

# Pipe loads in the case of a safety valve blowdown with phase change

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## 1 INTRODUCTION

For design of piping systems the dynamical response of the structure due to flow induced forces under normal and accident conditions has to be known.

As experimental tests can not provide all stresses, strains and displacements during transient loadings, in many cases the underlying analysis has to be carried out by a computer simulation of the piping system based on an appropriate numerical structural model.

This approach is of particular interest in design of nuclear reactor components, where also hypothetical accident conditions have to be considered.

As an example in the present paper we discuss the safety- and relief-valve systems of a KWU pressurized water reactor that functionally protects the primary reactorsystem against overpressure. This facility consists essentially of the pressurizer and the main blowdown pipes to the safety- and relief valves.

The transient loadings for this piping system emerge from flow induced forces during valve operation under normal conditions (steam discharge) and under accident conditions (subcooled water and 2-phase mixture discharge). The latter situation may occur in a few cases of anticipated transients without reactor shut down (ATWS).

On a fullscale KWU-test facility /1/ blowdown experiments were carried out to get knowledge about some physical parameters, to improve the fluiddynamic code for calculating load functions and to correct the structural model.

Which the load functions as input the resulting motions of the structural model were calculated.

## 2 THE PROBLEM AND THE APPROACH TO SOLUTION

The strains induced in the piping by the blowdown process have been evaluated earlier for the loadcase steam blowdown in some power plants. Insufficient knowledge in evaluating hydrodynamic loading and the thereby induced vibration of the piping had to be dealt with using conservative assumptions eg. the rate of valve stroke or the structural damping.

Another point of uncertainty is the stiffness of supports. Whereas for static loadings the assumption of very stiff supports normally leads to conservative results, in the dynamic case no such simple rule holds.

From a series of blowdown experiments of the test facility, see Fig.1, one typical test was chosen, showing steam blowdown followed by sub-cooled water-steam mixture.

Measurements of pressure, forces and displacements serve to adjust the hydrodynamical code and to correct the structural dynamical model.

### 3 EXPERIMENTS CARRIED OUT

In a first series of experiments, tests were performed with a very stiff and rigid support of the pipe. The pipe was supported in its horizontal and vertical axial direction, and the support loads as well as the in-pipe pressures were measured. In a second series of experiments the pipe supports were changed to allow for considerable pipe vibration, comparable to the situation in a power plant. The displacements, the snubber forces and the in-pipe pressures were measured, see Fig.2.

The first series of tests allowed a verification of the hydrodynamic codes described in chapter 4, the second series of tests allowed a correction of the structural dynamic parameters described in chapter 5.

### 4 ESTIMATE OF HYDRODYNAMIC LOAD FUNCTIONS

The hydrodynamic load functions which are input for the structural analysis have been determined with the postprocessor TRAF0 from fluiddynamic data generated with the Transient Reactor Analysis Code TRAC-PF1 by conducting post test calculations of the experiments.

While in single-phase blowdown (steam or subcooled water) the force amplitudes depend essentially on the valve stem velocity during valve-opening and closing-operation, in two-phase mixture blowdown they are very strongly affected by the degree of subcooling of the water-front that follows the initial steam discharge and hits the valve orifice.

In an earlier paper /2/ we have already reported on the single phase post-test calculation stressing the fact, that due to much smaller valve stem velocities under water conditions the force amplitudes are only slightly higher compared to those from a steam blowdown.

Conducting post-test calculations of the two-phase mixture experiments, we found that the code TRAC-PF1 as it stands was not capable to simulate the steep void gradients in the safety line caused by the propagating steam-water-interface in the various cases.

In order to fit the experimental data with respect to pressure gradients and the resulting measured pipe-support forces in the two-phase mixture tests, the code needed to be updated in its interphase correlations. With these corrections (for details see /3/) the experimental data could be reproduced with fairly close agreement.

