Fatigue Analysis of End Fitting Body of PHWR

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Abstract

The inlet and outlet of reactor coolant channel of pressurized heavy water reactor (PHWR) is connected to primary heat transport system piping by endfitting and associated hardware.Apart from different reactor transients,the component is subjected to thermal shock due to relatively colder heavy water injection during refuelling operation.The heavy water temperature injected in the endfitting body has been proposed to be changed from 93.3^{0}C to 23.3^{0}C to simplify refuelling operation.The present work has been done to assess the fatige behavior of the componenet in the new refuelling mode.The whole transient phenomenon has been divided in three phases. Phase one transient is caused by natural convection cooling of hot endfitting by heavy water which is at 23.3^{0}C.Phase two considers the transients caused by high velocity flow of heavy water in the endfitting when the seal disc is retracted back.In phase three, transient analysis has been done when the pressure of the entrapped heavy water is reduced to atmospheric value.

1. Introduction

The inlet and outlet of reactor coolant channel of a typical 235 MWe PHWR is connected to primary heat transport system piping by endfitting body and associated hardware as shwon in Fig.1.This component made of martensitic stainless steel grade 403 is subjected to internal pressure and thermal load due to hot pressurized heavy water coolant flowing through it.Besides there are also thermal shocks caused by differnt reactor transients.Another kind of thermal shock is caused by comparatively lower temperature heavy water injected during refuelling operation.The three phases of transients which have been considered in the analysis are as follows:

Phase one transient is caused by natural convection coolings of hot endfitting body(293^{0}C)by entrapped heavy water near the fuelling machine end.This causes transient thermal stresses at the location where the sealing plate makes contact with endfitting.In this case,about 0.5Kg of heavy water is trapped at various locations past the sealing plate.Out of 0.5Kg of heavy water, 0.25Kg cools the inside surface of endfitting body.This water is trapped in the annulas between endfitting body and seal plug.This phase continues for six minutes.Phase two transient is caused when the sealing plate is retracted back.This causes high velocity flow of heavy water in the annulas near the lip of endfitting body where the sealing plate was in contact.This phase continues for fifty minutes in which refuelling of channel is completed.After the refuelling is over the sealing plate is again put in position.Nearly eight minutes after phase two the pressure is brought to atmospheric condition and then fueling machine is disconnected.The cooling caused by phase change again induces thermal stresses.This is phase three transient condition.

2. FEM model

Two finite element models have been used for analysis.Model one used for thermal analysis has 793 elements and 937 nodes.This uses four noded isoparametric ring elements(Fig.2).Model two used for stress analysis is same as model one(with 793 elements),but it uses eight noded isoparametric ring elements.So number of nodes in this case is 2666.The temperature field obtained on model one is converted to suit model two by averaging the corner node temperatures to obtain midside node temperatures using shape functions.This helps to minimise memory and computer time required for transient temperature field analysis.Use of parabolic element for stress analysis ensures accuracy of peak stresses at sharp corners,lips etc.which is important from fatigue point of view.The geometry considered for analysis includes portion of endfitting body from fuelling machine to portion slightly away from feeder nozzles.Thus the geometry includes detailed contours of lips where the sealing plate makes contact.The feeder nozzle has been replaced by metal having thickness equal to the surrounding.This assumption will not affect the thermal stress in the region of interest.The boundary condition towards the calandria side has been applied by specifying displacement values obtained from earlier work/1/.In that work two dimensional eight noded isoparametric elements have been used through out the structure.The total number of nodes and elements are 1622 and 921 respectively.The computer program used for transient temprature analysis gives due consideration for temperature rise of entrapped water .Each time new temperature of heavy water is calculated with the flux obtained from earlier time step.New heat transfer coefficients are also set up for convective edges.This way transient behavior of heating of trapped water is accounted.

3. Results

In phase one transient maximum temperature difference across the sealing plate contact location is observed after 2.8 seconds of water injection.Similerly the component sees maximum temperature difference at the same location after 2.7 seconds and 3.8 seconds in phase two and three respectively.Temperature distribution at this section with respect to time for a typical phase is shown in fig.3. Stress intensities at different elements for this section are shwon in table#I for all the three phases.For fatigue life assessment sixty number of refuelling cycles are expected.Table#II shows the maximum alternating stress intensity for three phases obtained from above analysis.It may be observed that for phase one and three the usage factor are insignifiacnt.Usage factor for phase two is 0.002.So cumulative usage factor for new refuelling mode is 0.002.

