DFG 1/8

Criteria for the Selection of Significant Operating Conditions for Fatigue Analysis Demonstrated at a BWR Reactor-Pressure-Vessel Component

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Abstract

All operating modes for a component in a reactor-pressure-vessel (RPV) are given as envelopes for a 40 year period, including their frequencies of occurrence, in a comprehensive catalogue of load cases. The task is the selection and the documentation in a traceable form of the most critical load conditions, which contribute to fatigue, with the aim to proof that no fatigue failure during the total lifetime of the system is possible.

The operating conditions include 15 different load cases. Each load case is described by transients of the fluid flow-rate, the temperature in the pressure vessel, the temperature of the medium inside the component, the heat transfer coefficients at inner and outer component wall, the water level in the pressure vessel, and the hydraulic forces. Criteria for the selection of critical load data for the numerical analysis are stated and their application is shown.

1. Structure and Loading

The investigated feed-water distributor (FWD) is subdivided into 4 segments and supplied by 6 inlet nozzles. The circuit ring is connected with the inlet nozzles by means of a prestressed friction contact. Fig. 1 shows a survey of the geometry of the ring and its connection with the nozzles as well as the significant alternating load data temperature (T_M of the medium in the component, T_P of the RPV) and lifting hydraulic forces (F_H at the prestressed friction contact). All together 205 time points are necessary to describe the different load conditions. Each time point represents an interval of the transients with a complete description of the load average by 64 individual data resulting in about 13000 load data. The thus defined load states are of different duration. The loads alternate slowly, so that all load conditions may be taken as stationary.

2. Development and Application of Criteria

The aim of the investigations are statements on fatigue of material and necessary displacement tolerances at the prestressed friction contacts between inlet nozzles and circuit ring. This task requires an analysis of the stresses and deformations. The structure must not be calculated completely for all 205 time points, because equal load data or unsignificant loads are present, and the expense for a complete analysis of all time points would be unacceptable high. It is therefore necessary to develop criteria for the selection of the controlling load data of each load case and their further reduction to the most important load data which then are used for an envelopping numerical analysis. Fig.6 shows an outline of the development of the criteria - marked by the letters A to F - in a sequence corresponding to the working process. The relations to other criteria are quoted in parenthesis. The procedure is quite general and can be applied to any comparable problem. In the following it is explained for the FWD.

The behaviour of the structure under load may be subdivided into its global and local behaviour.

A) The global behaviour implies the nonlinear displacement tendencies (u) of the ring relative to the inlet nozzles in the inward or outward direction (Fig. 2). The controlling load data are the difference between RPV-temperature T_P (with inherent pressure in the RPV) and mean ring temperature T_S (different heat transfer coefficients $\alpha_{t,RPV} < \alpha_{t,FWD}$ are regarded) as well as the hydraulic forces in the FWD. The load data for the numerical analysis, which is accomplished herein by a FE-model (criterion D), are selected according to the following criteria E and F.

B) The local behaviour is characterized by constraints in the wall of the component, caused by temperature differences between the inside and outside of the wall ($\Delta T = T_o - T_i$) as well as forces in circumferential direction because of internal overpressure. The results are the stresses Q and σ (Fig. 3) without global constraints at the friction contacts. It may be investigated decoupled of the global analysis. Criterion E and F are used to select the controlling load data for the numerical analysis, which is mainly done by an exact solution.

C) Analytical model for the local behaviour. The local temperature stresses Q are calculated by an exact analytical solution while the local overpressure stresses σ are solved either exactly or approximately by a linear FE-calculation of a section of the ring.

D) FE-model for global analysis. The symmetry of the structure together with the symmetry of the load allows simplifications in the calculations. Symmetrical global load cases are calculated by use of a 1/4-FE-model. The two groups of unsymmetrical global load cases must be analysed by a FE-model of the total structure (Fig. 4 and 6). The nonlinear behaviour of the system demands that all load parts, which influence the global behaviour and act at the same time, are considered in one step. Later superposition of these load parts is not allowed.

