F1 2/4

Modelling of Coupled Self-Actuating Safety, Relief and Damped Check Valve Systems with the Codes TRAC-PF1 and ROLAST

U. Neumann, R. Puzalowski
Kraftwerk Union AG, R 152, Postfach 3220, D-8520 Erlangen, Germany
I. Grimm
INTERATOM GmbH, Postfach, D-5060 Bergisch-Gladbach 1, Germany

Abstract

Numerical valve models for simulation of selfactuating safety valves and damped check valves are introduced for the computer programs TRAC-PF1 and ROLAST. As examples of application post-test calculations and stability analysis are given.

1. Introduction

Self-actuating valves are employed as part of overpressure protection systems in various industrial applications, where constructive layout and operating principles may differ according to the requirements of the automatic control circuit involved.

An essential feature of the dynamical behavior of these valves is the strong coupling to their system-environment, i.e. via fluid properties, geometric design of vessels and connecting pipings have essential influence upon the valve motion that in turn feeds back to the dynamics of the structure through flow-induced forces.

For the layout of such a valve-piping system which encludes load estimates of the pipings and vessels as well as an analysis of dynamical stability of the valve it is necessary to estimate the valve motion taking into account the given geometrical and fluiddynamical boundary conditions.

In the present paper we introduce numerical models for analysis of the dynamical behavior of valve-piping systems being coupled in the described manner.

In particular the developed dynamic valve models here allow for simulation of

- self-actuating safety and relief valves
- self-actuating spring-loaded safety and pilot valves
- self-actuating damped check valves

as well as hydrodynamically coupled systems of these valve types in various combinations including the connecting pipings and vessel components.

To cover a wide range of applications the numerical fluiddynamic codes that have been used here are TRAC-PF1 [1] and ROLAST [2].

They have essentially the following features:

TRAC - one/three-dimensional two-phase, two-fluid, nonequilibrium hydrodynamics model (with a noncondensable gas field);
semi-implicit numerical solution techniques;

ROLAST - one-dimensional-two-phase equilibrium hydrodynamics model; Lax-Wendroff numerical solution technique.

The paper is organized as follows:

As application of the TRAC-model we present post-test calculations of experiments with a safety-valve system performing subcooled water and steam discharge. In a further application of the same code a post-test calculation of an experiment testing a damped check valve is given.
As an application of the ROLAST valve-model we study dynamic stability of a spring loaded pilot valve during steam and subcooled water discharge.

2. Valve models

Both of the above mentioned codes have valve-models implemented. The ROLAST valve-model is extensively described in [2] and is applicable in numerous cases.
The original TRAC valve component [1], however, was not sufficiently developed for our purposes and the improved TRAC valve-model that has been used here will be described briefly.
In order to account for the coupling of the equations of motion of the valve stem and the fluiddynamics equations of the basis code, TRAC had to be extended by an additional valve submodul that also features the treatment of variable control volumes which are necessary for the description of damped valve types.
In particular the underlying set of equations being simultaneously solved under the assumption of thermodynamical and mechanical equilibrium in the valve modul of the extended TRAC code in case of a single damping volume are given by:

the equation of motion of the valve stem

$$m\ddot{x} = -c_s x + \sum A_j p_j + F_0$$

and the fluiddynamic equations

$$\dot{p} = (\sum G_i - \rho A\dot{x})/V(\partial\rho/\partial p)_h - \dot{h}((\partial\rho/\partial h)_p/(\partial\rho/\partial p)_h)$$

$$\dot{G}_i = (\Delta p_i - \zeta_i(|G_i|G_i/(\rho A_i^2)) + (1/A_{e,i}^2 - 1/A_{a,i}^2)G_i^2/\rho)/\sum(L_i/A_i)$$

$$\dot{h} = (\sum G_i h_i + V\dot{p} - h\sum_i G_i)/\rho V$$

m and x denote the valve stem mass and position respectively.
The remaining variables are:

c_s - spring constant; F_0 - constant force term; p - pressure in damping volume V;
p_j - pressure on valve stem areas A_j and A;
ρ - density in V; h - enthalpie in V;
G_i, h_i - mass flow rate and enthalpie from adjacent TRAC-component i;
A_i, L_i - flow area and streamline length of G_i; ζ_i - loss coefficient of G_i.

