

Stresses Imposed by Coolant Channel End Shield Interaction in 200 MWe PHWR

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Summary

End shield of 200 MWe Pressurised Heavy Water Reactor (PHWR) is a composite tube sheet structure consisting of two circular tube sheets joined together by lattice tubes. Each lattice tube houses a coolant channel assembly which is connected to the end shield through shock absorber device. End shield assembly is suspended in the vault by hanger rods and its horizontal position is controlled by a set of pre-compressed springs. Coolant channel assemblies elongate due to their exposure to fast neutron flux in the reactor. This permanent elongation is monitored periodically. When growth of the channel exceeds a preset value, it is prevented from further elongation by the shock absorbing device. Resultant force exerted on the end shield makes it move. This paper describes a numerical method used for evaluating these forces and movement of the end shield. Stresses produced by these forces are calculated by using finite element method. Typical stress values are verified by strain gauge measurements.

1. Introduction

Core of Pressurised Heavy Water Reactor (PHWR) is contained in a stainless steel calandria. Each side of the calandria has an end shield. An end shield assembly consists of two tube sheets connected to each other with lattice tubes. End shield assembly is suspended in the vault by hanger rods and its horizontal position is controlled by a set of pre-compressed springs (Fig.1). Fuel is placed in zircaloy pressure tubes which are rolled on end fittings. End fittings are supported on the lattice tubes of end shield. Zircaloy pressure tubes undergo creep which is enhanced by fast neutron flux. When resulting elongation of the pressure tubes exceeds a preset value, its motion is arrested by shock absorber device. Force then produced causes rotation and linear movement of the end shield (See figure 2). A numerical scheme is described in this paper to determine these forces and associated movement.

The paper also outlines stress analysis of the end shield. The tube sheets are considered as equivalent solid plates which are discretised into plate elements joined together by beam elements at lattice locations. Peak stresses are found by using suitable multiplication factors found by photoelastic and finite element methods. Some typical results of theoretical analysis are verified by strain gauge measurements.

2. Mathematical Modelling

2.1 Creep Laws

Laws governing creep rate ($\dot{\epsilon}_c$) and growth rate ($\dot{\epsilon}_g$) have been studied on similar materials and geometries [1-5]. They are expressed by the following equations.

$$\dot{\epsilon}_c = \left(B\sigma + \frac{Cf}{a_0} \right) \phi \quad (1)$$

$$\dot{\epsilon}_g = \left(A\tau e^{-t\phi/\tau} + G \right) \phi \quad (2)$$

Where B, C, G are texture related constants; A, τ are transient material constants; ϕ is fast neutron flux ($E > 1$ Mev); t is time; σ is hoop stress

due to internal pressure; f is axial force resulting from interaction of pressure tube with end shield; a_0 is cross sectional area of pressure tube.

Elongation of coolant channels is measured periodically at reactor site. Material constants were obtained by fitting the results of numerical analysis in these measurements. Material constants published earlier [1] were used as guidelines.

2.2 Pressure Tube and End shield Interaction

Pressure tube freely elongates through a preset value ($=\bar{x}_{LIM}$). If creep growth exceeds this value, the pressure tube exerts a force f on the end shield making it rotate through an angle θ . Thus for a given pressure tube

$$\dot{x}_e + \dot{x}_g + \dot{x}_c = 2 \bar{x} \dot{\theta} \quad (3)$$

Where \bar{x} is the co-ordinate of a channel with respect to horizontal axis of the end shield assembly. \dot{x} denotes the pressure tube elongation rate. Subscripts e, c, g denote the elastic, creep and irradiation induced growth components respectively. It may be noted that symmetry of structure about vertical axis permits only this rotation. If total force acting on the end shield exceeds pre-compression imposed on it, end shield moves through a distance δ which is controlled by stiffness of springs holding end shield in position. Thus for a given pressure tube

$$\dot{x}_e + \dot{x}_c + \dot{x}_g = 2 (\delta + \bar{x} \dot{\theta}) \quad (4)$$

Set of equations (3) and (4) can be written for each channel. They along with equilibrium equations for the end shield define the problem completely. Equilibrium equation may be expressed by

$$\begin{aligned} -\sum f &= \delta KN_t + P_c \\ -\sum fz &= K \sum z_t^2 \theta \end{aligned} \quad (5)$$

Where N_t is the number of tilt control keys holding end shield in position. K and P_c are spring stiffness and pre-compression on tilt control keys respectively. z_t is co-ordinate of tilt control key with respect to horizontal axis of end shield. Summation on left hand side of equations (5) is done for all channels and on right hand side for all springs.

Integration of equations (3) through (5) is carried out by finite difference method. This scheme is rather simple compared to methods used by other authors [1-3]. A small time step is needed for satisfactory results. Pressure tubes make contact with end shield at different times which depends on fast neutron flux at their location. It is possible that such a contact is made during a time interval chosen for finite difference scheme. An adjustment of time step may be called, therefore. However, if time step is so small as to give negligible growth of pressure tube, such an adjustment may not be necessary.

