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Comparisons of Experimental Blowdown Data with the Results of a Fluid-Structure Coupled and an Uncoupled Code

R. Gehrmann
Brown Boveri Reaktor GmbH, Postfach 5143, D-6800 Mannheim 1, Germany

Summary

This paper compares the experimental data from a blowdown test at the German HDR facility (German standard problem No. 5) to two pre-test pressure wave propagation analyses performed with the explicit 3-D finite difference code PISCES 3D.

One calculation incorporated full fluid / structure coupling while the other treated the structural components as rigid bodies i.e. there was no fluid / structure coupling.
Comparison of the experimental results to the pre-test predictions shows the need to use fluid / structure coupled analytical methods to simulate the short term dynamics of this experiment.

1. Introduction

Pressure wave propagation and structural loading data obtained from a blowdown experiment at the HDR facility are compared to two pre-test calculations performed with PISCES 3D as part of the German standard problem No. 5. One calculation used a fluid / structure coupled version of the code and the other used a simpler uncoupled version.

PISCES 3D /1, 2/ is a three dimensional explicit finite difference program with Euler and thin shell structural processors developed to solve problems of continuum mechanics. A thermal equilibrium two phase fluid model is used to calculate fluid dynamics. In the fluid / structure coupled version of the program, the shell processor is based on the SADCAT-code developed at the Argonne National Laboratories and is formulated in an explicit finite element way. The thin shell processor calculates both plastic and elastic deformations following large-displacement small-strain theory.

2. PISCES 3D model description

The model (Fig. 2) of the vessel and the blowdown pipe are fully three dimensional. By neglecting asymmetric nozzles it is possible to model only one half of the vessel (Fig. 2, 3). This results in:

vertically	29 zones	(K = 1 - 30)
azimutal	13 zones	(I = 1 - 14)
radial	7 zones	(J = 1 - 8)

This creates 2639 volumes for the reactor vessel.
The blowdown pipe has 22 volumes (I = 1 - 12, J = 1 - 2, K = 1 - 3).

The thin elements representing the core barrel are positioned at J = 6, the actual location of the core barrel inside the vessel (Fig. 1, 3). That means, that the core region is radially modeled by 5 zones, the downcomer by 2 zones. The core barrel occupies no volume in this model (Fig. 3, 4). It lies between the interface of zone 5 and 6 (radially). The core barrel is assumed to be rigidly clamped on its upper end. The lower end of the core barrel is attached to a mass ring representing the core mass. The core barrel is simulated by 624 triangular shell elements, whose grid points have the same coordinates as the Euler points. To calculate bending moments and strains, the shell was divided radially into three sublayers. The material was assumed always to be elastic. In both calculations the reactor pressure vessel itself was always considered to be rigid. Only the core barrel was treated as a fluid coupled structure in one calculation and as a rigid structure in the other.

The expected initial conditions for the test were provided by the standard problem specification /3/. A temperature profile ranging from 221.5 °C (lower plenum) to 310 °C (upper plenum) was modeled in the inner region. A constant temperature of 238 °C was used in the downcomer and the blowdown nozzle. The pressure was set to 110 bar. The proper break opening time for the model was determined through sensitivity studies. The calculations were compared to an earlier experimental test case (V 31.1) and break opening time was varied until the same pressure to time slope at the nozzle was obtained. This was for a break opening time of 2 ms. Physical data for the structure was based on the average temperature of 240 °C.

E-modul:	1.8E11 N/m^2
Poisson ratio:	0.29
Density:	7810 kg/m^3
Weight of the mass ring:	6750 kg (1/2 model)

The fluid-structure coupling option:
The zone interface plane which represents the core barrel was modeled by "interactive points", i.e. points in the Euler grid which are movable. One fourth of the force on each of the 4 zones surrounding a grid point are summed up and transferred to the analog shell point simulating the core barrel. The shell responds according to its bending behavior. The new coordinates of the shell point are then transferred back to the Euler grid point. In that way, there is a continuous rezoning of the interactive Euler points. This simulates the movements of the core barrel.

The method of simulating the movement of the core barrel is effectively the local application of the arbitrary Lagrangian Euler technique (ALE).

