How to Deal with Inservice Piping Vibrations

J. P. Arnold, R. H. Loreck, F. C. Zerrmayr
Siemens UB KWU, Erlangen, FRG

Introduction

Piping planing and design follows primarily the specified operational and safety requirements that are defined by systems engineering terms. For the design, static - e.g. dead weight, temperature or inner pressure - and transient dynamic load cases, resulting from pump shutdown or valve operation, are considered.

Additional stresses, that might be induced by pipe vibrations resulting from special inservice conditions, cannot be accounted for in the design phase, since they are not known in advance. Since these vibrations are typically of stationary character, at least for specific plant operation modes, the associated stresses are to be held below the endurance level for the affected support and piping elements. To comply with it, operational vibrations are to be localized in due time, evaluated and if nesessary removed by adequate measures.

Pipe vibrations induced by pump operation or by a resonant tube effect are more likely to be of periodic character, while vibrations resulting from turbulent fluid flow or cavitation are essentially of stochastic nature.

Figure 1 shows an overview of the different vibration classes, the affected system parts, the risk of damage and failure mechanism.

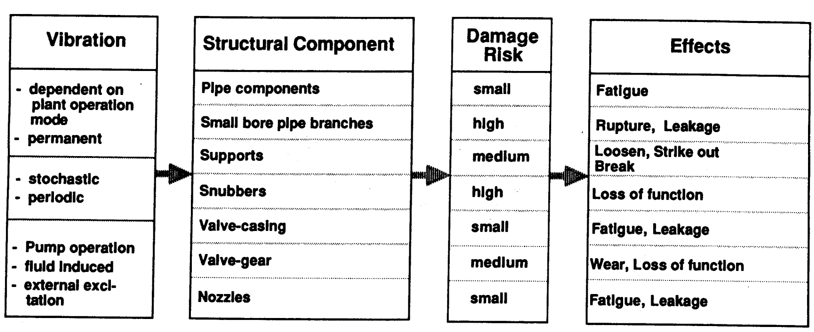


Figure 1: Overview of Inservice Pipe Vibrations

2. Inservice Inspection

If by visual inspection, or contact, a vibration is detected, the first question that arises is, if the amplitudes are within allowable limits. Small amplitudes can be tolerated, without producing any damage to the structural components, but if they are significant one should perform some measurements to gain some insight to the phenomenon. For further processing or interpretation of the measured values, the geometric-, material- and system data, a description of the support layout and of the pumps and valves including its operational conditions, are needed. The number, type and location of the measurements should be arranged so as to clarify the reasons for the vibrations, and on the other hand, to support the selection of the right countermeasures to be taken later, in order to reduce amplitudes within tolerable values.

Helpfull to find out the right locations of measurement points or additional supports, is the use of the computed eigenforms of the piping system. In some cases the use of an harmonic analysis to simulate the field situation can lead to the identification of the causes, and help to determine the design loads for additional supports.

With respect to the instrumentation, experience shows that for simple situations, portable receivers will give satisfactory results. However for more complex situations, a fixed installation is required. Depending on the field situation, electrodynamic (velocity), piezoelectric (acceleration), inductive (displacement) sensors or strain gages (stress, force) will be used together with a multichannel registration in the time domain.

To help interpretation of results, or to fix the countermeasures, it is recomendable as a rule not to limit the measurement arrangement to the smallest possible configuration, as will be shown in the next two examples. The problem in Fig. 2 was to determine the induced load in the support rod during partial load operation. In addition to the force also bending, acceleration and velocity in the adjacent pipe region were measured, so that the whole behaviour of the system could be analysed in more detail.

