Extending the Service Life of Piping Systems Through the Application of Viscous Fluid Dampers

By Frank P. Barutzki, Ph.D., GERB Vibrations Control Systems, Inc.

Introduction

Practical experience in power plants shows that the reliability and life expectancy of piping systems are largely determined by their dynamic characteristics and behavior. Dynamic loads are experienced during normal, continuous operation and during abnormal, potentially disastrous situations.

During normal operations the following dynamic excitations may occur:

- External Excitations (Vibration of the entire pipe or individual sections through connected equipment such as pumps or turbines.)

  Unacceptable pipe motions usually occur only when the natural frequency of the piping system matches the operating frequency of a connected piece of equipment. Even small excitation forces may cause large motions due to resonance effects, not only close to the excitation source, but also at greater distances.

- Internal Excitations (Vibration caused by internal pressure pulsations during unsteady fluid flow).

  Large changes in fluid velocity may result in measurable pulsations. Fluid flow is controlled intentionally by opening and closing valves. Unsteady fluid flow can also be caused by the piping arrangement itself, e.g. the number and location of elbows, tees and reducers. Pressure pulsations may exceed the maximum permissible pressure rating, or fall below the fluid vapor pressure resulting in cavitation.

Dynamic deflections may also be caused by abnormal, potentially disastrous events, such as an

- Earthquake
- Plane crash
- Explosion (blast)
- Pipe breakage

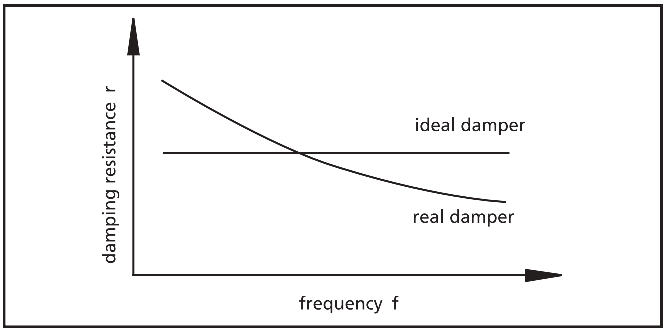
Operational vibrations usually show only small displacements and stress. Yet they can lead, on a long-term basis, to pipe fatigue and vibration crack corrosion. Alternating stresses that may be below the static yielding point of the pipe material can also lead to micro slips, which cause submicro-scopic

	Frequency Hz									
	2	4	6	8	10	20	30	40	50	60
Area	Vibration Velocity in um									
1	250	230	200	180	165	120	95	85	75	70
II	500	450	400	360	330	230	180	145	135	130
III	1250	1100	950	800	750	500	420	350	320	300

Table 1

Picture 1: Basic design of a Pipework damper

cracks near the top surface. Due to crack growth and unification, technical cracks may develop with a large stress peak at their tip. And finally, under continuously alternating loads, fatigue fractures may appear.



Picture 2: Frequency dependency of the damping resistance

As a result, operational vibrations are often the cause of pipe damage. Material fatigue increases with vibration velocity. The amplitude and frequency of the vibration are the determinant factors causing pipe damage.

By using viscous fluid dampers on piping systems, vibration amplitudes are significantly reduced and systems frequencies are lowered. There is less fatigue and the operating life of the pipe system is increased. The result is not only cost savings for the user, but also additional safety during normal operation as well as during abnormal, potentially catastrophic situations.

The successful installation of viscous fluid dampers requires a realistic evaluation of the destructive vibrations and an optimization of the damper in both size and mounting location.

The calculated and selective introduction of damping into the overall system is the main advantage of the viscous fluid damper. The nearly velocity proportional behavior allows both the computerized optimization of the overall system as well as the application of simple estimating procedures. Comparable damping values cannot be achieved with other elements, which operate for example on the basis of friction.

Evaluation of Pipework Vibrations

A main problem in the evaluation of operating vibrations in piping systems is the lack of internationally accepted and consistent criteria.

Based on the particular standard, displacement or velocity amplitudes are assessed depending on the frequency. Peak- or RMS-values are sometimes used as acceptable vibration limits. Some examples of evaluation criteria:

According to the method of R. Gamble and S. Tagart (3), which is based on the experience and the error analysis of 400 piping systems in American nuclear power plants, the maximum amplitudes are determined to be

* 0.50 mm for frequencies up to 10 Hz and
* 0.25 mm for frequencies between 10 Hz and 40 Hz.

