

The Verification to Structural Dynamic Calculations with KWUROHR Using Experimental Data

J. Lockau

Kraftwerk Union AG, Postfach 3220, D-8520 Erlangen, Germany

Dittrich

Ingenieurbüro, Heinrich-Delp-Str. 258, D-6100 Darmstadt, Germany

KWUROHR is a general purpose piping program using linear elastic theory. The qualification process underwent several steps:

1. Benchmark comparison with a variety of other piping programs showed very good agreement
2. The accuracy of the problem modelling can be demonstrated by the post-calculation of different experiments. The test samples have been chosen so that the complexity of the problems is increasing stepwise.

Taking a simple system with very stiff supports an excellent agreement of the eigenfrequencies could be found. In the next step a complex main steam line has been examined for a snapback. Finally the main steam line has been examined for the load case turbine trip including the problems of the thermo-hydraulic load. Even in the last case good agreement for the snubber loads could be found.

1. The Benchmark comparison against other codes

KWUROHR /1/ is a general purpose piping program using linear elastic theory.

The qualification process of KWUROHR started with benchmark comparisons against a variety of other well known piping programs among which ANSYS /2/, PIPESD /3/, PIPEDYN /4/, SAP-IV /5/, ADLPIPE /6/, STARDYNE /7/ and ROHR 2 /8/ can be mentioned. The comparison consisted of 8 test samples with / several options each /9, 10/. The following load cases have been tested:

1. Static loads (dead weight, pressure, temperature, external forces and moments, nodal displacement)
2. Dynamic loads (eigenfrequencies, eigenmodes, enveloped response spectrum, multiple support excitation, time history analysis)

The procedure is similar to the piping benchmark problems posed by NRC /12/ which is limited to enveloped spectra.

The result of this comparison showed good agreement between KWUROHR and the other programs mentioned above for the specific options which have been tested. Therefore it can be concluded that the mathematical formulation of the solution process of KWUROHR is equivalent to that of the other programs mentioned above.

2. Comparison against experimental data

Any realistic large piping system with many branches, supports and snubbers has some nonlinearities, such as gaps and friction. Thus the second question is: How can you model such system and what is the accuracy of the calculation?

Overall comparisons between tests and calculations have been performed since 1977 for several start-up experiments. The first comparisons showed rather poor agreement. This can be explained by the fact that not all of the boundary conditions of the experimental data were recorded and taken into account. Sometimes the complex system had to be analysed without the possibility of tracing down the sources of deviations.

2.1 Simple piping system

In the next step a rather simple piping system has been measured. The isometric drawing is shown in Fig. 1. The anchors are very stiff. This is also indicated by the fact that the piping system only has about 0.5 % damping. In the KWUROHR calculation 10^7 N/mm has been assumed for the lateral stiffnesses and 10^{12} Nmm/rad for the rotational stiffnesses of the supports. The system has been excited by an impulsehammer at different locations and the acceleration has been measured in position 5 in the Z-direction to analyse the mode shapes.

The evaluation of the eigenfrequencies and the maximum displacements shows excellent agreement between the measured data and KWUROHR and STARDYNE results (Table 1).

The 4th eigenmode is missing in the experiment since it has very little contribution in the Z-direction at position 5. Similar experiments done within the HDR-project are reported elsewhere in the conference and show larger discrepancies between measured and calculated data. These larger discrepancies may be attributed to the boundary conditions and especially the support stiffnesses. The assumption that some deviations in the stiffness of the elbows may account for the discrepancies registered in the HDR-project can be disapproved by the evidence above.

2.2 Snapback-experiment for a main steam line

A main steam line of the Philippsburg (KKP 1) BWR plant has been tested with a snapback (Fig. 2). The acceleration has been measured at the location of the snapback. The displacements have been recorded for 7 positions and all 3 directions. The piping system including the relief lines is rather complex and amounts to about 400 nodes.

