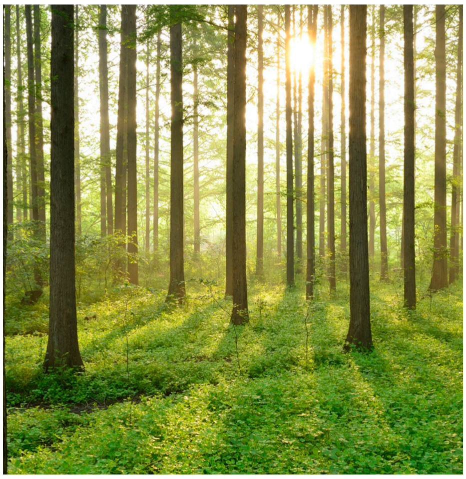
VIBRATION ELIMINATION USING 3D VISCODAMPER TECHNOLOGY

REPORT 2020:677



NUCLEAR

VIBRATIONS IN
NUCLEAR APPLICATIONS

Energiforsk

Vibration elimination using viscodamper technology

Summary of experiences from nuclear-, conventional-, and chemical plants

DR. FRANK BARUTZKI, DR. VICTOR KOSTAREV, DR. DMITRII PAVLOV & IRINA EVZIKOVA

ISBN 978-91-7673-677-7 | © Energiforsk June 2020

Energiforsk AB | Phone: 08-677 25 30 | E-mail: kontakt@energiforsk.se | www.energiforsk.se

Foreword

Pipe vibrations frequently occur in nuclear power plants and plant vibration experts spend a lot of time analysing the causes and implementing different mitigation methods. Viscous dampers have proven to be an interesting solution in many cases, compared to conventional dampers, to address pipe vibrations in nuclear power plants.

CKTI-Vibroseism is a research and development engineering company specialized in anti-seismic design and vibrational safety in Nuclear and Conventional power plants with long experience in designing and implementing high viscosity dampers. In this report senior experts Dr. Frank Barutzki, Dr. Victor Kostarev, Dr. Dmitrii Pavlov, and Irina Evzikova have summarized operational experience from using viscous dampers in vibration mitigation in nuclear-, conventional power- and chemical plants. The study has been carried out within Energiforsk's research programme Vibrations in Nuclear Applications. The stakeholders of the program are Vattenfall, Uniper, Fortum, TVO, Skellefteå Kraft and Karlstads Energi.

These are the results and conclusions of a project, which is part of a research programme run by Energiforsk. The authors are responsible for the reports content.

Sammanfattning

Denna rapport summerar tillämpade erfarenheter av att reducera vibrationer i rörsystem i kärnkraftverk och andra industriella anläggningar med hjälp av viskösa dämpare.

I studien summeras erfarenheter från vibrationsreducering i rörsystem med hjälp av viskösa dämpare, high viscous dampers (HVD). Till skillnad från andra typer av dynamisk dämpning så begränsar inte HVDs elasticiteten i rörsystemet, som andra dämpare, snubbers, gör. HVD är även ett effektivt verktyg för att uppgradera skyddet för seismisk aktivitet och extrema dynamiska laster. Denna typ av laster ingår dock inte i denna studie, som fokuserar på driftrelaterade vibrationer.

Rapporten ger en övergripande beskrivning av HVD-dämparens design och beskriver dess förmåga för att reducera vibrationer i rörsystem, genom tillämpade exempel från flertalet anläggningar. Vidare föreslås tröskelvärden för vad som kan anses som acceptabla vibrationer i rörsystem.

De grundläggande stegen för att lösa problem med vibrationer i rörsystem läggs fram vilket inkluderar undersökning av vibrationernas beskaffenhet, dynamisk analys, motivering av vald lösning för att reducera vibrationer, och olika typer av dämpare. Tillvägagångssättet illustreras med hjälp av ett flödesschema för att på ett strukturerat sätt analysera och reducera vibrationsproblem samt grundläggande krav på instrumentering för att mäta vibrationer.

Fallstudier har även inkluderats där effektiviteten av HVDs har varit begränsad. Detta förklaras med en bristande analys av vibrationerna och otillräckligt stöd av ingenjörsexpertis vid implementering. Låg dämpning av högfrekvensvibrationer över 40Hz och temperaturbegränsningar för vissa dämpare är ytterligare underliggande orsaker som undersöks.

Rapportförfattarnas samlade slutsats är att HVD ger den mest effektiva dämpningen av rörvibrationer, jämfört med andra typer av dämpare. Detta i jämförelse med alla andra existerande tillvägagångssätt, som beskrivs i de referenser som rapporten utgår ifrån. Erfarenheterna spänner över mer än tre årtionden, från de två företagen GERB och CVS.

Summary

This report provides information on the applied experience of eliminating vibrations in piping systems of nuclear power plants and other industrial facilities.

The gained experience involves cases of high viscous dampers/viscodampers (HVD) application for mitigation of operational vibrations by introducing significant damping into piping systems. In contrast with other dynamic supports they do not restrain piping elastically, for example like snubbers do. HVD also is an efficient source for seismic upgrading and extreme dynamic loads protection of systems but this extensive and worldwide experience is out of this report's scope, which concentrates on operational vibration issues only.

The report provides a general description of the damper design and describes the efficiency of HVDs in piping vibration reduction in several power plants and industrial facilities. In addition, the thresholds and allowable piping vibration levels are under consideration in the report.

The fundamental steps for resolving vibration problems in piping systems are given, including examination of vibrational state, dynamic analysis, justification of the proposed measures to reduce vibrations, types of damping devices selected as well as a general flow chart for the piping vibration mitigation approach and basic requirements for vibration instrumentation.

A few cases with limited HVD efficiency are also examined in the report. Limited efficiency as a result of lacking vibration analysis and engineering support in damper application along with a low dampening of high frequency vibration over 40 Hz, as well as existing temperature limits for some type of dampers are under consideration.

In general, due to comprehensive analysis and experimental experience the authors of the report conclude that using HVD technology is the best option for piping vibration mitigation in comparison to all other existing approaches mentioned in several references to the report. The authors have experience spanning more than three decades, from the companies GERB and CVS.

Table of Contents

List of Abbreviations

ASME	American Society of Mechanical Engineers
BPVC	ASME Boiler and Pressure Vessel Code
CVS	CKTI-Vibroseism Co. Ltd., Russia
DS	Damper Support
DU	Damping Unit
HVD	High Viscous Damper
GERB	GERB Schwingungsisolierungen GmbH & Co. KG
IAEA	International Atomic Energy Agency
KTA	Nuclear Safety Standards Commission
NPP	Nuclear Power Plant
PP	Power Plant
PSD	Power Spectral Density
PWR	Pressurized Water Reactor
RD	Regulation (Guidance) Document
RMS	Root-Mean Square
SRSS	Square-root-of-the-sum-of-the-squares
VDI	Verein Deutscher Ingenieure (the Association of German Engineers)
VVER	Water-Water Energy Reactor
3D, 6D	Three-directional or six directional spatial motion

1 Introduction

General safety requirements for nuclear power plants (NPP) are quite different to conventional fossil power plants. This is true especially in regard to seismic design and protection from different extreme dynamic loads of natural origin like earthquakes, or malfunctions internal to the plant.

A typical 1000 MWt NPP contains more than 70 000 meters of nuclear safety related piping with over 20 000 static supports and requires, due to specific safety regulation, hundreds to well over 1000 seismic dynamic restraints, if located in a high seismicity zone with 0.3g and higher peak ground acceleration. However usual seismic restraints as hydraulic and mechanical snubbers are not helpful in protecting piping from operational vibrations as they work dynamically like an elastic or rigid stopper rather than a dampening device.

1.1 USE OF DYNAMIC RESTRAINTS AS NUCLEAR POWER PLANT PIPE SUPPORTS

Piping systems itself are usually low damped oscillatory systems that can easily be excited by internal and external forces. This relates especially to nuclear piping having a number of lines with saturated steam and two-phase flow. The low damping leads to significant amplifications of oscillations in case the natural frequencies of the piping system are excited by forces with corresponding frequency content.

To reduce these motions different dynamic restraints are used. In general, all dynamic piping supports do not restrict system’s thermal expansions and other static motions or loads during start up, shutdown and normal operation conditions but restrain piping subjected to seismic or impact loads.

Since 2007 Edition ASME Boiler and Pressure Vessel Code Section III for Construction of Nuclear Facility Components Sub-section NF Supports recognizes three types of dynamic restraint support, a) Snubbers, b) Energy Absorbers c) Gap Restrains and d) Viscoelastic Dampers [37].

The ASME QME-1-2012, “Qualification of Active Mechanical Equipment Used in Nuclear Facilities” standard also considers and addresses the operating and maintenance requirements for these types of dynamic restraints.

The German KTA 3205 “Component Supports Structures with Non-integral Connections” issued by Nuclear Safety Standard Commission also determines viscodampers as a standard dynamic support for nuclear applications [38].

1.2 DAMPERS

The actual damping of a piping system considered in seismic and vibration analysis could be significantly increased by the application of viscodampers. This results in essential reduction of piping earthquake loads and/or essential mitigation of piping vibrations. Viscoelastic dampers as dynamic restraints also have no dead bands which may be present in other types of dynamic restraints due to clearances in joints. It is important for small cyclic or vibratory motion to restrain piping systems when subjected to very low amplitude and high frequency vibrations. Such motions are typically induced in piping by flow, reciprocal or rotational motion in components attached to the piping system.

One essential advantage of high viscos damper (HVD) technology is the very low maintenance and operational costs compared to the associated costs of the snubber technology. The operational characteristics of a viscoelastic damper (VD) in service can be determined simply by visually verifying the level of viscous fluid in the damper housing during normal outage period of the plant and by testing the fluid viscosity on a basis of several years period if dampers are located in very high radiation zones in reactor's proximity. Dampers are always installed in an upright position so that there is no potential for leakage of the viscous fluid. In theory, HVDs have an unlimited service life and can therefore last at least as long as the service life of the system where the dampers have been installed. According to TU the service life of VD dampers is formally defined as 60 years [30].

The viscodamper, HVD, or VD, addressed in the ASME Code, was invented initially in Germany in the 1930s and the HVD design was improved by Russian engineers in the 1980s. Because of its simplicity in design and construction, viscoelastic dampers have seen wide application in Europe both in initial application and in seismic re-evaluations and upgrades to resist both earthquake and operation vibrations in conventional plants as well as in NPPs. They are seeing wide application to current or new NPP designs in Europe, China, India and nowadays in the US and Japan where they are used as a supplement, or as an alternative to other types of dynamic restraints (mostly snubbers). Since early 90s more than 10 000 units of viscoelastic dampers have been installed around the world at nuclear and conventional power plants and industrial facilities. The modern history of HVD technology is rather long, and its stages and main developments can be traced from the documents listed in the references [1 – 30].

2 Piping Vibration Criterion and Operational Practice

Piping vibration is rather commonplace. We meet piping vibration on different levels constantly, while visiting industrial or manufacturing facilities and even in the daily routine. Often it is very difficult to find out the specific causes of piping vibration. Piping systems of power plants and chemical facilities are complex structures with a lot of elements that are subject to various loads and excitations, including dynamic loads. Vibration is one of them. Vibrations are often the cause of failure and damage, sometimes with serious and even catastrophic consequences.

In addition to piping and support fatigue problems, a serious worsening of working conditions could take place due to vibration induced noise covering different working areas. Including permanent human working places and especially control rooms of nuclear and conventional power plants. Plant operation safety concerns for personnel also exist in working with highly vibrating, pressurized, and hot piping systems.

Vibrations of piping can be caused by mechanical vibrations of the connected equipment and pulsations of the pressure of the medium inside the piping. Variable forces that cause vibration can occur during vortex formation in the region of areas with changing hydraulic resistance or during operation of pulse control devices, flow pulsations during cavitation phenomena and steam and water hammers.

The frequency of the disturbing forces can vary over a wide range and cause an increase in the vibration of the piping associated with mechanical or acoustic resonances. Even weak pressure pulsations, which in themselves do not cause problems, can significantly increase the vibration of the piping if they fall into the system's acoustic or mechanical resonance range.

It must be noted that conventional vibrating piping at power plant achieves standard 106 cycles in less than one year of operation. Meanwhile existing low cycle fatigue curves usually have a cut off cycles number just at 106.

