Stress Linearization and Strength Evaluation of the BEP's Flow Plates for a Dual Cooled Fuel Assembly

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1. Introduction

A fuel assembly is composed of 5 major components, such as a top end piece (TEP), a bottom end piece (BEP), spacer grids (SGs), guide tubes (GTs) and an instrumentation tube (IT) and fuel rods (FRs). There are no ASME criteria about all components except for a TEP/BEP. The TEP/BEP should satisfy stress intensity limits in case of condition A and B of ASME, Section III, Division 1 – Subsection NB [1]. In a dual cooled fuel assembly, the array and position of fuels are changed from those of a conventional PWR fuel assembly to achieve a power uprating. The flow plates of top/bottom end pieces (TEP/BEP) have to be modified into proper shape to provide flow holes to direct the heated coolant into/out of the fuel assembly but structural intensity of these plates within a 22.241 kN axial loading should satisfy Tresca stress limits in ASME code. In this paper, stress linearization procedure and strength evaluation of a newly designed BEP for the dual cooled fuel assembly are described.

2. BEP for dual cooled fuel

Fig. 1 shows a newly designed BEP. In the case of a dual cooled fuel assembly, two flow passages, an internal flow passage formed in the center of a fuel rod and an external flow passage located at gaps between fuel rods, exist to enhance thermal exchange and reduce the center temperature of a fuel rod. To minimize pressure drop due to the flow plate's hole pattern, the flow holes were designed to be aligned with internal/external flow passages of dual cooled fuel rods. Finally, the flow holes' area is increased about 6.5 % than the conventional one.

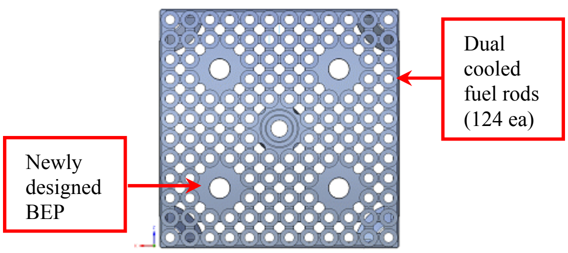

Fig. 1 Newly designed flow plate of a BEP overlapped with a dual cooled fuel rods.

3. Robustness evaluation of BEP with ASME code

ASME section III, Division 1 – Subsection NB says classification of stress intensity in vessels for some typical cases. BEP is included in the case of the perforated head or shell. So, the membrane stress is the stress averaged through cross section and the bending stress is calculated by averaging through width of ligament. Table 1 provides assistance in the determination of the category to which a stress should be assigned in the case of the perforated head or shell.

Table 1 Classification of stress intensity in vessels for perforated head or shell case (originated from Table NB 3217-1 of ASME NB-3200) [1].

Vessel part	Location	Origin of Stress	Type of Stress	Classification
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (averaged through cross section	P_m
			Bending (averaged through width of ligament, but gradient through plate)	P_b
			Peak	F

ASME code defines the limits of stress intensity for design condition A and B, also. S_m (design stress intensity) means 2/3 S_y (yield stress) or 1/3 S_u (ultimate stress). Table 2 summarizes stress categories and limits in the case of level A and level B services. The value of S_m is reported in the ASME, Section II, Part D [2] and terms relating to stress analysis are in Subsection NB-3213. The value of S_m for wrought and cast 304 stainless steel at normal bottom nozzle design temperatures of 600 ℉ is 16,400 psi.

Table 2 Stress categories and limits of stress intensity for level A and level B services (originated from Table NB 3222-1 of ASME NB-3200) [1].

Stress category	Limits of stress intensity for design conditions
P_m	S_m
P_L, $P_L + P_b$	$1.5S_m$
$P_L + P_b + Q$	$3S_m$
$P_L + P_b + Q + F$	S_a

* Pm : general primary membrane stress intensity
PL : local membrane stress intensity
Pb : primary bending stress intensity
Q : secondary membrane plus bending

F : peak stress
S_a : fatigue stress

4. Stress linearization and results

The maximum Tresca stress is appeared as shown in Fig. 2. The stress linearization procedure was conducted around this area. The membrane stress and bending stress could obtain by averaging through cross section, stress classification plane (SCL), but commercial FEM programs like ANSYS and ABAQUS [4], etc. just supply stress linearization function about SCL (stress classification line). So, stress components about 13 SCLs shown as Fig. 3 were obtained and averaged through width of ligament [3]. The principle stresses were calculated by using Mathmatica V3.0. And then the Tresca stress(σ_0) about 3 categories is obtained with Eq. 1. Calculated Tresca stresses are tabulated as Table 3.

