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Fatigue analysis of recuperative heat exchanger

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ABSTRACT: Recuperative Heat Exchangers figure among the most stressed components of the volume control system of a Pressurized Water Reactor plant. Subjected to severe thermal variations, their nozzles shall be designed to withstand fluctuating loads associated to the reactor operational cycles. This paper focuses on the problem of carrying out fatigue analysis for a radial nozzle welded to the cylindrical shell of the equipment discussing alternatives for modeling the nozzle attachment using axisymmetric models in lieu of three-dimensional ones.

1 INTRODUCTION

The volume control system connects the high-pressure and high temperature reactor coolant system to low-pressure and low temperature process auxiliary systems having among their main functions the compensation of volume changes, purification of reactor coolant, supply the pressurizer auxiliary spray, degasification and injection of boric acid, demineralized water and chemicals to control coolant properties.

Recuperative Heat Exchangers and High Pressure Coolers, connected after the former to the extraction strand, are responsible for cooling the extracted reactor coolant from temperatures of about 290 °C to approximately 50 °C, at H.P. Coolers outlet.

Considering the compromise between costs of heat loss in H.P. Coolers and manufacturing of Recuperative Heat Exchangers, the system is optimized regarding process requirements, exposing the components to severe temperature variations causing high thermal stresses, particularly in nozzles and tube-sheets.

Fluctuating thermal loads, associated to operational cycles of the plant, subject materials to fatigue what represents one of the most critical design limitations of the components.

This paper, taking for study the shell-side outlet nozzle of Recuperative Heat Exchanger, compares modeling alternatives for fatigue analysis purposes regarding the necessary simplification in models and procedures to adapt the problem to run in work-stations or even in micro computers.

2 LOADING

Recuperative Heat Exchangers are subjected to temperature and pressure transients corresponding to reactor operational events.

The complete set of loading cases, described by temperature and pressure versus time diagrams, holds an extremely large amount of information to be processed in a fatigue analysis run.

A preliminary reduction of data may be performed by grouping similar loading cases, disregarding small temperature and pressure oscillations and defining a new set of envelope curves.

Even so, for the case of Recuperative Heat Exchangers, a considerable number of envelope loading cases (ten to fifteen) remains after that simplification.

Further data reduction leads, in general, to overestimated loading assumptions.

The present analysis is based on two envelope loading cases (cooling and reheating), as shown in Figure 1, covering the most severe thermal transients specially defined for exemplification purposes.

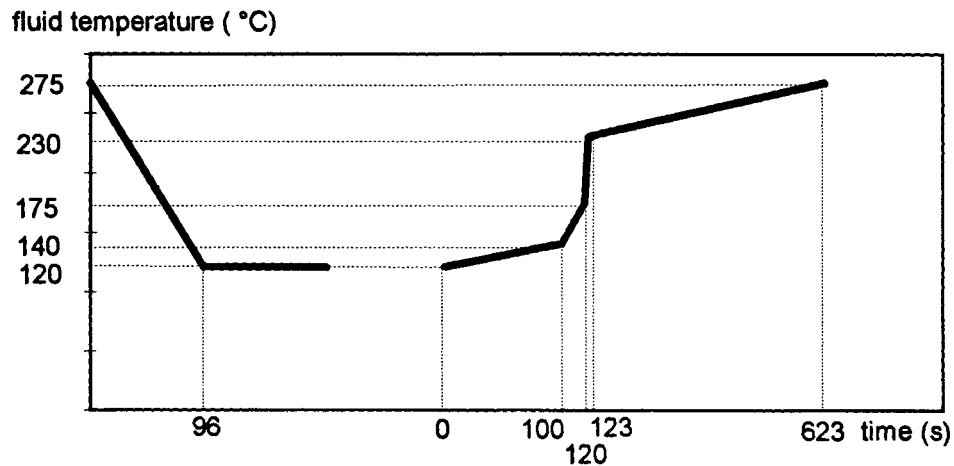


Figure 1 - Cooling and reheating load cases occurring 175 times.