An increasing concern of the engineering society regarding piping vibration can be seen in the trend to extend the existing ASME fatigue curves to cycle ranges up to 1011 and at the same time consider environmental effects of piping operation. However, at the moment a recognized international practice in piping vibration limits does not yet exist in contrast to turbines and other rotating equipment.

It is connected mainly with the diversity of piping operational conditions, layouts, diameters, and materials. Only a few national recommendations and guidelines were developed based on operational experience of safety related piping subjected to vibration loads.

ASME OMa S/G-2000 Standard Part 3 installs limits for piping vibrovelocities and vibration displacements based on a piping fatigue stress analysis according to ASME Code [31].

ASME OM piping screening criterion is 12.7 mm/sec of peak vibrovelocity and seems to be a very conservative piping vibration safety margin with guaranteed fatigue capacity independently on a piping layout and features. If vibration exceeds this level the Guide recommends performing additional analysis or to improve the piping vibration state.

ASME BPVC (NB-3622.3) recognizes inability to predict piping vibration on a design stage and thus indicates only that piping vibration must be in limits that guarantee safe operation [32].

In France, a recommended threshold RMS vibrovelocity for NPP piping is defined as 12 mm/s [33]. These data correlates to French standard in the gas industry.

Russian Boiler Standard RD 10-249-98 recommended to control piping peak vibrovelocity according to the following criteria: less than 15.0 mm/s is excellent; 15.0-25.0 mm/s requires additional measurements and analysis to confirm safety; more than 25.0 mm/s recommends improving vibration state of the system, [34].

The most comprehensive European guideline for piping vibration is VDI 3842 [35] that provides some screening criteria for piping vibrovelocities against frequency of vibration (Figure 1) based on rearranged Wachel allowable, [36], (Figure 2).

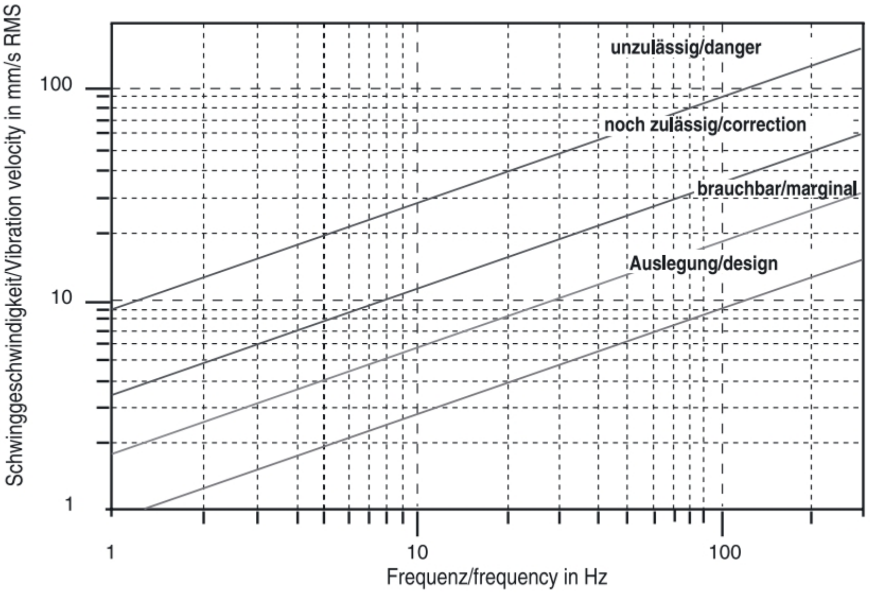


Figure 1. VDI 3842 limits for piping vibration (rear-ranged J.C. Wachel allowable)

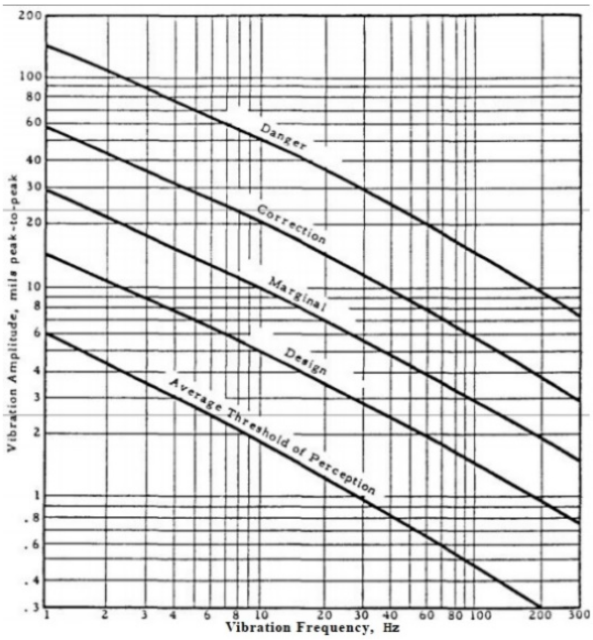


Figure 2. J.C. Wachel allowable values for piping vibration

According to VDI 3842 [35] vibrovelocities in the frequency range 3 to 30 Hz with corresponding values more than 6 to 20 mm/s RMS is recognized as “Required corrections” and 16-50 mm/s RMS as dangerous for piping safety.

The owner or the operating organization may therefore set more or less strict allowable values of vibration using different recommendations of codes and regulations and their own practice. For example, based on all available documentation and good nuclear plants’ operational practice the following thresholds for piping vibration at Loviisa NPP was approved: RMS vibrovelocity, in axial or cross-section direction, less than 7.5 mm/s; Peak vibrovelocity less than 20mm/s. RMS threshold was recognized as the primary limit and peak value as the secondary one.

In CVS’s long-term R&D and operational practice, the following values are used as thresholds for the allowable RMS vibrovelocity of the piping:

- Less than 12 mm/s piping RMS velocity means: Acceptable value, no problem with piping safety in general. Good operational quality.
- 12-25 mm/s piping RMS velocity means: Recommended to undertake periodic piping walkdowns, to analyse influence of vibration on piping safety and vibration measurement to control vibration state. Moderate operation quality.
- More than 25 mm/s piping RMS velocity: Recommended to undertake actions to reduce vibration or to fulfil comprehensive vibration analysis. Elevated risk for piping and supports integrity. Poor operation quality.

3 General description of viscoelastic damper

The first patent for an HVD, having a housing filled with bitumen, was obtained by Dipl. Eng. William Gerb in 1937. Since 1908 GERB Vibration Control Systems is engaged in the development, design, and manufacturing of elastic support systems for machinery, heavy industrial equipment, and structures like large steam turbines or entire buildings. Helical compression steel springs are usually the elastic component in these elements.

In 1937 GERB introduced viscoelastic fluid dampers to increase system damping and restrict dynamic motions of vibrating systems. The damper was originally used to dampen vibrations of diesel engines on ships and submarines. GERB VES Damper is shown in Figure 3.

Figure 3. VES type viscodamper.

GERB developed viscodampers for piping systems in the early 1970’s. They work as dynamic restraints, increasing system damping, limiting dynamic displacements but not interfering with slow pipe motions like thermal expansions.

The first application of viscodampers VES in the nuclear industry dates back to the early 80s of the last century as part of the “Konvoi project" at nuclear plants in West Germany. Dampers for nuclear applications have been developed and manufactured under strict quality assurance guidelines. GERB dampers type VES are tested by the German TÜV for the use as standard supports in NPPs [38].

In 1985, the Russian design viscodamper VD was invented, which differs from the original design in the presence of additional internal elements and a special silicone based high viscous liquid as working grease (Figure 4). These design variations allow to expand the dynamic range of the damper's characteristics and the temperature range and expansions of its application. In Figure 3 and 4 dampers are shown with assembling spacers between piston and housing that shall be removed in operation conditions. Thus, damper's piston and housing will be and shall be connected hydraulically only.

Figure 4. VD type viscodamper.

Since that time viscodampers VD have been widely used at NPPs with VVER reactors[1], and worldwide at BWR, PWR and Fast–Breed NPPs as seismic and vibration protection dynamic supports.

Nowadays dampers of both types, VES and VD, are manufactured by GERB GmbH under strict quality control.

VES type dampers are working with organic, bituminous, damping fluids with high temperature dependency. In agreement with the German TÜV the working temperature range of these damping fluids is defined by the operating temperature TB + 5°C/- 20°C. This temperature depends on the ambient temperature and the heat transmission from the hot pipe or equipment into the damper. Fluids for operating temperatures from 20° to 80°C in 10°C steps are provided.

VD type dampers are filled with a silicone-based fluid. The characteristics of VD dampers are slightly dependent on the temperature of the working fluid. Conventional VD dampers are applicable for ambient temperatures from -10 ° C to + 150 ° C that is the standard temperature range in NPP Reactor Containments or Confinement during normal operation and accidental conditions. This range could be extended to -50° C/+200° C by special order. When using VD dampers, the calculated dynamic characteristics obtained under normal testing conditions 20 ° C are slightly adjusted according to the existed experimental empirical dependence. That is why VD dampers are so called "nearly temperature independent".

Dampers are intended to protect NPP's systems, components, distribution systems, equipment and piping in a wide range of dynamic loading and to provide vibration damping in all directions of the system's dynamic motion. The most effective vibration damping exists within the frequency range from 0 to 40 Hz.

---

[1] Russian type of PWR reactor's system.

With increasing frequency of the dynamic excitation, the damping efficiency, viscos part of reaction force, decreases with concurrent increase of the dynamic elastic stiffness.

Commonly, a damper consists of a housing filled with working viscous liquid, piston, and some internal elements immersed in the working liquid. In general damping forces in the HVD are generated by shearing and displacing highly viscous fluid between piston and housing associated with their relative 6D motion. The overview of a VD damper is given in Figure 5.

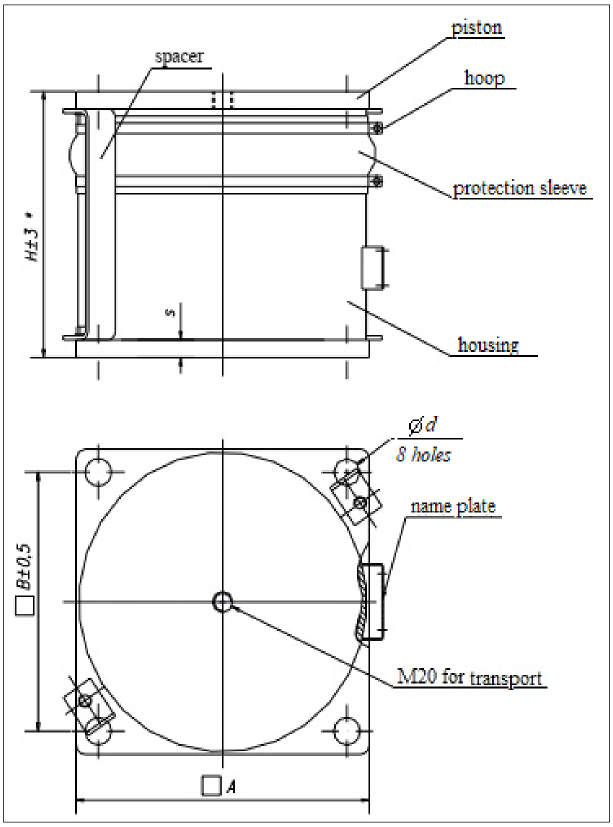


Figure 5. Overview of VD damper.

The protection sleeve attached to housing and piston by bands is used to avoid working liquid contamination by dust, water, decontamination agent, etc. For transportation, storage convenience, and for keeping “housing – piston” in mutual position spacers rigidly connecting housing and piston flanges are used. These spacers should be removed during damper installation.

There are holes in each square damper flange for connecting damper to damper support. Central hole in the piston’s flange is made for ring-bolt installation.

VD dampers nomenclature is based on a combination of piston and housing characteristic diameters and stiffness index. Dampers with the same piston and housing but with different number of internal elements differ in stiffness index numerated as 3, 7 or 15.

An example of damper designation with characteristic diameters of 325 mm and 219 mm and stiffness index “7” is as follows: “Damper VD 325/219-7 TU 4192-001-2050¬3039-01” or “Damper VD 325/219-7 TU” [30].

Overview and installation sizes of the most common types of VD dampers in the nuclear industry are shown in Table 1 (see also Figure 5).

