EUDRU Analysis Code for Fluid Dynamics in Piping Systems with Check Valve Closing

R. Wölk
Kraftwerk Union AG, Reaktortechnik, Berlinerstr. 295-299, D-6050 Offenbach/Main, Germany

Abstract

This paper compares analytical results obtained using the EUDRU computer program with measured results from the HDR-SRV 350 blowdown experiments V60.4, V60.5, V60.6 and V60.7. In these experiments water at a temperature of 220 °C and a pressure of 72 bar is allowed to expand by a rupture disc at the end of the pipe, whereupon a check valve closes resulting in a pressure wave. The total stroke of the valve was 130 mm. Case V60.4 featured abrupt damping, in the case V60.5 the valve was undamped and in V60.6 and V60.7 there was optimized damping. The computed results are postcalculations for experiment V60.4, V60.5 and V60.6, and precalculations for V60.7. In evaluating experiments V60.4, V60.5 and V60.6 the experimental time histories for valve stroke, pressure and mass flow upstream of the valve were approached by modelling in the calculations the loss coefficients of the valve. Using this step-by-step process with increasing understanding and improved adjustment of the calculations to the experimental results, it was then possible to arrive at a satisfactory precalculation for experiment V60.7.

1 Introduction

Within the HDR-project /1/, the investigation of a postulated pipe break and the flow behaviour of the fluid during safety valve closure /2/, /3/, /4/, are essential aspects both in terms of experiments and calculations. Calculations of the first three experiments using the EUDRU program /5/, /6/ have already been reported /7/.

This paper presents the accompanying calculations to experiments 60.4, 60.5, 60.6 and 60.7.

The general conditions were the same as for Experiment 60.1. Water at a temperature of 220 °C and a pressure of 70 bar flows through a nearly 40 m long loop at a velocity of 4 m/s (Fig. 1). The rupturing of a double diaphragm in the pipe causes reversal of the flow, this closing a check valve. The rapid deceleration of the flow by the closing valve causes a pressure rise and pressure waves in the pipe. The calculation and modelling of these flow processes were performed as in /7/ using the EUDRU program, by solving numerically EULER's one-dimensional differential equations according to the Mac Cormack method. For this, the valve-closing movement was coupled with the flow.

2 General conditions and input data

In contrast to the first three experiments, only valve parameters were changed. The experiments were carried out with the larger initial stroke of 130 mm and a somewhat differently shaped valve disc. The latter has no influence on the blowdown process. In addition, the height of the damping chamber in the valve was reduced to 44 mm and a further measuring ring was applied at the break location for measuring the density and mass flow.

The central pipe support was removed.

As regards the changes to the valve parameters, the most important are the change of damping profile and of damping clearance. The damping profile used in 60.1 to 60.3 was changed for 60.4 into a 45° inlet profile. As a result of the sudden inlet constriction a sharp change in the valve characteristics had to be expected. In a further experiment, 60.7, the damping clearance was increased to 0.5 mm in order to modify the valve characteristic with regard to closing time. This meant that experiments with three different clearances and the accompanying calculations were performed.

The modelling of the input data for these experiments is divided into the geometrical pipe and valve data and the fluidmechanical data. Whereas the geometrical input data for the precalculations and postcalculations are identical the fluid data for the postcalculations were adjusted to the results of the experiments. Of these, merely the flow loss coefficients at the valve disc (Fig. 2) and particularly the coefficient of the flow in the valve gap were adapted. The results of steady-state advance measurements showed losses at the valve disc to be of approximately half the magnitude of those shown in the blowdown experiments (Fig. 2), as a result of the different flow fields. The flow field in the pipe is determined by the sudden drop in pressure at the break location to saturation pressure. Here brief delayed boiling takes place, and expansion results in a reduction of temperature. The decompression wave runs into the pipe and accelerates the water in the direction of the break, which causes the valve to close. A pressure wave with a frequency of approx. 20 Hz then forms between valve and vessel.

3 Comparison of measurement with calculation

3.1 Experiment 60.4; rapid damping

In contrast to 60.1, more rapid damping was to be achieved by means of a 45° inlet profile, on the basis of a maximum stroke of 130 mm. The damped length of stroke was shorter due to the smaller damping chamber, 44 mm. The changes to these valve parameters resulted in a single pressure wave of 115 bar (Fig. 4) at the instant of the start of damping (Fig. 3). In the subsequent damping phase, this pressure wave was damped out by the optimized closing of the valve. The valve characteristics (Fig. 3) display the typical slow-quick pattern. At the end of the quick-closing phase, the closing speed changes from 4 m/s to 0.1 m/s. The valve runs through this damping phase at constant speed and closes after 620 m/sec. A mass flow surge (Fig. 5) occurs with each pressure wave. After three strong surges the mass flow reaches its maximum of 1700 kg/sec and is rapidly reduced in two steps by the closing valve and then tails off.