During the selected loading cases, internal pressure does not vary significantly. In order to consider its effects in the fatigue analysis, a range of pressure variation of 180 bar, occurring 200 times, is taken as an additional loading case.

3 FINITE ELEMENT MODELING

The shell-side outlet of Recuperative Heat Exchanger in Angra 2 nuclear power plant is a nozzle welded to the cylindrical body of the equipment.

In order to reduce computational effort and make the model generation as well as the stress analysis easier, axisymmetric models have been used.

To minimize deviations in results caused by the simplification of the model, corrections, regarding the effects of internal pressure, have been usually adopted in two different ways:

1. Doubling pressure on shell internal surface and
2. doubling shell radius

Once thermal loads, in the case in study, are significantly more important than pressure, the second alternative, which introduces additional geometric deviations, is not considered.

Finite element model generation and subsequent thermal, stress and fatigue analysis are performed by ANSYS 5.0 A program, running in a work-station Silicon Graphics R3000 (processor: 30 MHz, main memory: 16 Mb).

The two mentioned models are shown in Figure 2.

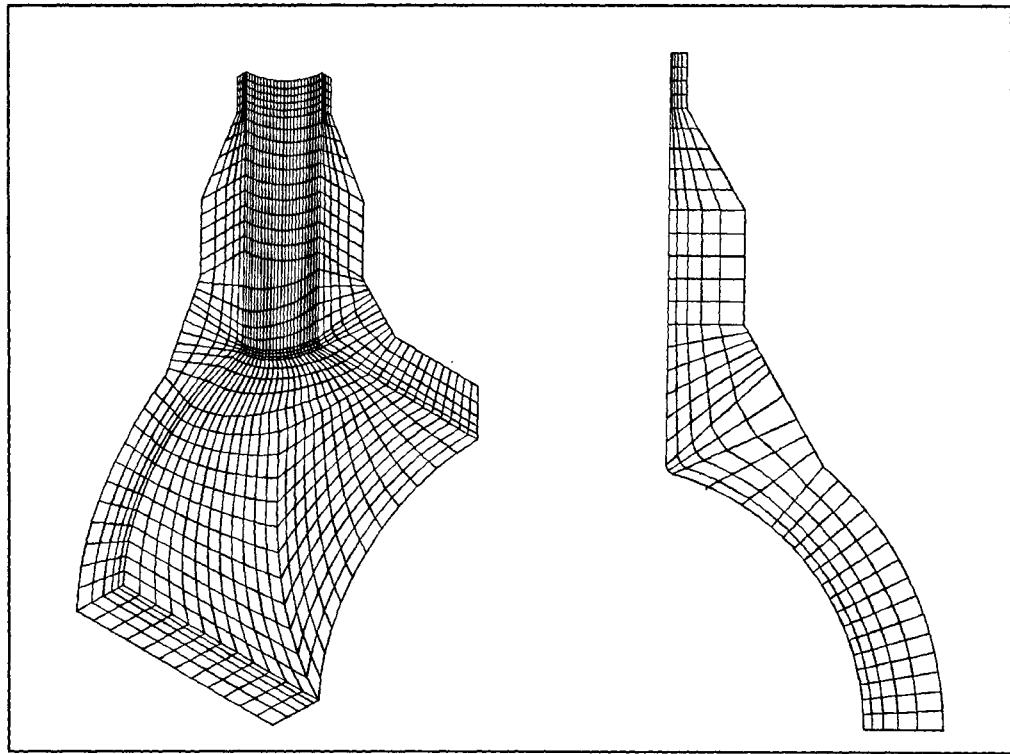


Figure 2 - Three-dimensional and the corresponding axisymmetric models

4 STRESS ANALYSIS CONSIDERING PRESSURE RANGE

Figure 3 shows the stress distribution for the three-dimensional and the axisymmetric tested models under 180 bar of internal pressure. One can observe that the maximum stress intensity in the 3-D model is about 44 % greater and occurs at a location not represented in the axisymmetric model which corresponds to a section of the former by a plane perpendicular to the shell axis of the equipment.

