Fatigue Cycle Evaluation of Endplate of 235 MWe PHWR Fuel Bundle

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ABSTRACT

In the fuel bundles of Indian PHWRs, the differential thermal expansion of pins leads to loading of the endplate. The varying axial gap between the pellets in different pins affects the pin expansion. Thus the startup and shutdown of the reactor causes variation in the stresses. Detailed analysis of endplate is carried out to estimate allowable fatigue cycles assuming statistical distribution of axial gaps.

1 INTRODUCTION

In the Indian PHWRs, fuel is in the form of bundles. Each bundle consists of 19 fuel pins arranged in two concentric rings of six and twelve pins around a central pin. The pellets are arranged axially and are surrounded by zircaloy-2 cladding to form a fuel pin. Fuel pins are kept in the form of cluster by the help of two zircaloy endplates. Differential temperature generated between the pins during the operation of the reactor. The net thermal expansion of each pin depends on the temperature of pellets and total axial gap between the pellets. The differential thermal expansion of the pins may lead to stresses in the endplate. These stresses vary with the startup and shutdown of the reactor. Detailed analysis of endplate is thus important to estimate allowable fatigue cycles.

2 GEOMETRY AND MATERIAL PROPERTIES

Fig. 1 shows the geometry of endplate with fuel pins. Thickness of the endplate is 1.57mm. The schematic diagram of fuel pellet with cladding is shown in Fig. 2. The length of one fuel pin is 493.0mm. Each pin consists of 28 pellets and total axial gap between pellets varies from 1.2 to 3.8mm. The material properties for UO_2 and cladding are taken from literature (Reymann 1978).

3 ANALYSIS OF PELLETS

Finite element model of pellet was prepared by using 160 four-noded axisymmetric elements and 189 nodes. The model is shown in Figure 3. Volumetric heat generation for outer, intermediate and central fuel pins were taken as 315, 259 and 236 W/cm^3 respectively. This combination of heat generation is expected to generate the maximum differential temperatures between the fuel pins of a bundle. Analysis was done for each pellet separately. Gap conductance and convective heat transfer coefficient from clad to fluid are 1.02 W/cm^2-°K and 5.31 W/cm^2-°K respectively. The finite element computer code WELTEM (Dutta et al. 1981) was used. Table 1 shows the computed salient temperatures. Thermal expansion was calculated for each pellet by using computed temperatures. Two dimensional finite element computer code PLAXIS (Burgohain 1977) was used. Table 2 shows the axial length of fuel pellets after the thermal expansion.

Table 1. Temperature(K) at different locations of fuel pins.

Locations	Centre pin	Intermediate pin	Outer pin
Fuel centre	1572.7	1712.3	2105.7
Fuel shoulder point	723.0	741.3	789.2
Fuel surface	656.6	667.1	694.0
Clad surface	558.8	560.2	563.8

Table 2. Axial lengths after thermal expansion of fuel pellet

Pellet locations	Axial length (mm) at the		
	Centre	Shoulder point	Outer diameter
Central pin	17.2596	17.6182	17.6101
Intermediate pin	17.2980	17.6292	17.6194
Outer pin	17.4306	17.6527	17.6380

4 ANALYSIS OF ENDPLATE

4.1 Calculation of differential displacements

The differential displacements experienced by the endplate depend on thermal expansion of fuel pellets and axial gap between the pellets. The total thermal expansion of all pellets is 2.81, 3.12, 3.77 mm for centre, intermediate and outer pin respectively.The axial gap between the pellets may vary between 1.2 to 3.8 mm. The axial gap between the pellets was subtracted from the total thermal expansion of all the pellets to obtain change in the distance between the two endplates at that location of fuel pin. This was calculated for all the 19 fuel pins of a bundle. The stiffness of both the endplates of a bundle are assumed to be identical. So the endplate of one side experiences half the displacement of the net expansion of fuel pin. Differential displacements were calculated from these data.