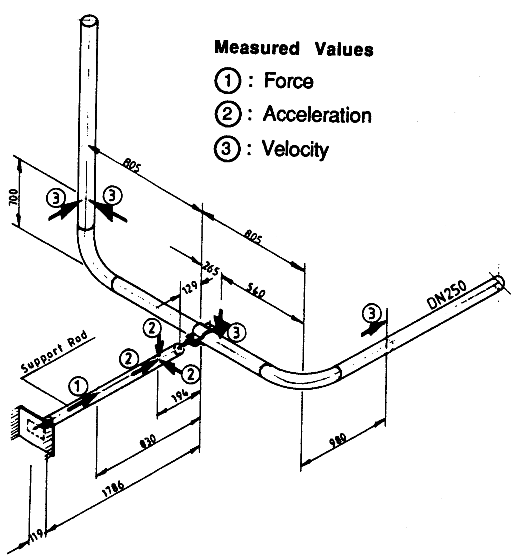


Figure 2: Test Points on Support Rod

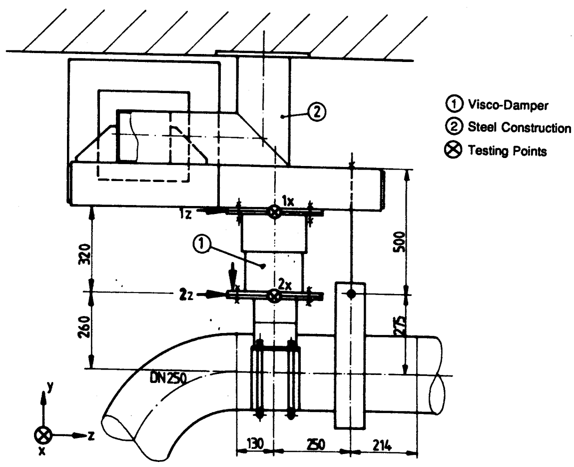


Figure 3: Testing of a Visco Damper

Fig. 3 shows the support structure for a visco-damper which was installed specifically to reduce operational shaking of the piping system. Instead of limiting the measurements to the piping area, velocity was registered also at two points of the damper itself. As can be seen from Fig. 4, there is a poor transmission of vibration from the pipe to the structure, showing that the device has no effective operation. This was accounted for, by using a replacement viscous mass consistent with the measured temperatures at the damper location.

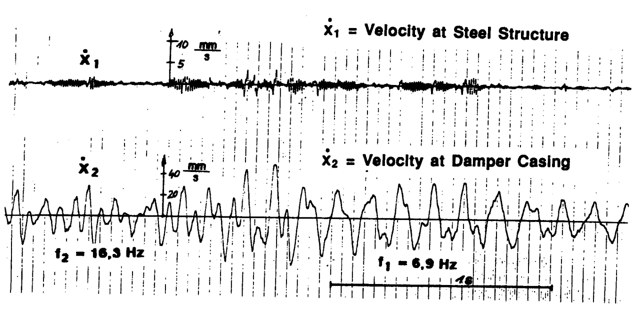


Figure 4: Velocity at Viscous Damper Test Points

3. Evaluation of measured results

In cases where allowables for accelerations or loads exist, a direct comparison with measured values will show if the vibration can be tolerated. In most cases however, one needs a mechanical equivalent model to transform measured amplitudes, velocities or accelerations into stresses and strains in order to assess for fatigue damage.

The mechanical simulation can be performed very easily by applying finite element techniques implemented on a portable PC, e. g. using the pipe programm described in / 1 /. Alternatively more simple equivalent models can be used, as shown in Fig. 5 for typical situations encountered on the field.