3. Stress Analysis

Since force exerted by the pressure tube is symmetric about vertical axis, one half of the end shield assembly can be used for stress analysis. Nominal stresses are found by equivalent plate method. Peak stresses are obtained by using multiplying factors obtained by experimental and theoretical analysis.

3.1 Calculation of Nominal Stresses

For the purpose of this analysis the perforated tube sheets are replaced by equivalent orthotropic plates [4,5]. Elastic constants are assumed to be same for both plane stress and bending problems. The equivalent plates are discretised into thin plate/shell elements for use with computer program SAP4 [6]. The lattice tubes are idealised as beam elements. Figure 3 shows the discretisation used for analysis. Calandria side tube sheet, when deformed under load exerted by pressure tubes, touches the baffles (see figure 1). The support points depend on amount of deflection. The analysis^{is} therefore, done in steps taking proper cognizance of change of support points.

3.2 Calculation of Peak Stresses

Peak stresses can be obtained from nominal stresses by using stress multipliers. Since tube sheets and lattice tubes are joined by partial penetration welds, it is not possible to use published data. Stress multipliers were determined by a combination of photoelastic technique and finite element method [7]. Table 1 shows the stress multiplier values, for in-plane and bending loads.

3.3 Experimental Verification of stresses

The method of stress analysis is based on many assumptions. In order to

verify the results, a 1:10 scale model was made. It was subjected to internal pressure and strain gauges used to monitor deformation at some typical locations. Details are given in ref. [7].

4. Results

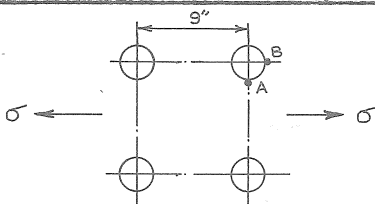
Material constants and other parameters used for analysis are given in Table 2. Error is limited to ± 30 percent for approximately 80 percent of observations. Highest flux channel makes contact with end shield after approximately 17600 full power hours of operation. End shield moves linearly after 19600 full power hours of operation. As seen from figure 4, force in a pressure tube increases rapidly till it starts moving, beyond which total force is controlled by stiffness of springs (figure 5). Figure 6 shows deflection and rotation of end shield. Nominal stress intensity due to arrested movement of pressure tubes is maximum near the centre of end shield and is approximately equal to 14.8 MN/m^2 .

5. References

- [1] Causey, A.R., McEwen, S.R., Jamieson, H.C. Mitchell, A.B., Analysis of Pressure Tube Elongation and End Shield Interactions in CANDU Reactors, Proceedings Fifth Intl. conf. on Structural Mechanics in Reactor Technology, August 1979, Paper F 1/2.
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- [4] Slot, T., O'Donnell, W.J., Effective Elastic constant for Thick Perforated Plates with Square and Triangular Penetration Patterns, First National Congress on Pressure Vessels and Piping, San Francisco, Calif, May 1971.
- [5] Meijers P., Plates with a Doubly-Periodic Pattern of Circular Holes Loaded in Plane stress or Bending, First Int. Conf. on Pressure Vessel Technology, Delft, Sept⁹, Oct, 1979.
- [6] Bathe, K.J., Wilson, E.L. and Peterson, F.E., SAP IV : A Structural Analysis Program for Static and Dynamic Analysis of linear systems. Univ. of California, June 1975.
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Table 1

Stress Multipliers for Different Loads.



Type of Load	Point	Stress Multiplier	Determined by
Tension	A	4.6	FEM and photoelasticity.
	B	-0.07	
Bending	A	5.3	Photoelasticity
	B	4.1	
Pure shear	A or B	6.57	Photoelasticity

Table 2

Constants used in Analysis

B	0.67×10^{-28}	t in hours
C	0.122×10^{-19}	$\dot{\rho}$ in m^2/s
G	0.56×10^{-24}	a_0 in mm^2
A	0.94×10^{-24}	σ in MPa
τ	0.10×10^{22}	