4.2 Computation of strains

Half of the endplate was modelled due to symmetricity in the geometry. There were 313 plate bending elements and 459 nodes. Each node has 6 degrees of freedom (three displacements and three rotations). Fig. 4 shows the finite element mesh. The model was analysed for differential displacements, which were obtained from the thermal expansions of the fuel pins. Eight different combinations of statistical distribution of axial gaps have been assumed. The gap is assumed to be constant for all the fuel pins lying in one ring. Table 3 shows the assumed distribution of gaps and corresponding net differential displacements. Computer code NISA was used. Strains were computed for all the elements. Two types of boundary conditions have been used at the locations where the fuel caps are welded with the endplate. In the first condition the endplate was allowed to rotate at that location whereas in the second case these rotations were not allowed.

4.3 Fatigue cycle evaluation

The computed strains were used to calculate principal strains. The maximum principal strains were used to calculate number of fatigue cycles using the relations given in literature (O'Donnell et al. 1964). The conservative results are obtained when nodes on endplate are assumed to be fixed at the locations of fuel pins. The allowable cycles for all the combinations of thermal expansions are shown in Table 3 for this case. The minimum value of fatigue cycles is 120.

5 DISCUSSION

Conservatively an endplate is expected to see about 100 fatigue cycles during its stay in reactor core. Present calculation shows that the minimum allowable fatigue cycles is 120. Some of the conservatisms in the analysis are the use of extreme axial gap values between the pellets, the assumption of fixity condition at the location of fuel pins, the use of irradiated material fatigue data and the assumption of unyielding pellets. While this shows the adequacy in design of endplate from fatigue cycle consideration there is scope for futher refinement of analysis and realisation of greater power cycling capability.

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Table 3. Fatigue cycle evaluation procedure for endplate

Case		Centre pin	Intermediate pin	Outer pin	Max. principal strain, ϵ_t	$E\epsilon_t/2$ (Kg/mm^2)	Fatigue cycle
	A	1.2	1.2	1.2			
1	B	1.6125	1.9201	2.5761	.5832E-02	11.991	3000000
	C	0.8062	0.9601	1.2880			
	A	3.8	3.8	3.8			
2	B	0.0	0.0	0.0	.000	0.00	-
	C	0.0	0.0	0.0			
	A	1.2	1.2	3.8			
3	B	1.6125	1.9201	0.0	.1779E-02	36.583	1300
	C	0.8062	0.9601	0.0			
	A	1.2	3.8	3.8			
4	B	1.6125	0.0	0.0	.2871E-02	59.031	230
	C	0.8062	0.0	0.0			
	A	1.2	3.8	1.2			
5	B	1.6125	0.0	2.5761	.3403E-02	69.975	160
	C	0.8062	0.0	1.2880			
	A	3.8	1.2	3.8			
6	B	0.0	1.9201	0.0	.3815E-02	78.450	120
	C	0.0	0.9601	0.0			
	A	3.8	1.2	1.2			
7	B	0.0	1.9201	2.5761	.3283E-02	67.507	170
	C	0.0	0.9601	1.2880			
	A	3.8	3.8	1.2			
8	B	0.0	0.0	2.5761	.2362E-02	48.571	450
	C	0.0	0.0	1.2880			

* A=Axial gap between pellets (mm).
B=Total differential displacement (mm).
C=Differential displacement for one endplate (mm).

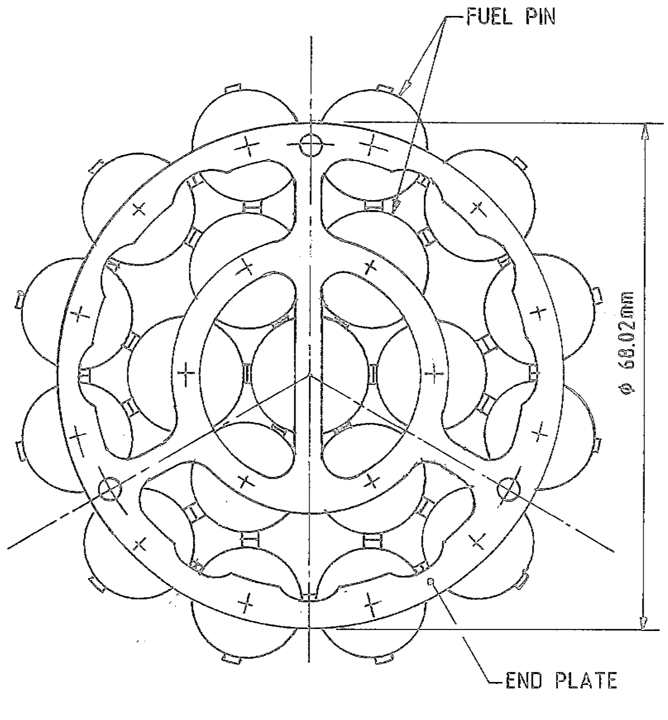

FIG. 1 DETAILS OF END PLATE OF 235MWe PHWR FUEL BUNDLE.