In France, the limit of the vibration velocity for feedwater lines in nuclear power plants with capacities of 1300 MW (4) is an RMS value of 12.0 mm/s.

Russia uses the Standard PTM 38.001-94, with the following classifications

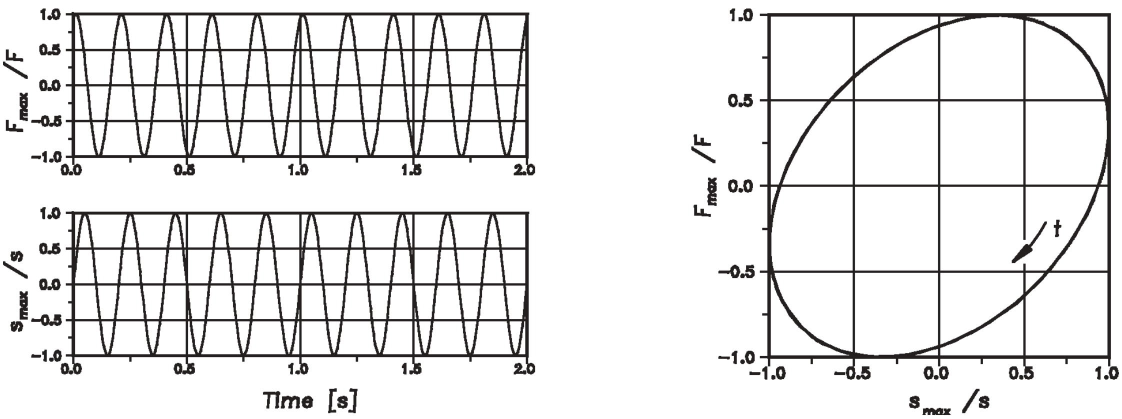
(I) Damage is not possible,

(II) Damage is improbable

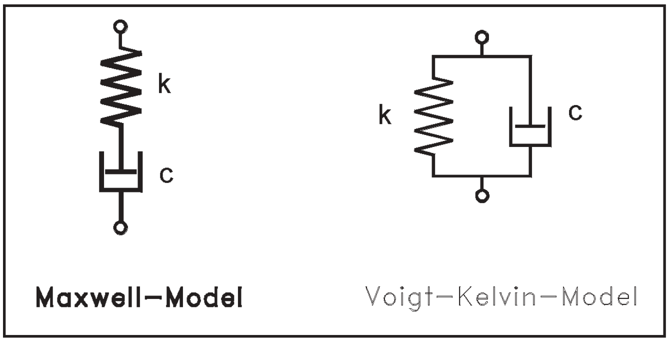
(III) Improvement is required and damage is possible.

Permissible displacement amplitudes are specified in µm for the individual areas depending on the frequency. (see table 1)

Currently the ANSI/ASME OM3-1982 Procedure 1 has become widely accepted.



Picture 3: Time history and force displacement loop.



Picture 4: Rheological models

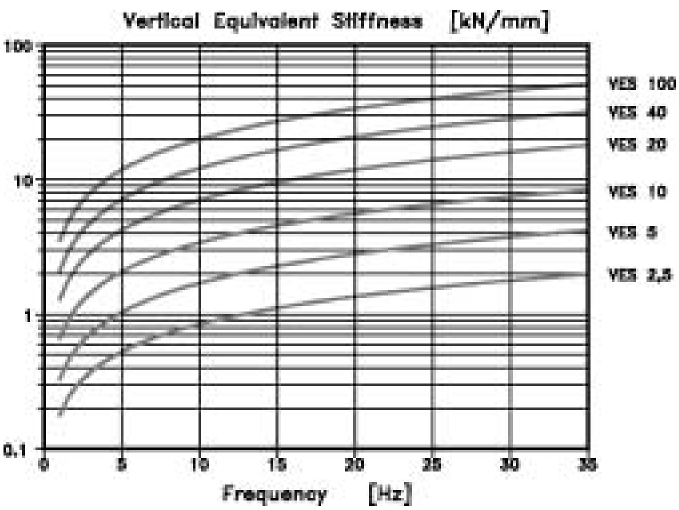
$$V_{allow} = \frac{C_1 \cdot C_4 \cdot (0.8 \cdot S_{el}) \cdot 3.64 \cdot 10^3}{C_3 \cdot C_2 \cdot K_2}$$