E) Extreme FWD-wall-temperatures and their distribution. Extreme global and local behaviour (criteria A and B) is caused by extreme temperature differences $(T_P - T_S)^{min}_{max}$ and ΔT^{min}_{max}. The variably distributed temperature in the different sections for unsymmetric load cases causes deviation of the circular shape of the ring and a tendency for relative displacements in tangential ring direction, which results in additional constraints because of the lack of tolerable relative displacements at the friction contact. The difference between the mean structural temperatures of adjoining sections i and j, $|T_{mi} - T_{mj}|max$, is decisive. All four (symmetry) or five (unsymmetry) extreme temperature differences of each load case are calculated after a heat transfer analysis and marked in the given transients (Fig. 5).

F) The maximum and minimum hydraulic forces $F_{h\,\substack{max\\min}}$, together with the extreme temperatures, cause globally (criterion A) maximum relative displacements u_{max} and maximum constraints (and thus constraint stresses $\bar{\sigma}_{max}$, see Fig. 2) between ring and inlet nozzles. $F_{h\,max}$ causes locally the largest stresses σ. The two extreme values of each load case are marked according Fig. 5.

The number of time points with different extreme load data is reduced to 43 after comparison of the marked extreme values for all load cases (exemplarily demonstrated in Fig. 5 by a scanning-pattern image). 30 time points are referred to the global behaviour.

3. Accomplishment of the Calculations

The local temperature stresses Q, which predominate the total stress level, are calculated for each time point. The global load cases, which must be calculated by a nonlinear analysis, are reduced into three groups, according to criterion D. It is sufficient for a safe fatigue- and displacement-analysis to envelope each group by its extreme load cases. On this behalf, two fictitious data sets, which include the largest constraint and displacement tendencies as described in A, E and F, are summarized for the symmetrical load cases. Within the two unsymmetrical groups, always one of the differences $|T_{mi} - T_{mj}|_{max}$ or $(T_P - T_S)_{max}$ (criterion D) may be decisive. Thus always two load cases must be calculated for each group. All together, two symmetrical load cases with the 1/4-FE-model and four unsymmetrical load cases with the 1/1-FE-model remain for the global analysis. In the following fatigue analysis for selected points of the structure the extreme local stresses Q and σ of each load case are superposed by the extreme global stresses $\bar{\sigma}$ of the proper group. Q, σ and $\bar{\sigma}$ are the values of the selected point. The correct superposition and calculation of the alternating stress intensity follows by retracing the selection of load data as required by the criteria A to F (documented in Fig. 5) and the following envelopping in groups.

4. Closure

The introduced selection concept is suitable for a computer aided compilation. As a presupposition, the transient catalogue must be prepared to match the computer requirements. Hence the heat transfer analysis, selection and comparison of extreme load data as well as the preparation of the input data for the FE-analysis can be accomplished in an easily controllable and economic way.

* This analysis has been carried out for
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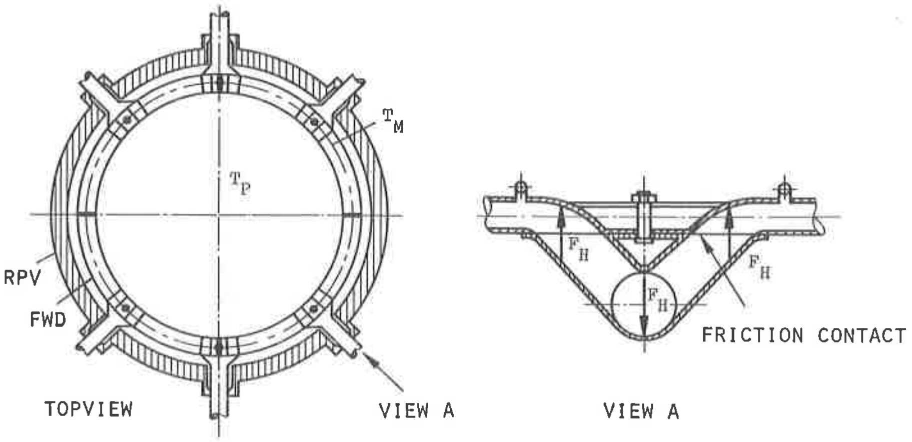
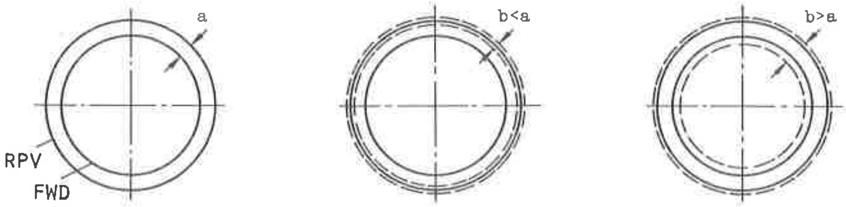