The coupling of these equations to the basis TRAC-equations is via pressure, mass flow rate and the valve area which becomes a function of x.

3. Applications

3.1 Simulation of a safety-valve system

As a first application of the TRAC valve-model we present post-test calculations of experiments testing a safety valve under subcooled water and steam conditions [3], [4]. The safety valve system consisting of the safety valve, a spring loaded pilot valve, the pressurizer vessel and the connecting pipings is shown in Fig. 1 schematically.
Here the safety valve is operated essentially through the pressure in the damping volume that in turn is controlled by the pilot valve.
A comparison of computational results and experimental data is given for the case of subcooled water discharge in Fig. 2-4 and for steam discharge in Fig. 5.
The opening times of the safety valve are in the range between 70 and 80 ms while those of the pilot valve are 40 ms (for subcooled water). Here especially the time histroy plot of the stem position of the pilot valve shows strong dependence of the stem motion on geometrical parameters of the connecting pipings: in this particular case the length of the feed line causes a stepwise opening.

3.2 Damped check valve simulation

In order to demonstrate the applicability of the TRAC valve-model to damped check valves as well, a post-test calculation of an experiment with a feed water check valve (German standard problem No. 4) has been performed. The test Facility is briefly sketched in Fig. 6. The valve closing was initiated through a simulated pipe rupture of the blow down pipe, which was loaded with subcooled water. Fig. 7 and 8 show the computational results of the TRAC estimate compared against the experimental data.

3.3 Dynamical stability of spring loaded pilot valves

We finally turn to dynamical stability of spring loaded pilot valves that has been analyzed for some valve and feed line parameters with the ROLAST valve-model.
We find as a result that spring properties, valve seat geometry, upstream fluid conditions as well as piping length and flow area are the most significant parameters that affect valve performance.
As an example we present calculations that involve variations of the feed line flow area. Fig. 9 shows an unstable operating valve with a given feed line flow area A_0 and length L_0. Upon change of the area A_0 to $A_1 > A_0$ over a length $L_1 < L_0$ between pressurizer and valve seat the valve motion becomes stable.

4. Conclusions

The above stated results show that both valve models enable us to treat various problems in valve piping systems numerically. Besides the cases presented here TRAC especially opens up the posibility of analyzing valve performance under two-phase flow conditions and additionally fluid mixtures encluding a noncondensable gas.
On the other hand single phase problems such as stability analysis were easiest to handle with ROLAST.

References

/1/ TRAC-PF1: An Advanced Best Estimate Computer Program for Pressurized Water Reactor Analysis NUREG/CR-3567 LA-9944-MS

/2/ Kellner, "Programmsystem SAPHYR, physikalische und mathematische Grundlagen" Interatom-Notiz: 70.02588.4

/3/ Butkereit, Dernbach, "Experimentelle Untersuchungen zur Funktionstüchtigkeit der Druckhalter-Sicherheitsventile bei ein- und zweiphasiger Durchströmung" Abschlußbericht Förderungsvorhaben BMFT/GRS 159 494

/4/ Puzalowski, Neumann, "Berechnung hochtransienter Vorgänge sowie Stabilitätsuntersuchungen an Sicherheitsarmaturen mit TRAC-PF1" to be published in: Tagungsbericht Jahrestagung Kerntechnik Munich 1985

