Influence of Supports on the Vibration Behavior and on Stresses of HDR Piping Systems

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Summary

The vibration behavior of the PDL and URL piping systems of the decommissioned nuclear power plant HDR at Kahl, West Germany, was measured at various types of excitation and determined in advance by calculation. These precalculations were performed, independently from eachother, by three different institutions.

The purpose of the study was to determine by comparison with the experimental results the validity of linear calculation methods when applied to strong excitations.

One of the main points of the evaluation was to investigate the effects of the piping supports on the vibration behavior and on the stresses in the piping systems.

For a closer determination of the effects of the supports on the piping systems parameter calculations were performed with different idealizations of the supports.

This was done for the snapback load cases using the direct integration method. The program system used was SAP IV.

The characteristics of the supports (spring hangers, constant force hangers and sway braces) were determined experimentally. They were all more or less nonlinear (hystereses, gaps).

In the calculations the supports were mainly taken as linear, in some cases, however, also as nonlinear springs.

1. Introduction

The structures of the PDL and URL piping systems and the models, load cases, and calculation methods used are described.

For the PDL system the influence of the type of support of the header, where the PDL is connected, and the points of impact in the region of hanger KH 511 are discussed on the basis of snapback load cases with strong excitation.

The results concerning the URL system are also briefly commented upon.

2. Structures investigated

Figure 1 shows an isometric of the primary steam line which runs from the reactor pressure vessel to the primary steam header. In the horizontal part there are two constant force hangers and in the vertical part there is one pair of spring hangers. The primary steam header itself is supported near where the primary steam line is connected to it.

The general setup of the recirculating loop URL is shown in figure 2. The loop contains 12 constant force hangers and 12 sway braces and there is a pair of spring hangers at each of the vertical sections. The system consists of two recirculation pumps and the piping connecting these to the reactor pressure vessel. In the left-hand branch there is a fixed point designated URL 70.

3. Experimental determination of the pipe support characteristics

In order to properly take account of the boundary conditions of the piping models for the precalculations at medium and high levels of excitation the behavior of some selected pipe support elements was investigated more closely /1/. In this connection the mounting conditions including clearances, exact locations and positions, design details and force-displacement characteristics were determined, the latter by means of static tests on a test bench.

Figure 3 demonstrates the main deviations of real pipe support characteristics from ideal. The force exerted by constant force hangers is not exactly independent of path and it also depends on whether the deviation increases or decreases. The real characteristics of the sway braces examined deviate only little from ideal. The curves obtained show only little hysteresis. Rather considerable clearances of up to 20 mm have, however, been measured at the attachment structures of the sway braces. Also for the spring hangers examined only small deviations from ideal have been found as regards the characteristics and the hysteresis behavior.

4. Parameter calculations with different idealizations of the supports

4.1 Models, load cases and calculation method

The models used in the parameter calculations were taken basically the same as in the precalculations. Some simplifications were, however, introduced. The number of degrees of freedom was considerably reduced, in particular for the URL system. In the calculations for the PDL system some nodal points were taken out. The resulting model is shown in figure 4. In the URL system the pipe branch between the reactor pressure vessel and fixed point URL 70 was also taken out as its influence on the rest of the system is relatively small considering the torsional and translational springs assumed for this fixed point. The valves were taken as lumped masses located on the axis of the respective pipe in contrast to the precalculation, where some more complicated valve model was used. In the new model pairs of spring hangers were taken as single spring hangers with axes coinciding with the respective pipe axis. Also the spring hanger support assemblies were no longer taken account of and the number of nodal points in the calculation was reduced. The URL model resulting from these simplifications is also shown in figure 4. It was found that these simplifying assumptions were only of negligible influence on the natural frequencies and the free vibration mode shapes, both for the PDL and the URL systems.

Idealization of the supports was first taken the same as in the precalculations. The spring and the constant force hangers for both systems and the sway braces for the URL system were taken as linear springs, in the case of the constant force hangers with a spring constant corresponding to the measured inclination of the hysteresis loop. For the sway braces the calculations were based on the spring constants of the precompressed spring assemblies, not taking account of the precompresssion, however.