Fig. 1: Survey of Geometry and Loading



a distance FWD/RPV-wall, cold

b distance FWD/RPV-wall under load

$(T_P - T_S)_{min}$

$F_{Hmax} \rightarrow u_{max}$

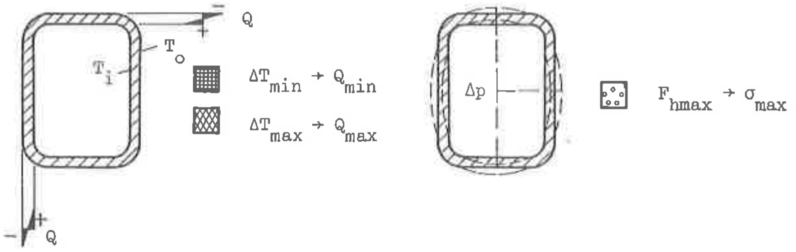
$F_{Hmin} \rightarrow \overline{\sigma}_{max}$

$(T_P - T_S)_{max}$

$F_{Hmax} \rightarrow u_{max}$

$F_{Hmin} \rightarrow \overline{\sigma}_{max}$

Fig. 2: Global Behaviour under Load



Temperature difference $T_o > T_i$

internal overpressure

Fig. 3: Local Behaviour under Load

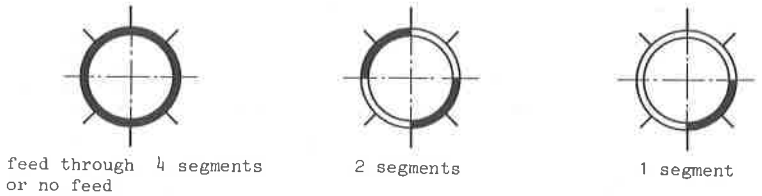
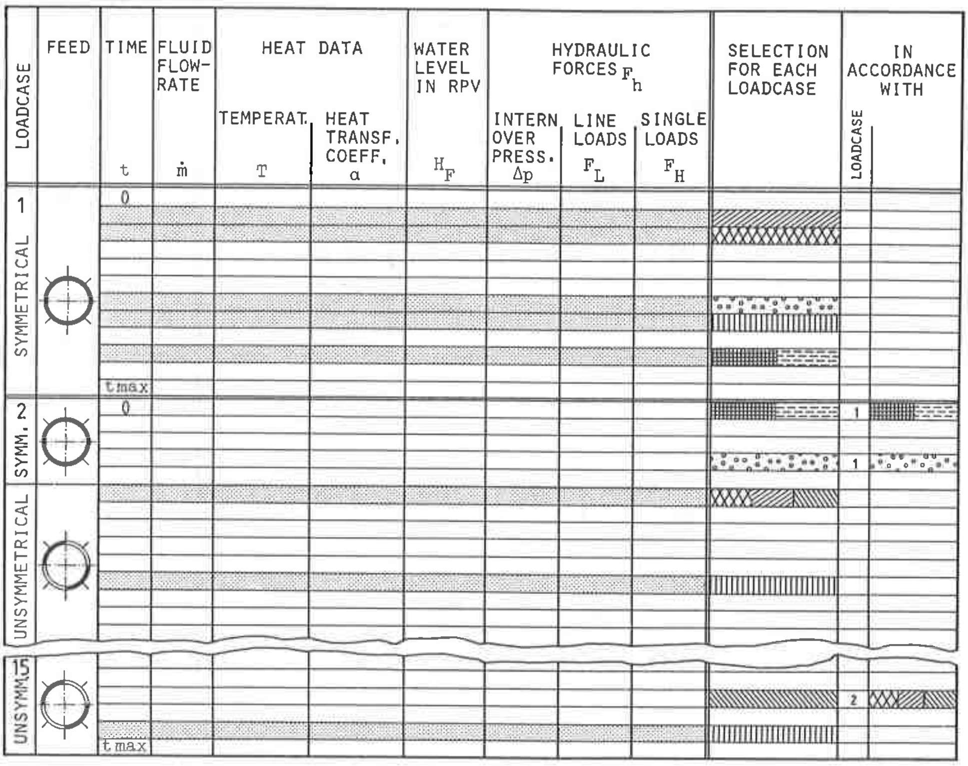
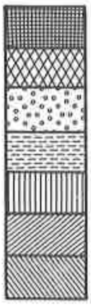


