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Structural Integrity Evaluation of the KALIMER-600 Reactor Core Support Structure

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1. Introduction

KALIMER-600(Korea Advanced LIquid MEtal Reactor, 600MWe)[1] is a pool type sodium-cooled liquid metal reactor. Since the normal operating temperature of KALIMER-600 is 545°C, the reactor structures in the hot pool region are designed and evaluated according to the elevated temperature design rules such as the ASME Boiler and Pressure Vessel Code Section III, Subsection NH[2]. Since the core support structure of KALIMER-600 is in the cold pool region under 400°C, a high temperature inelastic behavior is not expected. Thus the stress and fatigue limits are the main concerns to assure the structural design integrity following the ASME Subsection NG.

In this paper, the evaluations of the stress and fatigue damage for the core support structure of KALIMER-600 are carrried out in the case of a normal operation condition using the rules of ASME Subsection NG[3]. To obtain the stress values, a heat transfer analysis and a stress analysis under a combined loading condition are performed. From the stress distribution results, the critical sections are selected and the stress and fatigue limits are evaluated for the selected regions.

2. Core Support Structure

2.1 Design Feature

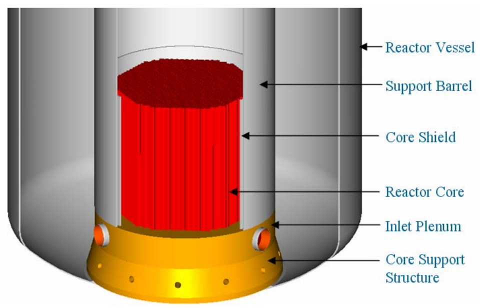

Figure 1. Schematic Drawing of Core Support Structure

The core support structure provides the restraint of the reactor core assemblies necessary to maintain them in their geometry during all modes of reactor operations and to transfer the weight loads of the reactor internal structures to the reactor vessel(RV).

The core support structure of KALIMER-600 is the detached type as shown in Fig.1 and it adapts a very simple design concept and fabrication procedure. The holds are prepared to allow for primary sodium flows through the skirt strucrure. The core support structure is a single piece of forging with the lower grid plate of the inlet plenum and fabricated in the inlet plenum side cylinder by welded webs. The core support structure is resting on the RV core support pad which is a integrated forging with the RV bottom head. This detached core support structure from the RV core support pad eliminates the excessive thermal stresses caused by the difference of the thermal expansions, and has an advantage of an ISI by eliminating the welding parts. The core support structure is made of 316 SS and the inner radius, height and maximum thickness are 285.5cm, 85.0cm, 23.0cm, respectively.

2.2 Steady State Stress Analysis

The radial and axial thermal gradients of the core support structure in the cold pool region which includes the inlet plenum, the support barrel and the reactor vessel are calculated using the ANSYS[4] finite element analysis software for a normal operation applying an axisymmetric analysis model. Fig.2 shows the calculated temperature distribution of the core support structure including the reactor vessel and the inlet plenum. The cold pool region temperature is about 390°C and the temperature difference between the inner surface and the outer surface of the RV is about 60°C. The maximum temperatue region is the central part of the inlet plenum upper grid plate.

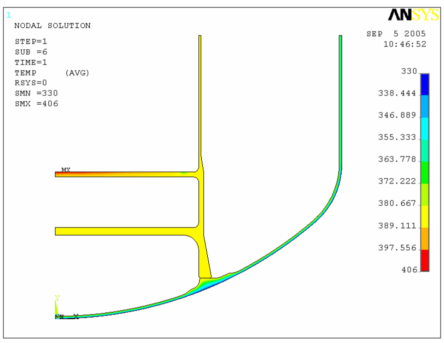

Figure 2. Temperature Distribution

The stress distribution results are obtained with the combined thermal gradient and mechanical loadings. The thermal gradient can be obtained by the heat transfer analysis result and the mechanical loadings are composed of the structural dead weight and the sodium weight. The structural dead weight applied to the core support structure is the sum of the internal structures including the support barrel, inlet plenum, core, core shield, reactor baffle structure and the baffle plate. The sodium weight is distributed to the inner surface of the RV as a pressure. The contact elements are applied between the core support structure and the RV core support pad. Fig.3 shows the stress distribution result of the core support structure including the RV for a normal operation. The significant stresses occurred at the part of the RV core support pad.