The principal calculation parameters were the loss coefficients of valve and damping. Whereas the losses at the valve disc fluctuated only minimally around a parabola, depending on stroke, in precalculations, postcalculations and experiments, a correct figure for the loss coefficient in damping could only be obtained with postcalculation, which gave: $\xi_{DT} = 7.5$ and supplied the experimental curves. The valve characteristic with the quick and slow phase, the maximum pressure surge with subsequent damping and the corresponding mass flow pattern through the valve coinside in calculations and measurements in terms of their typical characteristics and extreme values.

3.2 Experiment 60.5; completely undamped

This experiment was carried out with a completely undamped valve. The aim of this was to achieve a maximum pressure surge and as great as possible a load on the pipe. In this case the valve closes after 80 ms at a velocity of 17 m/s (Fig. 6), the valve characteristic displays merely the parabolic quick-closing phase. A pressure surge of approx. 255 bar is generated in the pipe, which oscilate between the vessel and the valve. This was produced by the sudden stopping of the maximum mass flow of 1800 kg/s.

In this test it was not necessary to model the valve damping for calculations. In order to obtain the correct pressure surge, the curve of the loss coefficient at the valve disc was parameterized in such a way that the valve was open for as long as possible and then very rapidly closed in the last closing phase. A result of this was that a high mass flow was generated, which was subsequently stopped rapidly. The program thus calculates the experimental closing characteristic (Fig. 6), which was too short and not parabolic in the precalculations, and the associated pressure wave curve (Fig. 7). The full maximum of the associated mass flow curve (Fig. 8) is not attained in the calculation, but the time derivative relevant to the pressure surge is however achieved.

3.3 Experiment 60.6; optimally damped, large initial stroke

In contrast to 60.4, this experiment was carried out with an optimized damping profile as for 60.1. This condition was employed in order to investigate the influence of the damping profile as compared to 60.4 and in order to investigate the initial stroke as compared to 60.1. Compared to 60.4, the valve characteristic in this case displayed an even longer damped phase, with a closing time of approx. 720 ms (Fig. 9). Here the pressure surge at the start of the damping phase reaches a value of only 100 bar (Fig. 10).

When modelling the calculation for this experiment on the basis of the input of an optimized flow area in the valve, the loss coefficient assumed for the precalculations, being $\xi_{DT} = 4.5$, was too low. Not until the postcalculations of 60.4 had been successfully concluded, did the calculations of 60.6 give a result of $\xi_{DT} = 9.5$ for the experimental pressure wave measurement (Fig. 10), with the maximum pressure value of 100 bar. Within the quick-closing phase, the characteristic shows a horizontal curve, which indicates a brief interruption of valve moment as a result of the reflection of the pressure wave. This was accounted for in the calculations by the temporary opening of the valve.

3.4 Experiment 60.7; Larger damping gap

In order to investigate the influence of the damping gap, this was set at 0.5 mm in 60.7. This represented an intermediate value, between 1 mm in 60.3 and 0.3 mm in the other experiments. It was expected that the larger gap would result in a shorter closing time and a slight increase in the pressure surge. In comparison to 60.7, the closing time was substantially reduced to 315 ms as a result of a quicker damped closing-phase (Fig. 11). In comparison to 60.6, the pressure wave was increased, but not to any considerable extent, to a maximum value of 105 (Fig. 12). A consequence of the shorter damping phase is the occurrence of greater oscillations in the closed pipe following complete closure of the valve.

With a larger gap being taken as a basis, a loss coefficient in the valve of $\xi_{DT} = 4$ was assumed for the calculations. This value, together with the postcalculations of the previous experiments, led to the most accurate results of precalculations in this experiment, both in terms of the stroke-time-history (Fig. 11) and the pressure-time-history (Fig. 12). Due to the somewhat earlier start of the closing movement in the calculation, the pressure curves occur correspondingly earlier, but this does not affect the quality of this calculation.

Conclusions

a) The four experiments described here with their accompanying calculations are distinguished from experiments carried out earlier by the valve parameters, such as, stroke, damping and clearance of the valve. These were varied in these experiments and show the sensitive influence they have on valve characteristics and the pressure-time-history both in experiments and calculations.

b) The most important parameters for the calculation are the loss coefficients at the valve disc and in valve damping.

c) The loss coefficients of the valve disc measured in a steady-state condition are roughly half as great as the values for blowdown; the latter after slight change were used in the calculations.

d) With the exception of 60.7, the valve damping assumed was too low in precalculations. Only when the postcalculations were carried out did the correct value lead the agreement with the results of the experiments.

e) When the experimentally determined loss coefficients now available are selected, the pressure surge calculation with the EUDRU program gives results which correspond well with the experiments.

