Influence of a Cyclic Events Configuration on a Elevated Temperature Structural Integrity

Chang-Gyu Park[a*], Gyeong-Hoi Koo[a], Jae-Han Lee[a]
[a]*Fast Reactor Technology Development Division, Korea Atomic Energy Research Institute, 1045, Daedeokdaero, Yuseong-gu, Daejeon, 305-353, Korea*
[*]*Corresponding author: chgpark@kaeri.re.kr*

1. Introduction

A nuclear power plant generally undergoes the various types of operating events for a plant life time. The cyclic events for a life time may bring about a structural failure such as fatigue damage. The structures of the LMR(Liquid Metal Reactor) operated in a elevated temperature environment are seriously affected by a thermal deformation and strain. Therefore, the thermal transient condition is a key factor for ensuring the structural integrity for the LMR reactor structures. Since it is not easy to consider the entire operating events at the preliminary or conceptual design stage, the LMR structural integrity is evaluated with representative duty cycle events. In this study, the influence of the elevated temperature structural integrity evaluation per the combination and sequence of the duty cycle events is investigated.

2. Structural Integrity Evaluation for the Elevated Temperature Structure

2.1 ASME Subsection NH

The structural integrity evaluation of ASME Code Class 1 components in a elevated temperature service shall comply with the requirements of the ASME Section III, Subsection NH[1]. The criteria of ASME-NH are divided into the load controlled rules and the strain controlled rules. The strain controlled rules are subdivided into strain limits and a creep-fatigue damage evaluation. The strain limits by a elastic analysis method in Subsection NH restrict the accumulated inelastic strain to 1% or less. The simplified inelastic approach of the elastic analysis method can evaluate the structural integrity less conservatively than the elastic approach. Since the simplified inelastic analysis is too complex, the structural integrity in this study is evaluated by using the SIE ASME-NH program. SIE ASME-NH[2] is a computerized program of ASME Pressure Vessels and Piping Code Section III Subsection NH. SIE ASME-NH can decrease the calculation time and induce an exact calculation compared with a manual calculation.

2.2 Evaluation Model

The target model used in this study is the IHTS hot leg piping of the ABTR(Advanced Burner Test Reactor) system[3]. It is constructed from 40.6cm OD, 1.27cm thick-walled Type 304 stainless steel piping. It is attached to the S-CO_2 and IHX as shown in Fig.1.

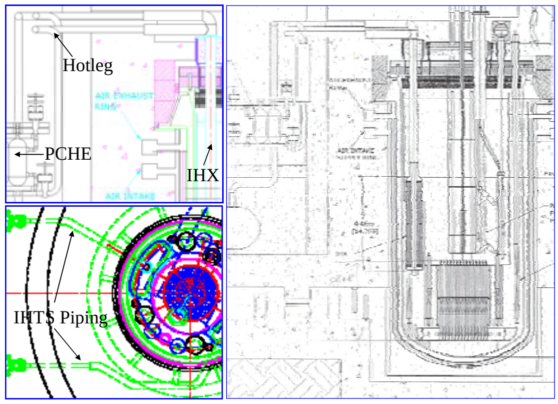

Fig. 1. ABTR IHTS piping.

2.3 Thermal Load Cycle Type

The specified two duty cycle event types for the thermal transient operations in this study are considered as thermal loads as follows.

(a) Cycle type-1(CT-1) : heatup from a hot standby to a full power and a reverse operation with a hold time at a full power operation as shown in Fig. 2.

(b) Cycle type-2(CT-2) : heatup from a refueling to a full power and a reverse operation with a hold time as shown in Fig.3.

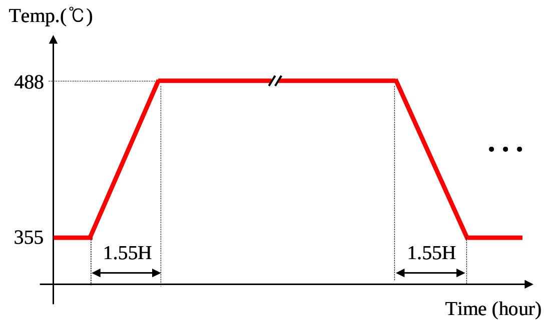

Fig. 2. CT-1 Thermal Load History

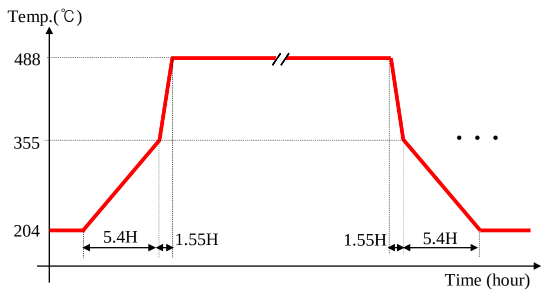

Fig. 3. CT-2 Thermal Load History

2.4 General Assumptions for Analysis

The used heat transfer mechanisms are assumed as follows;

(a) Piping is supported at the IHX and PCHE only and a intermediate support is not applied.