The evaluation of the displacement time function is done using Fourier-transformation. A set of measured eigenfrequencies for each detector position and each direction is generated. The comparison with the calculation (Fig. 3) shows larger deviation than in case 2.1 which was performed under well defined laboratory conditions. The reason for this is of course the more complex structure of the system and the less defined boundary conditions, such as supports hangers, snubbers, etc.

In the next step the time functions of the experiment and the calculation are converted to response spectra. From this the frequency content of the systems answers due to the snap back excitation can be analysed. The acceleration spectrum for the point of excitation (Fig. 4) shows rather good agreement in the range of the lowest eigenfrequency at 3.2 Hz.

The harmonic content of the measured data is much lower than the calculated data between 8 and 23 Hz. The 3rd peak between 24 and 28 Hz is again quite well matched. The relatively high values of the measured spectrum is probably caused by rattling effects in the gaps of the supports. The calculation has been performed for the damping values of 5 % and 10 %.

As the direct intergration method had to be applied due to the size of the problem, the Rayleigh damping coefficients have been adjusted for the frequency range between 2 and 40 Hz. For the fundamental modes below 20 Hz, which contribute most to the system response, the measured damping is well above 10 %. This can also be derived from the response time history (Fig. 5). The measured acceleration quickly decays to 0 whereas the calculated acceleration shows significant values up to 2 sec. This clearly

indicates that the friction in the supports strongly contributes to the damping of the system.

The evaluation and the comparison of the displacement spectra partly show excellent agreement and partly large discrepancies. The agreement is best near the position of the snap-back and gets worse leaving the neighbourhood of the excitation.

This also indicates that the nonlinearities play an important role which cannot be reproduced using linear methods. In spite of all inaccuracies, however, the conservatism of the calculational approach can be demonstrated.

2.3 Dynamic behaviour of a main steam line for load case turbine trip

The main steam line, shown in Fig. 2, is excited with time dependent pressure forces caused by fluid dynamic events during the load case turbine trip. Accompanying the stepwise elevation of power steps of the plant displacement measurements have been made at the same positions used in the snapback tests and some further positions (snubbers). These measurements have been simulated by calculations.

The calculations have been made using the Direct-Integration method (KWUROHR) to solve the equations of motion. Time dependent forcing functions resulting from a fluid-dynamic calculation (/1/) were used as loading for the system. Fourier-Transformations of these forcing functions were used to determine parameters of the calculation in the range of frequencies of loading. Maximum forces were found in the frequency range of 3,5 Hz - 60 Hz depending upon the loading position, so that a time step of $t = 0.001$ sec was determined with regard to the necessities of the Wilson Theta-Method (KWUROHR). Using this time step, frequencies up to 100 Hz can be taken into account. The mass or stiffness-dependent coefficients have been chosen in such a way that the damping corresponds to 4 % of the critical damping at the frequency points of 2 Hz and 80 Hz. At 4 Hz and 60 Hz the damping values are still 3 % of the critical damping and a minimum of 1.8 % occurs at 25 Hz. During a second calculation damping was doubled over the whole range of frequencies.

Comparing the Fourier-transformed displacement results from the measurement and the calculation at check point WA 4 (see Fig. 2 for location) for example, good agreement for all the 3 directions is evident (Fig. 6-8). Markable divergence of the calculation results and the measurements appear in displacement values near supports and snubbers. This together with very good agreement in maximum values of snubber forces at measuring points DMS1-DMS3 (Tab. 2) indicates significant friction effects at supports, gaps and snubbers.

The damping of the system proved to be higher than assumed. Maximum values did not appear before the 2nd - 4th oscillation in the calculation and at the end of the calculated time (1.5 sec), displacement and force values were not below 30 - 40 % of maximum values whereas oscillating behaviour of the measured data show much stronger influence of damping. After about 2 - 3 oscillations the movement at measuring locations fade away. This effect is also due to the damping of the fluid-dynamic forcing functions.