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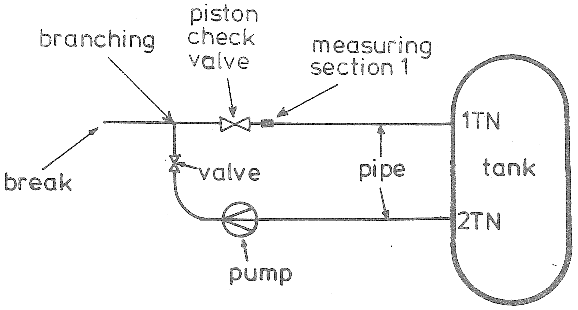

FIG. 1 SKETCH OF THE EXPERIMENTAL LOOP
1TN... 1^{st} tank nozzle
2TN... 2^{nd} tank nozzle

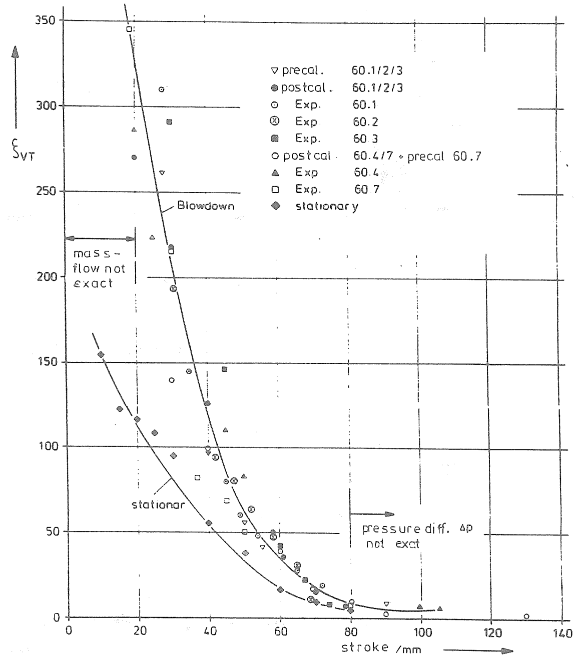

FIG. 2 COMPARISON OF STEADY-STATE AND BLOWDOWN RESISTANCE OF PISTON CHECK VALVE

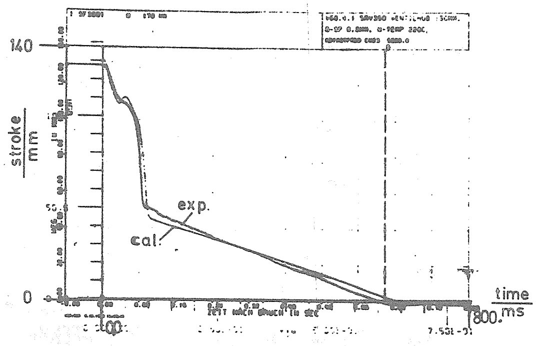

FIG. 3 comparison: calculation/experiment 60-4
stroke-time-history of piston check valve

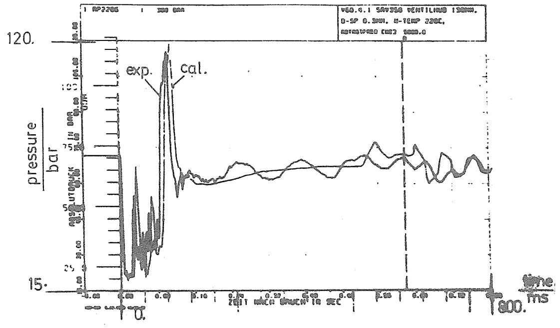

FIG. 4 comparison: calculation/experiment 60-4
pressure -time-history / measuring section 1

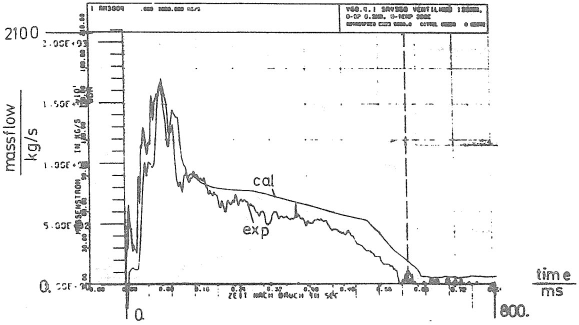

FIG. 5 comparison: calculation/experiment 60-4
massflow-time-history / measuring section 1

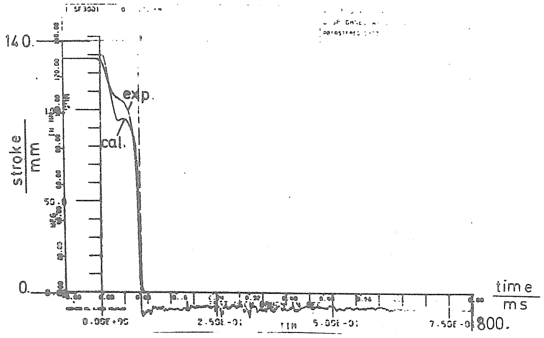

FIG. 6 comparison: calculation/experiment 60- 5
stroke-time-history of piston check valve