4. Conclusions

It is concluded from above analysis that phase two transient is more severe than phase one and phase three.The maximum stress intensity for pressure and thermal load is 582.59 Mpa in phase two,which exceeds 3Sm limit/3/.The simplified elastic plastic analysis according to ASME section III/2/shows that 3Sm limit on membrane secondary stress is met.Phase one and phase three are not significant as they do not contribute to the cumulative usage factor.The cumulative usage factor in the new refuelling mode is 0.002.The pressure stresses are considered only in phase one as it remain constant in phase two and three.Thermal stress intensities caused by differnt reactor transients are also insignificant/3/.So they will also not contribute to the cumulative usage factor.The seal plate contact location is highly stressed due to sealing forces and thermal transient.It is felt that effort must be directed towards better inspection of seal surface at this location.

5. Reference

/1/ P.S.Bandyopadhyay,B.Murali and H.S.Kushwaha-"Axi-symmetric stress analysis of endfitting body of pressurized heavy water reactor".-An internal unpublished report,R.E.D.,B.A.R.C.,Bombay-400085,India.

/2/ASME B&PV Code section III,Division1-subsection NB and Section III Appendices,1977 American Society of Mechanical Engineers.

/3/Design Manual RAPP-31100,Coolant channel assemblies,DAE,RAPP,Anushakti,India.

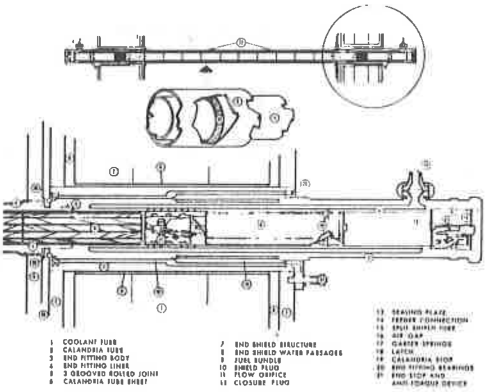
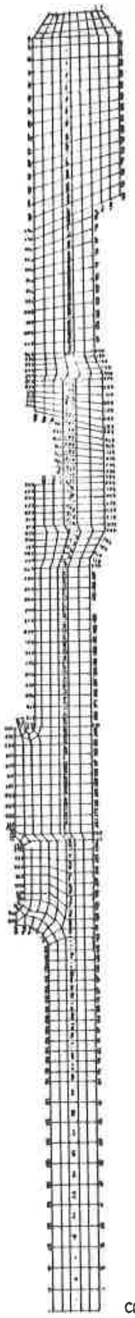