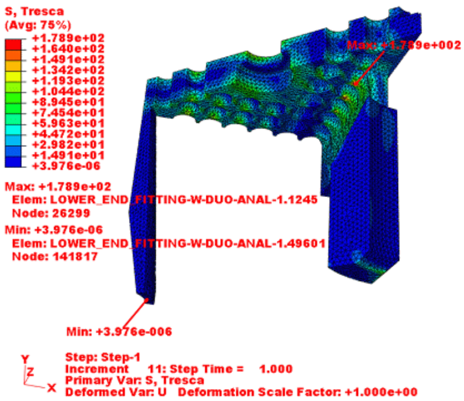

Fig. 2 Tresca stress distribution (unit: MPa).

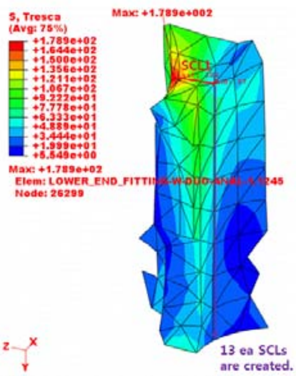

Fig. 3 Stress classification lines for stress linearization.

$$\max\left(\left|\sigma_1-\sigma_2\right|,\left|\sigma_2-\sigma_3\right|,\left|\sigma_3-\sigma_1\right|\right)=\sigma_0 \qquad (1)$$

Here are,
σ_1, σ_2, σ_3 : principle stress

Table 3 Tresca stress for newly designed BEP and stress intensity limits for SUS304 (unit: MPa).

Classification	Tresca stress	Stress intensity limits	Tresca stress/stress intensity limits (%)
P_m	30.27	113.1	26.76
$P_m + P_b$ at point A	44.37	169.7	26.15
$P_m + P_b$ at point B	19.27	169.7	8.96

The ratios of Tresca stress over stress intensity limits are lower than 30 %. That is to say the safety ratio of BEP is about 3.7. Therefore a newly designed bottom end piece of dual cooled fuels satisfies the stress criteria in the case of condition A and B of ASME code.

4. Conclusion

New shapes of flow plates of bottom end piece for a dual cooled fuel assembly were designed to minimize the flow blockage. Because flow holes of newly designed BEP were designed to align exactly with inner/outer flow passages of a dual cooled fuel assembly for cooling the center of fuel rods and the flow holes' area is increased to decrease pressure drop, the robustness of bottom end piece could weaken. So strength evaluation process for BEP is needed and the SAR (safety analysis report) requires that BEP has to satisfy the stress intensity limits in the case of condition A and B of ASME, Section III, Division 1 – Subsection NB. Usually, ASME code uses Tresca stress criterion to do more conservative analysis. In this study, Tresca stress intensity criteria are used. And stress linearization procedure about BEP is conducted for strength evaluation of BEP. Finally the newly designed BEP is enough for stress intensity limits.

ACKNOWLEDGEMENTS

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REFERENCES

[1] The American Society of Mechanical Engineers, "2007 ASME Boiler & Pressure Vessel Code, Section III, Division 1, Subsection NB, Class 1 Components Rules for Construction of Nuclear Facility Components", 2007.
[2] The American Society of Mechanical Engineers, "2007 ASME Boiler & Pressure Vessel Code, Section II, Part D, Properties (Customary) materials", 2007.
[3] Woo-Seok Choi, Tae-Wan Kim and Ki-Seog Seo, Shape Optimization of Perforated Reactor Head Considering a Stress Linearization, Vol 4, pp 22-29, 2008.
[4] H.D. Hibbit, G.I. Karlsson and E.P. Sorensen, ABAQUS Theory Manual (V6.8-1), 2008.