F1 3/5

Strain Measurements at the HDR-Pipe-System under LOCA-Load: Effects on Elbows and Displaced Weldings

H. Hunger

Kernforschungszentrum Karlsruhe GmbH, Projekt HDR-Sicherheitsprogramm, Postfach 3640, D-7500 Karlsruhe 1, Germany

Abstract

This paper characterizes some effects which have been detected during strain gauge measurements on a test piping with feed water check valve oscillating under blowdown-load. The ovalization of a pipe elbow subjected to in-plane-bending affects the connected straight pipe; this is shown by means of circumferential stresses. Very high LOCA-load produces plastic strain and changes the pipe dynamics. Artificial displaced welds increase the local strain but no defects have occurred. One example compares stresses from measurement and post-calculation. Moreover there are given some remarks on the optimization of the comparison of measurement and calculation.

1. Introduction

As part of the German HDR-Safety Program 10 blowdown-tests with feed water check valve have been performed simulating loss-of-coolant-accidents (LOCA) by means of the modified recirculating loop of the HDR-facility. As some reports on verification of computer codes or dealing with the hydrodynamic effects (Scholl /1/) and with the behaviour of this piping system already exist, this contribution shows some recent experience found while evaluating the strain measurements.

During the tests mainly the damping piston of the valve was varied; the greater part of the tests was realized under boiling water conditions (pressure 70 bar, temperature in the pipe 220 °C, temperature in the reactor pressure vessel 285 °C). The valve closing after blowdown induces high pressure waves in the piping (the so called water hammer) resulting in oscillations of the pipe system (the lower the valve damping, the higher the pressure peaks).The test piping leads from the HDR-reactor pressure vessel to the feedwater check valve and then to the break nozzle which releases the blowdown within 3 ms. At 13 cross-sections, mostly close to the elbows, 8 strain gauges have been mounted in order to measure global bending, torsion and local effects.

Fig. 1 shows the test piping, the cross sections with instrumentation (labelled with letters A....N), and the usual scheme of the strain gauges (additional details in Doltsinis et al. /2/).

2. Effect of the elbow s ovalization on circumferential stress

At two points of the cross sections it is possible to calculate the local circumferential stress σ_{circ} from circumferential strain ε_{circ} and from longitudinal strain ε_{long}. For the state of plane stress there is (with ν = Poisson`s ratio and E = Young`s modulus):

$$\sigma_{circ} = E/1-\nu^2 \cdot (\varepsilon_{circ} + \nu \cdot \varepsilon_{long}). \qquad (1)$$

This stress is compared with the theoretical circumferential stress due to internal pressure σ_{pt} (D_i, D_a = inner/outer diameter of the pipe):

$$\sigma_{pt} = 2\, p_i/u^2-1,\ u = D_a/D_i. \qquad (2)$$

The more the two stresses differ from one another, the greater is the effect of ovalization caused by adjoining elbows.

Fig. 2 shows the two stresses σ_{circ1}, σ_{circ2}, and the theoretical stress σ_{pt} at the cross-section PA being in a sufficient distance from elbows; therefore the curves are rather similar, a little difference is caused by the real wall thickness at the two points. The stresses in Fig. 3 belong to cross-section M1 placed at the beginning of the elbow; here the pressure effects vanish. The measurement shows that the known effect of ovalization of pipe elbow`s cross-sections under bending load affects the connected straight pipes, too. Therefore, measured dynamic circumferential strain determined at two points of each cross-section shows not only the influence of the varying pressure but also considerable effects of superimposed local bending. The oscillation of the two stresses (at an angle of 90° from one another) clearly illustrates the oval shape of the cross-sections. This effect is reduced by adjacent thick-walled parts. Additional investigations made with a pipe test rig (-piping partly taken from HDR -) by Diem et al. /3/ show that the effect of ovalization in the straight pipe vanishes only at a distance of two diameters (2D) or more from the elbow, as for thin-walled elbows, and at 1D, as for thick-walled elbows.

3. Plastification effects

The maximum bending moments in the oscillating piping occur near the fixing points (see Fig. 1). The maximum strains are measured in the adjacent elbows, i.e. in the cross-sections J and N. During the tests with damped valve-closing over-elastic strains have scarcely been measured, whereas a test with undamped valve-closing has shown partial plastic deformation at these high-loaded points of the piping.