3. Results and comparisons

Figures 5 to 8 show sketches of the predicted core barrel deformations at 5 to 90 ms into the blowdown. The core barrel movement has been exaggerated in the figures to make the deformation more visible. Figures 9 to 12 compare representative transducer signals from the blowdown experiment to the corresponding precalculated results of PISCES 3DE (uncoupled) and PISCES 3DELK (coupled). The transducer shown in figure 9 is located in the downcomer about 1 m above the break nozzle. The fluid / structure coupled solution is in very good agreement with the experiment. The phase shift starting at 80 ms could be caused by vibration of the reactor vessel itself. The measured displacements of the vessel are nearly of the same order as the displacement of the core barrel and will certainly have an influence on the pressure wave propagation. This was not considered in the analysis since the effort for the additional fluid / structure coupling of the reactor pressure vessel would have been considerably higher. Figure 10 shows the pressure differential between the downcomer and the inside of the core barrel at a position a little below the opening of the blowdown pipe. Except for a slight phase shift after 60 ms the agreement between the experiment and the coupled version results is excellent. At least for the HDR facility, figure 9 and 10 clearly demonstrate the necessity of using fluid / structure coupled programs for the pressure wave propagation analyses. The uncoupled calculation shows poor agreement in both amplitude and phasing right from the beginning. Figures 11 and 12 show displacement and strain at two locations as predicted by the fluid / structure coupled calculation. Although the geometrical modeling of the structure was relatively rough in comparison to that used in advanced structural codes, both displacement and strain also show good agreement to the experiment.

The results of these two pre-test calculations clearly show the importance of using fluid / structure coupled methods to perform best estimate blowdown pressure wave analyses.

4. References

/1/ PISCES 3DE, User's Manual (Version 1)
Physics Int. Company, San Leandro Calif.

/2/ Theory Manual Shell
Physics Int. Company, San Leandro Calif.

/3/ Müller, W. Ch.: Spezifikation zum Deutschen Standardproblem Nr. 5
GRS, Oktober 1981

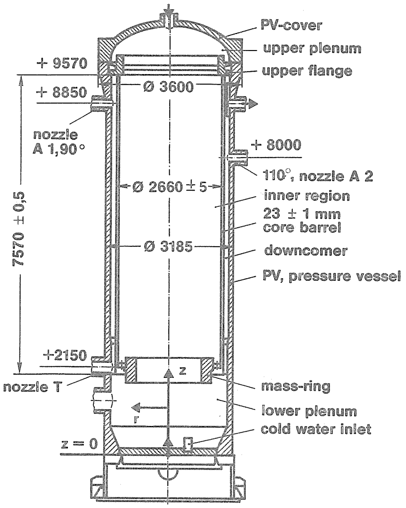

Fig. 1 Reactor pressure vessel and core barrel

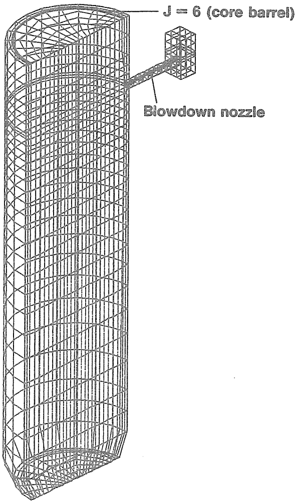

Fig. 2 Reactor pressure vessel (PISCES 3 D MODEL)

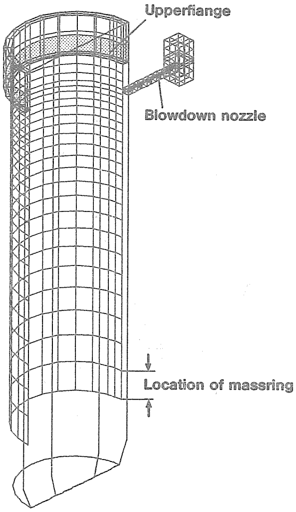

Fig. 3 Core barrel (PISCES 3 D MODEL)

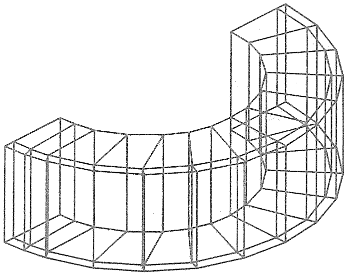

Fig. 4 Massring (PISCES 3 D MODEL)

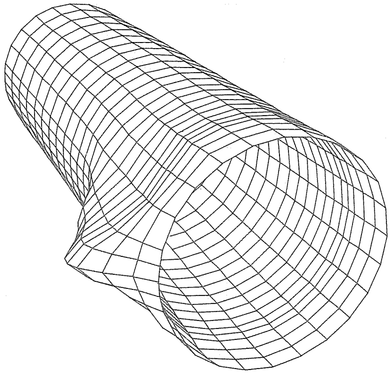

Fig. 5 Core barrel movement (5 ms)