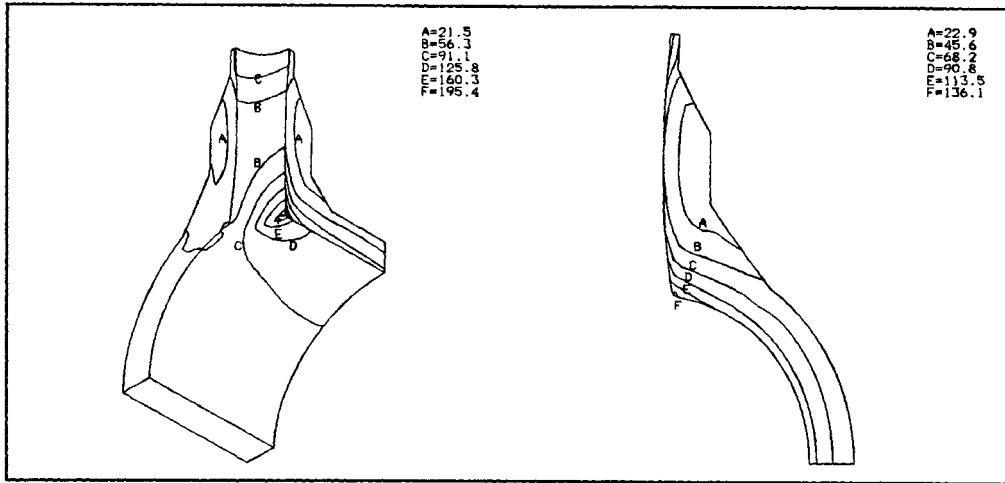


Figure 3 - Stress intensity distribution in the 3-D and in the axisymmetric models considering internal pressure.

5 STRESS ANALYSIS CONSIDERING TEMPERATURE TRANSIENTS

It is selected, for comparison of stress intensity fields, the instants at 96s and 123s, in the diagrams corresponding to cooling and reheating, respectively, which can be considered as a satisfactory approximation of the instants associated to the maximum thermal stresses.

It can be noticed, from Figures 4 and 5, that the maximum stress intensities in both models reach almost the same value (0.9% and 2.4% greater in axisymmetric model for, respectively, cooling and reheating).

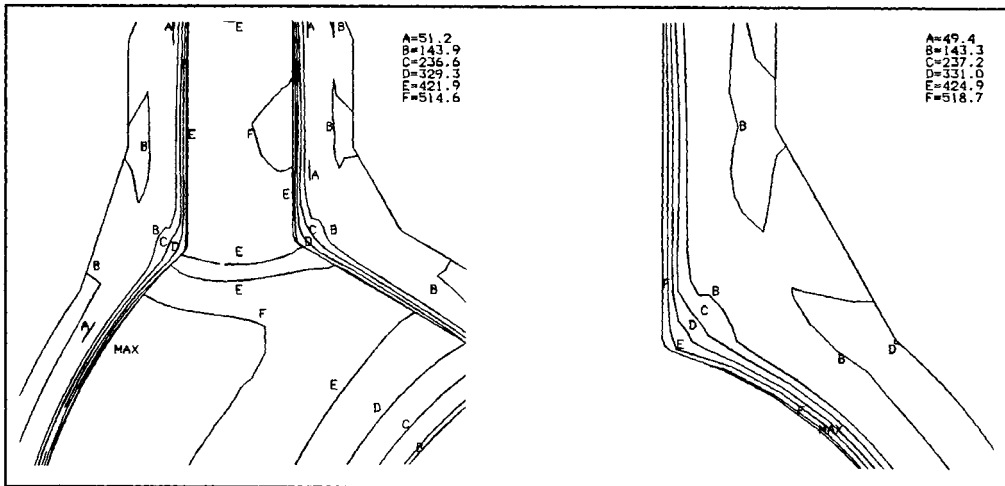


Figure 4 - Stress intensity distribution in 3-D and in the axisymmetric models considering thermal loads corresponding to cooling. Maximum values are 561 MPa and 566 MPa, respectively, for 3-D and axisymmetric models.