C_1	Factor for mass distribution
C_2, K_2	Parameter for stress condition
C_3	Factor for pipe contents and insulation
C_4	Factor for restraints

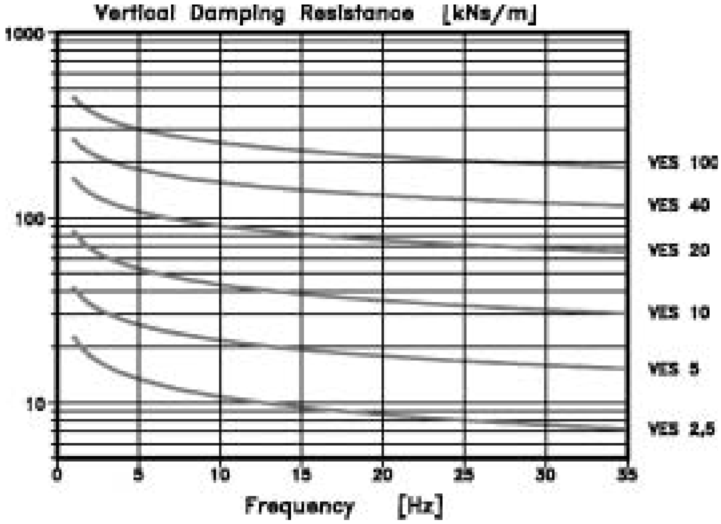
($0.8\ S_{el}$) Fatigue limit

The bases for the use of the specified formula are the measured or calculated values of the velocity, displacement and corresponding frequency. By using of the physical correlations for a beam between bending moment and elongation, these values are assigned to stress levels. Factors reflect the geometry, installation condition, load distribution and stress concentration of the piping system and/or section.

The pipe sections with unacceptable high vibrations must be analyzed dynamically with the goal of reducing the vibrations to acceptable values. An attempt should be made to improve the responsible source of vibrations. If this is not possible or sufficient, viscous fluid dampers are then an optimal way to achieve this goal.



Picture 6: Vertical equivalent stiffness (VES type)



Picture 5: Vertical damping resistance (VES type)

Viscous Fluid Dampers as Pipework Dampers

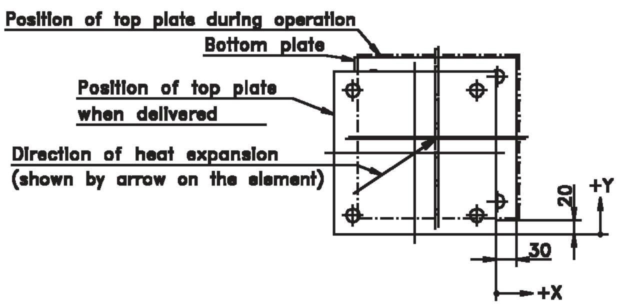
Pipework dampers consist of a damper pot, containing a highly viscous damping fluid and a damper piston, picture 1. The piston is immersed in the damping medium and can move in all directions up to the limiting damper case. Therefore, the damper is effective in all six degrees of freedom.

The damping forces result through shearing and displacing of the damping fluid. They are approximately proportional to the relative velocity v between the damper piston and damper case. The proportionality factor is called damping resistance r.

$$F = r \cdot v$$

In order to assure the proper function of the damper, one damper component, either the piston or the damper pot, has to be fixed. For practical applications this means that sufficiently stiff support and mounting is required. Then, the absolute velocity of the moving part can be used for the design calculations.

With the ideal viscous damper, the damping resistance r is frequency-independent, as shown in picture 2. Therefore, the damper force is ideally proportional to the velocity. In addition, when harmonically loaded, the phase angle between the viscous damper force and the displacement would be 90°.