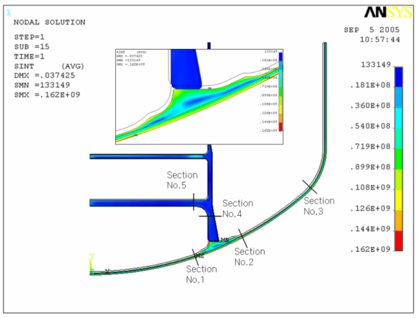

Figure 3. FE analysis result

3. Structural Integrity Evaluation

3.1 Stress Limits

The Level A and B Service Limits of the ASME Subsection NG should be satisfied as follows.

Primary Membrane Stress Intensity :

$$P_m \le S_m \tag{1}$$

Primary Membrane plus Bending Stress Intensity :

$$P_m + P_b \le 1.5 S_m \tag{2}$$

Primary plus Secondary Stress Intensity :

$$P_m + P_b + Q \le 3 S_m \tag{3}$$

where, S_m is the design stress intensity value which is given in ASME Section II, Part D for a core support structure material.

From the stress analysis result, the critical sections for evaluating the structural integrity by the ASME design code are selected as showin in Fig.3. Table 1 shows the evaluation results at each section. From the Table 1, the stresses of these sections satisfy the rules of the service limits with enough margins.

Table 1. Stress limit checks (MPa)

Section No.	$P_m \le S_m$		$P_m + P_b \le 1.5S_m$		$P_m + P_b + Q \le 3S_m$	
	P_m	S_m	$P_m + P_b$	$1.5S_m$	$P_m + P_b + Q$	$3S_m$
No.1	14.9	115.1	15.1	172.5	161.4	345.3
No.2	16.4	115.1	17.0	172.5	142.4	345.3
No.3	34.7	115.1	36.5	172.5	125.6	345.3
No.4	8.8	112.4	10.8	169.5	12.7	337.2
No.5	12.8	112.4	17.0	169.5	17.0	337.2

3.2 Fatigue Damage Analysis

The fatigue damage should be satisfied by the cummulative usage factor as shown in Eq.(4).

$$U = \sum_{i=1} U_i = \sum_{i=1} \frac{n_i}{N_i} < 1.0 \tag{4}$$

where, n_i is the specifiecd number of repetitions and N_i is the maximum number of repetitions which can be obtained from the design fatigue curve during its life time.

In this study, we consider the cyclic loading inducing the fatigue damage which is caused by the thermal load from the hot standby to the steady state operation. The total service life of the KALIMER-600 reactor is 60 years and the refueling interval is minimum 18 months. Therefore, the number of fatigue cycles by considering the reactor operation with a 50% margin is $n = 60$ during the reactor life time. N is obtain by applying the alternating stress intensity value(S_{alt}) which is a half of the maximum principal stress range for the stress cycle to the applicable design curve of ASME Figure I-9.0[5].

From the stress analysis results, the cummulative usage factors at each section are almost zero. So we can say that the fatigue damage for the refueling load of the KALIMER-600 is negligible.

4. Conclusion

In this paper, the structural integrity evaluation for the KALIMER-600 core support structure was carried out using the ASME Subsection NG.

The temperature distribution of the core support structure was calculated first and the stress distribution was calculated by considering the combined loading condition. To confirm the structural integrity, the stress limits and the fatigue damage were assessed for the critical sections. From the stress results, all the sections satisfied the rules of the service limits and a significant fatigue damage did not occur for the refueling load. So the core support structure including the RV bottom head maintains enough structural integrity for the refueling load of a normal operation.

Future efforts will be concentrated on a structural integrity assessment for all kinds of transient events including the Level D Service Limits.

ACKNOWLEDGMENTS

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