As an example fig.3 shows the valve inlet pressure of a post-test calculation compared with the experimental data of a two-phase mixture blow-down test with 15 K subcooled water. In fig.4 the associated normalized force time-history  $F/F_{\max}$  for the longest straight pipe segment of the safety-valve line is given. Since in the region of

moving-mixture front the calculated in-pipe forces are about 20 % too low compared with the experimental results, a scaling of the loadfunctions by a factor of 1.2 restricted to this region was performed.

## 5 RESPONSE OF PIPING DUE TO HYDRODYNAMIC LOADING

The analysed part of the test facility comprehends the two vessels simulating the pressurizer, the blowdown piping, the safety valve with the attached steam dome, the piping to the relief tank and parts of the feeding pipe. These components were transformed to a finite element beam model with the computer code KWUROHR. The four snubbers were represented by linear springs. Stiffness of steamdome supports and the vessel support were calculated using simple beam equations. However the vessel support stiffnesses associated with rotation are in doubt due to incertitudes in the fastening of the double-T-beams to the concrete. Therefore experimental results were used to fit these stiffnesses.

Along the two greater straight parts of the blow-down piping the stiffnesses in axial direction at the nodes 55 and 68 were measured. Furthermore from the displacement signals W9 and W10, see fig.5 and 6, an eigenfrequency of about 3,4 Hz was estimated. The vessel support stiffness mainly affects both the piping stiffness at node 55 and the mentioned eigenfrequency, which is associated with a motion in axial direction at node 55. From the table below you can see that in this point a certain degree of optimization is reached, since the ratios of calculated to experimental values equal one.

The response of piping was determined by direct integration of the equations of motion including the hydrodynamic functions mentioned above. One parameter till open was the degree of critical damping. From the whole recorded time histories at W9 and W10 a value of about 5 % can be derived. For the whole structure this value seems to be somewhat too high. In a first run of integration a value of 1 % critical damping results in a mean value of the ratio calculated to experimental range of all signals of 1.05. However, 3 % critical damping seems to be a good compromise, leading to the results listed in the table below. As a further example fig.5 and fig.6 show the calculated time histories for the signals W9 and W10 in comparison to experimental results.

## 6 CONCLUSION

Steam blowdown with mixture of subcooled water represents a very complex loading for the pressurizer-safety valve system. Having adjusted the hydrodynamic loads and structural parameters to experimental data, a computer model is available to calculate similar load cases. On the other hand, our experience is confirmed that in the case of complex loadings a reliable evaluation of strains and stresses in a piping is only possible based on experiments.

## REFERENCES

- /1/ Simon, U., A.Knapp, W.von Rhein, F.Agemar, W.Hofbeck & R.Puzalowski. 1986. Untersuchungen zur Funktionssicherheit der Druckhalter-Sicherheitsventile beim Abblasen von heißem Druckwasser und vollem Massendurchsatz in Originalgeometrie. Förderungsvorhaben BMFT 1500 636/7.

/2/ Puzalowski, R. & U. Neumann. 1986. Numerical simulation of self-actuating valves and its application. 1st. Int. Multiphase Fluid Transients Symposium. ASME, FED-Vol.41, p.85

/3/ Puzalowski, R & U. Neumann. 1987. Interfacial mass, heat and momentum transfer correlations in fast propagating two-phase mixture fronts. To be published in Proc. of 1987 ICHMT Int. Symposium on Transient Phenomena in Multiphase Flow.

TABLE

	exp.value	calc.value	ratio calc/exp.
<u>Stiffness in N/mm</u>			
node number 55	4400	4260	0.97
" " 68	7200	8110	1.13
<u>Eigenfrequency in Hz</u>			
Signals W9, W10	3,4	3,58	1,05
<u>Displacement ranges in mm</u>			
W9	8,4	6,94	0,83
W10	12,4	8,46	0,68
W12	26,0	22,9	0,88
W13	8,0	5,55	0,69
W14	9,5	7,76	0,82
W15	11,4	10,5	0,92
W16	6,0	6,93	1,16
<u>Force ranges in KN</u>			
D8	92	57,3	0,62
D9	36	44,3	1,23
D10	58	65,2	1,12
D11	17	16,9	0,99

$$\text{Total mean value} = \frac{\sum_{i=1}^n \frac{\text{calc}}{\text{exp}}}{n} = 0,936$$

$$\text{Total root mean square value} = \sqrt{\frac{\sum_{i=1}^n (1 - \frac{\text{calc}}{\text{exp}})^2}{n}} = 0,195$$

