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Component fatigue life evaluation using fragmentary load histories

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ABSTRACT: On-line data acquisition for fatigue monitoring was not begun in numerous nuclear power plants until many operating years had already passed. Now, with a complete load history recorded over several years' time, the current fatigue status of those components particularly susceptible to fatigue is determined. An example of automated fatigue calculation is discussed. Particular attention is given to the problem of inadequate load data from the time before implementation of on-line data acquisition. This report shows how it is possible to use the detailed analysis of the complete database in evaluating the load history for the time for which the load data are incomplete.

INTRODUCTION AND OBJECTIVES

Stress and fatigue analyses based on specified service loading combinations were carried out during the functional design of the systems, components and parts in the reactor power stations. These service loading combinations were prepared by building on experience gained in operation and using data about installations in operation. On-going, carefully directed and highly specified measurements and investigations were carried out locally in parts of the system and have shown that there are deviations regarding the specified service loading combinations. As a result, a fatigue monitoring system to record the component loadings and calculate material stresses in selected areas of the primary cycle was installed. One of the systems monitored is the pressurized water reactor pressurizing system. The component to be studied is the surge line which connects the pressurizer to the reactor coolant line (Fig. 1).

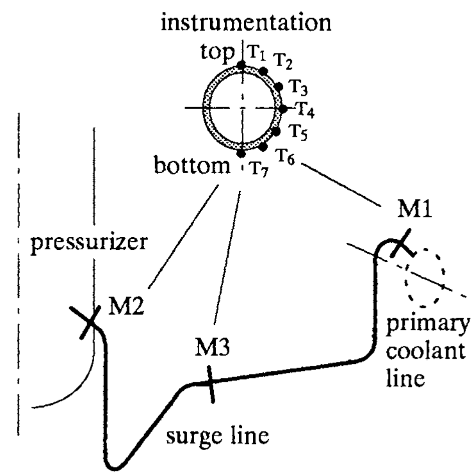

Fig. 1 Schematic layout of surge line and instrumentation at measurement sections

Temperature transients occur in the surge line as a result of the system pressure control. The pressure is maintained via spraying and heating processes in the pressurizer. Because of the higher temperature in the pressurizer compared to the reactor coolant line, transients occur in the form of shock and layering. Measuring planes, each having 7 thermocouples distributed over half the circumference, were applied to the pressurizer nozzle, the reactor coolant line nozzle and the horizontal portion of the line (Fig. 1) to record these temperature transients.

The operation data before the installation of the fatigue monitoring system must be evaluated in order to determine the current degree of fatigue based on the loading measured at the component (Fig. 2). The selection of the periods relevant to the fatigue analysis is determined by the service condition incidents which have occurred in the installation. Periods when the installation is in steady state power operation or in cold state can be excluded. As a result the installation load history calculated here is divided into the sections initial start-up and power operation with and without the fatigue monitoring system.

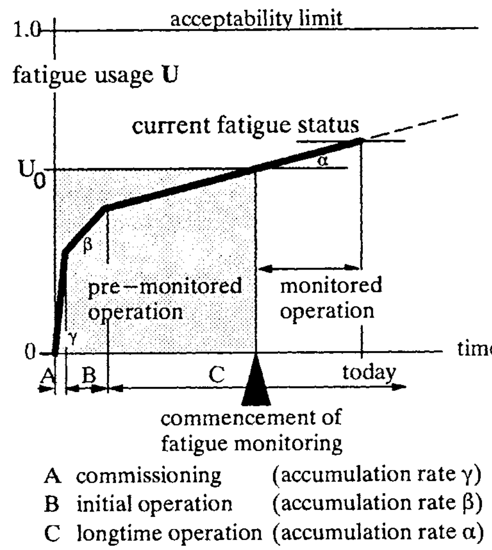

Fig. 2 Service life analysis

GENERAL RESULTS OF AUTOMATED FATIGUE CALCULATIONS

The advantages of monitoring operating fatigue through on-line data acquisition and off-line analysis and fatigue calculations have been reported previously (Schön, Baumann,1994, and Golembiewski, Miksch, 1991, 1993, also Golembiewski, Tulke, 1993). However, we wish to present one example of automated fatigue analysis performed to date. The loads on the surge line measured in service consist of pressure and temperature profiles. The temperatures are also measured with additional thermocouples on the outer surface of the components in order to record local load phenomena such as thermal stratification. FAMOS fatigue calculations (= FAMOS stage 3) automatically convert the outer wall temperatures to inner wall temperatures and then to stress profiles. In this example, temperature excursions ΔT_{out} are measured on the outer wall (Fig. 3a), which result from much larger temperature excursions ΔT_{in} on the inner wall surface (Fig. 3b). It is clear from this that the consideration of outer wall temperature profiles alone does not provide sufficient information on processes affecting fatigue. The associated calculated stress history shows the corresponding stress peaks (Fig. 3c). However, the contributions to equipment fatigue are determined not by these individual stress peaks, but by stress ranges calculated by the Rainflow algorithm. Stress ranges of this type often result from two stress amplitudes in opposing directions. This clearly indicates that it is simply not possible to correctly evaluate an individual phenomenon seperately. The chronological history of the phenomena must be properly accounted for in calculating fatigue. This requires automated calculation of continuous load histories.