Table 1. VD damper sizes.

Damper Type	Weight, (kg ±5%)	Dimensions (mm)				
		H*	A	B	d	s
VD 108/57-3	6	152	130	106	14	8
VD 159/76-3	15	197	180	150	18	10
VD 159/76-7	15	197	180	150	18	10
VD 219/108-3	30	236	238	200	22	15
VD 219/108-7	31	236	238	200	22	15
VD 219/159-3	36	236	238	200	22	15
VD 325/159-3	82	333	342	286	33	20
VD 325/159-7	86	333	342	286	33	20
VD 325/159-15	91	333	342	286	33	20
VD 325/219-3	92	333	342	286	33	20
VD 325/219-7	96	333	342	286	33	20
VD 426/219-3	153	378	434	368	39	25
VD 426/219-7	157	378	434	368	39	25
VD 426/219-15	165	378	434	368	39	25
VD 426/325-3	176	378	434	368	39	25
VD 426/325-7	181	378	434	368	39	25
VD 630/325-3	466	556	646	542	60	35
VD 630/325-7	479	556	646	542	60	35
VD 630/325-15	491	556	646	542	60	35
VD 630/426-3	503	556	646	542	60	35
VD 630/426-7	517	556	646	542	60	35
VD 630/426-15	548	556	646	542	60	35

*** damper’s nominal height**

Maximum dynamic loads which do not influence the dampers working capacity, nominal load, are given in Nominal loads. Dynamic data for VD dampers have been obtained by testing prototype models with the GERB quality assurance procedures in accordance with KTA 3205.3 requirements [38]. All the tests were conducted in the frequency range from 0 to 40 Hz at a working liquid temperature of 20 ± 5° C.

Shift of piston from its nominal, central, position within the allowable displacements makes no impact on damper dynamic behaviour.

Nominal position is noted for damper housing-piston concentricity with damper rated height H* (see Table 1 and Figure 5).

Allowable linear, horizontal and vertical, displacements are the maximal relative "housing-piston" displacements from nominal position. Allowable angular displacements are the possible piston rotation in degrees from nominal position around a horizontal axis passing through the piston flange centre point.

Allowable relative linear and angular damper "housing-piston" displacements from normal position are listed in Table 2.

Table 2. Nominal loads and allowable displacement of VD dampers.

Damper type	Nominal load		Allowable displacement (±) from normal position		
	Horizontal	Vertical	Horizontal	Vertical	Angular
	H	H	mm	mm	degree
VD-108/57-3	1750	1200	13	13	9
VD-159/76-3	3800	2650	27	25	11
VD-159/76-7	8100	4500	25	25	11
VD-219/108-3	7200	5050	41	24	11
VD-219/108-7	15500	8500	39	24	11
VD-219/159-3	10000	7000	15	24	6
VD-325/159-3	16000	11000	67	40	14
VD-325/159-7	34000	18500	64	40	14
VD-325/159-15	68000	27000	58	40	14
VD-325/219-3	21000	15000	37	40	9
VD-325/219-7	46000	25000	34	40	9
VD-426/219-3	27000	19000	87	45	18
VD-426/219-7	58000	32000	84	45	18
VD-426/219-15	120000	47000	78	45	18
VD-426/325-3	36000	25000	34	45	7
VD-426/325-7	80000	44000	31	45	7
VD-630/325-3	60000	42000	134	74	11
VD-630/325-7	130000	70000	130	74	11
VD-630/325-15	260000	100000	122	74	11
VD-630/426-3	80000	56000	84	74	11
VD-630/426-7	175000	95000	80	74	11
VD-630/426-15	350000	140000	72	74	11

Dampers are not restricting thermal displacements of equipment and pipelines. Total resistance force of damper during warming up, start-up, of systems at positive ambient temperature does not exceed 200 N, app. 20 rg force.

Dampening can be applied in the following ambient conditions of dampers installation:

- Maximum temperature ambient range: from -50°C to +200°C;
- Relative humidity: up to 100%.
- Dampers are not pressurized and have no environmental pressure restrictions.
- The value of the integral absorbed dose is limited to 2*105 Gr.

Detailed information about VD dampers is contained in the TU [30]. Overview of VES damper is shown in Figure 6.

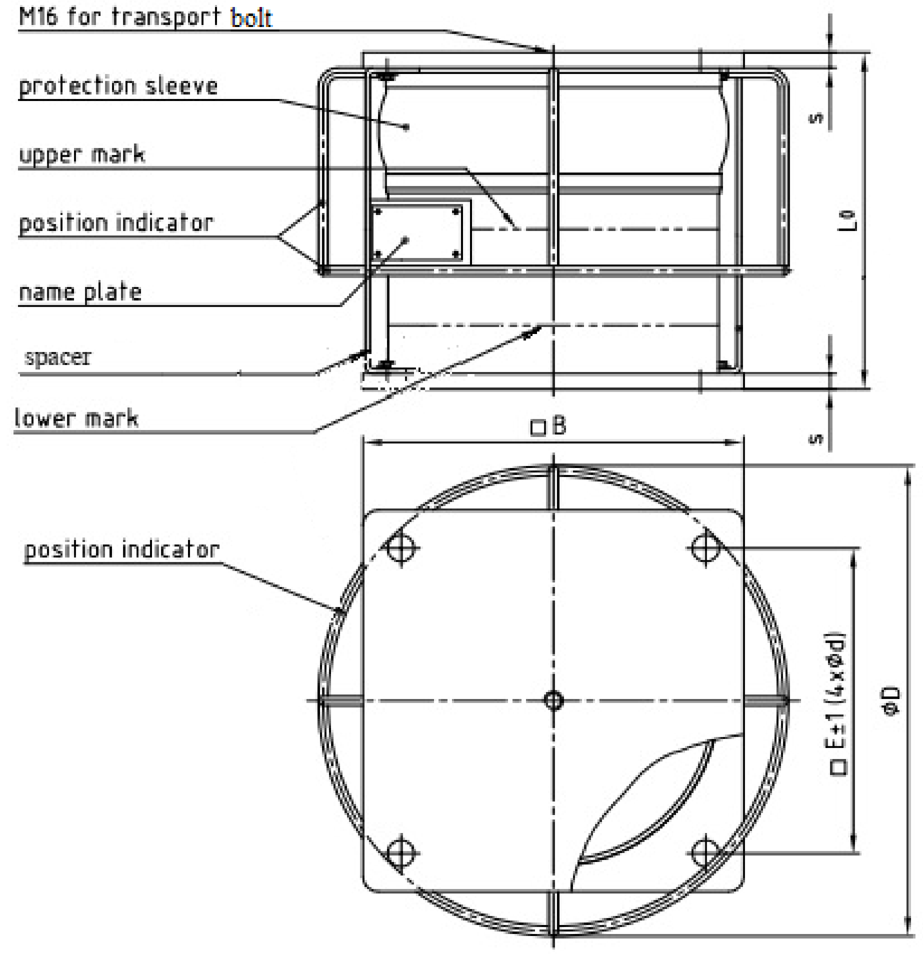


Figure 6. Overview of VEW damper.

Nominal loads and sizes of VES dampers are given in Table 3.

Detailed information about VES dampers is contained in the KTA rules [38] and Test Certificates [28,29].

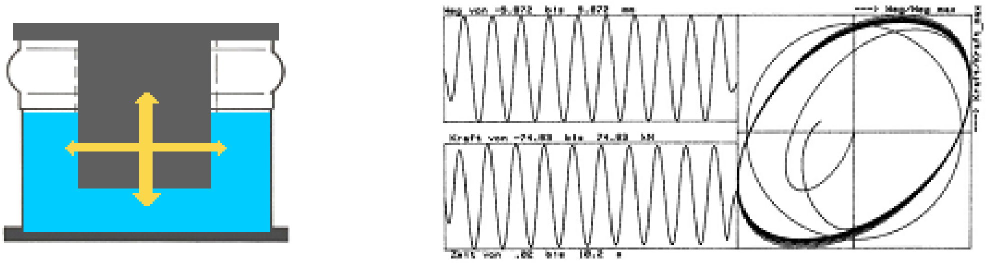
Nominal loads and sizes of VES dampers are given in Table 3.

Detailed information about VES dampers is contained in the KTA rules [38] and Test Certificates [28,29].

Table 3. Nominal loads and sizes of VES dampers.

Type	Nominal load Fn,	Max expansion		Dimensions						Screw joint thread
		vert.	hor.	□B	∅ D	∅ d	□ E	s	L_0	
	kN	mm		mm						
VES-2.5/V40/H40	2.5	40	40	190	269	14	145	8	240	M12
VES-2.5/V80/H50	2.5	80	50	225	330	14	180	10	380	M12
VES-5/V40/H40	5.0	40	40	205	294	14	160	8	240	M12
VES-5/V40/H100	5.0	40	100	374	561	26	290	16	320	M24
VES-10/V40/H40	10,0	40	40	257	336	18	200	10	240	M16
VES-10/V40/H120	10.0	40	120	450	698	32	350	10	260	M30
VES-10/V50/H50	10.0	50	50	317	411	22	245	13	280	M20
VES-20/V40/H40	20.0	40	40	317	391	22	245	13	280	M20
VES-20/V40/H60	20.0	40	60	436	526	32	330	20	350	M30
VES-20/V40/H80	20.0	40	80	480	648	22	410	15	305	M20
VES-20/V40/H120	20.0	40	120	540	768	38	420	13	300	M36
VES-20/V50/H50	20.0	50	50	374	461	26	290	16	320	M24
VES-20/V80/H50	20.0	80	50	330	426	26	250	20	410	M24
VES-30/V40/H40	30	40	40	374	441	26	290	16	320	M24
VES-30/V40/H80	30	40	80	500	666	26	420	15	320	M24
VES-40/V40/H40	40	40	40	394	471	26	310	18	335	M24
VES-40/V40/H80	40	40	80	545	712	26	465	20	365	M24
VES-50/V40/H40	50	40	40	436	486	32	330	20	350	M30
VES-50/V40/H120	50	40	120	645	891	32	545	20	375	M30
VES-75/V40/H40	75	40	40	491	521	38	365	25	390	M36
VES-75/V40/H90	75	40	90	565	741	38	450	25	410	M36
VES-75/V40/H120	75	40	120	675	921	38	555	25	395	M36
VES-100/V40/H40	100	40	40	511	551	38	385	30	405	M36
VES-100/V40/H80	100	40	80	650	816	38	550	30	480	M36

As the piston of a VD and VES damper is immersed in viscous fluid it can move in all directions. Its motion is limited by hydraulic forces in the fluid and restricted only by the damper housing. Therefore, they dampen motions in all directions, see Figure 7(a).



(a) (b)

Figure 7. Damper forces (a) and force vs displacement amplitude curve (b).

The damping force results from shearing and displacing the damping fluid. The force is approximately proportional to the relative velocity between damper piston and housing.

The actual damper response to dynamic loads consists of elastic and viscous components due to the viscoelastic behaviour of the fluid and some elasticity of the damper's steel construction. Thus, a damper is not only adding damping to a structure but also implement some additional dynamic stiffness.

HVDs are used to limit the vibrations of elastically supported systems in case of resonances or when being subjected to shock-type, transient, or random excitation. They add damping to the system and reduce occurring vibrations by dissipating mechanical energy, Figure 7(b). The damper does not take up load any static loads.

The damper does not have any wear parts or seals. It works under atmospheric pressure and does not develop any internal pressure during operation.

In-service inspections are not required. Maintenance measures during standard outages are limited.

Different parameters are used to select dampers for specific tasks. These parameters have been determined experimentally for each type of damper.

Vertical and horizontal damping resistance, kNs/m:

> This damper property is used when performing dynamic analysis. The results of the dynamic analysis show if the installed damper, damping resistance, is suitable for necessary vibration mitigation. If not, a damper with a different damping resistance is used or the number of dampers is increased.

Vertical and horizontal equivalent stiffness, kN/m:

> This damper property is used when performing dynamic analysis. The results of dynamic analysis show if the installed damper equivalent stiffness is suitable for vibration mitigation. If not, another damper is used or the number of dampers is increased.
>
> This damper property is also used when designing damper support. To provide an effective damper performance, the stiffness of the

damper support must be at least five times higher than the stiffness of the damper at the fundamental vibration frequency.

