Investigation of a Pipe System Under Dynamic Loads

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Abstract

A pipework from the HDR facility (decommissioned reactor) together with the hanger and dashpot was mounted in a test field and subjected to various types of loading:

- static loading through individual forces and momenta applied to the free pipe end,
- excentric excitation by shaker,
- excitation through hammer blow with a view to determination of the natural mode behavior,
- excitation with a snapback system.

The vibration behavior was investigated of the pipework exposed to the influence of varying boundary conditions, namely internal pressure, water charge, constant force hanger, and dashpot. The experiments were paralleled by appropriate computations. The methods of computation used were assessed and verified by a comparison of the results of testing with the theoretical results.

1. Test Program

The pipework investigated - see Fig. 1 - consists of a main pipe, 250 nominal width, 16 mm wall thickness, and a bypass, 80 nominal width, 5.6 mm wall thickness. The pipe is excited by hammer blow, snapback (abruptly split steel cord), and excentric shaker for determination of the natural mode behavior and limited by a hydropulser for recording the forced vibrations. The following configurations of the pipework were studied in experiments:

- pipe empty; filled with water; filled with water and with internal pressure applied;
- pipe with hanger and/or dashpot;
- pipe with hydraulic cylinder coupled to it.

All experiments are calculated with two FE-models - ASKA and KWU-ROHR - and a comparison is made between measurements and computation.

2. Natural Vibration Behavior of the Pipework

The experimental investigations of the natural vibration behavior of the pipework led to the determination of a total of seven natural modes for the system. Four eigenmodes occur in which the entire pipework undergoes movements; three eigenmodes develop in addition in which only the bypass, NW 80, undergoes noticeable displacements while the main pipe, NW 250, stays at rest. In Fig. 2 the first four mode shapes have been represented graphically; Fig. 3 is a compilation of the results of natural frequencies.

All types of excitation applied - hammer blow pulse, shaker, snapback - identify, except for minimum local differences, the same natural modes and natural frequencies. The exemplary comparison of the lowest natural frequencies for the empty pipework confirms that the scattering band is narrow: snapback and pulse tests give 5.7 Hz, the shaker tests 5.3 Hz. The frequency range up to 50 Hz was considered.

The most important findings concerning the natural vibration behavior of the pipework in the course of parameter variation are:

According to expectation, filling with water leads to a reduction of the natural frequencies - in this case by about 10%. Although the internal pressure - 100 bar - causes the system to get stiffer, it actually does not produce any noticeable change in natural frequencies. Both in the water case and in the case of water charge combined with internal pressure the natural modes do not differ from the natural modes of the empty pipework.

The constant force hanger exerts an influence on the natural vibration behavior, but only on those eigenmodes with displacement fractions in the direction of hanger impact. For instance, after installation of the constant force hanger, a frequency of 8.9 Hz can be measured whereas in the empty pipework and with the corresponding eigenmode a frequency of 6.1 Hz was obtained.

The dashpot modifies those eigenmodes of the pipework which at the place of installation of the dashpot exhibit distinct displacement fractions in the direction of dashpot impact.

Similar to the constant force hanger, the hydraulic dashpot leaves unimpaired those natural modes in which only the bypass vibrates whilst the main pipe with the point of attachment of the hanger or dashpot flange stays at rest.

As has been expected, no effect on the behavior of the pipework can be recognized normal to the direction of dashpot impact.

3. Computation of the Natural Behavior

Two models of computation were used. The ASKA computation models includes 318 degrees of freedom. Modeling is performed with beam elements, the pipe bends being modeled by polygons of three or five beams. The stiffness of those beam elements which are used in this computation to model the pipe bends, is modified by correction factors. The points of clamping are considered to be rigid.

Unlike ASKA, the second model involving KWU-ROHR uses pipe elements, the element library including elbow elements as well. The elbow elements are based on the beam theory. The stiffness of the underlying bent beam is likewise modified by a correction factor. The number of degrees of freedom in this case is 408. In the model with KWU-ROHR finite stiffness values are assumed; both for the upper and lower fixed points the values are 10^7 N/mm (translation) and 10^{12} Nmm/rad (rotation), respectively.