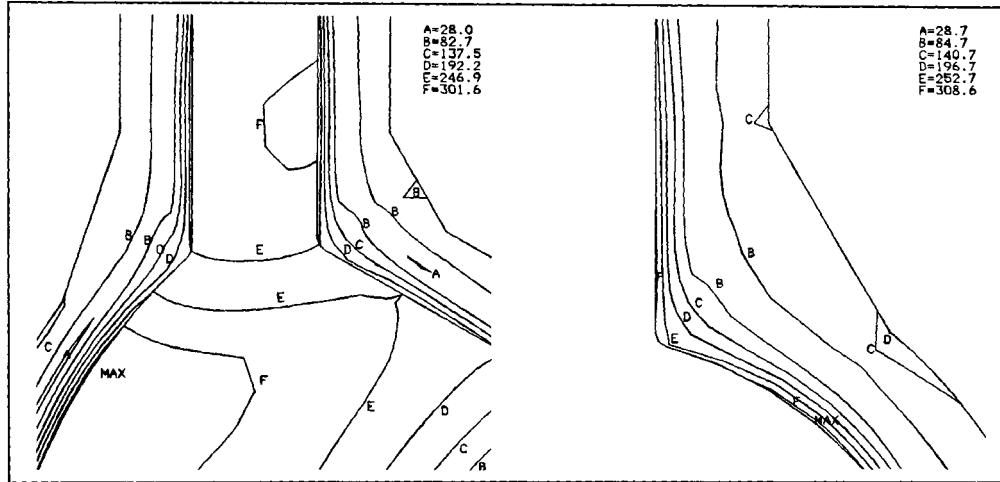


Figure 5 - Stress intensity distribution in 3-D and in the axisymmetric models considering thermal loads corresponding to reheating with maximum values of 392 MPa and 337 MPa, respectively, for 3-D and axisymmetric models.

6 FATIGUE ANALYSIS

Fatigue analysis, according to ASME Code, Section III, Division 1, is performed taking in account thermal transients, resulting from extremely conservative assumptions, and an additional loading case, corresponding to an estimated pressure range considering the complete loading data for the plant. The summary of the results is presented in Table 1.

Model		3-D	Axisymmetric
Thermal loading	Alternate stress intensity, Sa (MPa)	445	451
	Ke (according to ASME Code)	2.64	2.88
	Used cycles, n	175	175
	Allowed cycles, N	329	242
	Partial fatigue usage, n/N	0.53	0.72
Pressure loading	Alternate stress intensity, Sa (MPa)	106	74
	Ke (according to ASME Code)	-	-
	Used cycles, n	200	200
	Allowed cycles, N	1.74 E7	1.00 E11
	Partial fatigue usage, n/N	0	0
Combination	Cumulative fatigue usage, n/N	0.53	0.72

Table 1 - Summary of fatigue analysis results.

7 CONCLUSIONS

The approach discussed in this paper can be used as a basis for reducing computational effort for the performance of fatigue analysis applied to the Recuperative Heat Exchanger or to some other equipment which presents similar geometric features and loading patterns.

The thermal transient analysis and the subsequent stress analysis for the selected temperature distribution show that the used axisymmetric model is suitable as an alternative to three-dimensional ones whose employment would be extremely time consuming.

On the other hand, considering the effects of internal pressure, a significant discrepancy is verified between the results obtained from the tested 3D and the axisymmetric models. Maximum stress intensity in 3D model is about 44 % greater.

The definition of stress cycles associated to internal pressure variations, depends, in the present case, only of one static run. This way, it is proposed an alternative solution for the problem of performing the fatigue analysis of the Recuperative Heat Exchanger that combines the use of three dimensional solid models for assessing the extremes of stress intensities related to internal pressure cycles and a corresponding axisymmetric model for thermal transient and further stress analysis associated to the temperature cycles of the fluid circulating inside the equipment.

Cumulative damage can be easily computed by Miner's criterion considering the contribution of a set of thermal transients and an additional one of stress cycles due to pressure variations.

REFERENCES

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