Nominal vertical and horizontal loads, kN.

Damper reaction loads applied in the horizontal and vertical direction. Nominal loads are maximum values of dynamic loads at which the damper maintains full operability and integrity.

When performing dynamic analysis, the damper loads from the piping are determined. These loads must not exceed nominal loads. If this is impossible, a damper with higher nominal loads must be selected and/or an additional damper should be involved.

Allowable vertical and horizontal displacements, mm.

Allowable horizontal and vertical displacements are the maximal relative “housing-piston” displacements from nominal centre position. These displacements are determined by the geometric dimensions and the condition of invariability of the damping characteristics.

When choosing the type of damper, it is necessary to take into account that the thermal displacements of the piping in total with the dynamic displacements of the place of damper installation should not exceed the values of allowable displacements. In case of larger thermal displacements, the damper can be pre-set, basically doubling the allowable displacements. If this is not possible, a damper with larger allowable displacements must be selected.

HVDs have some essential advantages against other devices: non-stuck soft operation with high damping ability; damping of any dynamic impact including operational vibration, water and steam hammers, seismic, and other dynamic loads; six degree of freedom damping ability in one unit; low maintenance and inspection costs; high temperature and radiation stability. VD type dampers have low temperature dependency characteristics.

Dampers have been successfully used for many years for vibration reduction of piping systems and components in different installations:

- nuclear power plants.
- conventional power plants.
- chemical, petrochemical, and industrial plants.
- offshore facilities.

HVD has been added to the types of dynamic restraints, November 2007, covered by ASME B&PVC Section III - Subsection NF. Hence, they are an acceptable type of dynamic restraint for piping and nuclear components in accordance with ASME B&PVC Section III [37].

HVD are covered by German Nuclear Code KTA and European Nuclear Code for Light Water Reactors [38].

HVD are accepted by Nuclear Authorities of all Nuclear States in Europe, including Russia, as well as in Japan, China, and India.

HVD are considered by International Atomic Energy Agency (IAEA) as a tool for seismic protection and seismic upgrading of NPPs.

4 Damper supports

Dampers operate as a part of damper support, which consists of one or several dampers and attachment joints connecting the damper with building structures and equipment. Damper supports can be designed in several ways, Figure 8, Figure 9 and Figure 10

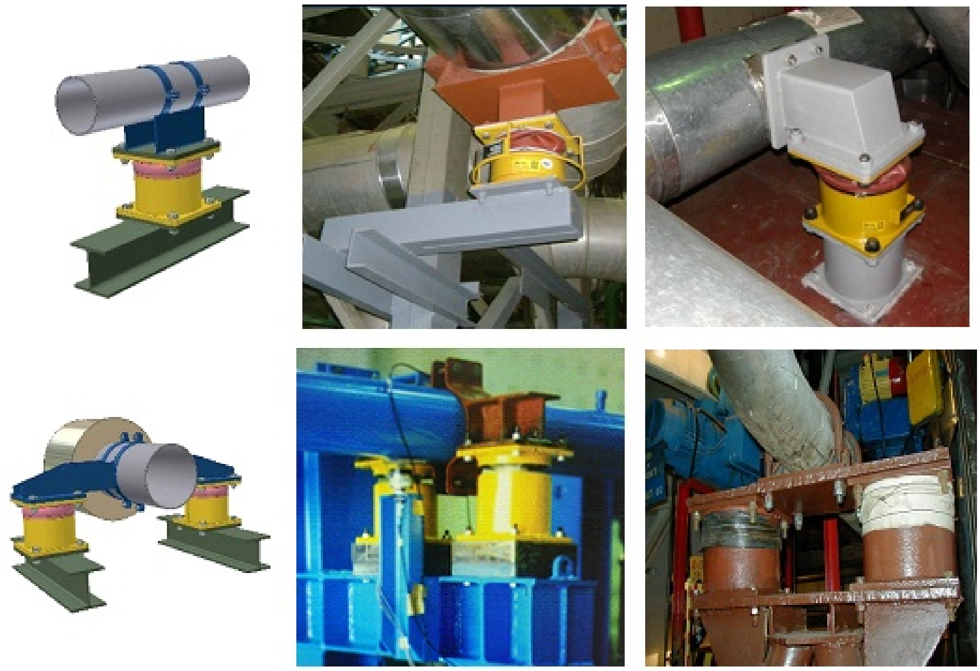


Figure 8. Damper pistons attached to the piping and housing attached to the rigid structure.

Figure 9. Damper housings attached to the piping and piston attached to the rigid structure.

Figure 10. Damper piston attached to one pipe and housing attached to another.

This damper support installation method is suitable for piping with different dynamic properties. It makes possible to damp two separate piping with one damper.

The stiffness of the damper support must be at least five times higher than the stiffness of the damper at the fundamental vibration frequency.

5 Mathematical model and experimental data of high viscous damper

To carry out a dynamic analysis of systems equipped with HVDs, a mathematical model of the 3D viscodamper was developed and verified, which allows the calculation to be carried out correctly.

Dynamic stiffness of HVD is significantly changed over frequency range, since the damper's dynamic properties are a function of working liquid as well as arrangement of the damper's internal elements. Working viscous liquid used defines a damper's viscoelastic behaviour. The simplest mathematical model describing such behaviour is a Maxwell model which consists of spring element and ideal viscous damper connected in series, Figure 11.

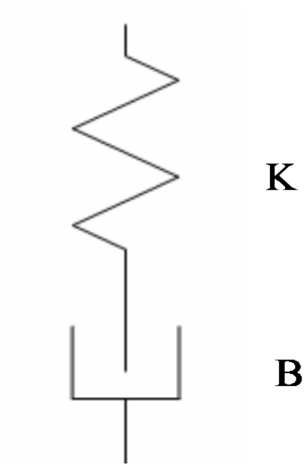


Figure 11. Maxwell viscoelastic model.

Such model demonstrates the following features, which are typical for the measured HVD properties:

- the reaction of HVD at the low frequency loading range is considered mostly as a viscous and may be described by an expression: R = -B*v, where R, reaction force, v, velocity of a piston relatively to the housing, B, damping resistance;
- for the high frequency loading range the damper's reaction shows essentially elastic character and may be described as: R = -K*x, where x, relative displacement "piston-hosing", K, stiffness ratio.

In the Maxwell model K is a stiffness of spring element, B is damping coefficient for the ideal viscous element. The parameter named as a characteristic frequency of the Maxwell model is often used in various applications and is ◎0 = K/B.

Real HVDs have more complicated dynamic characteristics than the simplified model, shown in Figure 11. However, a set of two Maxwell chains demonstrates appropriate results for engineering purposes. Such a model is shown in Figure 12.

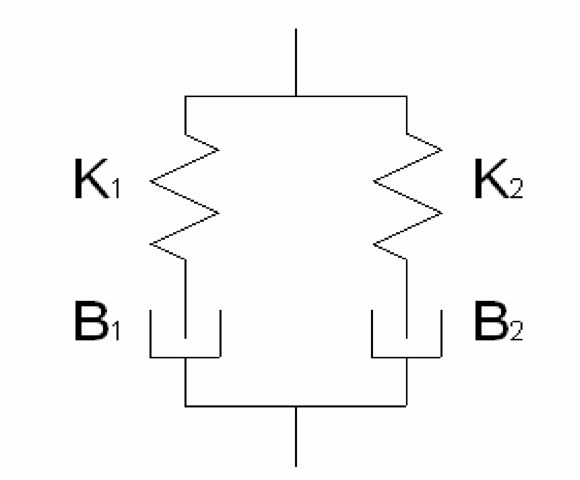


Figure 12. Scheme of the mathematical model of high viscous damper.

Figure 13 depicts an example of experimental data approximation for determining of HVD model characteristics.

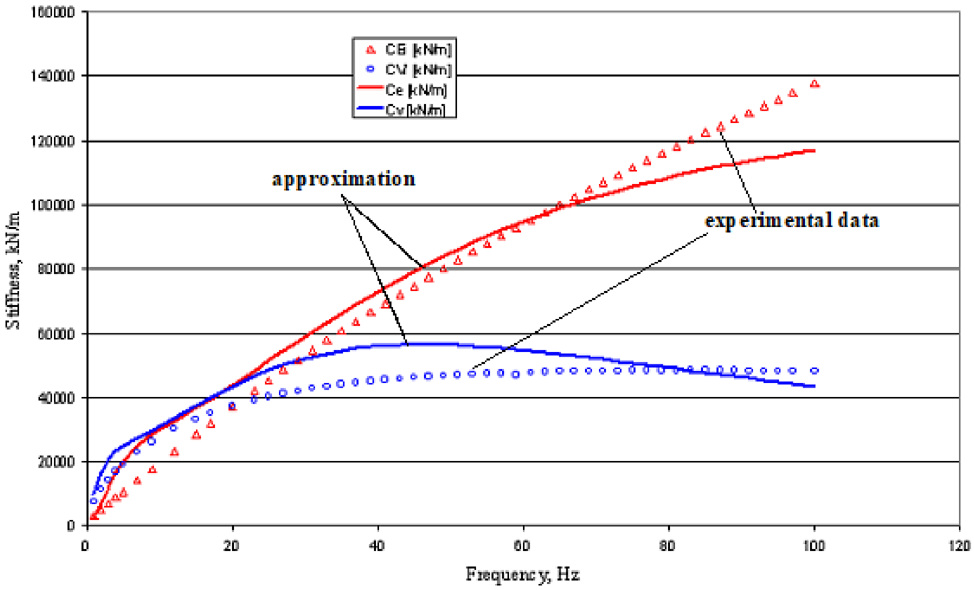


Figure 13 Approximation of the experimental data with the use of 4-parameters Maxwell model of HVD.

Above described modelling of HVD by means of the 4-parametrical Maxwell model is suitable for time history analysis. Maxwell model of HVD is realized only in a few piping software packages: ROHR2[2] and dPIPE[3] [39]. It is necessary to note however that most of commercially available piping software packages use spring elements to model damper for dynamic analysis. This can lead to incorrect results as this approach neglects damping native to HVD.

Dampers of VD type nomenclature is based on a combination of piston and housing characteristic diameter values and stiffness index.

---

[2] http://www.rohr2.com

[3] http://www.dpipe.ru

Figure 14 through Figure 17 show the examples of horizontal stiffness values vs frequency of VD dampers with different housing, piston and stiffness indexes.

Figure 18 and Figure 19 give limiting curves regarding the vertical damping resistance and vertical stiffness of VES dampers.

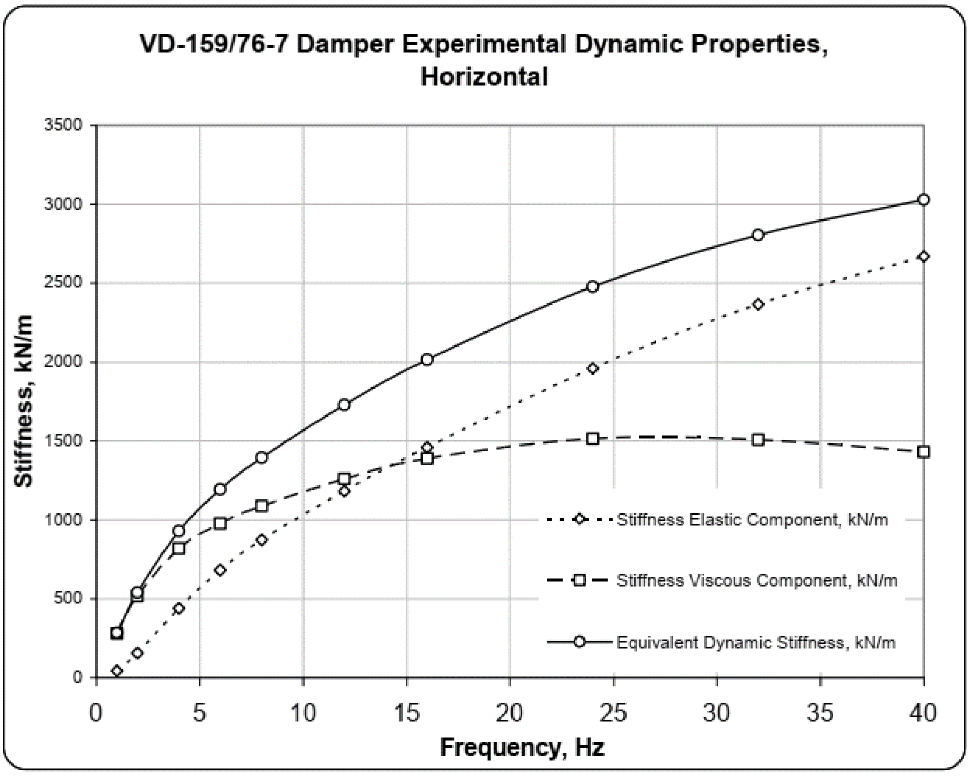


Figure 14. Horizontal stiffness of VD-159/76-7.