Calculation of complex piping systems is a good tool to predict forces at any point of the system, whereas the accuracy of displacements often depend on uncertain boundary conditions and nonlinear effects (frictions, clearance, etc.).

References

- /1/ KWUROHR Benutzer-Handbuch Version 4.4
Techn. Bericht R 14-10-79, August 79
- /2/ "ANSYS-Engineering Analysis System" ANSYS
Examples Manual, Cybernet Services, Control Data Cooperation
- /3/ "PIPESD-Pipe Static and Dynamic Analysis Program",
PIPESD User Information Manual, Cybernet Services,
Control Data Cooperation
- /4/ "Construction Industry Programs, PIPDYN: Dynamic Analysis of Piping
Systems" Computer Seismics Cooperation, Los Angeles, Calif.
- /5/ R.L. Norton "SAP-IV-A Structural Analysis Program for Static and
Dynamic Analysis of Linear Systems Examples University of Southern
California, Department of Civil Engineering, August 1974
- /6/ "ADLPIPE-Static and Dynamic Pipe Design and Stress Analysis, User
Information Manual, Arther D. Little Co., Cambridge, Massachusetts
- /7/ "STARDYNE-Static and Dynamic Structural Analysis System", MRI-
STARDYNE, User Information Manual Control Data Cooperation
- /8/ "ROHR2-Programm zur Festigkeitsberechnung von Rohrleitungssystemen",
Benutzer-Handbuch April 1979, Version MBP Dortmund
- /9/ Beispiele zur Qualitätssicherung des Programmsystems KWUROHR Standard
Rutherford, Geidel, Techn. Bericht KWU/R 14-15-79, Okt. 1979, Kl. 1
- /10/ Beispiele zur Qualitätssicherung des Programmsystems KWUROHR/Modal-
Analyse (Mehrfachanregung), Rutherford, Sterkel,
Techn. Bericht KWU/R 14-23-79, Dez. 1979, Kl. 1
- /11/ Bestimmung der Last-Zeit-Funktion bei TUSA aus 100 % Leistungsbetrieb
Arbeitsbericht TÜV-Baden Az. 116-528-6.1 vom 17.12.79 Koch
- /12/ Piping Benchmark Problems
NUREG/CR - 1677 Vol.1

Tab. 1

mode	Experiment with Impulshammer					MURR - calculation					STARONE - calculation				
	frequency		max. rel. displacement			frequency		max. rel. displacement			frequency		max. rel. displacement		
	(Hz)	position ¹⁾	x	y	z	(Hz)	position	x	y	z	(Hz)	position	x	y	z
1	3,5	5	0,60	-0,26	1	3,5	32	0,46	-0,12	1	3,5	32	0,46	-0,12	1
2	4,9	5	1	0,25	-0,88	4,8	30	1	0,25	-0,78	4,9	30	1	0,25	-0,78
3	5,5	4	0,21	0,26	1	5,5	20	0,20	0,30	1	5,5	20	0,20	0,30	1
4	1)	1)	1)	1)	1)	7,8	20	0,34	0,34	1	7,8	20	0,34	0,34	1
5	9,1	7	1	0,14	0,97	8,9	52	1	-0,03	0,82	9,0	52	1	-0,03	0,82
6	13,2	6	1	0,13	-0,89	13,0	45	1	0,04	-0,93	13,1	45	1	0,04	-0,93
7	15,9	4	-0,36	1	0,00	16,0	22	-0,36	1	-0,04	17,0	22	-0,36	1	-0,04

1) the 4. eigenmode has been not measured by the experiment due to the bad position of the accelerometer for that mode
 2) see fig. 1

Tab. 1: Experiment on a 50 mm pipe
 Comparison of the measured and calculated frequencies and eigenmodes



Tab. 2

Measuring Location	Calculated Snubber Force (kN)	Measured Snubber Force (kN)
DMS 1	42	33
DMS 2	95	94
DMS 3	66	78