Fig. 4: Feed Conditions





ΔT_{min} minimum difference of wall temperatures

ΔT_{max} maximum difference of wall temperatures

F_{hmax} maximum hydraulic forces

F_{hmin} minimum hydraulic forces

$(T_P-T_S)_{min}$ minimum difference of RPV- and average ringtemperature

$(T_P-T_S)_{max}$ maximum difference of RPV- and average ringtemperature

$|T_{mi}-T_{mj}|_{max}$ maximum difference of average temperature of adjacent ringsegments

Fig. 5: Transients of Load; Selection, Indication and Comparison of Extreme Data

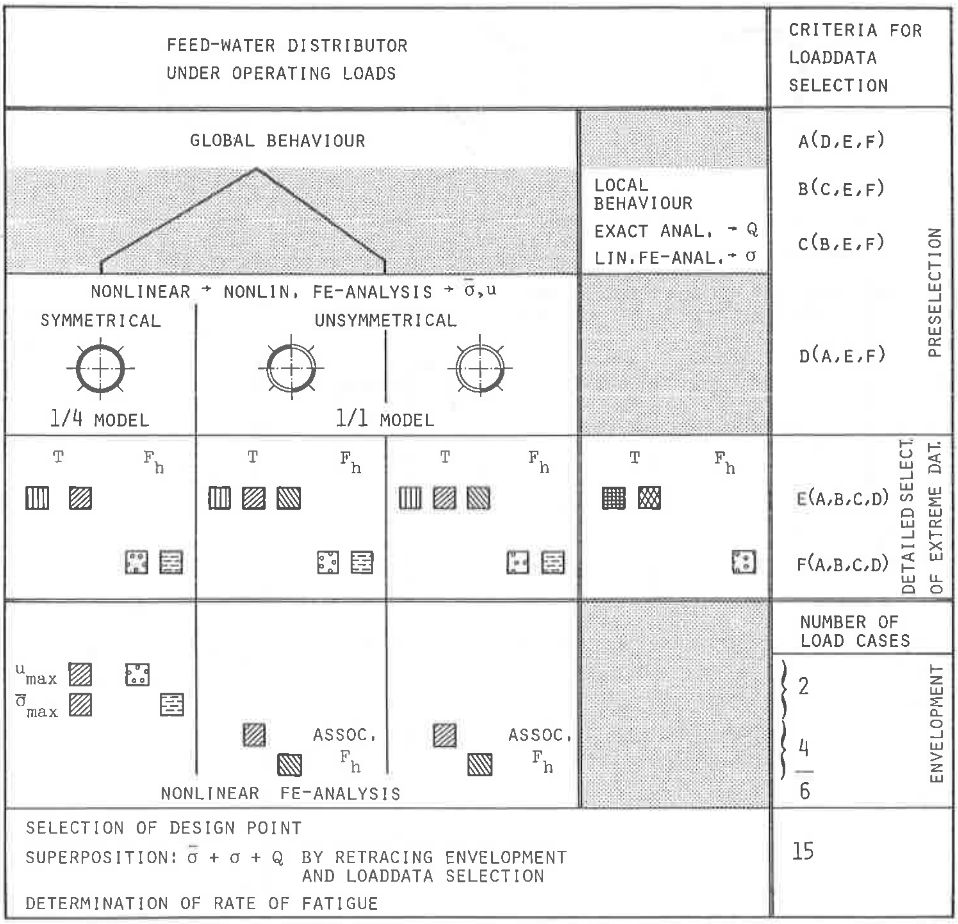


Fig. 6: Outline of the Procedure