In Fig. 4 the longitudinal strain (gauge 1) of the cross-section J is plotted for the case of damped and undamped valve closing. The measured maximum strain amounts to 4.25 °/oo at J, and 5.2 °/oo at N, respectively; the curves show a considerable plastic deformation at approximately 170 msec, that, as a result, leads to oscillations around a new mean value. This curves and others illustrate that the amplitude of the main bending oscillation (which also represents the main stress) is smaller in the case of undamped than in damped

valve closing. This effect can be explained with the energy dissipation caused by plastification acting as an oscillation damping for the pipe.
A Fourier-analysis of the dynamic behavior (as an example the bending stress σ_{b1} of cross-section G in Fig. 5) verifies that the plastification results in damping the low eigen-frequencies (5 and 8 cps); on the other hand, the high load produces some high eigen-frequencies in the range of 30 to 60 cps, which contribute little to the entire stress, however.

4. Increased stress due to displaced welds

In most tests a specimen was included in the long vertical part of the piping consisting of four rings with 3 artificially displaced welds (16, 30 and 53 % displacement). The initial aim was to detect the occurrence of cracks or leaks during the low and high blowdown loads. Fig. 6 shows the assembled specimen with strain gauges attached to five points of maximum and minimum edge displacement, labelled a, b, ..., e (Notice: the points "a" and "b" coincide with cross-section PA in Fig. 1). The longitudinal stress σ_{long} at the points "a" and "e" (calculated by analogy to eq. (1) changing ε_{long} for ε_{circ}) is plotted in Fig. 7 for test V60.4.1 (damped valve). A clear increase of stress is recognizable at the disturbed welds growing with the edge displacement. Table I summarizes the averaged factors of increase of strains and of stresses at points "c, d, e" as compared with the undisturbed points "a" and "b", respectively. That shows considerable dynamic increase of the axial strains measured in the middle of the notches; on the other hand nowhere plastic strains occurred because of the high elasticity of the material WB35 ($R_{p0.2,220°}$ = 400 MPa). Furthermore, no defects have been detected after termination of the tests. Such high undetected edge displacements cannot occur in practice, nevertheless they seem to be not dangerous even in the case of blowdown if the number of cyclic loadings is low.

5. Comparison of calculation and measurement for a bending and a total stress

For the two tests with damped and undamped valve improved post-calculations based on the FEM-code ASKA have been carried out (see /5/). Computed stresses and stresses calculated from measured strains only coincide well if the exact geometric parameters of the piping (e.g. wall-thickness) are used and especially if the excitation forces acting on the structure are determined correctly from the fluid pressures (see Meier /4/). Strain measurements close to pipe elbows or to differences in wall-thickness are not computable by the usual beam-type computer codes.
Fig. 8 shows as an example of good concurrence of measurement and calculation the bending stress σ_{b1} at cross-section F (calculated from strain gauges 1 and 3 in Fig. 1) for the undamped valve test V60.4.1. The result of post-calculation of the undamped valve test V60.5 are not so satisfactory as the linear calculation obviously cannot consider the dynamic effects of plastification characterized in chapter 3.

Usually a reduced stress is applied as a criterion of the total stress in a cross-section of the pipe (e.g. the von Mises hypothesis). This reduced stresses is mostly influenced by the underlying strength theory. In these tests the measured and calculated reduced stresses don`t coincide very well in spite of the improved calculation. Fig. 9 illustrates that for cross-section F (same as in Fig. 8). The reduced stress σ_v is defined substantially by the bending stress of Fig. 8; nevertheless the comparison of calculated and measured stress is not so satisfactory. The time of maximum stress is not reproduced correctly by the calculation. If the physical facts are to be realized more clearly, one should prefer the comparison of calculated and measured stress through the individual parts.

