

HDR-Investigations of Check Valve Closure and Resultant Water Hammer Effects

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SUMMARY

The presented investigations are based on the Loss of Coolant Accident (LOCA). They concentrate on the first blowdown phase after pipe break of a feedwater line.

The effect of such a break is moderated by quick closing check valves, by which the loss of coolant water is reduced and optimal post accident conditions are obtained.

Unfortunately the closure of the valve can cause high pressure peaks (water hammer effects) in the feedwater system which potentially could produce safety relevant secondary damage.

The system loading by these effects has been analysed. The HDR-Investigation-results led to an improvement of the feedwater system safety by verifying damping measures of quick closing check valves. Pressure peaks obtained with undamped valves in the range of 300 bars, are reduced to zero or a few bars above the normal operation pressure in feedwater systems.

For the analytical simulation of valve closure the following dominant acting forces are identified: the blowdown flow resistance of the valve cone and the damping piston force. The analytical description and quantification of the forces depends on blowdown flow and valve friction parameters. These have been evaluated and are presented for practical use.

1. OBJECTIVES

For licensing purpose it is necessary to prove that secondary damage caused by check-valve closing induced pressure peaks after LOCA in a feedwater system of a Nuclear Power Plant can be avoided. This is the background for the HDR-Investigations for which the following general aims were:

- Experimental and analytical verification and quantification of pressure peaks.
- Testing of damping methods - these are mechanisms which limit the valve closing velocity in order to reduce pressure peaks.
- Verification and assessment of analytical methods used to calculate pressure peaks as a function of valve closure behavior.

The following HDR-Findings are presented:

- Experimental results concerning the phenomena of valve closure, the generated pressure peak (water hammer) and the most important influencing parameters;
- Analytical results concerning the force balance for the motion of the valve cone and the main input parameters for the calculations of the pressure behavior.

2. EXPERIMENTAL ASPECTS

A feed water check valve ND 350 mm, similar to the type which exists in many German nuclear power reactors, is installed in an existing HDR-Loop of 350 mm pipe diameter (Figure 1).

The main components of this loop are: pressure vessel (1), pump (7), quick closing valve (to preserve the pump during blowdown) (5), break nozzle (8), and the test check valve itself (4).

Before triggering the pipe break, the feed water operation is simulated with 4 m/s flow velocity, 220 degrees C water temperature and 70 bar pressure in the system. After break the blowdown flow takes place from the reactor pressure vessel via the feed water check valve and the break nozzle.

Two components should be considered at more detail:

- Test check valve (figure 2):
The valve is kept open by the feed water flow (direction of arrow). A feed water pipe break causes a flow reversal. Blowdown mass flow is built up by the system pressure of 70 bar as opposed to the atmospheric ex-

ternal pressure. The armature is closed by the blowdown flow. To influence the closing motion, a damping device is provided. It consists of a piston (2) mounted on the valve rod (1), which immerses into a damping cylinder (3). The displacement of water by the damping piston causes a counter force. Thus the closing motion of the valve is slowed down in dependence upon the dimension of the gap, which defines the overflow cross section between piston and cylinder. During the test runs, the parameters influencing the damping are varied from heavily damped condition to undamped. Specifically, the starting point of damping, the shape angle as well as the damping gap or overflow cross sections are varied.

- Break nozzle (figure 3):

The pipe break is initiated by means of double burst disks. The plant pressure is increased up to the simulated feed water operational pressure of 70 bar. Half this pressure is established between the burst disks. To trigger the break, the pressure between the burst disks is incremented until, at approximately 50 bar pressure difference, the outer disk breaks. The inner disk follows instantaneously whereby the total pipe cross section is cleared within three milliseconds.

2.2 Test matrix (figure 4)

Based on the capabilities of the test facility and the original test valve the following parameters are varied:

- valve and valve damping parameters:
 - . total valve lift (90 mm/130 mm) and damping section of lift related to total lift (65 mm/90 mm, V60.1 - 3; 44 mm/130 mm, V60.4 - V60.7)
 - . gap between damping piston and cylinder (0,3 mm - V60.1/2/4/6; 0,5 mm - V60.7; 1 mm - V60.3; undamped (15 mm) - V60.5)
 - . shape angle of entering area into damping (30°/10° - V60.1/2/3/6/7; 45° - V60.4)

- thermodynamic parameters:
 - . feedwater conditions (220 °C, 70 bar - V60.1/3-7)
 - . cold water conditions (50 °C, 70 bar - V60.2)

3. HDR-EXPERIMENTAL RESULTS

3.1 Surview (figure 5)

The closing time of the valve is dependent on the damping parameters and covers a range of about 0,082 sec to 0,73 sec. In the case of the damped valve the pressure peaks vary between 5 bar and 46 bar above the system pressure of 70 bar, that produces a total pressure of 75 bar to 116 bar. For the undamped case 253 bar are measured. The loss of fluid-mass shows no significant differences and is in all cases much smaller than one cubicmeter.

3.2 Feedwater system loading during blowdown and check valve closure

After pipe break depressurization waves move from the break region into the system. The depressurization step amounts about 50 bar that is from 70 bar to 20 bar saturation pressure.

The pressure waves are reflected and subsequently quickly damped so that a nearly stationary pressure drop along the flow line is observed (figure 6).

The blowdown flow forces check valve closure.

Valve closure brakes the blowdown flow and thus pressure pulses are initiated.