For the URL system additional calculations were run assuming nonlinear springs for constant force hangers and sway braces.

The connections of both systems to the reactor pressure vessel were taken as fixed points. The connection conditions of the PDL at the header and of the URL at fixed point 70 were simulated by translational and torsional springs.

The load cases investigated by the parameter calculations were Snapback PDL-X 27 KN and Snapback URL-X' 220 KN. The Snapback load cases were chosen because of the direct excitation of the piping and further because the required force for the statical deflection was measured. Moreover, measured values for damping were used so that the parameter calculations could essentially be limited to the investigation of the pipe supports.

All calculations were run with the computer code SAP IV using the direct integration method.

4.2 Inspection of the pipe supports in the HDR plant

Comparison of the precalculation results with the test measurements led to some discrepancies the cause of which could not be clearly determined. It was, therefore, decided to inspect the pipe supports in the HDR plant before starting with the parameter calculations. In the case of the PDL system the pipe suspensions and the support at the header received particular attention. The results on hand gave rise to suspecting some point of impact somewhere in the system. This suspection could, in fact, be confirmed by inspection: the suspension assembly of constant force hanger KH 511 had struck against adjacent pipes in direction +Y and also horizontally on both sides in a direction approximately at a right angle to the primary steam pipe axis. On one side there was a line the insulation of which showed some damage. On the other side there were a number of smaller diameter pipes where scratch and impact marks were detected. In fact, it required as little as manual shaking at the primary steam line in the direction of the points of impact to make the support assembly hit the adjacent lines.

Inspection of the header support did not lead to additional information of any bearing and the same was true for measurements of the wall thicknesses of the PDL which were done at various places. Neither was new informatioon gained from inspecting the URL system.

5. Comparison of the measurement and the calculation results at Snapback excitation

5.1 PDL system

In the parameter calculations the points of impact at hanger KH 511 were taken account of by linear translational springs. These springs and the torsional springs at the header were varied during the calculations.

Already one of the first calculations with spring constants $C_{X/-Z} = C_Y = 50$ N/mm for the point of impact and a torsional spring constant of $C_t = 10^{10}$ Nmm/rad for the connection at the header - zero translational displacements having been assumed for this latter point - led to measurements and calculation results approaching eachother very closely. Figures 5 and 6 show the accelerations for reference points PDL 503 and PDL 506 respectively in direction X comparing measurements with pre- and parameter calculations. As can be seen the agreement between parameter calculation and measurement is very good. Figure 7 shows the displacement in direction Y of the primary steam pipe at hanger KH 511, again from the 3 sources. Also this figure shows good agreement between measurement and parameter calculation. The initial displacement for the measured values ist not shown correctly which is due to a faulty measuring range setting. Figure 7 further gives a table showing the maximum bending and torsional stresses for points PDL 501 and PDL 508. Inspection shows that for PDL 501 the values from the parameter calculations are in better agreement with the measurements than those from the precalculation. Replacing the torsional spring at the header by a fixed restraint leads to considerably higher stresses at the header and lower stresses at the reactor pressure vessel nozzle.

5.2 URL system

The big discrepancy between measured and precalculated accelerations could not be explained by influences from the supports. A much more likely reason was the delay in releasing the pipe at its excitation point as was noticed immediately after the test. Parameter calculations taking account of this delay did in fact lead to a much better agreement between measurement and calculation. For the sway braces calculations with both linear and nonlinear springs were run. For strong excitations the differences between the calculation results for the piping system appeared to be of no importance. It could finally be shown that only when assuming nonlinear springs for the sway braces and including in the calculations the clearances as measured and the real precompressions, calculated and measured curves of force vs. time are in good agreement.