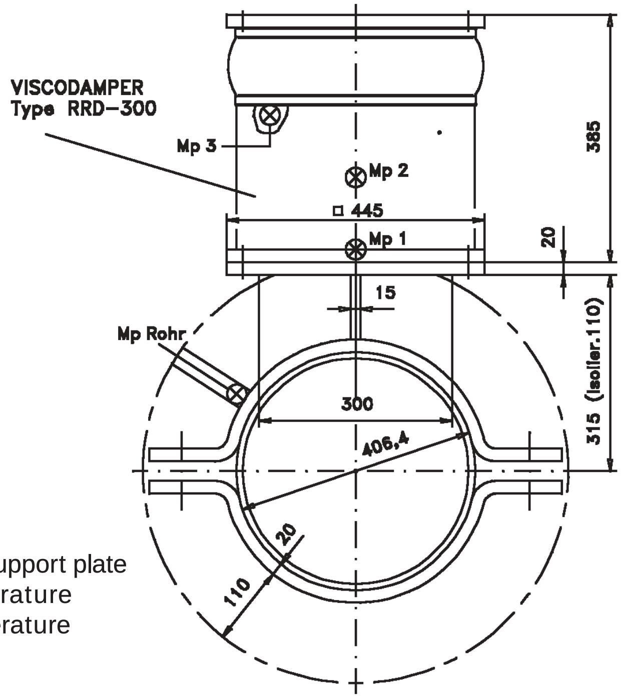
Picture 7: Preset of Pipework damper in case of large thermal deflections

Tube	Measuring Temperatures [°C]			
	Mp1	Mp2	Mp3	
300	102	77	62	I
250	81	59	49	I
225	75	55	45	I
210	70	52	45	I
175	64	45	41	I
150	55	42	38	I
125	50	41	38	I
144	47	39	36	I
300	86	66	48	II
300	55	...	40	III

Ambient Temperature: 20°C

I: directly attached
II: attached with insulating board
III: attached with spacer construction

Mp1: Temperature at support plate
Mp2: Housing temperature
Mp3: Mediums temperature



Picture 8: Heat transfer test (measurement points and stationary values)

In reality, viscous dampers have phase angles of 60° to 80°, since there is always an elastic component of the damper force in addition to the viscous component. Therefore, the phase angle may be used as a measure of the quality of a viscous damper.

Picture 3 shows the standardized time history of force and displacement as well as the resulting hysteresis loop for a phase angle of 70° between force and displacement.

The area of the stationary force displacement loop is a measure of the damping effect and corresponds to the dissipated energy per cycle. The dissipated energy causes the damping medium to rise in temperature. As a result, viscosity and damping resistance modify themselves until the damper adjusts to a thermodynamic balance. Ideal damping behavior with a 90°- phase shift between damper force and displacement would result in a circle.

The achievable damping depends on the damping medium, the internal design and the damper load. Static loads are not supported due to the velocity proportional behavior of the damper.

Slow movements, like thermal expansions of the pipe, only cause very minor resistance forces. The viscous elastic qualities of the damper can be described with rheological models, which are formed from the combination of ideal springs and dampers, picture 4. The Voigt-Kelvin-Model is well known and often used for the description of many vibration problems.

For the description of the basic damper behavior, the Maxwell-Model suits well since it has ideal relaxation qualities. It is able to describe the viscous elastic qualities of the damper for harmonious excitations as well as for sudden shock-type loads. However, the larger the depicted frequency range is, and the more variables there are to be considered, the more complex the mechanical models have to be.

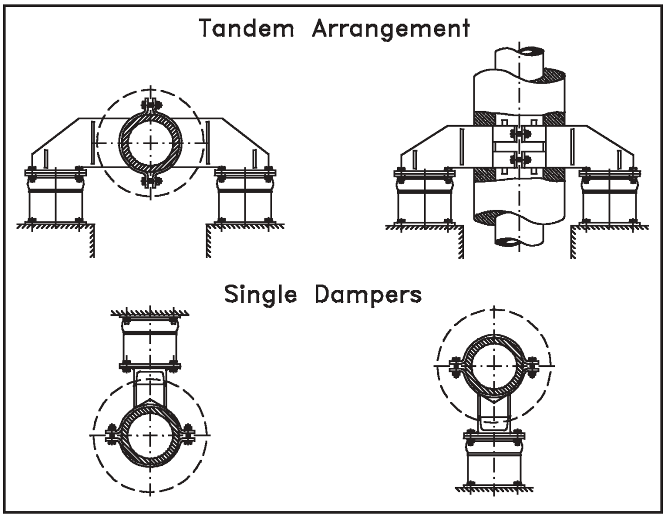
Different parameters are used to select dampers for specific tasks. These parameters must be determined experimentally for each damper. Pipework dampers may be characterized by the following:

