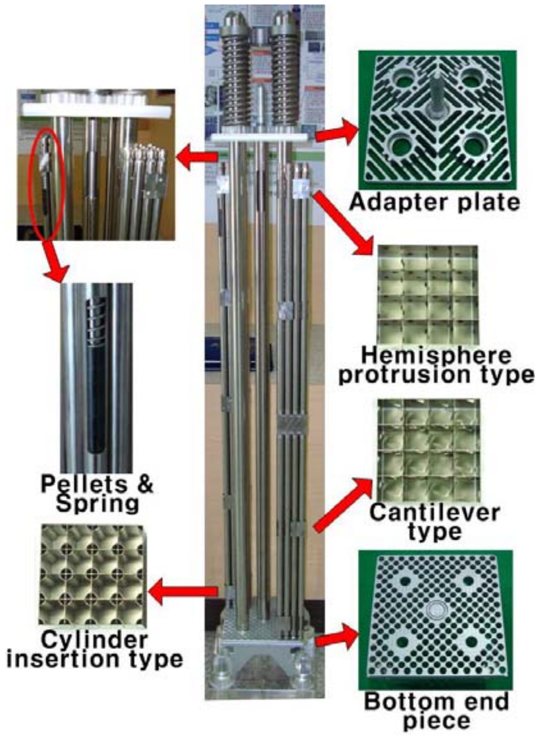


Fig. 2. Mockup of a dual-cooled fuel assembly.

4. Conclusions

Basic design of the structural components of a dual cooled fuel for OPR-1000 has been completed. Mechanical design criteria as well as functional requirements for each component were validated by analysis and experiment. A mockup assembly of a half length was fabricated, through which the feasibility of fuel assembly constitution was verified. Mechanical behavior and integrity of a dual cooled fuel will be studied consecutively.

ACKNOWLEDGMENT

This work has been carried out under the Nuclear R&D Program by MEST Korea.

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