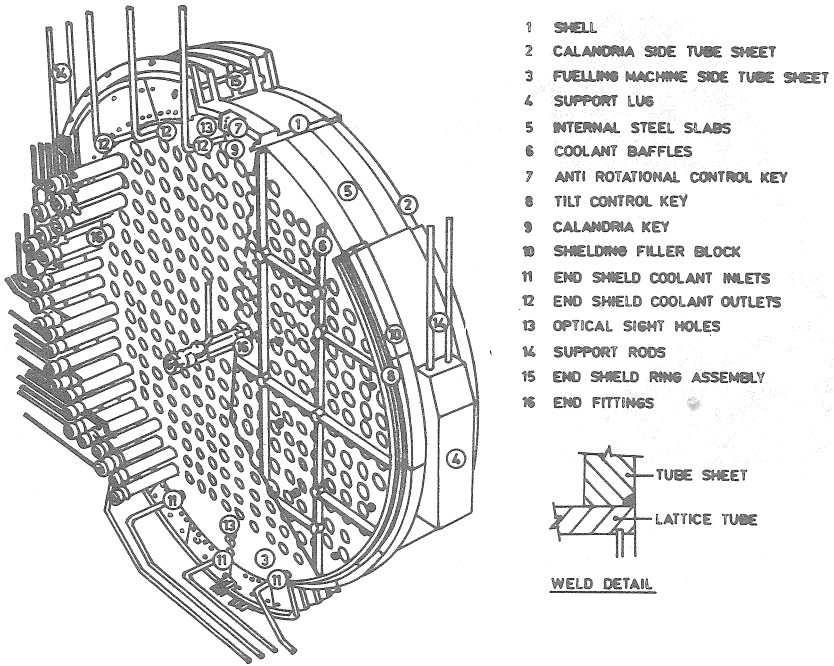


FIG.1 END SHIELD OF A TYPICAL 200MWe PHWR

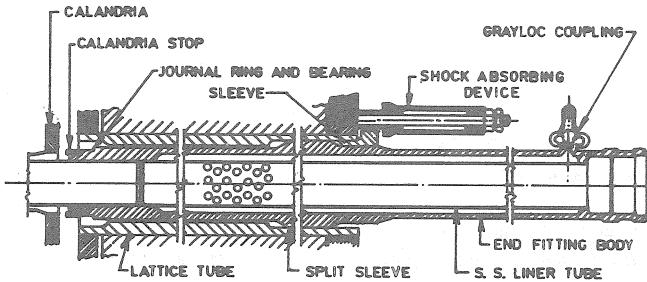


FIG.2 GENERAL LAYOUT OF COOLANT CHANNEL, END FITTING AND SHOCK ABSORBING DEVICE

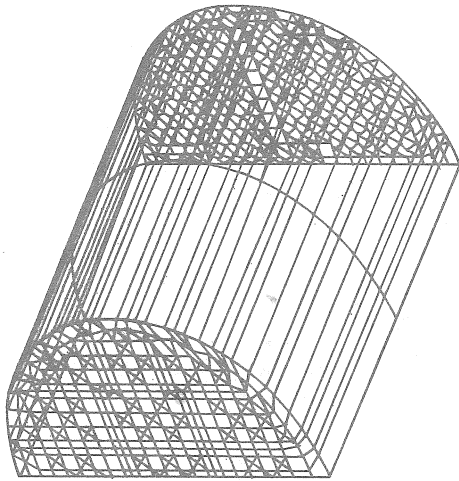


FIG. 3. FEM MESH USED FOR FINDING STRESSES DUE TO CREEP LOAD (LATTICE TUBES ARE NOT SHOWN HERE)

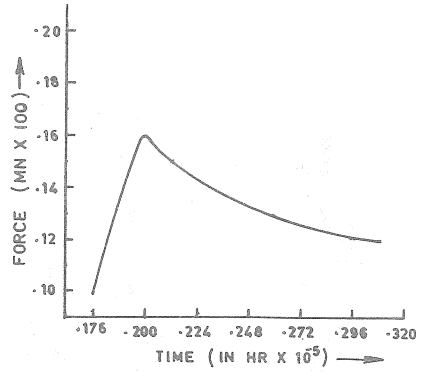


FIG. 4. FORCE ACTING ON CHANNEL L-11 (WHICH SEES MAXIMUM FLUX) AS A FUNCTION OF TIME

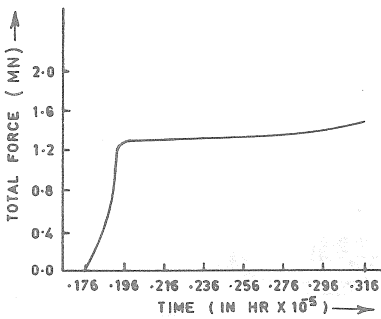


FIG. 5. TOTAL FORCE ACTING ON END SHIELD AS A FUNCTION OF TIME.

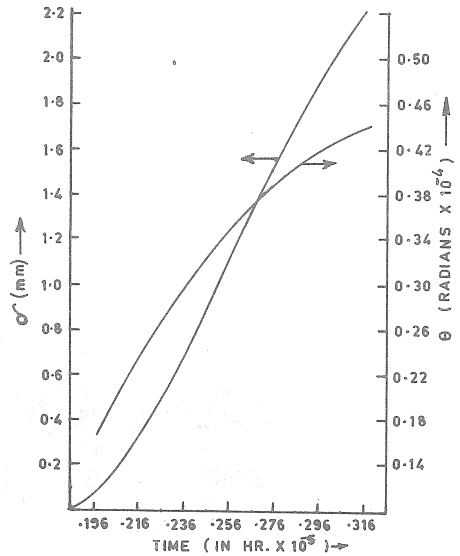


FIG. 6. DEFLECTION & ROTATION OF END SHIELD AS A FUNCTION OF TIME