Comparison of the measured with the calculated natural frequencies (Fig. 3) shows that the two models of computation describe well the natural vibration behavior of the pipework without hanger and dashpot. But it is important in this context that the exact actual sizes (not the nominal sizes with sometimes 20% higher wall thicknesses) are used for the pipework.

The constant force hanger is neglected in the computations of the natural vibration behavior. However, contrary to the calculations, the actual natural vibration behavior in the experiment is influenced by the constant force hanger. To be able to properly describe numerically the effect of the constant force hanger on the natural vibration behavior it is not sufficient to consider the static characteristic hanger line.

Regarding the dashpot installed the measurement confirms the information derived from computation that the dashpot exerts a clear influence on those eigenmodes with displacement fractions in the direction of installation of the dashpot. In Fig. 3 the natural frequencies measured of the pipework with the dashpot installed are compared with the corresponding calculated results.

The computations made describe relatively well the natural vibration behavior which is evident from the comparison of the measured with the calculated natural frequencies in Fig. 3.

4. Computation of the Snapback Load Case with Dashpot

In the snapback test considered the pipework is deflected from the static position at rest in z-direction using a steel cord. The deflection force is 10 kN and the point of steel cord attachment is at the free pipe end. After abrupt splitting of the cord within 20 to 50 ms the pipework undergoes coastdown in the absence of external load. In separate laboratory tests a mean spring rate of the dashpot of about 20 x 10^6 N/mm was determined for the frequency range of interest of 0 to 20 Hz.

The computation involving KWU-ROHR describes the dashpot by a linear spring with the stiffness 19.5 x 10^6 N/m. In the ASKA computation the following model of the time sequence was developed: In the initial state the dashpot is loaded statically and therefore does not exert a force on the pipework. For the pre-test calculation it is assumed in the first phase of snapback that the pipework can move without constraint towards its unloaded position at rest until the gap of the dashpot supposed in the computation of 3.7 mm has been overcome. In the post-test calculation the dashpot is assumed to have no gap. The crucial point in dashpot treatment is then considered to be a uniform return of the working point of the dashpot into the position at rest of the pipework. This returning of the working point is achieved by displacement of the foot point of a spring having the stiffness of the dashpot of about 18 x 10^6 N/m during the snapback process. Contrary to the 0.3 s assumed in the pre-test calculation, this linear displacement of the foot point of dashpot is supposed to last about 20 s in the post-test calculation. The accurate duration of this time interval is not important for the analysis of the vibration processes; the assumption "slow return" will suffice. Likewise, the precise knowledge of the mode of motion of this process is of secondary importance. The comparison of the pre-test calculation with the post-test calculation and measurement shows (Fig. 4) that the assumption of linear, slow return is sufficient to reach a good agreement between measurement and calculation.

5. Literature

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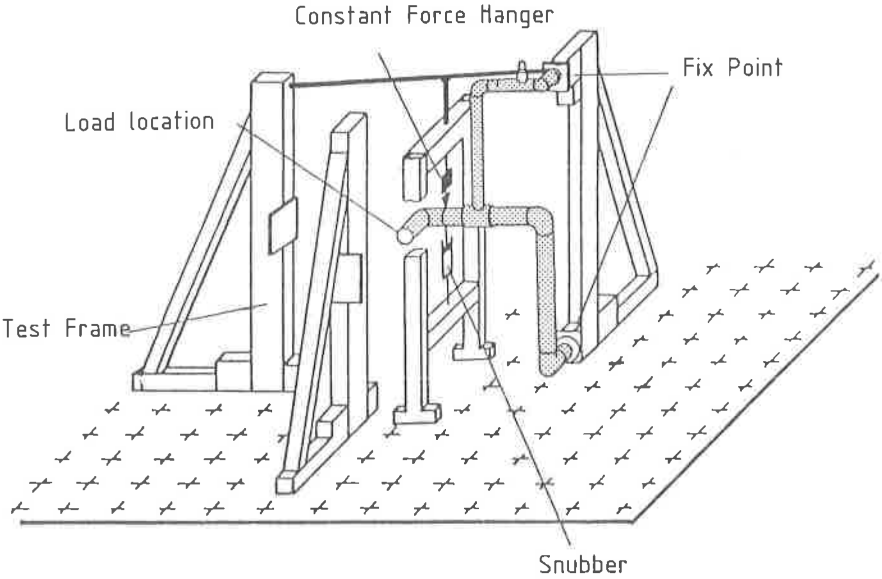