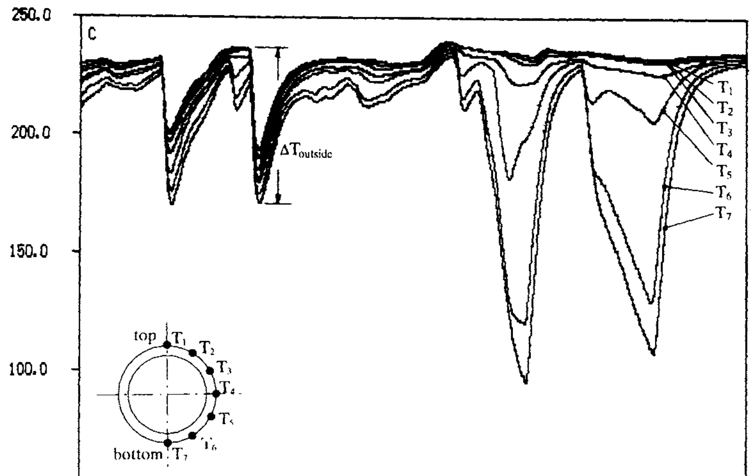

Fig. 3a
Measured outside surface temperatures

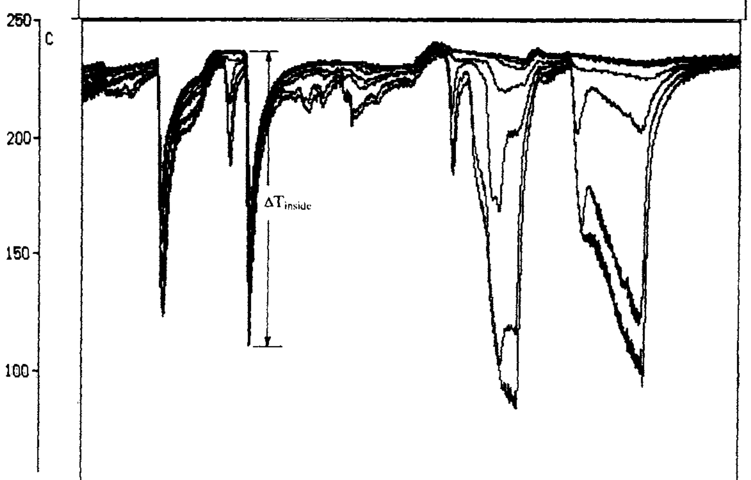

Fig. 3b
Calculated inside surface temperatures

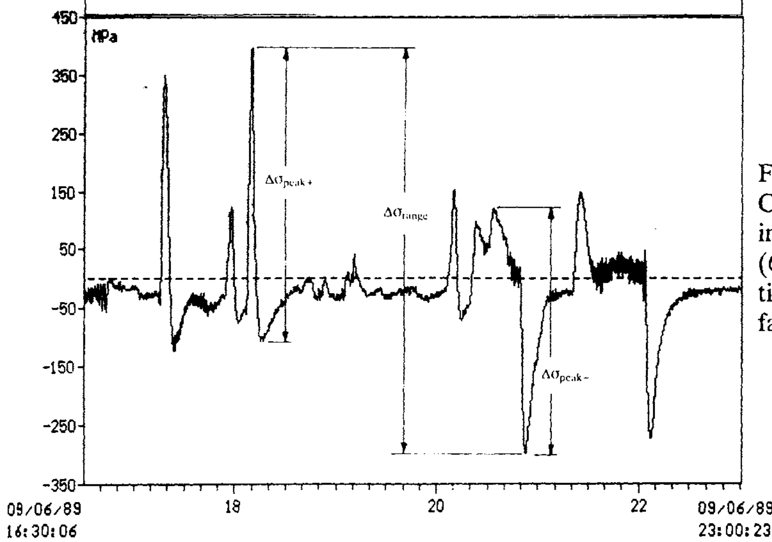

Fig. 3c
Calculated stress intensity
(6 o'clock position, inside surface)