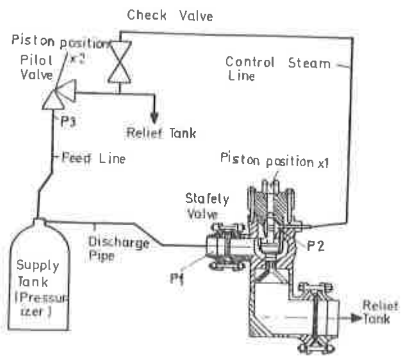


Fig.1 Schematic of the ATWS Test Facility 3 and instrumentation

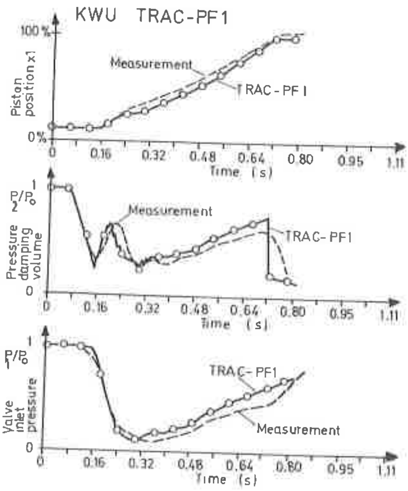


Fig.2 Comparison of experimental data and TRAC post-test calculation of a safety valve test under subcooled water conditions. P_0 = set pressure

Fig.3

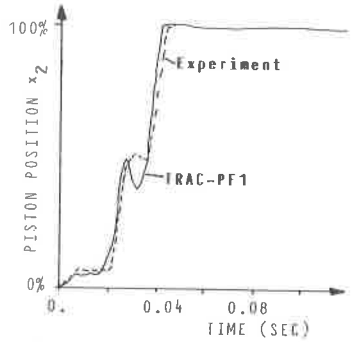
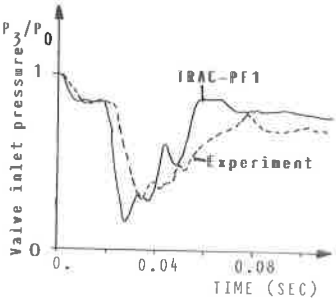
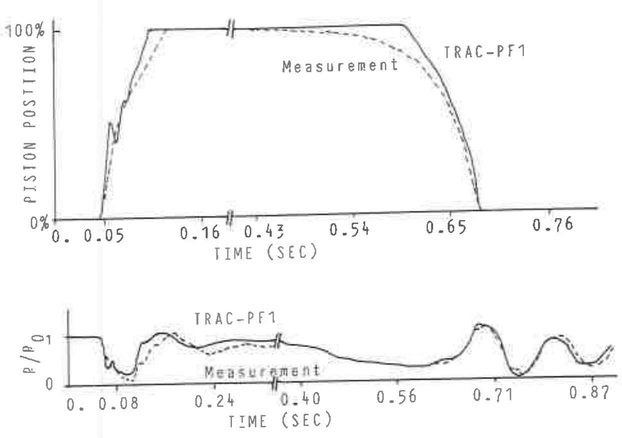


Fig.4



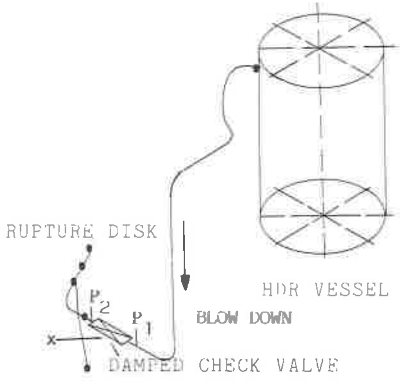
Comparison of experimental data and TRAC post-tets calculation of a pilot valve test under subcooled water conditions



P = valve inlet pressure
P_0 = set pressure

Fig.5 Comparison of experimental data and TRAC post-test calculation of a PWR comissioning experiment