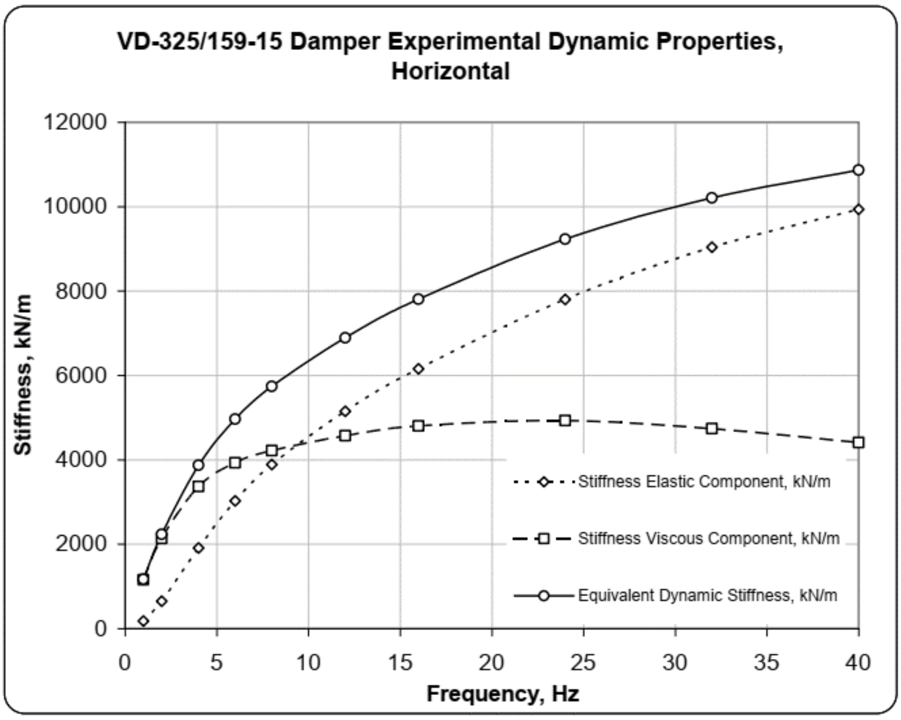


Figure 15. Horizontal stiffness of VD-325/159-15.

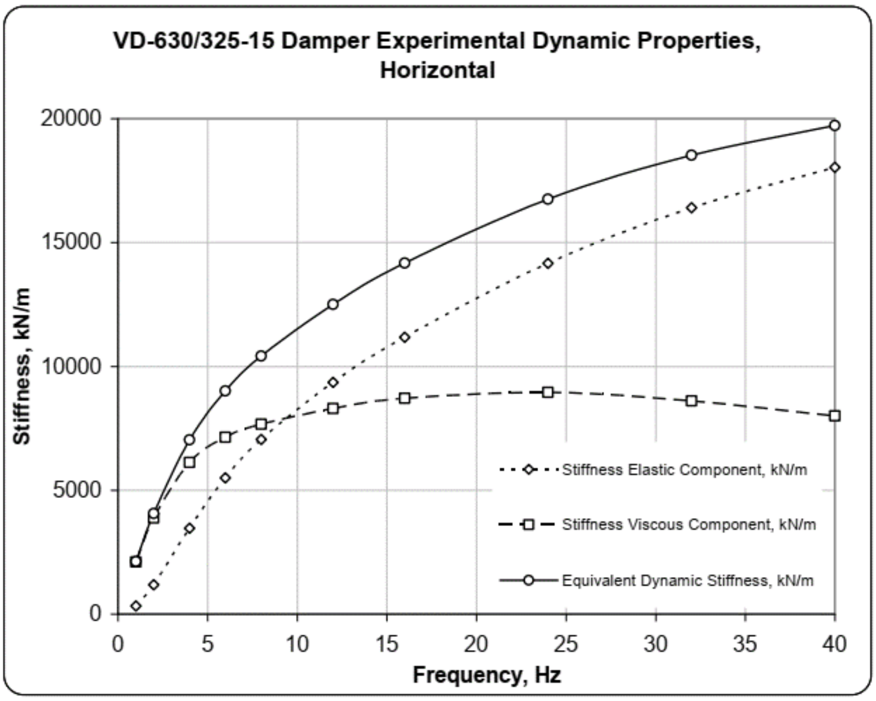


Figure 16. Horizontal stiffness of VD-630/325-15

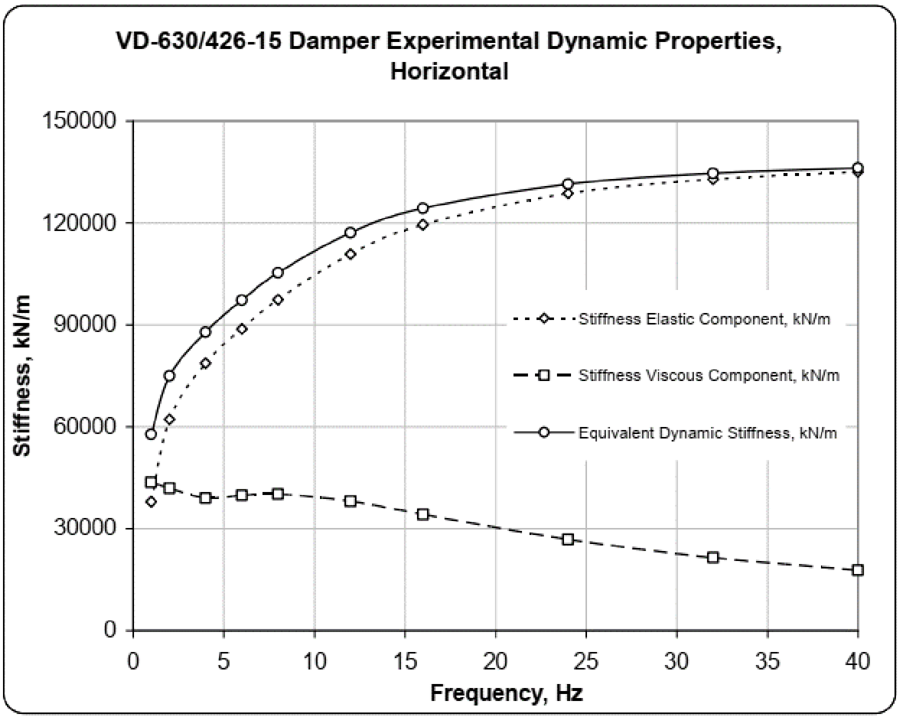


Figure 18. Horizontal stiffness of VD-630/426-15.

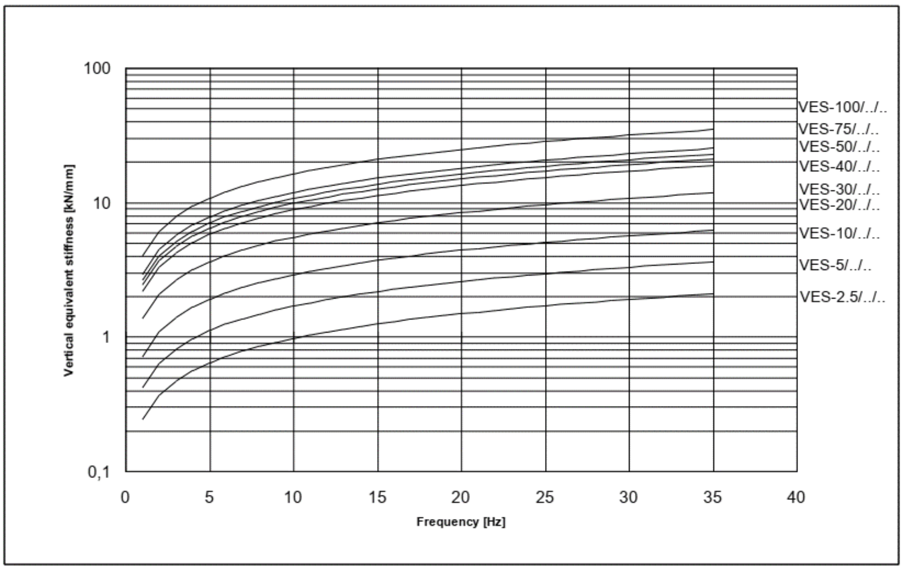


Figure 17. Limiting curves regarding the equivalent vertical stiffness of VES dampers.

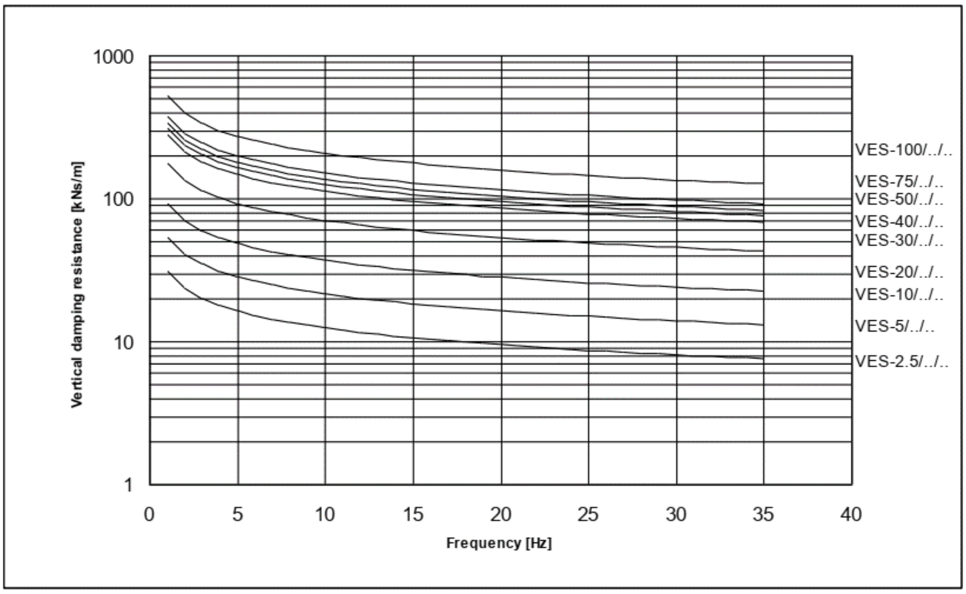


Figure 19. Limiting curve regarding the vertical damping resistance of VES dampers.

6 Operational vibration mitigation

The main stages of work for resolving vibration matter of piping using viscodamper technology is schematically shown in the flowchart illustrated in Figure 20.