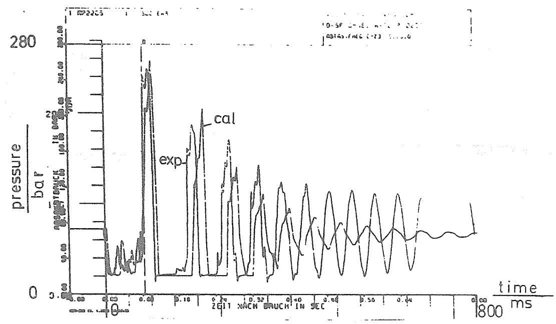

FIG. 7 comparison: calculation/experiment 60- 5
pressure -time-history / measuring section 1

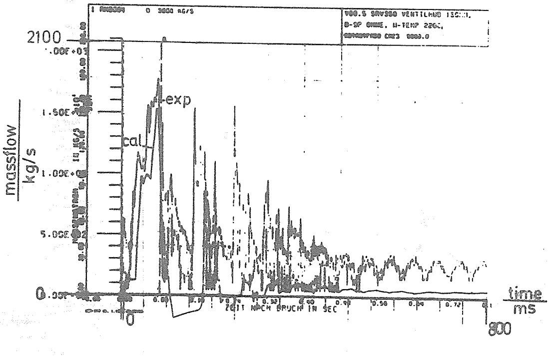

FIG. 8 comparison: calculation/experiment 60-5
massflow - time - history / measuring section 1

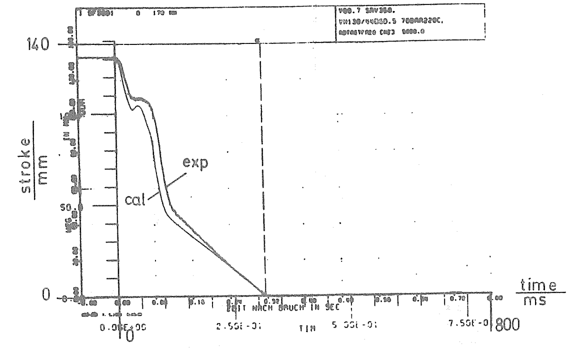

FIG. 11 comparison: calculation/experiment 60.7
stroke-time-history of piston check valve

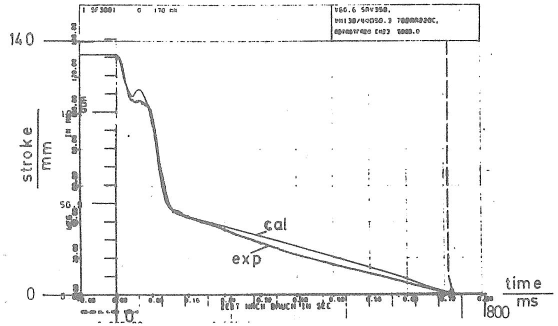

FIG. 9 comparison: calculation/experiment 60.6
stroke-time-history of piston check valve

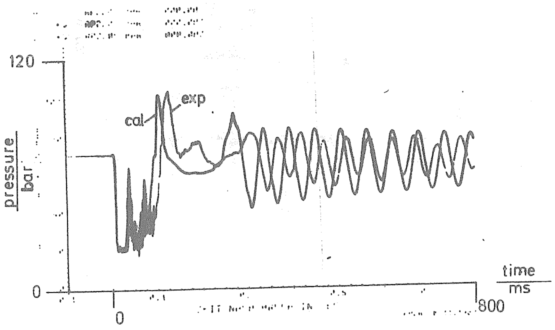

FIG. 12 comparison: calculation/experiment 60.7
pressure-time-history / measuring section 1

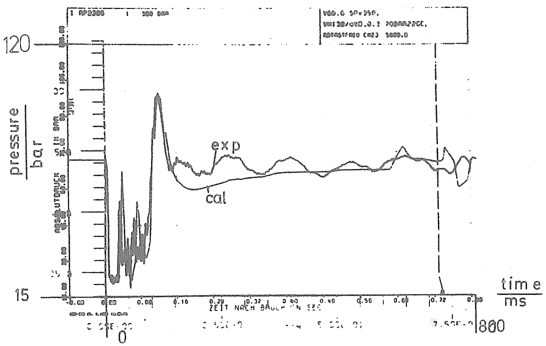

FIG. 10 comparison: calculation/experiment 60.6
pressure-time-history / measuring section 1