Fig.6 Schematic of the PHDR test facility and instrumentation



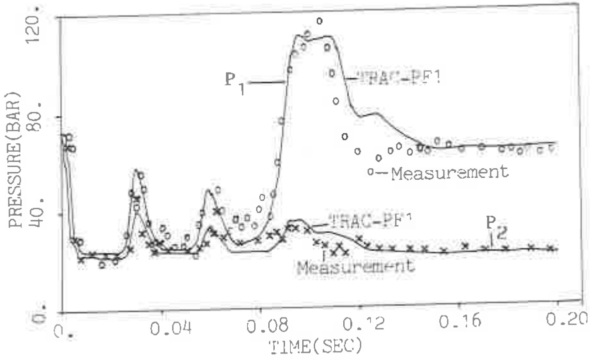


Fig.7 Comparison of experimental data and TRAC post-test calculation of PHDR blow down test V60.4

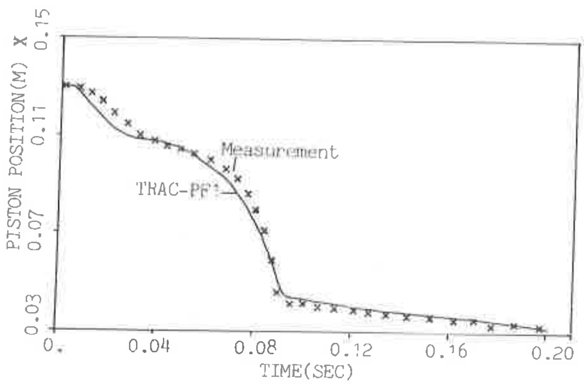


Fig.8 Comparison of experimental data and TRAC post-test calculation of PHDR blow down test V60.4

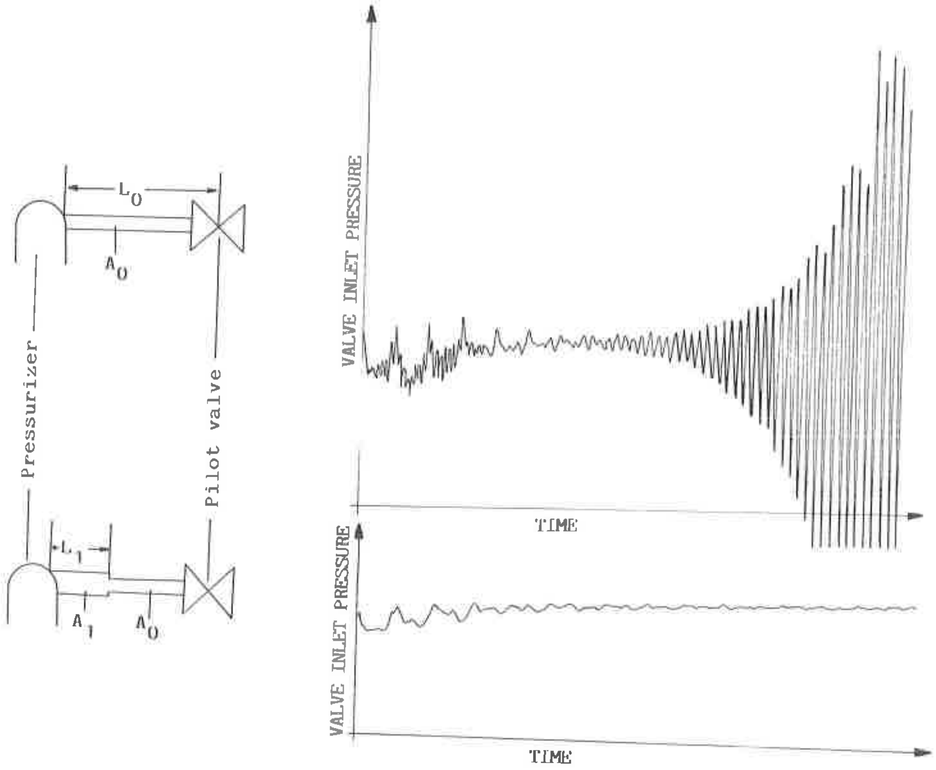


Fig.9 Dynamical stability analysis of a spring loaded safety valve with ROLAST