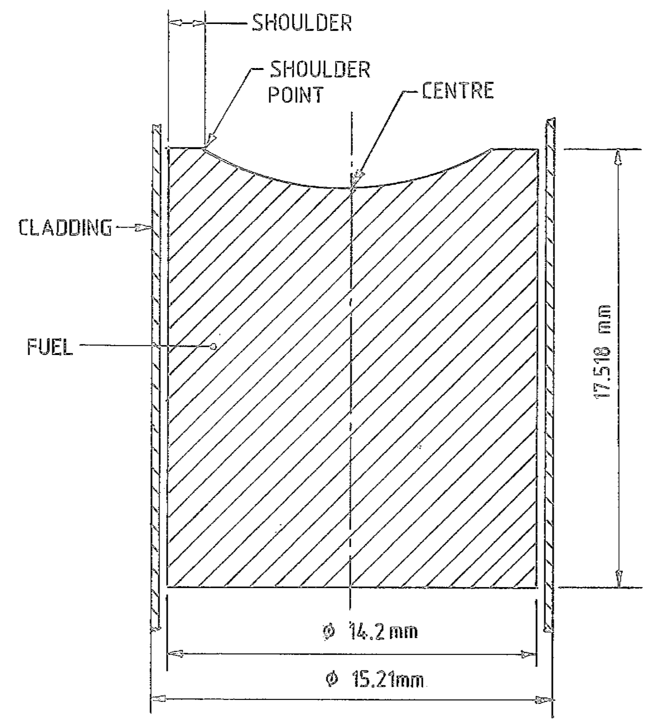

FIG. 2 SCHEMATIC DIAGRAM OF FUEL PELLET OF 235 MWe PHWR.

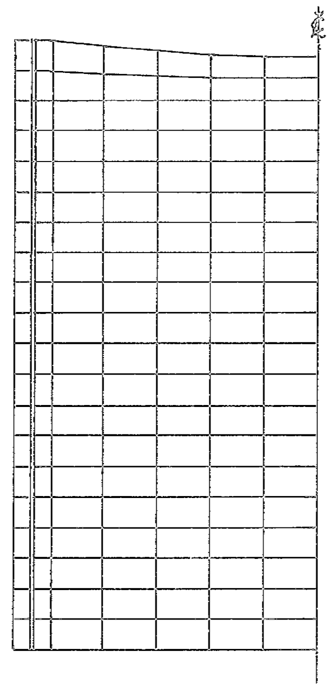

FIG. 3 AXISYMMETRIC FINITE ELEMENT MESH OF FUEL PELLET

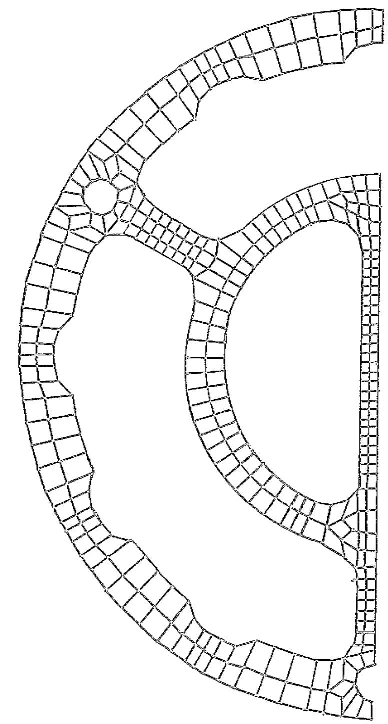

FIG. 4 FINITE ELEMENT MESH OF END PLATE