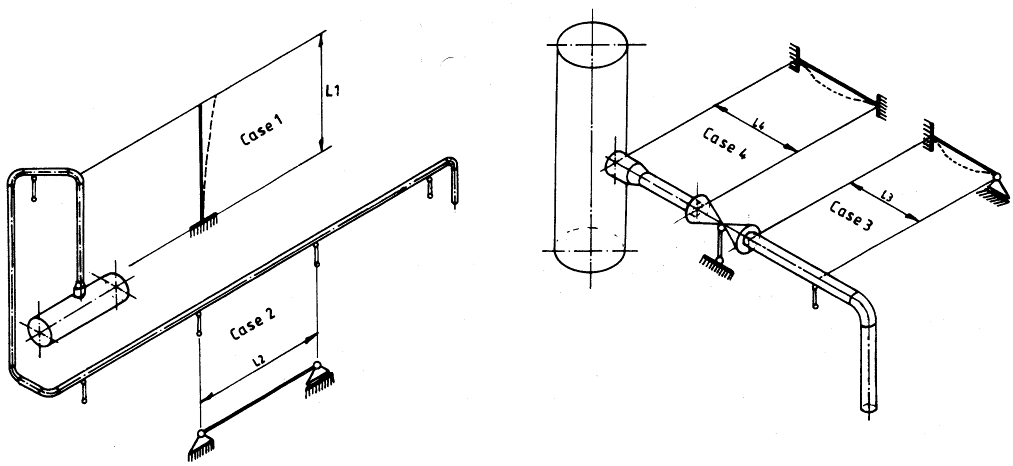


Figure 5: Typical Pipe Configurations

Since closed solutions for the dynamic response of a beam are known / 2 /, admisible maximum amplitudes as a function of pipe diameter and support distance can be represented as in Fig. 6, for a given pipe material and boundary conditions.

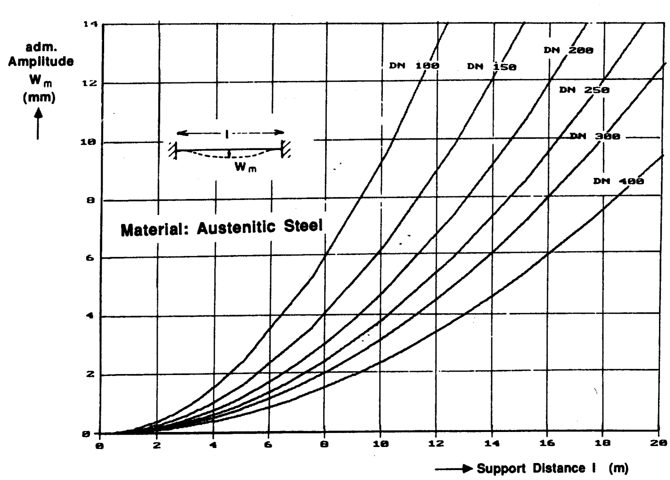
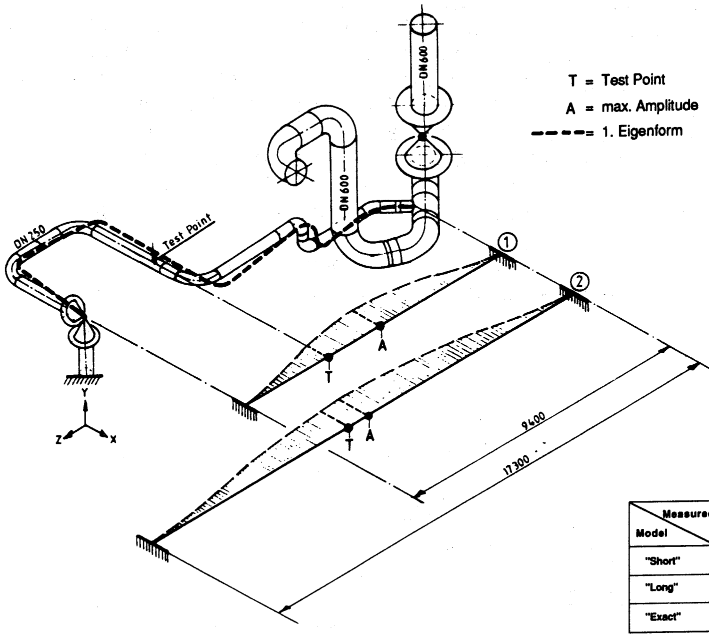


Figure 6: Admissible Amplitudes, Fixed End Conditions

Fig. 7 shows the application of the equivalent beam method in a real situation, where the max. measured amplitude was 1.6 mm.



	Amplitude Test point [mm]	Frequency [Hz]	max.Stress N/mm²
Measured / Model	1,6	5,2	-
"Short"	2,0	19,0	25,5
"Long"	2,0	6,0	5,4
"Exact"	2,0	5,2	6,3

Figure 7: Example DN 600 / DN 250

Fig. 8 shows a sample time history and the corresponding amplitude spectrum. Since the pipe segment under consideration (DN 250) ends on a stiff valve, respectively on a major pipe (DN 600), fixed ends were selected. As support distance, the projected and the total pipe lenght were taken. As shown in Fig. 7, Model 2 is the more realistic one, however Model 1 also results in admissible, but very conservative stresses.