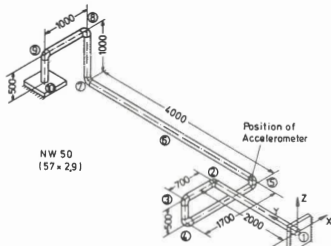


Fig 1 Isometric Drawing of Test Sample

WA 1 X	3.2	8.0	15.4
WA 1 Y	3.2	7.4	15.8
WA 1 Z	2.5	5.2	15.2
WA 3 X	3.2	8.0	15.4
WA 3 Y	2.5	5.2	15.2
WA 3 Z	2.5	5.2	15.2
WA 5 X	3.2	8.0	15.4
WA 5 Y	3.2	7.4	15.8
WA 5 Z	2.5	5.2	15.2
WA 6 X	3.2	8.0	15.4
WA 6 Y	3.2	7.4	15.8
WA 6 Z	2.5	5.2	15.2
WA 7 X	3.2	8.0	15.4
WA 7 Y	3.2	7.4	15.8
WA 7 Z	2.5	5.2	15.2
BA 1 Z	3.2	8.0	15.4

Fig 3 Comparison of Frequencies KKP1 Snapback

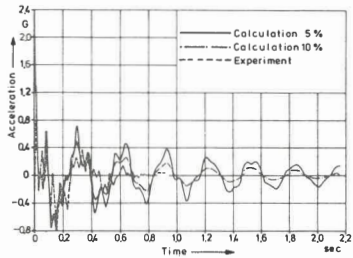


Fig 5 KKP1 Main Steam Line Snapback Acceleration Time History at the Place of the Snapback

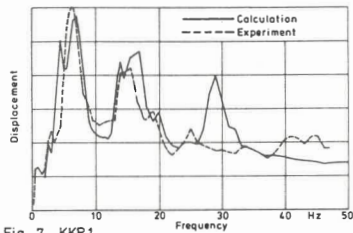


Fig 7 KKP1 Loadcase Turbine Trip 100% Position WA4 Direction Y Displacement Response Spectra

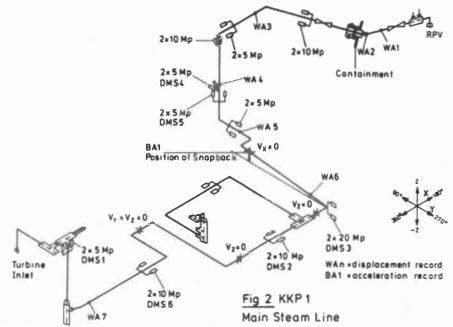


Fig 2 KKP1 Main Steam Line

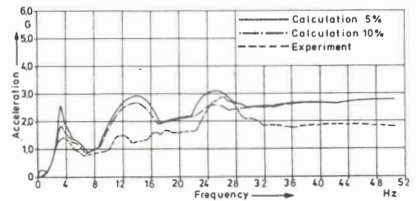


Fig 4 KKP1 Main Steam Line Snapback Acceleration Spectrum at the Place of the Snapback

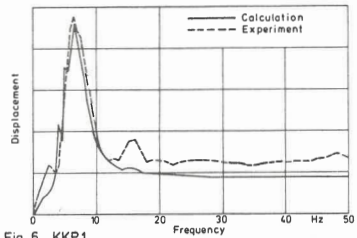


Fig 6 KKP1 Loadcase Turbine Trip 100% Position WA4 Direction X Displacement Response Spectra

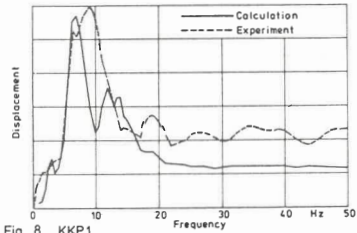


Fig 8 KKP1 Loadcase Turbine Trip 100% Position WA4 Direction Z Displacement Response Spectra