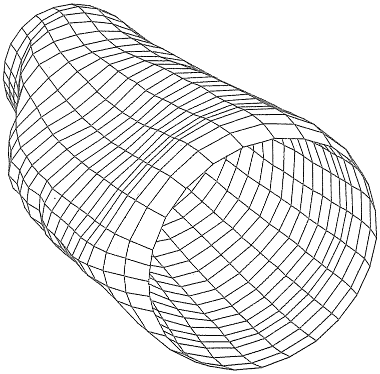

Fig. 6 Core barrel movement (15 ms)

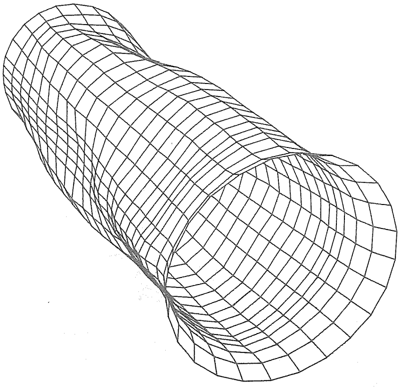

Fig. 7 Core barrel movement (50 ms)

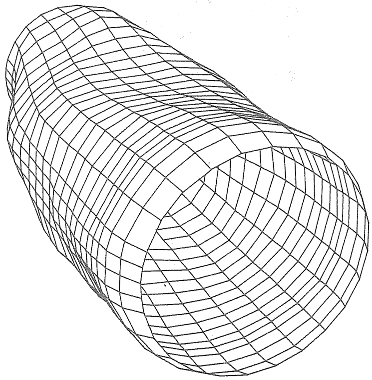

Fig. 8 Core barrel movement (90 ms)

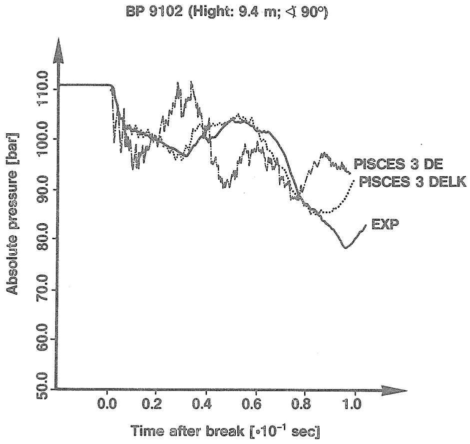
BP 9102 (Hight: 9.4 m; ∢ 90°)

Fig. 9 Absolute pressure

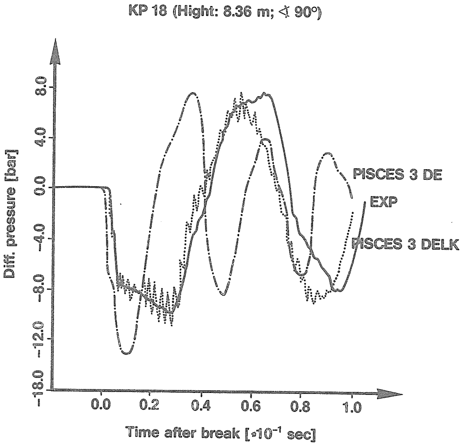
KP 18 (Hight: 8.36 m; ∢ 90°)

Fig.10 Difference pressure

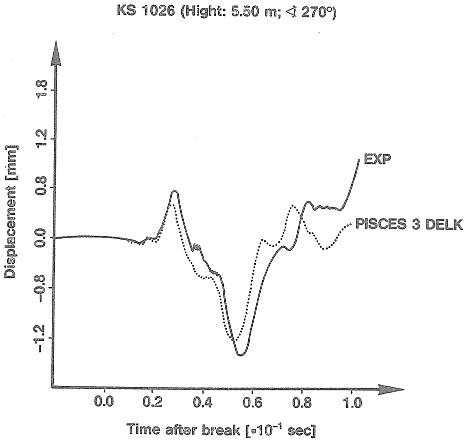
KS 1026 (Hight: 5.50 m; ∢ 270°)

Fig. 11 Displacement

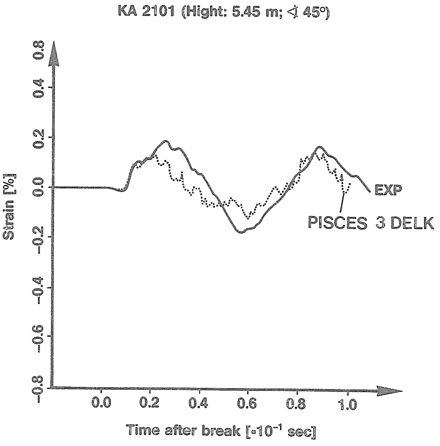
KA 2101 (Hight: 5.45 m; ∢ 45°)

Fig. 12 Strain