3.3 Valve closure generated pressure pulses (water hammer properties)

In order to analyse the observed pressure peak phenomena, we have to consider two different effects: First the effect, which occurs at the final closing point, when the valve cone reaches its seat and the blowdown flow is definitely stopped. At this time a high pressure peak of more than 250 bar - that means a real water hammer - is obtained with the undamped valve (figure 7).

The reason is, the valve cone is strongly accelerated by the blowdown flow and both cone and mass flow are then suddenly stopped when the cone reaches its seat.

For the case of a damped valve the sequence of events is quite different: In this case the cone acceleration is limited by the damping effect and in consequence the blowdown flow is also reduced. So one observes no significant pressure pulse at the closing point.

But for these conditions a pressure rise occurs in the system at the initiation point of the damping (figure 8). This is the time at which the damping piston reaches the entrance into the damping cylinder forming a small gap between cylinder and piston, for example 0,3 mm. This pressure is to understood as a braking effect of the cone movement, which causes a restriction of the blowdown flow and lead to a pressure increase upstream the valve. This pressure rise depends on the damping parameters of the valve (figure 9).

The damping parameters varied are:

- damped section of valve lift related to total valve lift (H_D/H : 65/90; 44/130);
- damping gap between piston and cylinder (s : 0.3; 0.5; 1.0);
- shape of the damping entrance area, given as angle between shape surface and cylinder axis (α : 45°; 30°/10°).

For the case of the damped valve the range of the total pressure rise is 75 bar to about 120 bar. Within this range the pressure values vary. They are moderately reduced by

- smaller damping gaps (from 1,0 mm to 0,3 mm)
- enlarged damping section related to the total valve stroke (from 44/130 to 65/90);
- smoothed entering shape into damping zone (from $\alpha = 45^\circ$ to 30°/10°).

The general conclusion is, that all of the tested damping parameters are capable to eliminate water hammer.

Even a total pressure pulse of 120 bar, which is the observed upper limit with damped case is comparable to the loading produced by the initial pipe break itself.

4. ANALYTICAL RESULTS

For calculation of the pressure pulses a correct simulation of the valve closing dynamics coupled with the blowdown mass outflow is needed.

Three forces are identified as the dominant forces acting on the valve spindle (figure 10):

- the blowdown flow force at the valve cone (F_T);
- the damping force acting on the damping piston (F_D);
- and the inertia (F_B).

An adequate description of the flow force and the damping force is essential, therefore flow restriction parameters (f_T, f_D) are needed.

Values for those parameters, available from stationary flow tests proved to be inappropriate for the blowdown calculations. They turned out to be small by up to a factor of two to four (figure 11).

In order to model blowdown events with a feedwater check valve correctly appropriate blowdown parameters must be available. These parameters have been evaluated as one of the results of the PHDR-Investigations.

These parameters describe specific valve properties; therefore their transfer to other valves is problematic. But if no measured blowdown values are available for a similar valve, as a first approach, it is proposed to combine its stationary flow restriction parameters, which are usually known, with the HDR-evaluated quotient of blowdown restriction to the stationary loop flow parameters.

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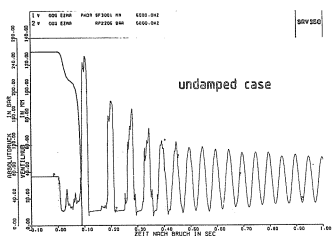


Fig. 7. Valve closure and pressure pulse undamped case

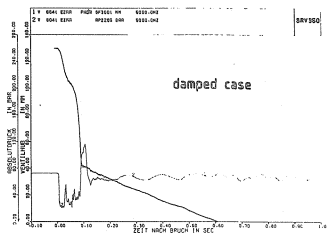


Fig. 8. Valve closure and pressure pulse damped case

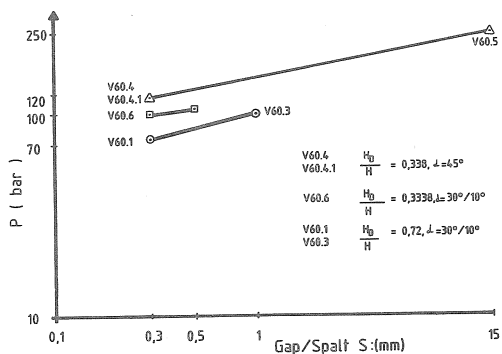
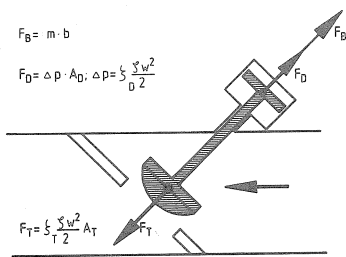


Fig. 9. Valve closure generated pressure pulses



Motion equation: $F_T - F_D - F_B = 0$

Fig. 10. Force balance on valve spindle

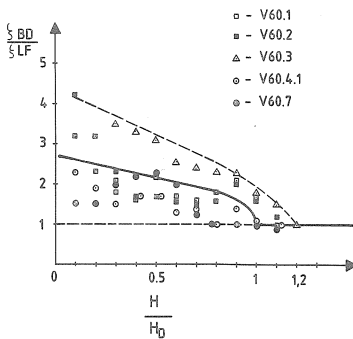


Fig. 11. Quotient of flow restriction values (blowdown conditions over stationary loop flow) Versus total stroke over damped stroke