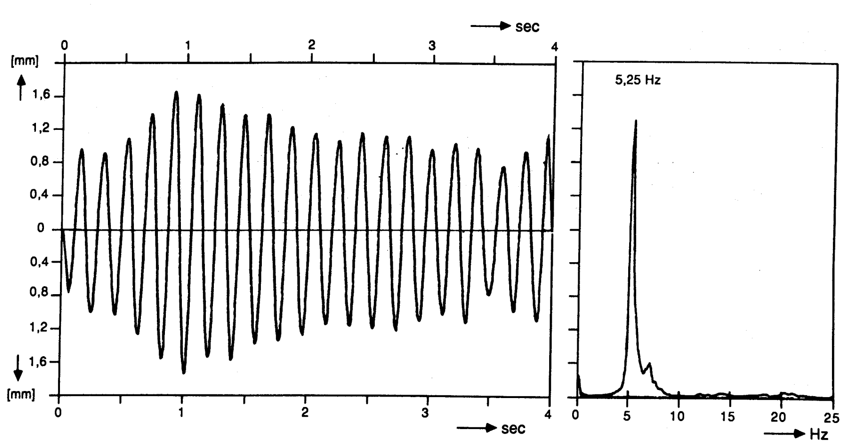


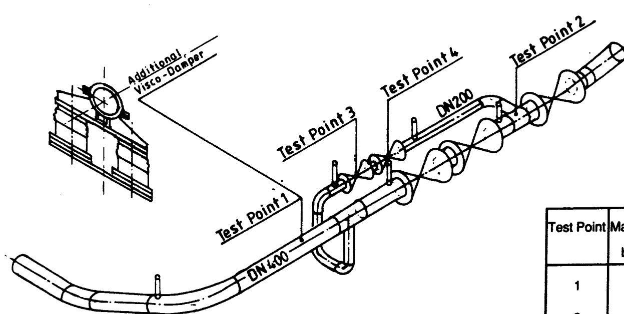
Figure 8: Measured Displacement Time History and Spectrum

Generally, the model should have a fundamental frequency higher than the measured value to not underestimate the resulting stresses.

4. Countermeasures

The best method to reduce operational shaking is of course to remove the cause. Since this is not always possible, e. g. when pumps are originating the disturbances, alternatively the dynamic behaviour of the system can be improved by reducing clearences at supports, adding supports e. g. viscous dampers, adding masses or changing the pipe layout. Viscous dampers are very effective in reducing dynamic amplitudes / 3 / by introducing high damping into the system. They act in all directions with a force proportional to the velocity. The selection of the damper should consider the proper ambient temperature and the correct piston position for service conditions, as these two parameters strongly influence the damping effect.

Fig. 9 shows a practical application. Two viscous dampers on one support location, a feed water line, reduced dynamic amplitudes by a factor of four and higher.



Test Point	Max. Amplitude [mm]	
	before	after
1	1,00	0,10
2	0,95	0,20
3	3,90	1,00
4	3,80	1,00

Figure 9: Feed Water Valve Station

5. Conclusion

In spite of the inherent design against dynamic effects, piping may show an undesired dynamic behaviour during operation. To deal with it, reliable methods and countermeasures for the pipe itself are available. For support structures and valves, mainly valve operating gears, simple procedures or guidelines based on a few measurements points, which permit a fast and reliable assessment of the effects, have to be developed in future.

6. References

/ 1 / Caesar II, Pipe Stress Analyses for the Chemical, Petroleum, and Power Industries. Coade Engineering Software, Houston, Tx. 77024

/ 2 / Biggs, J. M.: Introduction to Structural Dynamic, Mac Graw-Hill, New York 1964

/ 3 / Kuitzsch, W., Delinic, K., Zernmayr, F.: Die Reduzierung von Rohrleitungsschwingungen im Betrieb und im Störfall mittels viskoser Dämpfer, VDI Berichte Nr. 603, 1986, S. 263-292