6. Conclusions for future investigations

Summing up all experiences (see also Meier, Hunger /5/) there are some necessary conclusions in performing future HDR-tests and accompanying calculations with a new pipe system: Strain measurements comparable to usual calculations are only available from pipe cross-sections in long straight parts of the piping, away from elbows, welds, and other disturbing points. The real local stress in elbows must be recorded by a detailed instrumentation with strain gauges, especially if zones of plastic deformation are expected. Static stress of elbows has been calculated up to now by means of large-scale FEM-programs, but there is a lack of simple elbow-models which could be inserted in the known beam-type codes in order to make possible faster and cheaper computation of oscillating pipe systems including elbows. Moreover, nonlinear FE-codes covering overelastic stress should be verified by means of new tests now.

References

/ 1 / SCHOLL, K.-H., HANSJOSTEN, E. "Investigations on Closing Behavior of Feed Water Check Valves during a Loss of Coolant Accident" (in German), Ergebnisbericht SRV 350, PHDR Technischer Fachbericht Nr. 18-83 (Juni 1983)

/ 2 / DOLTSINIS, C., JANSKY, J., BEISSWÄNGER, F. "Stresses in Piping Systems due to Blowdown Load-Comparison between Experimental and Theoretical Results", Proc. 7th SMIRT, Chicago, Ill., Aug.22-26, 1983, Paper F1/5.

/ 3 / DIEM, H., MÜLLER, K., BEISSWÄNGER, F. "Beanspruchung und Versagen von Rohrkrümmern", Auswertebericht zu Rohr-Prüfstands- und Blowdown-Versuchen, PHDR Technischer Fachbericht Nr. 56-85 (Februar 1985)

/ 4 / MEIER, D. "Calculation of the Fluid Induced Forces Acting on a Pipe by means of the Surface Integral and its Application to a Blowdown Test in the HDR", Proc. 8th SMIRT, Brussels, Belgium, August 19-23, 1985, Paper F1 3/4.

/ 5 / MEIER, D., HUNGER, H. "Investigations of Vibration Behavior and Stress in a Piping System with Feed Water Check Valve under LOCA Loading" (in German), Auswertebericht Versuchsgruppe SRV 350, PHDR Technischer Fachbericht Nr. 43-84 (November 1984).

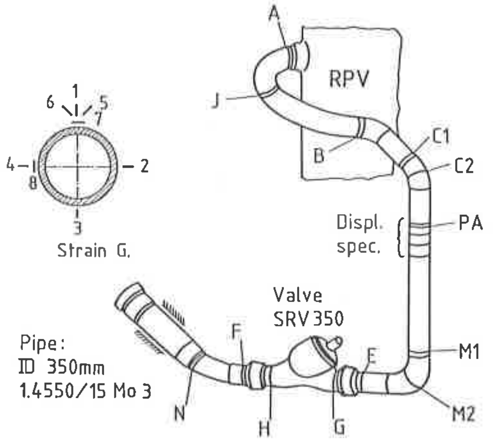

Fig. 1 SRV 350 test piping with measuring cross-sections and scheme of the strain gauges

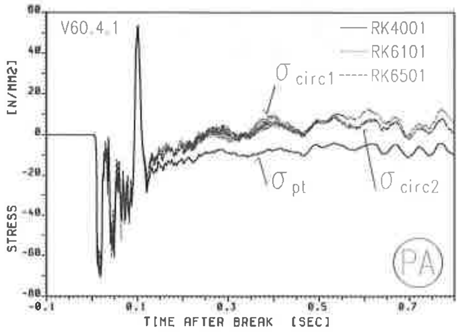

Fig. 2 Circumferential stresses at cross-section PA (no effect of ovalization)

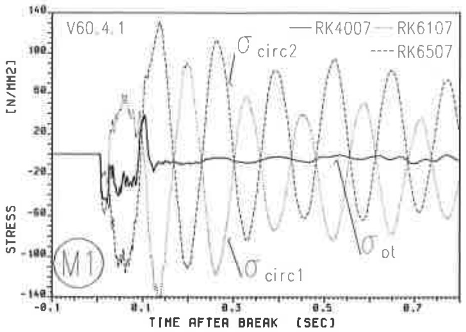

Fig. 3 Circumferential stresses at cross section M1: Maximum effect of ovalization (adjacent elbow)