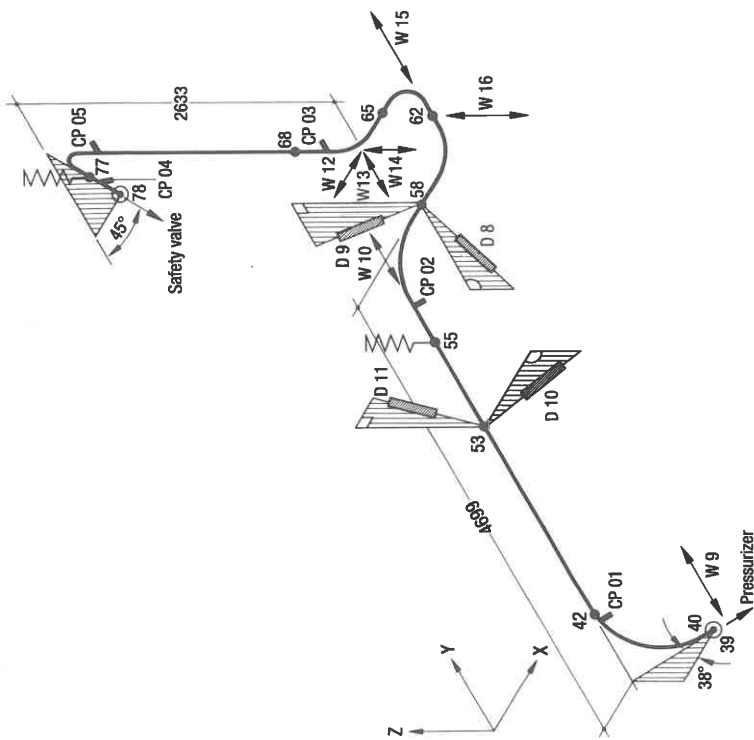


Fig. 2: Piping between pressurizer and safety valve. Locations of the pickups for a) pressure: CP..., b) displacement: W..., c) snubber force: D...