- The vertical and horizontal damping resistance [kNs/m]
- The vertical and horizontal equivalent stiffness [kN/mm]
- The nominal load [kN]
- The permissible vertical and horizontal displacements [mm]

The damping resistance is primarily used for operational vibrations. It is determined, assuming ideal viscous behavior, experimentally from the dynamic amplitudes of force and vibration velocity over a large frequency range. Picture 5 shows the vertical damping resistance of the aptitude tested damper series VES. The frequency influence is clear: the damping resistance decreases with increasing frequency.

The equivalent stiffness is an auxiliary parameter, which may be used for computational programs, which cannot work with damping forces acting in single spots. During intermittent excitation the damper is handled like an elastic spring which otherwise is not existent.

For this purpose the equivalent stiffness was defined in accordance to the stiffness definition of a snubber. The equivalent stiffness must be measured similar to the damping resistance for each damper, picture 6. This parameter must not be mistaken for the elastic stiffness



Picture 9: Damper arrangements

The damping behavior of some damping fluids depends strongly on temperature. Therefore, for these dampers the damping effect depends on the proper determination of the working temperature in the damping medium during continuous operation, and the proper selection of the damping fluid. It is understood that the operational temperature is the highest temperature inside the damping medium during continuous operation. This temperature is influenced by the ambient temperature, the medium temperature inside the pipe and the potential heat transfer.

However, there is a clear difference between the temperature of the pipe medium and temperature in the damper. For example, it has been found in heat transmission tests that at a medium temperature of 300(C in the pipe, a temperature of only 62°C occurs in the damper. The values indicated in picture 8 show the stationary temperatures in each case.

Installing insulating plates or spacer constructions between the damper and pipe can further reduce the operating temperature.

Pipework dampers are mounted at the locations where experience or detailed calculations show that the largest displacements (antinodes) will occur. In most cases, it is better to employ several small dampers instead of one big damper, and to distribute them uniformly over several points of support. As a result, more mode shapes

part in the damper force. The equivalent stiffness should only be used for emergencies and not for normal operational vibrations, since the energy dissipating qualities and the phase shift between force and displacement don't come into play.

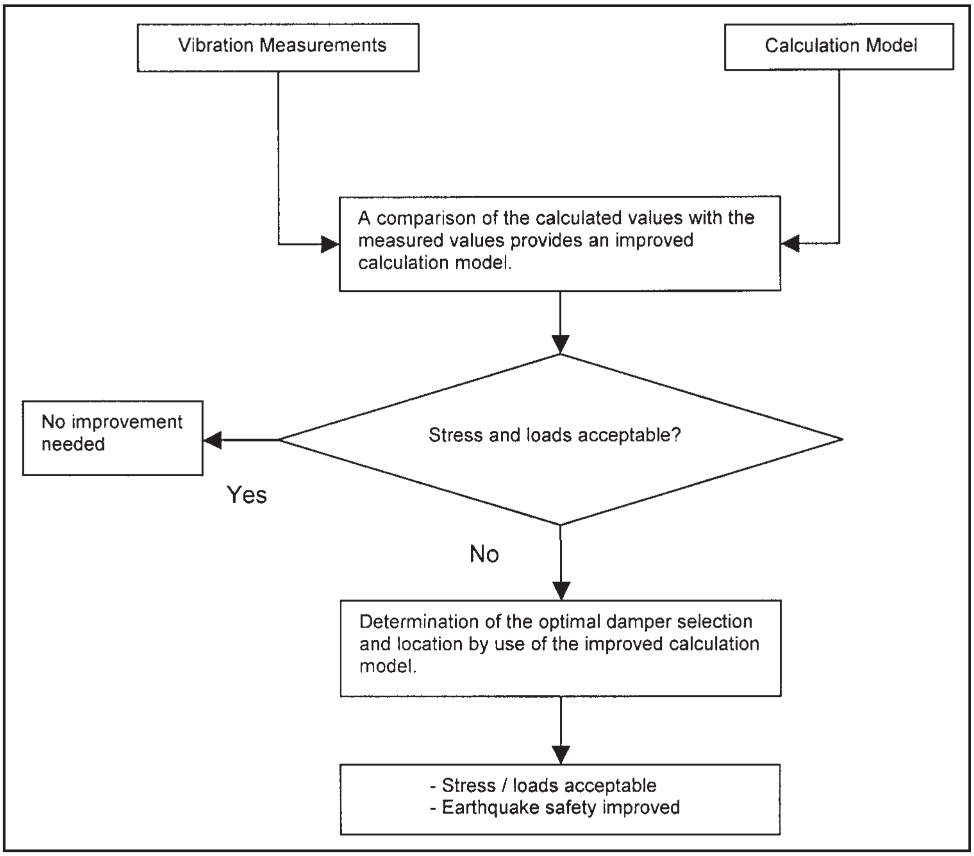
The damper design and/or selection can also be made on the basis of the nominal force FN. The rated load is the three-dimensional, dynamic force, which is approved as the maximum damping force at operating temperature.