FATIGUE ANALYSIS PROCEDURE

Time frame with on-line data acquisition

The load data recorded over this time frame are very complete and are stored digitally. In addition to the operating parameters (internal pressure, coolant temperature, pressurizer temperature, etc.) they also include local thermal stratification data. The load history is evaluated automatically with the FAMOS fatigue calculation program. This software tool is set for the component (pressurizer nozzle, elbow, RCL nozzle) to be analyzed. The component configuration file, or component file, contains data for selected points on the component, such as

- Geometry (wall thicknesses, radii),
- Material parameters (Young's modulus, yield strength, tensile strength, thermal conductivity, S-N-curves),
- Reference stresses from standard loads (internal pressure, internal forces and moments, thermal transients), which are determined in precalculations, e.g. by finite element calculations,
- Program control parameters (input, output, calculation procedure).

The results of fatigue calculations with FAMOS stage 3 are partial and cumulative usage factors for the areas considered. In addition, the program prints out the Markov matrices, maximum stress profiles and stress range frequency plots generated by the Rainflow algorithm. The plausibility of the results can be verified from the plotted temperature and stress profiles.

This software tool thus individually evaluates recurring load cases. In this example, the results show that the components considered in the 'startup' load case can be subject to significantly divergent partial usage factors (Fig. 4). This is due to the individual operating procedure, which has a large influence on the loads on these components.

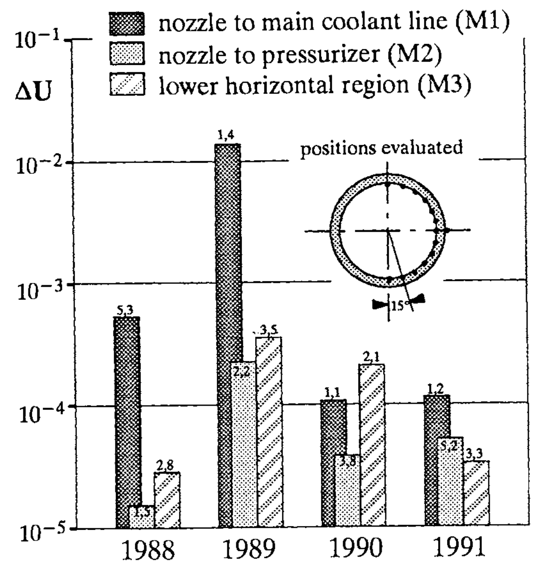

Fig. 4 Cumulative usage factors of startup conditions (Golembiewski & Tulke, 1993)

Time frame before on-line data acquisition

In the time frame before on-line data acquisition, the scope and quality of the available load data are very modest. The data can be output in the form of written reports or may be stored digitally on magnetic tape. In any case, these data are always derived from operating parameters and do not include any locally measured thermal loads.

The results from the automatic fatigue analysis described above can be used here to fill in the gaps in the load data. The general prerequisites are as follows:

- The largest possible database from the period of on-line data acquisition (several years)
- An automated, load case-specific analysis of this database
- Sufficient and suitable information from the time frame previous to on-line data acquisition to enable detection of all load cases relevant to fatigue.

For the example of the surge line examined here, reactor startup and shutdown are known to be load cases which are relevant to fatigue. The on-line database contains continuous data for six years of operation. The 8 startups over this time yield a cumulative increase in fatigue. Likewise the 7 shutdowns yield a cumulative increase in fatigue. The component fatigue can be calculated for both load cases, permitting evaluation (multiplication) by the number of startups and shutdowns which occurred in the pre-on-line history. However the analysis is more precise if the operating parameter signals relating to the loads can be correlated for both time frames. With the current example of the surge line the pressurizer water level is well-suited to this purpose. Long, involved startups result in more fluctuations in pressurizer level. The procedure proposed is as follows:

- A variation in the pressurizer level, averaged over all 8 startups, results in a specific increase in fatigue $\Delta U_{mean,startup}$, and similarly $\Delta U_{mean,shutdn}$ for the shutdowns.
- The corresponding fluctuations in pressurizer water level from the pre-on-line period during startups and shutdowns, multiplied by $\Delta U_{mean,startup}$ or $\Delta U_{mean,shutdn}$, yield the increase in fatigue over this period due to startup and shutdown.

This enables analysis of load cases while accounting for their individual duration as well as their individual profile. It is apparent that the more detailed the information on the loading in the pre-on-line period the better the results of automated fatigue calculations can be correlated.

CONCLUSION

The task of re-evaluating a component's current status of fatigue is facilitated, economized and the results enhanced if a substantial part of the loading history exists in digital form from on-line data acqisition. The detailed results derived from this database can be correlated to loading information of earlier periods which is often of much lower quantity and quality.

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