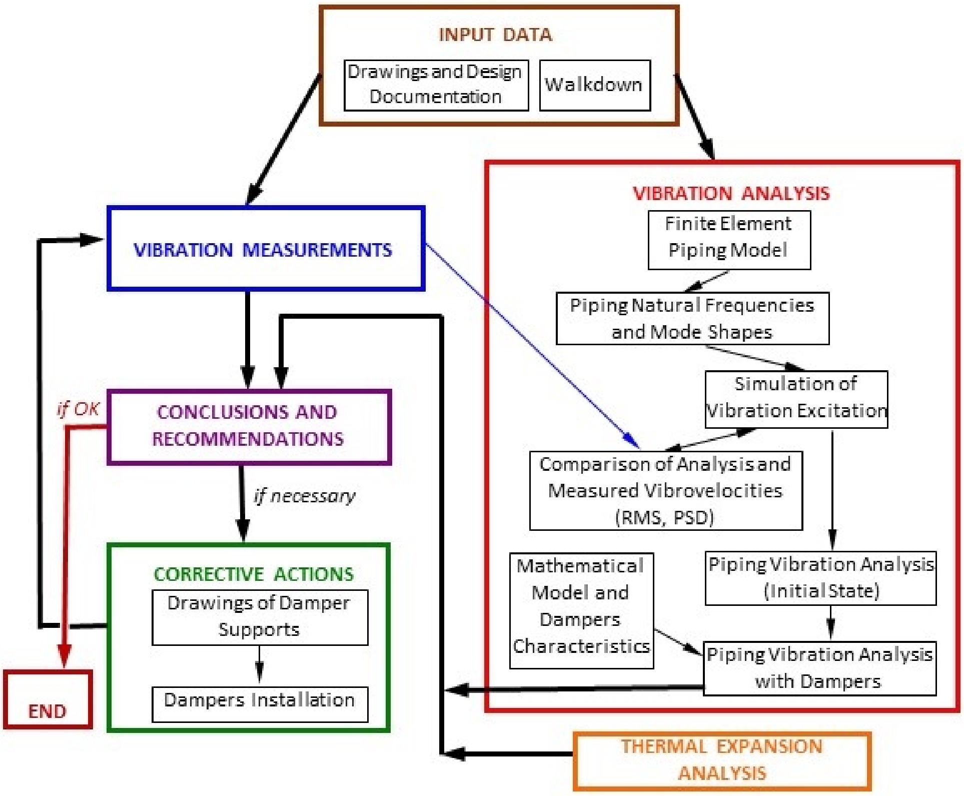


Figure 20. Flow-chart of work process when working to solve vibration issue with viscodamper.

6.1 INPUT DATA

The purpose of this stage is to prepare data for future work phases: vibration measurements and vibration analysis.

The geometry layout and support system of considered piping is defined at an initial stage according to the design drawings and sketches provided by the customer. Sometimes the in-formation regarding some piping supports, valves, penetrations, and geometry of considered systems may be incomplete due to objective reasons. This information is collected and checked during walkdown and used for the preparation of finite-element models for further calculations, Figure 21. Vibration measurement points are shown in frames.

Walkdown is required for choosing the places of vibration measurements and to prepare a general measurement scheme, Figure 22. Vibration measurement points are depicted in frames.

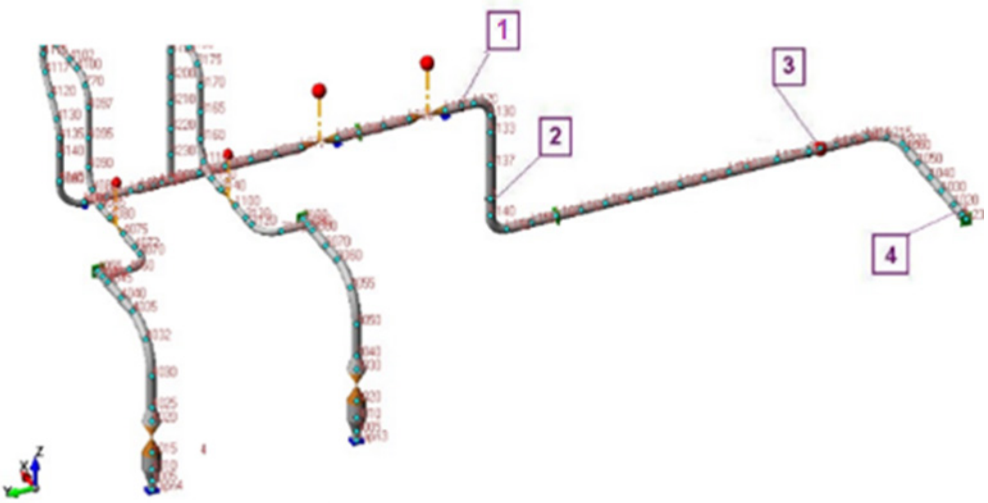


Figure 21. Example of finite-element piping model.

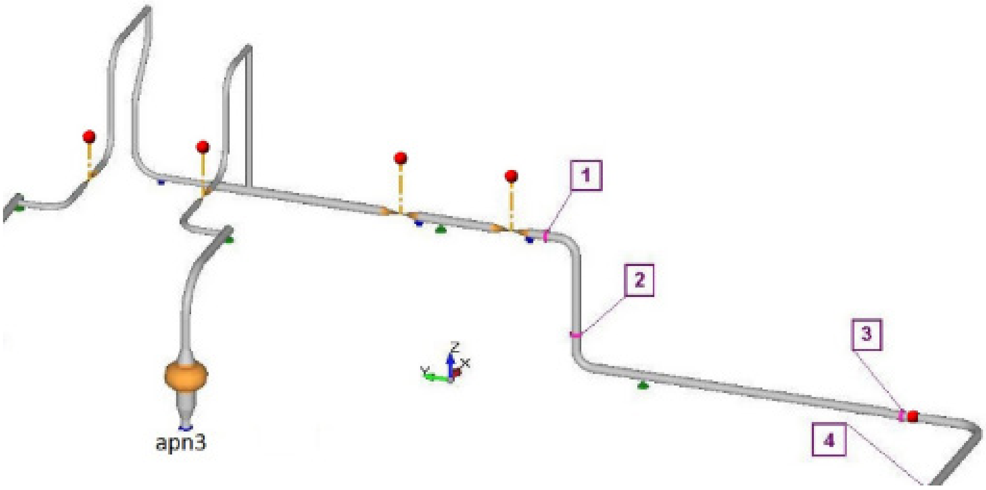


Figure 22. Example of vibration measurement scheme.

Often the preliminary examination of operating piping allows identification of the zones with most vibration and, in some cases, to determine some possible reasons for increased vibration of some piping sections. For example, damage or improper installation of conventional static supports.

6.2 VIBRATION MEASUREMENTS

In CVS experience the vibration measurements are performed by several multi-channels portable signal analysers MIC- 200[4] or MIC-300[4], Fig. 23 and Fig. 24.

---

[4] Manufactured by research and production association Mera, Russia; www.nppmera.ru.

The piezoelectric transducers assembled on magnetic platforms (Fig. 25) or on special removable clamps (Fig. 26) are used to measure vibration. The measurements are performed simultaneously in three orthogonal directions: transducer No 1, along the pipe axis; transducer No 2, along the tangent to the pipe cross section; transducer No 3, along the radius of the pipe cross section. It is possible to take measurements at several points simultaneously.

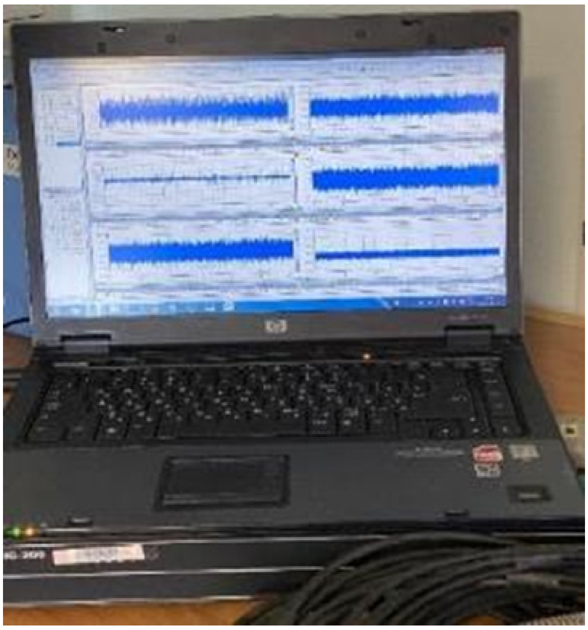


Figure 23. Multi-channel, portable signal analyser MIC-200.

Figure 24. Multi-channel, portable signal analyser MIC-300.

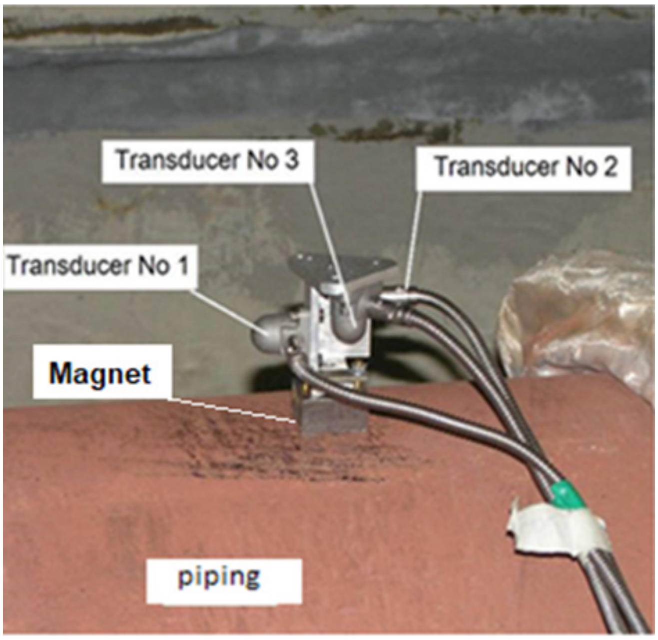


Figure 25. Magnetic platform with transducers on the pipe

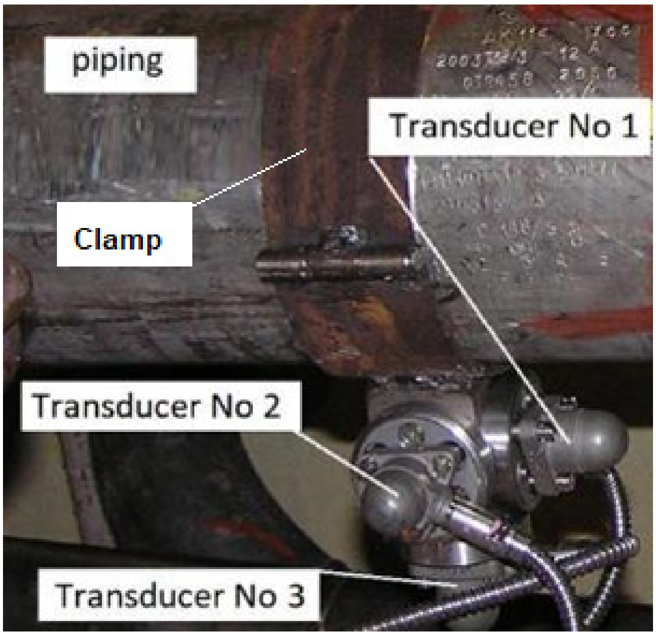


Figure 26. Removable clamp with transducers on the pipe.

The acceleration signals from transducers pass through the charge pre-amplifier, main amplifier and the analog low-pass filter. Then the signals are processed by analog-digital converter and recorded as files. Further processing of signals is carried out by a special program and the result of obtaining root-mean square (RMS) and peak values of vibrovelocities, and vibrovelocity signals in frequency domain as power spectral density (PSD) for each transducer (direction). The full RMS of vibrovelocity in each measurement point is determined by the rule of square root of the sum of squares of “transducer” values. The full PSD, as an algebraic sum of “transducer” values.

Usually, without the task to research something special, the following main technical parameters of vibration measurements are used:

Frequency measurement range:	2.0 to 1000 Hz;
The duration of measurement:	60 - 120 seconds;
Sampling frequency:	2000 Hz;
Low pass filter cut-off frequency:	≤ 1000 Hz.

All parts of the instrumentation with cables and transducers are subjected to calibration and testing in the Saint Petersburg State Regional Center for Standardization, Metrology and Testing (FBU "Test-St.-Petersburg").

6.3 VIBRATION ANALYSIS

When the piping vibration level is high and there is a need to reduce it, vibration analysis is required in order to determine the feasibility of viscodamper’s technology for this purpose, and then, if confirmed, choosing dampers number, types, and the best available places for their installation.

The computer software code for piping dynamic analysis dPIPE 5[5] is used for this purpose.

To create the calculation models the finite-element approximation of piping and corresponding equipment is used. The maximum distance between the nodes of the model is determined by the frequency range of interest for the piping under consideration. All pipes are modelled by the straight, run, and the curved, bend or miter. pipe elements. The modelling of piping details and equipment is carried out by reducer, valve, expansion joint, rigid, flex or structural elements. The support system is modelled by means of guide, sliding, restraint, spring, anchor supports and also spring and rigid hangers.