References

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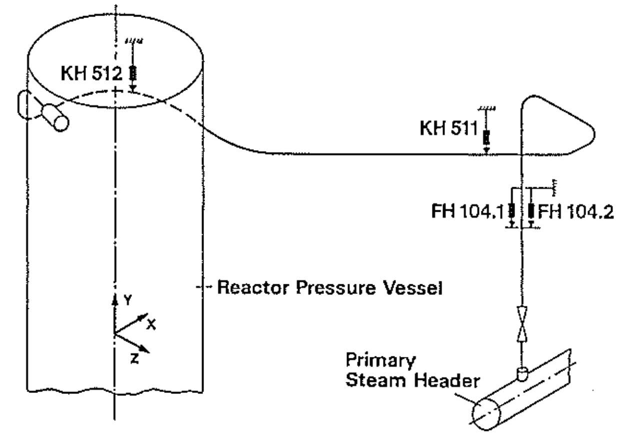


Fig. 1: Primary Steam Line
Pipe Hanger Position

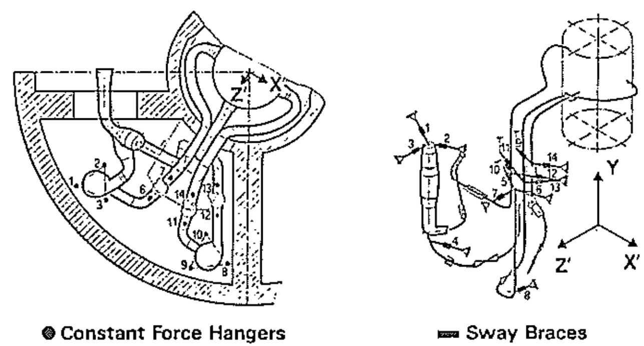


Fig. 2: Recirculating Loop
Arrangement of the Constant Force
Hangers and Sway Braces

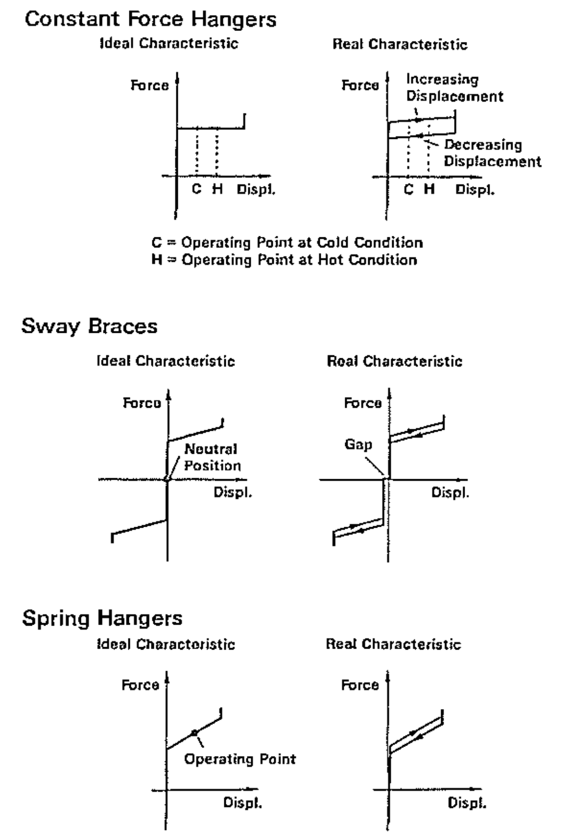


Fig. 3: Ideal and Real Characteristics of Constant
Force Hangers, Sway Braces and Spring Hangers