Dynamic impacts should always be below this load limit, which is also determined experimentally for every damper, and which is mainly determined by the qualities of the damping medium.

If the dampers are loaded above the rated nominal load, the damping medium may shear off the damper piston (F > 1,7 x FN). However, this process is reversible, and after a short time the damper is again fully functional. A replacement of the damping medium is not required.

The permissible displacement is the sum of all straight movements, i.e. the thermal expansion of the pipeline, the operating oscillations and the impulse response.

In the case of great thermal expansion, the dampers may be preset in all three directions, so that the damper pistons moves close to middle position with increasing temperature and thermal expansion, picture 7.



Picture 10: Procedure for the reduction of operational vibrations of piping systems [12]

can be effectively dampened. In order to avoid the transfer of moments to the pipe, they may be used symmetrically in the so-called tandem arrangement as shown in picture 9.

The most important qualities of the Pipework dampers can be summarized as follows:

- Effectiveness in all degrees of freedom

- High damping forces with shock-type excitations

At great load rates in emergency cases, the pipework damper develops high resistances forces. As a result, unacceptable deflections, e.g. during earthquakes, aircraft crash or pressure pulse, are suppressed.

- Damping of operational vibrations

Pipework dampers increase the overall damping of piping systems. They are effective in emergencies as well as during operational vibrations.

- Immediate response without delay, time lag or minimum response shift

The damper piston is always in contact with the damping medium so that the damper immediately responds as a dynamic restraint.

- Small resistance forces during slow movements

Pipeline movements due to thermal expansions are not hindered.

- Maintenance freedom

Pipework dampers are virtually maintenance-free since they are simply designed, have no wearing parts, and the damping media are not susceptible to aging.

Procedure for the Reduction of Operational Vibrations
The procedure for the reduction of operational vibrations is depicted in picture 10. The evaluation is performed in accordance with ANSI/ASME requirements [5], and the structural analysis is carried out using a computation model that was adapted as well as possible to real measurements. Unreliable load parameters are determined as conservatively as possible.

In general, unexpected peaks and irregular load increases are balanced by the “good-natured” behavior of the viscous fluid damper. Because of the peak reduction and energy dissipation, deflections are unable to build up and resonance effects are softened.

The goal of the damper selection is to optimize the introduced damping in such a way that the “decisive”, mostly low frequency modes receive the maximal possible modal damp-ing. As a result, the modes having the greatest component in the total value of the dynamic response are significantly reduced.

By installing as many dampers as necessary, damping can be select-ively inserted into the structure at the optimal positions so that the “dangerous” modes are effectively reduced and resonance effects eliminated. This practice reduces metal fatigue of the piping and therefore increases the service life of all related pipe components.

In existing plants, this practice must be complemented by site inspections to find a compromise between the optimal, calculated mounting points and the installation options feasible on site.

Results
The use of viscous fluid dampers to reduce operational vibrations was applied with great success, on feedwater line at the NPP PAKS (Hungary). Pictures 11 and 12 show how stress and deflections were reduced by this measure.