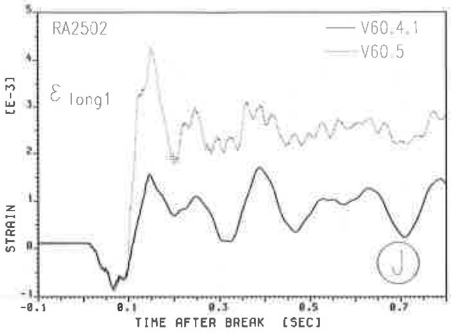

Fig. 4 Longitudinal strain of cross-section J: Plastification

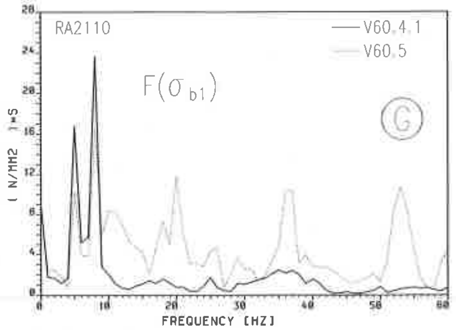

Fig. 5 Typical Fourier-analysis (bending stress σ_{b1} of cross-section G)

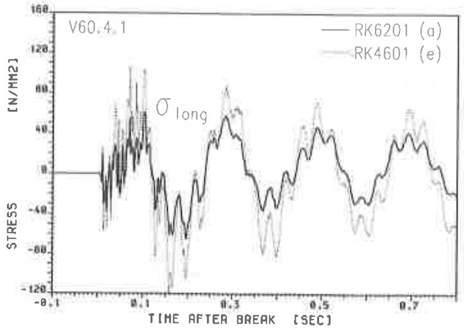

Fig. 7 Longitudinal strain influenced by edge displacement (damped valve)

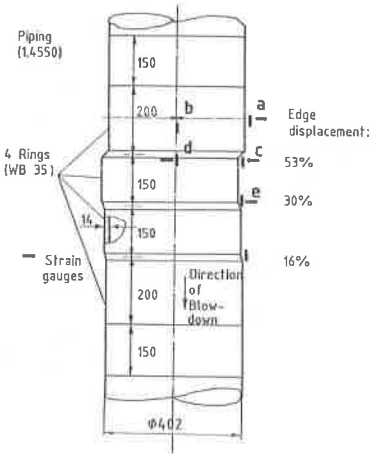

Fig. 6 Specimen with artificial displaced welds and strain gauges

Table I Increase factors of strain and stress, respectively, due to edge displacement

Edge displacement		0 % ("d")	30 % ("e")	53 % ("c")
V60.4.1 V60.5	Longitudinal Strain	1.1 1.2	1.6 1.7	2.6 2.7
V60.4.1 V60.5	Circumferen-tial Strain	1.2 1.4	1.2 1.1	- 1.1
V60.4.1 V60.5	Longitudinal Stress	1.1 1.2	1.8 1.8	- 2.8
V60.4.1 V60.5	Circumferen-tial Stress	1.4 1.4	1.3 1.2	- 1.4

(Compared with undisturbed points "a", "b")

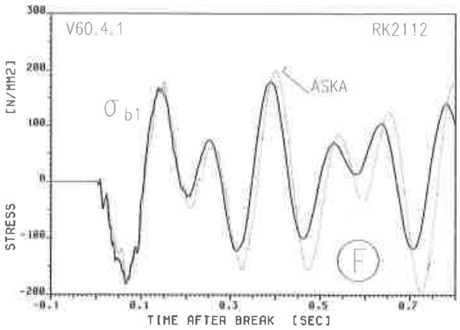

Fig. 8 Bending stress σ_{b1} at cross-section F: Measurement and calculation

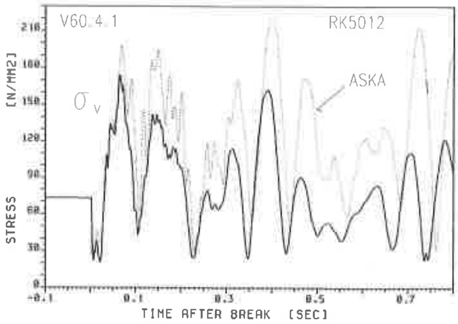

Fig. 9 Reduced stress σ_v at cross section F: Measurement and calculation