The input vibration excitation is generated using analysis results, piping’s natural frequencies and mode shapes obtained earlier in the analysis, and experimental results obtained in piping vibration measurements. Excitation is defined as a set of either multi-harmonic modal forces at piping natural frequencies with random phase angles or multi-harmonic dynamic forces, applied by twos in bends. The amplitudes of both types of forces are determined by iterative procedure. The values of forces’ amplitudes should produce analytical piping vibration with RMS values and PSD spectra of vibrovelocities that corresponds to the experimental ones obtained in vibration measurements in all measurement points. Figure 27 illustrates the results of iterative fitting of the input vibration excitation. We consider the input vibration excitation to fit well when difference between measured and analytical values are not more than 10% in average.

---

[5] www.dpipe.ru

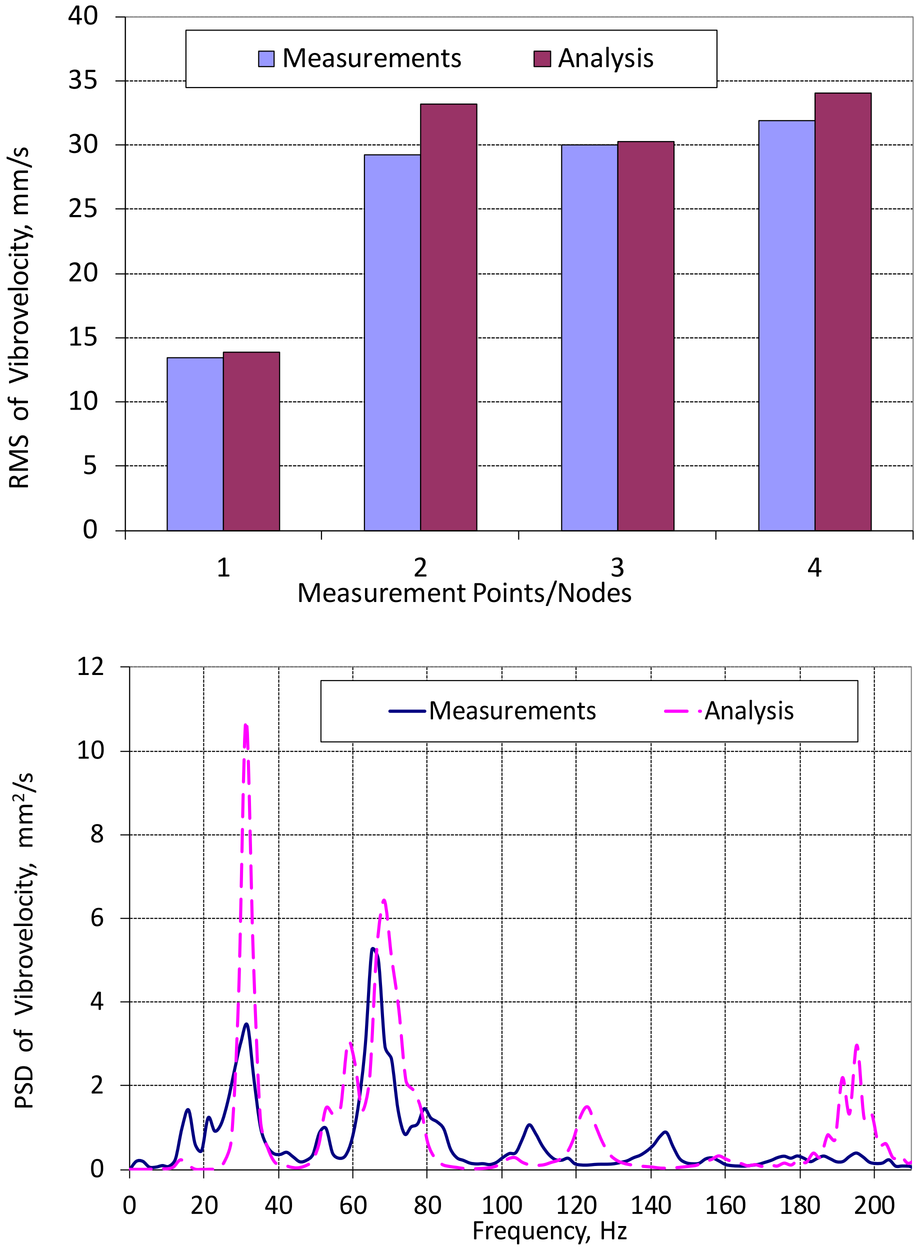


Figure 27 Experimental and analysis results of piping vibration: RMS of vibrovelocity (a) and PSD spectra in one of the measurement points (nodes) (b).

After piping vibration analysis has been carried out in initial state, the analysis with the same vibration excitation and installed viscous dampers is carried out. In this analysis the Maxwell mathematical model and dampers characteristics obtained in damper tests are used.

The analytical results show the potential damper influence on the vibration state and suggests a similar on-site vibration reduction.

Rather often there is a need to compare different types of dampers in order to choose the best one. Figure 28 shows the supposed results of piping vibration reduction by different types of dampers.

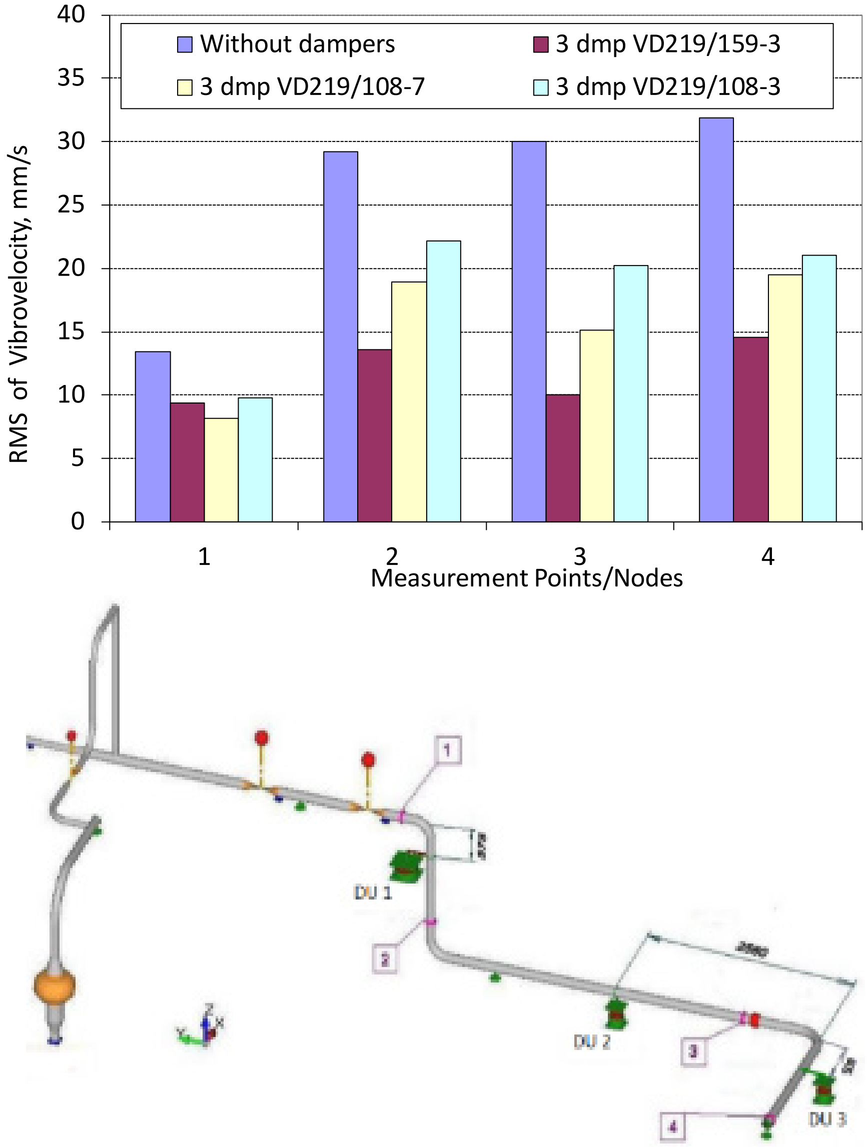


Figure 28. Analytically predicted influence of dampers on piping vibration (a) and the layout of this piping with measurement points (in frames) and dampers (b).

6.4 THERMAL EXPANSION ANALYSIS

The choice of damper type depends upon various factors including piping thermal expansion displacements. Dampers must not be allowed to interfere with piping thermal expansion, so the gap between damper housing and piston should be sufficient for thermal movement. These gaps differ for different damper types and it is necessary to know piping thermal displacements for proper damper choice. Therefore, thermal expansion analysis is usually carried out. dPIPE 5 is used for this purpose. Piping thermal expansion can be seen in Figure 29.

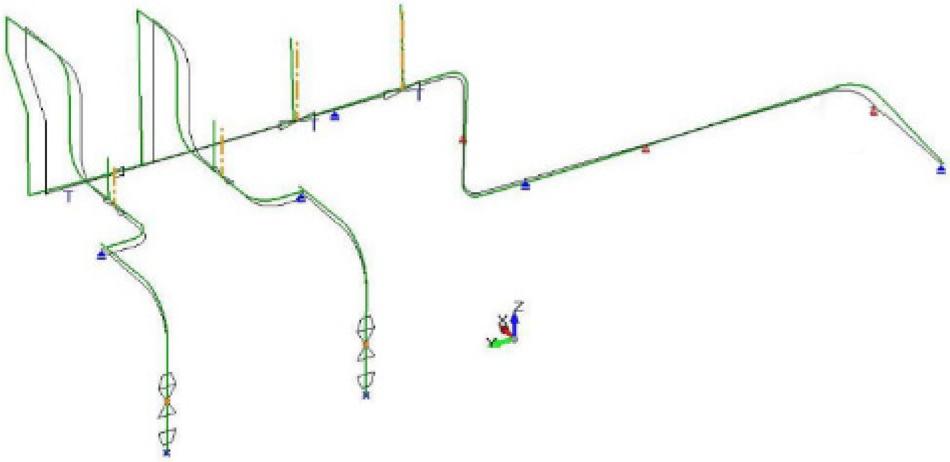


Figure 29. Results of piping thermal expansion calculation. Green line is "hot state".

6.4.1 Conclusions and recommendations

The results of vibration measurements, vibration analysis, and thermal expansion analysis come together at the stage of decision making. The necessity of vibration reduction and damper installation, the effectiveness of these activities, number of dampers, damper type, places of installation, all these factors are estimated from the perspective of quality-price combination.

6.5 CORRECTIVE ACTIONS

After damper types are chosen, and their places of installation are agreed, sets of damper support drawings are carried out, including the installation drawings of damper supports, see Figure 30,and detailed drawings.

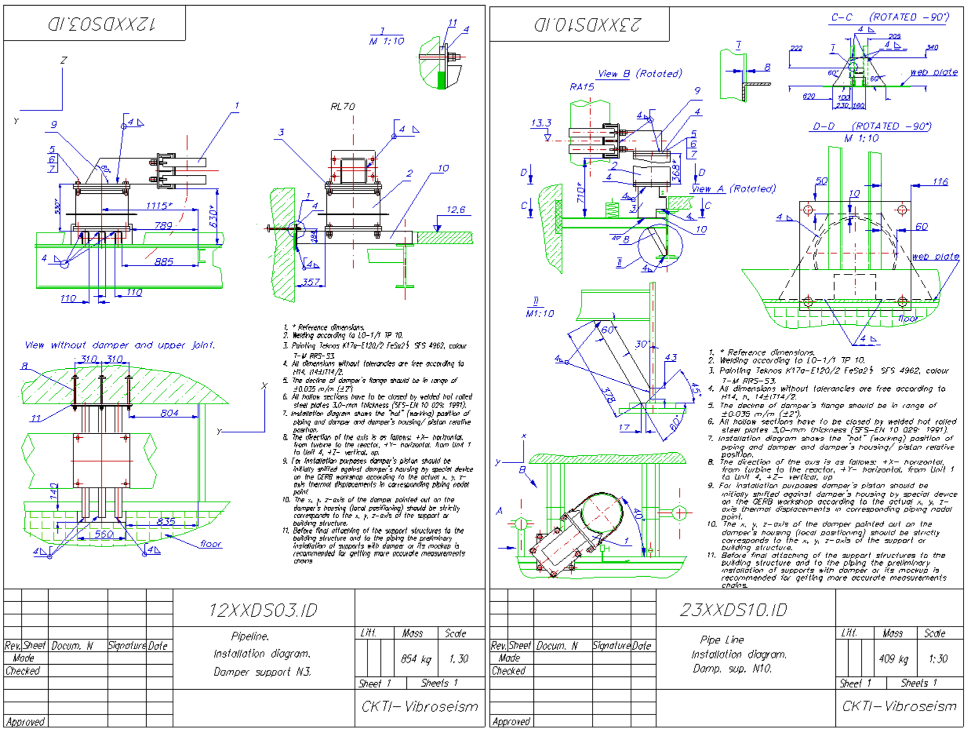


Figure 30. Examples of installation drawings of damper supports.