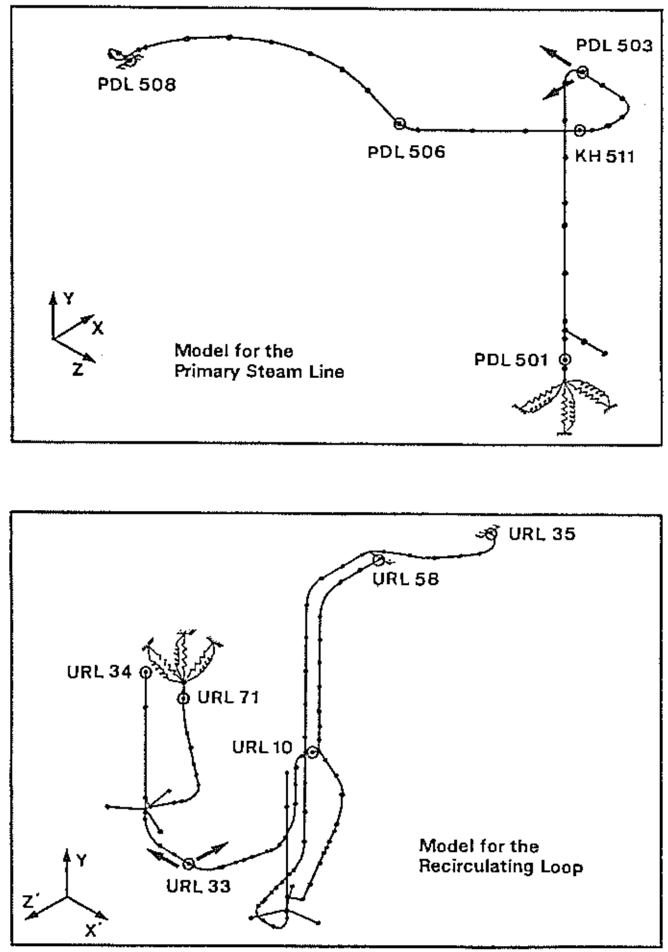


Fig. 4: Modified Models for the Primary Steam Line and the Recirculating Loop for Parameter Calculation Reference Points for Displacements, Accelerations and Stresses

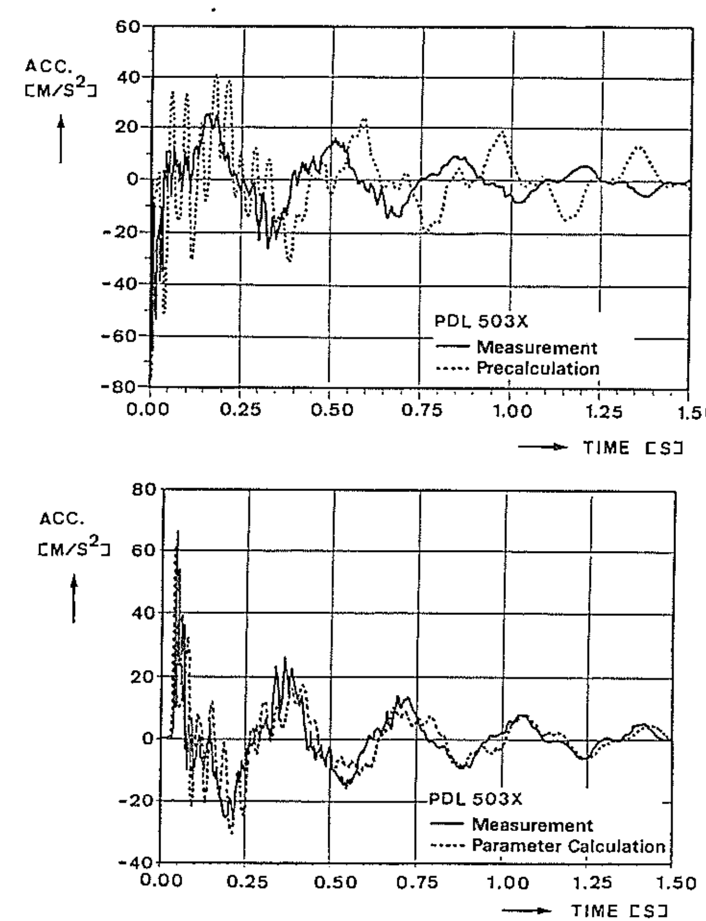


Fig. 5: Snapback PDL-X 27 KN Acceleration in Direction X at Reference Point PDL 503

- from Measurement and Precalculation (Sign inversed)
- from Measurement and Parameter Calculation (Calculated with Translational Springs at Point of Impact at the Hanger KH 511 and with Torsion Springs at the Header)

