In-Service Lifetime Monitoring of Piping Systems Taking into Account External Forces and Moments Besides Internal Pressure and Temperature

F. Bietenbeck
RW TÜV, Essen, FRG

K. Rohler
Deutsche Babcock AG, Oberhausen, FRG

1. Introduction

The continuous registration of the cumulative creep and fatigue damage of highly loaded components of high pressure piping in the creep range by means of lifetime monitoring systems contributes to maintaining the reliability and availability of the plant and, with preventive maintenance, delivers useful information about the actual state of material damage. In addition, the records of lifetime monitoring systems permit to derive parameters for an optimized operation and better utilization of the service life of the plant.

Lifetime monitoring systems presently installed in high pressure piping in the creep range normally record pressures and fluid temperatures as well as the through wall temperature gradients in thick-walled components such as fittings and valves. On the basis of these data, the increase in creep and fatigue damage of the monitored components is determined through routines implemented in the central processing unit of a personal computer (Brockel, 1983; Speitkamp, 1987).

However, relevant creep and fatigue stresses result not only from system-independent parameters such as internal pressure and temperature but also from additional, system-induced external loads.

Below it will be shown how external loads can be measured and integrated into an existing lifetime monitoring system for piping systems. The purpose is to get better information on the actual creep and fatigue damage and indications regarding incipient notable changes of the system behaviour in order to take early countermeasures. By due selection of a few characteristics - in this case pipe displacements and support forces - and their registration by appropriate measuring instruments, the behaviour of the piping system shall be recorded and monitored at acceptable cost.

2. Characteristics of system behaviour

To determine the range of laods to which a high pressure piping in the creep range is possibly exposed under long-term operating conditions, imbalanced load cases (thermal expansion, pressure) are calculated on the basis of the design conditions. In addition, conceivable system deviations, e.g. friction, restraints or weight imbalances, which might occur in the course of time and to which the piping system responds in a very sensitive way are analyzed by simulating the equivalent force and displacement load cases. The measurable system responses thus obtained which in all load cases are functionally connected with the mostly loaded components are the characteritics of the system behaviour (Fig. 1).

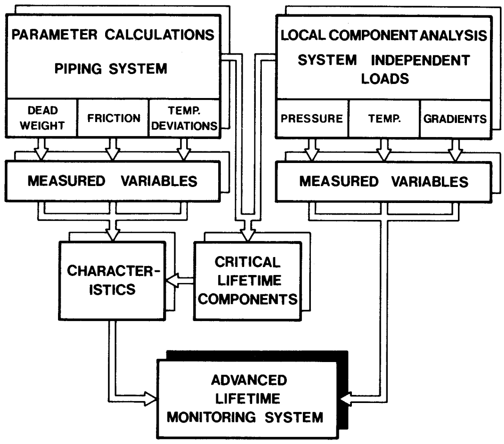

Fig. 1:
Advanced lifetime monitoring system

flow chart

Piping system analysis

The first step of determining measurable characteristics for monitoring external loads at critical lifetime piping components is a piping system analysis of all operating conditions on the basis of actual data (piping and cross-section geometry, masses, connection stiffnesses, etc.). This analysis forms the basis for the parameter calculations described below.

Parameter calculations

The way in which piping behaves under special operating conditions, e.g. imbalanced load cases and condensate flow, change of the constant or spring hanger characteristics, support friction, etc. is studied by analyzing the piping system simulating these parameters. The effect of misalignments of constant or spring hangers on the external loads at the piping components can, for example, be simulated by an intentional modification of the hanger forces in the computer model. In the same way variations can be calculated with different frictional forces in supports and snubbers, with different connection stiffnesses and displacements, with weight imbalances in hangers or with operating conditions which deviate from the design conditions. The purpose of such parameter calculations is to show the sensitivity with which the piping responds to conceivable changes of the initial parameters and to obtain information about the system behaviour.
The theoretical studies are supported by accompanying measurements at certain points of the piping e.g. by determining cold and hot positions of spring and constant hangers during operation or recording of thermal displacements at component nozzles (Arens-Fischer, 1988; Koschel, 1986).

Determination of critical lifetime components

The above parameter studies deliver for all piping components a range of external forces and moments which are to be combined with the system-independent component loads due to internal pressure and temperature gradients. Analytical procedures such as those given in ASME III, NB-3685 for bends or WRC Bulletin 107 or 297 for Tees are preferentially used for this purpose. If detailed stress analyses are needed, FEM methods are applied.