Fig. 1 Scheme of the pipework test installation and its natural frequencies

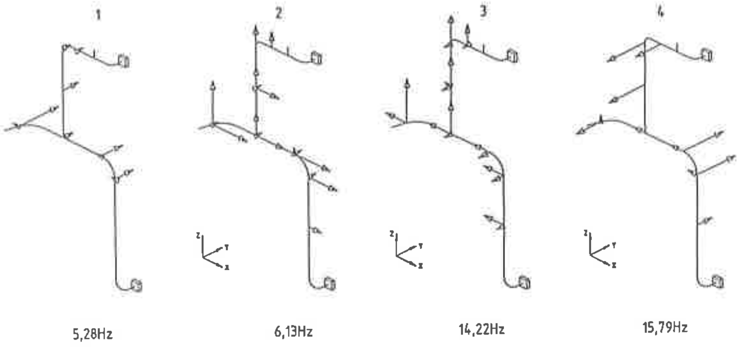

Fig. 2 First four mode shapes of the test pipework

Eigenfrequencies in /Hz/

Nr.	Measurement				Calculation results Dashpot (Z)			
	RL	RL with Water	RL Constant-hänger	RL Dashpot (Z)	RL ASKA	RL KWU-ROHR	RL ASKA	(Z) KWU-ROHR
1	5,3	5,0	5,1	5,1	5,9	5,9	5,9	6,4
2	6,4	5,8	--	--	7,3	7,2	--	--
3	14,7	14,0	15,3	--	16,5	16,2	--	--
4	15,8	14,7	15,6	15,6	17,6	18,9	17,6	18,7
5	18,3	15,6	18,1	18,0	18,5	17,3	18,5	18,0
6	43,0	36,8	43,1	43,1	42,1	41,4	42,2	41,0
7	45,5	40,5	45,5	45,5	47,7	44,7	48,1	45,2
8	--		8,9	8,3			11,4	11,1

Fig. 3 Natural frequencies of the test pipework with dashpot (measurement and calculations)

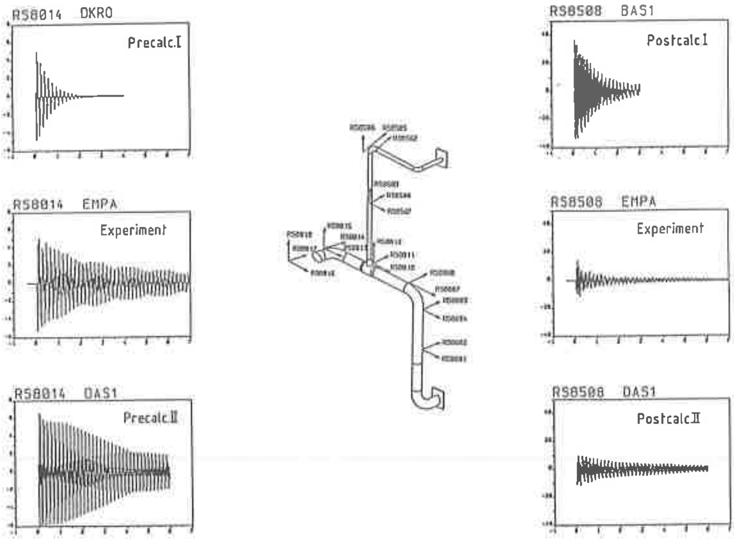

Fig. 4 Comparison of Measurement and Calculation for the Snap-back-Tests