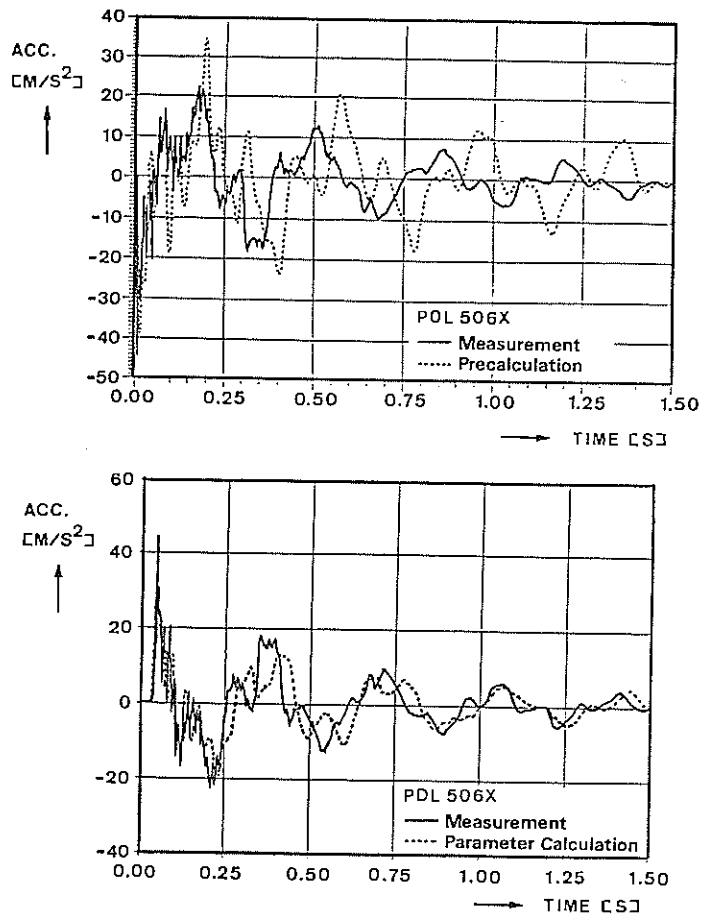
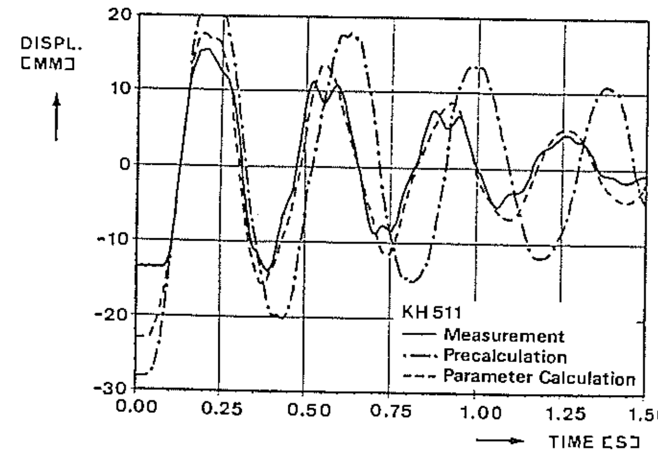


Fig. 6: Snapback PDL-X 27 KN Acceleration in Direction X at Reference Point PDL 506

- from Measurement and Precalculation (Sign inversed)
- from Measurement and Parameter Calculation (Calculated with Translational Springs at Point of Impact at the Hanger KH 511 and with Torsion Springs at the Header)



Test	Location	Typ of Determination of Data	σ_B [N/mm²]	σ_T [N/mm²]
V 64.1.1.2 (Snapback PDL-X 27 KN)	PDL 501	Measurement	104,0*	18,0*
		Precalculation	148,0	22,0
		Parameter Calculation	127,0*	16,4
	PDL 508	Measurement	73,0	-10,0
		Precalculation	73,0	- 7,0
		Parameter Calculation	66,0	- 5,5

*) Maximum Value Obtained at Static Load

Fig. 7: Snapback PDL-X 27 KN

- Vertical Displacements at the Hanger KH 511 from Measurement, precalculation and Parameter Calculation (the Latter with the Assumption of Translational Springs at the Point of Impact at the Hanger KH 511 and of Torsion Springs at the Header)
- Bending and Torsional Stresses at Reference Points PDL 501 and PDL 508 from Measurement, Precalculation and Parameter Calculation