The subsequent installation of dampers increases the service life of the piping system. In addition, earth-quake safety is improved. Picture 11 depicts how the dampers effectively reduce the stress values in the pipe. It is also clear that the success of the measure depends on the optimal selection of the dampers. Picture 12 shows again the success of the procedure by comparing the deflec-tions with and without dampers. The deflections could be reduced to 10% of their initial values. In addition, the dampers are not only effective at the mounting points but also smoothen the overall dynamic characteristics of system. The calculated values were confirmed by control measurements after the completion of the works.

Bibliography

[1] Schwahn, K.- J.: Nachweis der Reduzierung von Strukturschwingungen mittels viskoser Dämpfer. VGB Kraftwerkstechnik 69, Heft 10, Okt. 1989.

[2] Dubbel: Taschenbuch für den Maschinebau, S. 256, 15. Auflage. Herausgeber W. Beitz und K.-H. Küttner. Springer Verlag Berlin Heidelberg, New York, 1981.

[3] Gamble, R.M.; Tagart, S.W.: A Method to Assign Failure Rates for Piping Reliability Assessment. PVP-Vol. 215, Fatigue, Fracture, and Risk, ASME 1991.

[4] Seligman, D.; Guillou, J.: Flow induced vibration in a PWR piping system. Transactions of the 13th SMIRT, Porto Alegre, Brazil, August 13-18, 1995.

[5] Requirements for Preoperational and Initial Start-up Vibration Testing of Nuclear Power Plant Piping Systems. ANSI/ASME OM 3-82.

[6] Reinsch, K.-H.; Barutzki, F.: Technischer Bericht - "Rohrleitungsdämpfer" GERB Schwingung-siolierungen, Ausgabe 1997.

[7] Reinsch, K.-H.; Barutzki, F.: Dämpfung von Schwingungen in Rohrleitungssystemen. Hand-buch "Rohrleitungstech-nik" - 6. Ausgabe, 1994, S. 142-147, Vulkan-Verlag Essen.

[8] Schwahn, K.-J.; Reinsch, K.-H.; Weber, F.: Beschreibung der Eigenschaften viskoser Dämpfer unter Zugrun-delegung rheologischer Ersatz-modelle, dargestellt am Beispiel von ohrleitungs-dämpfern. VDI Berichte Nr. 627, S. 263-292, 1986.

[9] Kuitzsch, W., Delinic, K.; Zerrmayr, F.: Die Reduzierung von Rohrleitungsschwingun-gen im Betrieb und in Störfall. VDI Berichte Nr. 603, S. 263-292, 1986.

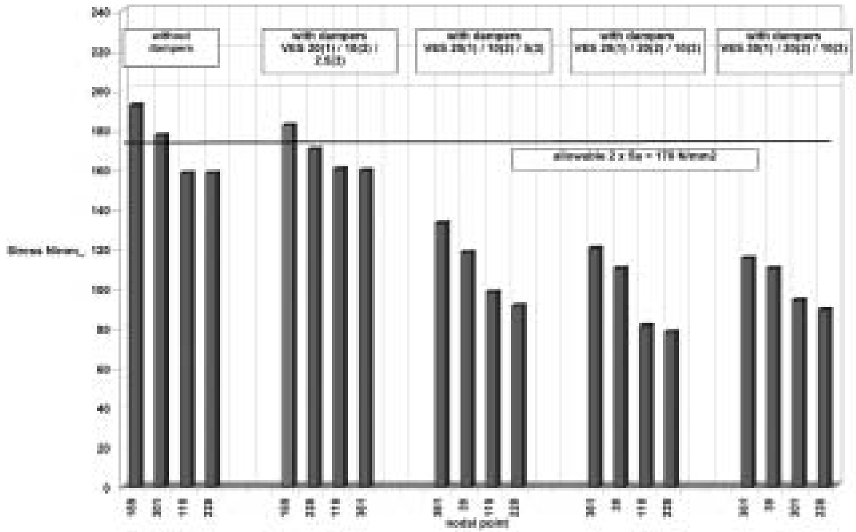
[10] Delnic, K.: Eigenschwingungs-verhalten von Strukturen bei Einsatz von Dämpfern. VDI Berichte Nr. 627, S. 375-401, 1987.