Whether, and in which form the external loads influence the lifetime of the different piping components must be studied on a case-to-case basis. While external loads due to the initial restraint of the global thermal expansion of a piping enter the creep damage only in part, as a function of the relaxation behaviour (FDBR-Richtlinie , 1987), they take full effect in the cyclic fatigue damage (Fig. 2).

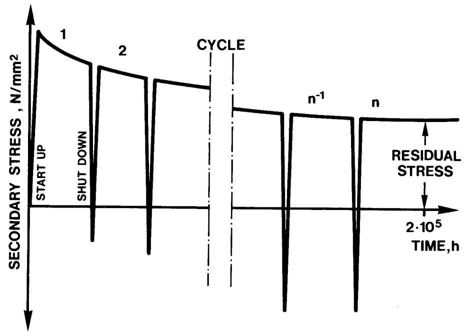

Fig. 2:
Relaxation of secondary stresses

As the relaxation of stresses due to restrained thermal expansion of the piping leads to an appropriate reduction of the reaction forces in the supports, this effect can normally be monitored by simple instruments (e.g. by measuring the forces in struts) and taken into account in the determination of relevant creep stresses.

The results of these combined analyses taking into account system-independent loads and external loads, give the critical lifetime components (Fig. 1).

When installing lifetime monitoring systems in existing plants, the selection of the piping components to be monitored should in any case be based not only on the utilization of the design stresses but also on the results of NDE tests as well as operating experiences with the piping.

Determination of influence functions

After the critical lifetime piping components have been determined, it is necessary to find with the help of the results of piping system analyses so-called influence functions for the external forces and moments at the piping components as a function of the measured characteristics. What is meant by the term of influence factor, shall be explained by the following example:

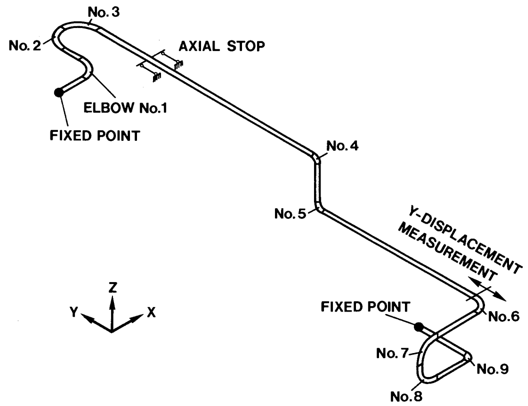

Fig. 3:
High pressure piping in the creep range

Determination of influence factors

Figure 3 shows the isometric drawing of a main steam piping system. One of the components exposed to high loads at this piping which therefore needs monitoring is elbow No. 5. As displacement measurements and accompanying piping analyses during the commissioning stage showed, the significant loading of the elbow is, apart from internal pressure, an "in-plane" bending moment due to restrained thermal expansion. Because of the given geometry and the supporting conditions a direct relationship can be established between the axial displacement of the main piping running in Y-direction downstream of the elbow considered and the elastic"in-plane" bending moment during the first startup of the piping.

In this case there is in addition an almost linear relationship between the relaxation of the relevant stresses due to the restraint of thermal expansion in Y-direction and the reduction of the force in the axial stop, as has been shown by inelastic piping system analyses.

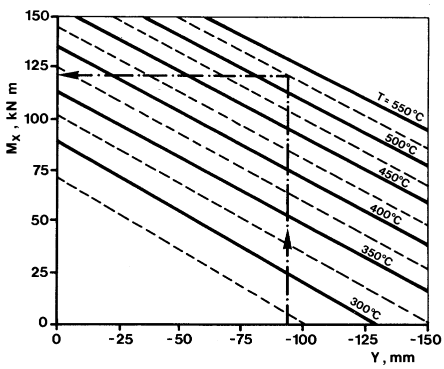

Fig. 4:
Elbow No. 5 in plane moment due to y-displacements at elbow No. 6

Influence factor

The significant external load in elbow No. 5 can be followed by measuring the axial displacement at elbow No. 6 and measuring the force at the struts of the axial stop. From the measured displacement the elastic moment Mx in elbow No. 5 is calculated as a function of the steam temperature at the time of measurement. The influence function Mx = f(Y, T) for the elbow No. 5 has been shown in Figure 4. The creep-relevant bending moment is obtained by multiplying the elastic moment with a relaxation reduction factor which in this case is formed by the ratio between the initial and the actual force in the axial stop.