FIG.1

ENDFITTING BODY AND

ASSOCIATED HARDWARE



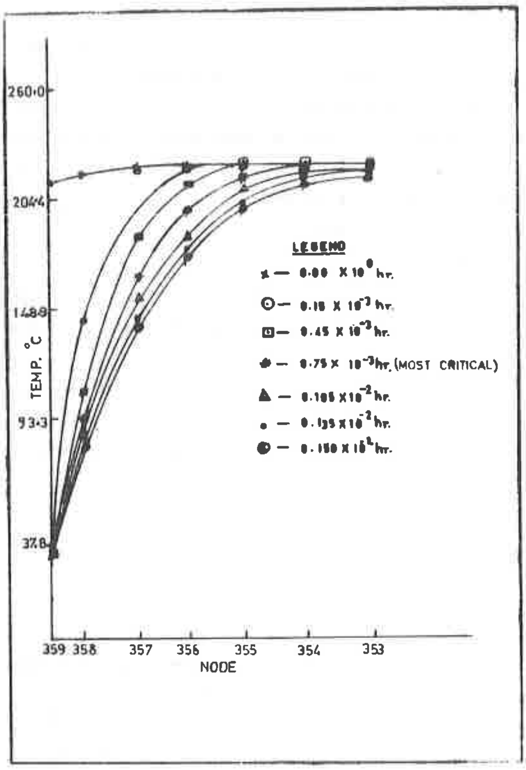


FIG.3: PHASE TWO
TEMPERATURE DISTRIBUTION AT SECTION
(NODE: 353-359) WITH RESPECT TO TIME

FIG.2, MODEL ONE
FINITE ELEMENT DISCRETIZATION OF
ENDFITTING BODY FOR THERMAL ANALYSIS
TYPE OF ELEMENT: TWO DIMENSIONAL FOUR NODED
AXI-SYMMETRIC ELEMENTS
TOTAL NO. OF NODES: 937
TOTAL NO. OF ELEMENTS: 793

SIMPLIFIED ELASTIC PLASTIC ANALYSIS FOR PHASE-2

σ_θ=HOOP STRESS , σ_r=RADIAL STRESS , σ_z=LONGITUDINAL STRESS , σ_{rz}=SHEAR STRESS,

$\sigma_{1,2}$=PRINCIPAL STRESSES, SI=STRESS INTENSITY

1. Element no.	2. Gauss point no.	3. Thermal+ Pressure stresses (MPa)	4. Pressure stresses (MPa)	5. Thermal stresses (3)-(4) (MPa)	6. Membrane part of thermal stresses (MPa)	7. Range of membrane part of sec.stresses (MPa)
317	3	σ_r = 0.869 σ_z =-151.32 σ_{rz}=-1.0750 σ_θ=-71.402	σ_r =-0.183 σ_z = 1.250 σ_{rz}= 0.577 σ_θ= 24.2	σ_r = 1.053 σ_z =-152.57 σ_{rz}=-1.65 σ_θ=-95.6	$(\sigma_{317}+\sigma_{322})/2$ σ_r= 2.3445 σ_z= 125.40 σ_{rz}=-0.5990 σ_θ= -24.130	σ_θ=-24.13 σ_1= 125.4 σ_2= 2.34 SI= 149.62
322	2	σ_r =-7.05 σ_z = 427.45 σ_{rz}= 1.434 σ_θ= 85.74	σ_r =-10.69 σ_z = 24.06 σ_{rz}= 0.979 σ_θ= 38.4	σ_r = 3.64 σ_z = 403.38 σ_{rz}= 0.455 σ_θ= 47.34		
305	3	σ_r = 1.065 σ_z =-132.6 σ_{rz}=-3.892 σ_θ=-64.39	σ_r =-0.181 σ_z =-3.76 σ_{rz}= 0.352 σ_θ= 22.06	σ_r = 1.246 σ_z =-128.8 σ_{rz}=-4.24 σ_θ=-86.46	$(\sigma_{305}+\sigma_{310})/2$ σ_r= 14.15 σ_z= 173.92 σ_{rz}= 25.33 σ_θ= 211.91	σ_θ= 211.67 σ_1= 177.88 σ_2= 10.204 SI= 201.33
310	2	σ_r = 16.92 σ_z = 530.23 σ_{rz}= 64.76 σ_θ= 556.13	σ_r =-10.13 σ_z = 53.5 σ_{rz}= 9.86 σ_θ= 45.85	σ_r = 27.05 σ_z = 476.73 σ_{rz}= 54.896 σ_θ= 510.28		

TABLE#I

USAGE FACTOR CALCULATION FOR THREE PHASES

Phase	Type Of Load	Sri Maximum stress Intensity Range (MPa)	Sai Maximum Altert-nating stress intensity range (MPa)	No.Of Cycles For Failure From Fa-tigue Curve (Ni)	Usage Factor * ni/Ni
1	Pressure +Thermal	277.85	138.92	$>10^6$	Insignif-icant
2	Thermal	487.46	326.81 **	3.25×10^4	0.002
3	Thermal	188.23	94.113	$>10^6$	Insignif-icant

CUMULATIVE USAGE FACTOR =0.002

* ni=60 CYCLES FOR EACH PHASE BASED ON 30 YEARS OF REACTOR LIFE

** BASED ON ke=1.34 AS PER NB 3228.3 OF ASME B&PV CODE SECTION 3

TABLE#II