[11] Katona, T.; Ratkai, S; Zeitner, W.; Richter, G.; Delnic, K; Reinsch, K.-H.: Reduktion der Betrieb-sschwingungen der Speise-wasserleitung des KKW Paks.20 MPA - Seminar in Stuttgart 1994.

[12] Zeitner, W.; Katona, T.: Ratkai, S.; Reinsch., K.-H.: Reduction of operational Vibrations. ENS Topsafe, 95, Budapest 1995.

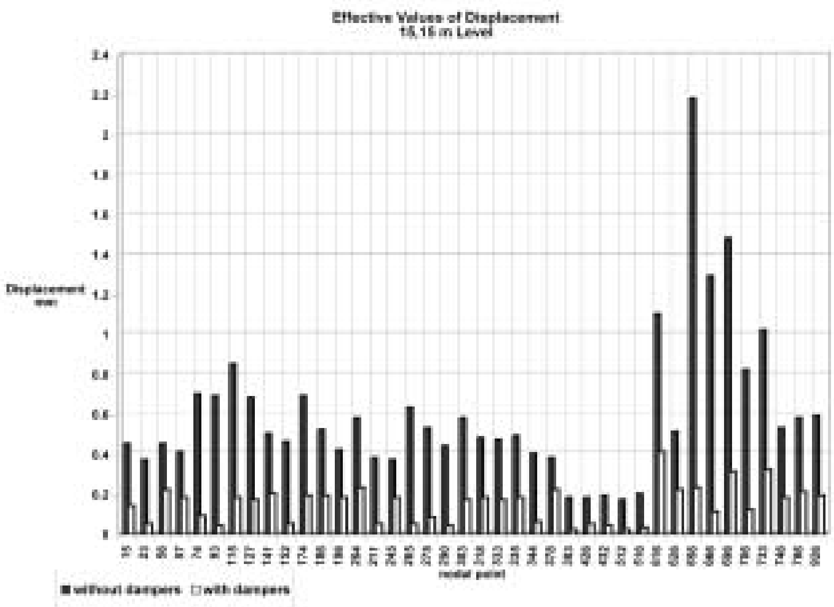
[13] KTA-Richtlinie 3205.3: Kompo-nentenstütz-konstruktionen mit nichtintegralen Ansch-lüssen, Teil 3: Serienmässige Standard-halterungen. Carl Heymanns Verlag, Köln, 1989.

[14] TÜV Hannover / Sachsen-Anhalt e.V.: Prüfbescheid zu der TÜV-Eignungsprüfung von VISCO Dämpfern der Fa. GERB, Berlin (Prüfbescheid Nr. T08-84-01, März 1984 / Rev. 2 August 1992).



number and type of dampers					
	Variant 0	Variant 1	Variant 2	Variant 3	Variant 4
(1): 30RL20 DN 400	0	2 x 2 x VES 20	2 x 2 x VES 20	2 x 2 x VES 20	1 x 2 x VES 30
(2): 30RL21-26 DN 250	0	12 x 2 x VES 10	12 x 2 x VES 10	12 x 2 x VES 20	12 x 2 x VES 20
(3): 30RL21-26 DN 80	0	24 x 1 x VES 2,5	24 x 1 x VES 5	24 x 1 x VES 10	24 x 1 x VES 10

Picture 11: Influence of the viscous fluid damper on the stress values for different damper designs and selections. Machine house, height 15.15 m.



Picture 12: Influence of viscous fluid dampers on the reduction of the vibration amplitudes. Turbine house, height 15.15 m, calculated values with and without dampers.

[15] TÜV Hannover / Sachsen-Anhalt e.V.: Prüfbescheid zu der TÜV-Eignungsprüfung von ISCO Dämpfern der Fa. GERB, Berlin (Prüfbescheid Nr. T08-91-12, Juni 1991 / Rev. 1 August 1992)

***Frank P. Barutzki**, Ph.D., is vice president and Director, U. S. Operations, for GERB Vibration Control Systems, Inc., 1950 Ohio Street, Lisle, IL 60532: (630) 724-1660; gerbusa@gerb.com; Internet www.gerb.com*