3. Instrumentation

Selection of measuring techniques

According to our experience, inductive displacement transducers are particularly suited for the long-term measuring of piping displacements.

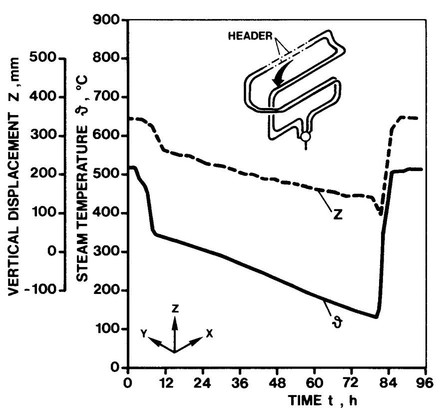

Fig. 5:
Measured variables at hot reheat piping

Figure 5 shows the vertical displacements and the steam temperatures of a hot reheat line recorded at a constant hanger (see flash) over a typical operating period. In this case the transducer was attached directly to the casing of the constant hanger so that complex auxiliary structures were not needed for the guiding of the transducer.

Regarding the measurement of hanger forces we have good experiences with foil resistance strain gauges which are applied directly at the rods. The forces are immediately determined by the computer from the strains measured and to exclude measuring errors due to bending in the rod either 2 strain gauges are opposed to each other or 4 strain gauges are staggered by 90 ° (redundancy).

Calibration and testing

At testing stage the installed instrumentation is to be checked for due functioning and is calibrated under some typical plant conditions of the monitored piping such as startup and shutdown. Displacement measuring points can be checked and adjusted by point measurements conducted with simple mechanical measuring instruments. The results of these verification measurements are carefully documented so that in case of future failure of a measuring system the zero position can be reproduced.

Computer processing of measured data

The measuring signals of the measuring points at which the characteristics of external loads are picked up must be converted in the central processing unit of the lifetime monitoring system into equivalent load data.
The time intervals at which the measurable data for external loads must be scanned and processed depend basically on the type of the measured variables. The concept presented here is mainly designed to record loads which are relevant for creep damage, result from restrained thermal expansion and weights and permit a relatively rough time grid due to their small change rates.

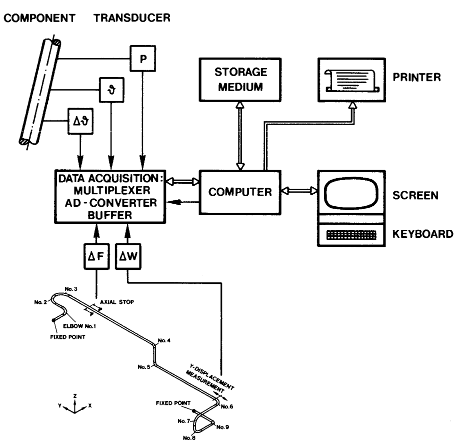

Fig. 6:
Advanced lifetime monitoring system

data flow

Integration into a lifetime monitoring system

The flow sheet in Figure 6 shall show how this concept for the measuring of external loads can be integrated into an existing lifetime monitoring system. The underlying basic system is the E R N A system (Brockel, 1983; Speitkamp, 1987) developed by Deutsche Babcock, Oberhausen. The system provides for "on-line" recording of the service life expended by creep and cyclic fatigue caused at piping components by pressure, temperature, and wall temperature gradients. The described concept for recording and processing external loads can basically also be implemented in any other lifetime monitoring system.

4. Summary and outlook

A concept has been presented for the measuring of system-induced external loads in high pressure piping in the creep range and their integration into a computer-controlled lifetime monitoring system for the "on-line" determination of cumulative creep and fatigue damage.

The main features of the concept are:

- simple and proved instrumentation
- economy due to limitation to the main measurable data (= characteristics)
- possible stepwise extension (modular design).

With a view to an economic utilization of power plants, also beyond the designed lifetime, it is indispensable to monitor the system behaviour of high pressure piping. In the presented concept monitoring takes place on line so that lifetime-relevant system changes are detected in good time and appropriate actions can be initiated, e.g. adjustment of the operating behaviour or preventive maintenance.

It is planned to further develop the concept within the framework of international cooperation and to acquire first operating experience.

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