(b) Piping is assumed to be fixed at the components and a piping nozzle analysis is not considered in this preconceptual design.

(c) The linearized transient temperature behavior for a heatup and cooldown operation is assumed.

(d) Coolant temperature is not affected by the piping heat transfer and maintained constant through the whole piping layout

(e) Coolant temperature is the same at a given time

(f) A small heat flux exists from the outer surface of the piping to the surrounding air by a natural convection with a heat transfer coefficient of 1.0W/㎡ · ℃

3. Structural Integrity Influence according to Load Cycle Configuration

The elevated temperature structure is significantly affected by the operating temperature and hold time because of its long-time operation. Since the stress relaxation and creep strain have a time-dependent behavior, the cycle events configuration may effect the structural integrity result. The FE transient heat transfer and stress analysis using ANSYS[4] are carried out to evaluate the structural integrity.

3.1 Events Combination

The assumed number of events in this study are 180, 1080 and the assumed cyclic hold time is 70 hour, 570 hour for CT-1, CT-2 respectively. Case-1 and Case-2 as shown in Fig. 4 are for representing the combined cycle histories for a plant life time with CT-1 and CT-2. Here, the influence according to the events combination is investigated.

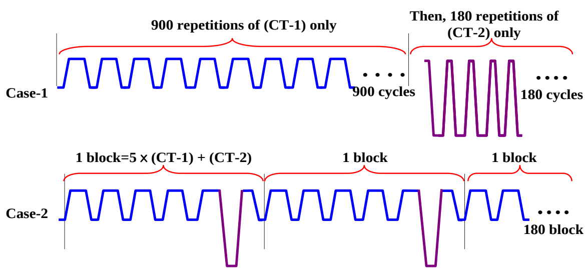

Fig. 4. Load cycle combination

3.2 Events Sequence

The stress intensity ranges of the two events are different and thus the stress behaviors are also following a different time history path. The initial stress intensity may effect the time historic behavior of the elevated temperature structure. CT-1 has a larger stress intensity than CT-2 as an initial value. The influence by the sequence of the events as shown in Fig. 5 is investigated.

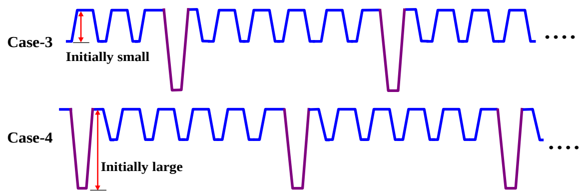

Fig. 5. Load cycle sequence

4. Conclusions

Table 1 shows the structural integrity evaluation results for each case by using the SIE ASME-NH program. In the Table, the stress controlled limits are not shown because those values are maintained constant for a load history. It is found that the initial event has influence on the creep ratcheting strain. That is, initial large event brings about a conservative value and vice versa(Case-3 Vs Case-4). Additionally, the creep-fatigue damage is significantly affected by the configuration of the time-step block in the case of having over-a hundred cycles of event(Case-1 Vs Case-2). The larger time step size induces a very conservative creep damage calculation, though the elapsed time in the case of having a large time step size is decreased remarkably more than that of the small time step size. In conclusion, the structural integrity evaluation needs to be carried out through a precise configuration of the load events since the elevated temperature structures have a time-temperature-dependent behavior and it can change the structural integrity result.

Table 1: Evaluation results for each case

	Creep ratcheting strain	Creep damage	Fatigue damage
Case-1	0.1407	0.8616	0.4465e-3
Case-2	0.1406	0.7561	0.7889e-4
Case-3	0.1406	0.7561	0.7889e-4
Case-4	0.1420	0.7561	0.7889e-4

ACKNOWLEDGEMENTS

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REFERENCES

[1] ASME Boiler and Pressure Vessel Code Section III Division 1 Subsection NH, 2004 Edition, New York, 2004.
[2] G. H. Koo, Computer Program of SIE ASME-NH Code, KAERI/TR-3526/2008.
[3] Y. I. Chang, et. al, Advanced Burner Test Reactor Preconceptual Design Report, ANL-ABR-1, ANL, 2006.
[4] ANSYS User's Manual for Revision 10.0, ANSYS Inc.