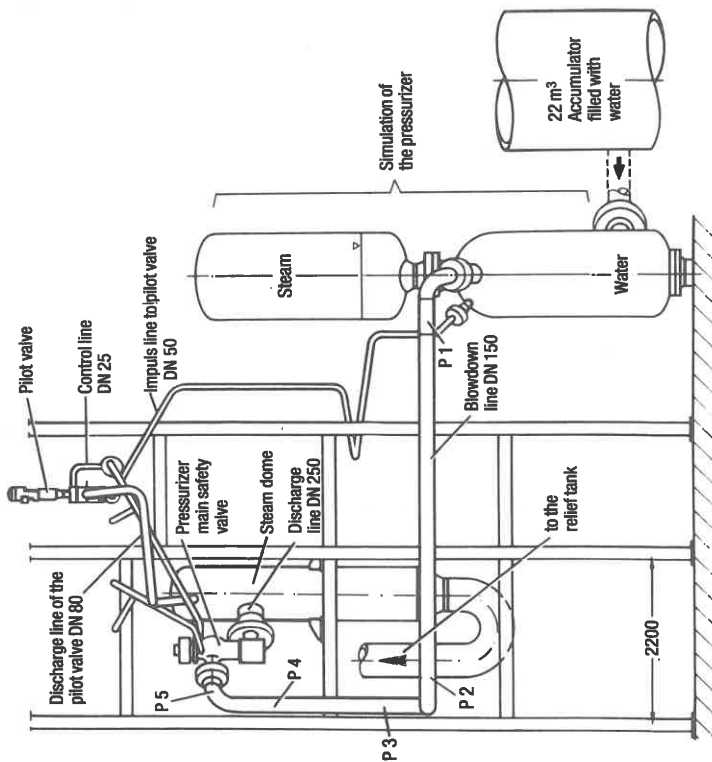


Fig. 1: Full scale test facility of a KWU pressurizer safety valve system

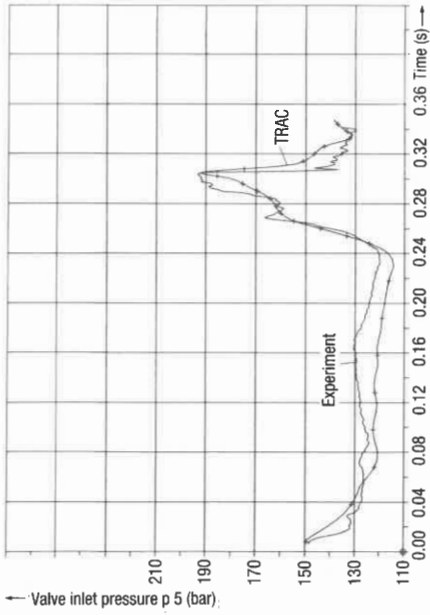


Fig. 3: Comparison of a TRAC-post-test calculation with experimental data of a 2-phase-mix force blow down with 15 K subcooled water

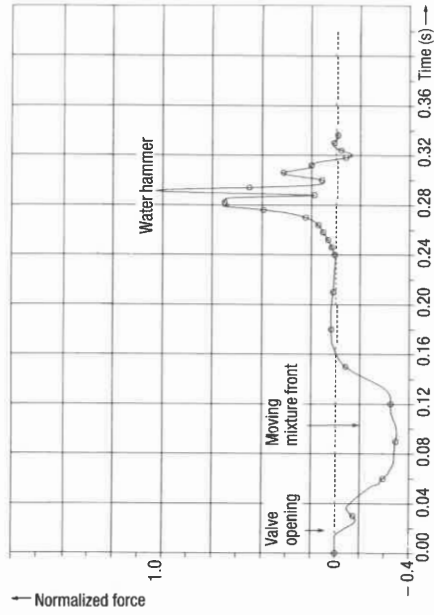


Fig. 4: Resulting force on the longest straight pipe segment of the blow down line

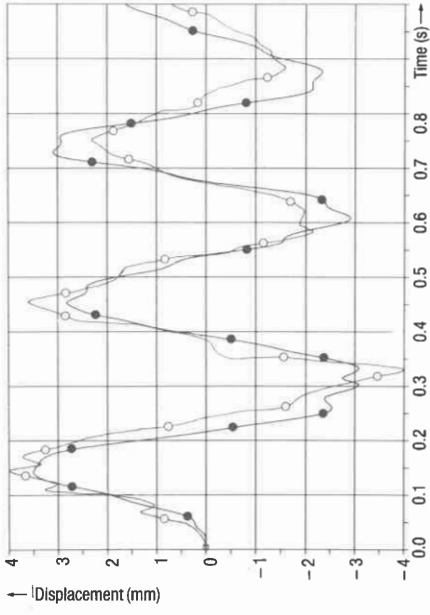


Fig. 5: Comparison experimental (○) to calculated (●) displacement time history at W 9

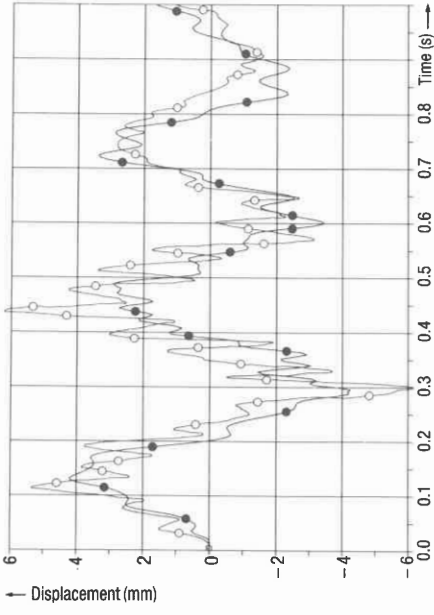


Fig. 6: Comparison experimental (○) to calculated (●) displacement time history at W 10