To provide an effective damper performance, the stiffness of the damper support must be at least five times higher than the stiffness of the damper at the fundamental vibration frequency, as mentioned in Section 4. Therefore, when designing a damper support, we evaluate the stiffness of the structure.

Sometimes there is a need of strength assessment of the damper support including:

- calculation of the metal structure of the support itself.
- calculation of welds in the most loaded nodes of the support.
- calculation of anchor bolts if they are used to attach the support to building structures.

When piping thermal displacements are significant in comparison with the gap between damper housing and piston, there is a need to shift damper piston flange relative the housing flange. Sometimes the best arrangement of the damper support requires turning upper and lower damper flanges relative to each other.

All these pre-settings are carried out by GERB GmbH in its workshop, using analysis and design information, see Figure 31. After shifting/rotating, the flanges are fixed relative to each other by special brackets connecting them. This is how the dampers would arrive for on-site mounting.

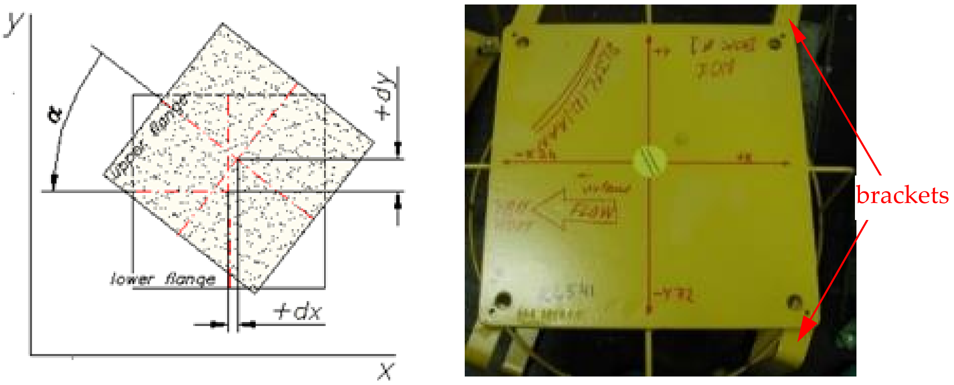


Figure 31. Example of damper pre-setting: (a) scheme of shifting and rotation of damper flanges; (b) real damper with shifted flanges

CVS usually participate in the installation process by performing author's supervision.

6.6 FINAL VIBRATION MEASUREMENTS

After the dampers have been installed, vibration measurements are carried out in order to find out the vibration level after installation.

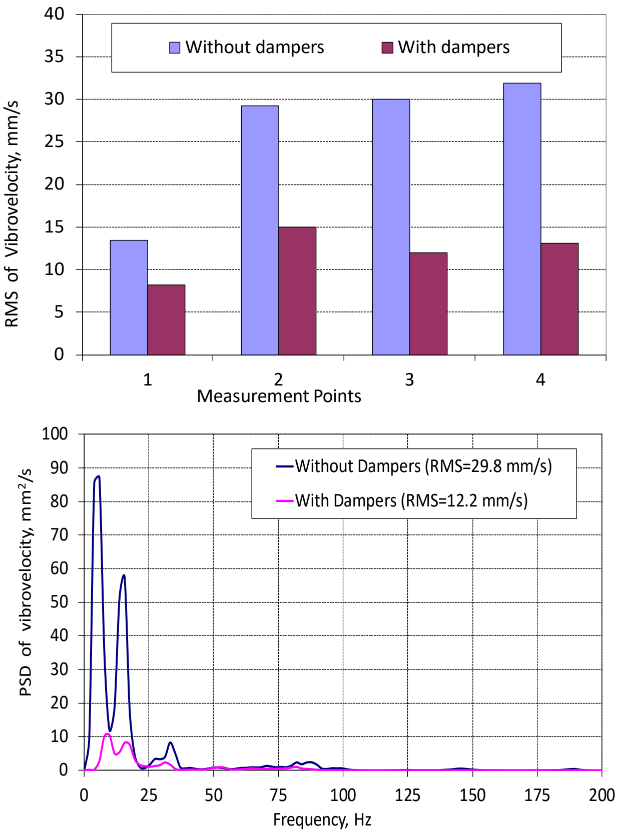


Figure 32. Example of vibration measurement results before and after installing dampers.

6.7 ADDITIONAL ANALYSIS

Some supplement analyses are sometimes required to be done when viscous damper technology is implemented:

- assessment of the vibration level at different frequency ranges.
- fatigue analysis.
- seismic analysis in order to obtain information about the behaviour of piping and the effect of dampers on it during an earthquake.
- determination of loads transferred from the piping through the damper to building structures.

7 Vibration reduction results using viscodamper technology

For more than 30 years CVS have used viscodamper technology for piping vibration elimination in nuclear and conventional power plants, chemical and other facilities. Some of the facilities, where CVS have been working during these years are introduced in detail in the following text while others are briefly listed.

7.1 KOLA NPP, POLYARNYYE ZORI, RUSSIA [42]

Kola NPP consists of four Units with VVER-440 type pressurized water reactors. The first Unit started its operation in 1973, the fourth – in 1984. In 1991-2005 the 1st and 2nd unit systems, components, and equipment were modernised which brought them in accordance with new nuclear safety requirements and extended the service life of the plant. Since 2007 the reconstruction of Units 3 and 4 has been carried out as well. The modernisation has made it possible to increase power capacity with up to 107% compared to initial capacity. Power upgrading leads to corresponding increase of flow velocity in feed-water piping and steam piping and may have negative consequences such as increase of existing piping vibration.

Figure 33. Image of Kola Nuclear Power Plant.

NPPs operational practice obviously shows correlation between piping operation reliability and service life limit on the one side and the level of piping operational vibration on the other.

High piping vibration can lead to piping wall fatigue, essential wear, and even failure of piping supports. Vibration may also be the source of noise covering different plant areas including work rooms for NPP staff or control rooms.

Considering all the possible negative effects of vibration several activities were carried out to resolve vibration matter of piping of different systems. Each piping system may have many sources of vibration which cannot be eliminated by optimizing its design or components in majority of cases. Usually there is an objective necessity for implementation of external devices that can reduce vibration.

HVD technology was chosen for this purpose based on the positive experience in vibration elimination.

7.1.1 Acquiring input data

The purpose of this stage was to prepare data for future work phases: vibration measurements and vibration analysis.

The geometry and supporting layout of considered feed water pipelines have been defined at an initial stage according to the design drawings and sketches provided by Kola NPP. It should be noted that due to objective reasons the information was incomplete regarding some piping supports, valves, and penetration and, in some cases, geometry of considered systems. This information was compiled as a result of a special walkdown and used for the preparation of finite-element analysis models.

A preliminary examination of operating pipeline allowed to correctly choose the measurement points and to create a general measurement scheme.

7.1.2 Vibration measurements

The vibration measurements were performed by several multi-channel portable signal analysers MIC-200[6].

The piezoelectric transducers assembled on magnetic platforms were used to measure vibration. The magnetic platforms were placed directly at piping in special openings in insulation. The measurements were performed simultaneously in three orthogonal directions: the transducer No 1 was installed on the tube axis, No 2, tangential to the cross-section of the pipe, No 3, the radial cross section of the tube, as it shown in Chapter 6 of this report. Measurements were carried out simultaneously at two points along pipeline.

---

[6] Manufactured by Mera Co., Russia.

The results of measurements in Table 4 shows that vibration of RL31, RL33, RL35, RL74, RL76 piping of Unit 3 and RL31, RL33, RL35, RL72, RL74, RL76 piping of Unit 4 is essentially higher than acceptable level and should be reduced.

Table 4. Maximal values of piping vibration at each pipeline section of RL systems.

Unit 3			**Unit 4**		
Point No.	Location	RMS of vibrovelocity (mm/s)	Point No.	Location	RMS of vibrovelocity, (mm/s)
5RL125	RL31	46.4	7RL102	RL31	19.7
5RL128	RL33	34.8	7RL302	RL33	37.4
5RL127	RL35	47.3	7RL502	RL35	20.0
6RL133	RL72	14.7	8RL202	RL72	41.8
6RL137	RL74	17.3	8RL402	RL74	38.3
5RL143	RL76	16.7	8RL602	RL76	32.0
56RL21	Feed water collector	14.1	78RL047	Feed water collector	6.5
5RL03	Feed water electric pumps pipelines	7.8	78RL042	Feed water electric pumps pipelines	9.8
56RL16	Feed water electric pumps collector	6.4	78RL018	Feed water electric pumps collector	4.1
56RL47	Feed water heaters pipelines	3.5	8RL025	Feed water heaters pipelines	6.1

7.1.3 Vibration analysis

For piping vibration analysis of above-mentioned RL piping systems of Unit 3 and 4 basic analytical procedures have been applied as shown in the flowchart, see Figure 20. The computer software code for piping dynamic analysis dPIPE 5 was used for this [39].

The complex calculation models of the examined piping systems have been developed on the basis of design documentation and walkdowns performed for this purpose. The one performed for Unit 4 is given in Figure 34.

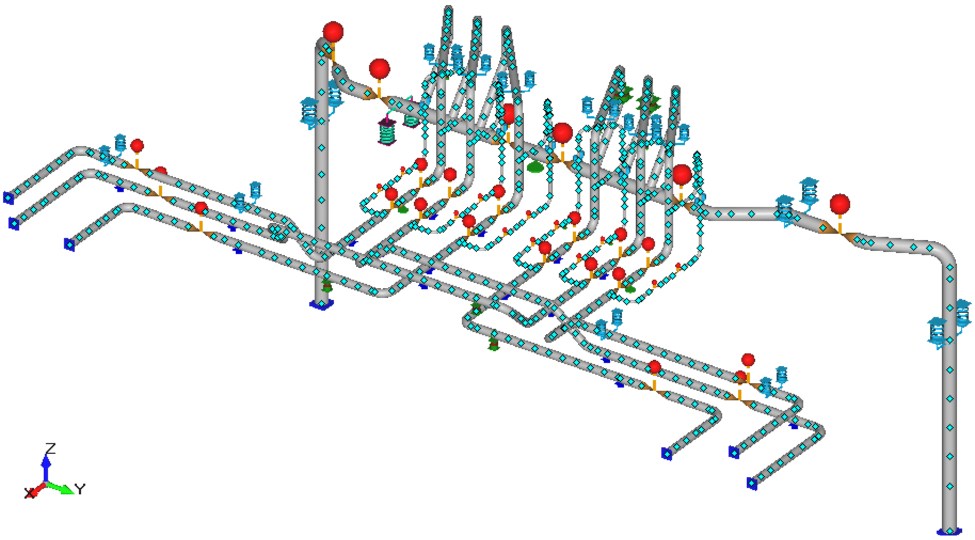


Figure 34. Complex calculation model of RL system of Unit 4.

To create the calculation models the finite-element approximation of pipelines and corresponding equipment was used. The maximal distance between model nodes was defined from the requirements of accurate modelling of dynamic behaviours of the piping systems. All pipes were modelled by the straight, run, and by means of the curved, bend, pipe elements. The modelling of equipment was performed by means of rigid beam elements with lumped masses located in the centre of gravity. Boundary conditions for piping systems, piping supports and anchorage, were modelled by the boundary and spring elements.

The input vibration excitation was generated using analysis results, piping natural frequencies and mode shapes, and experimental results obtained in piping vibration measurements. Excitation was defined as a set of multi-harmonic modal forces at piping natural frequencies with random phase angles and amplitudes developed by an iterative procedure. The values of modal forces' amplitudes should have produced analytical piping vibration with RMS values and PSD spectra of vibrovelocities that corresponded or even covered the experimental ones obtained in vibration measurements. Figure 34 illustrates this procedure for RL 74 pipeline of Unit 4.

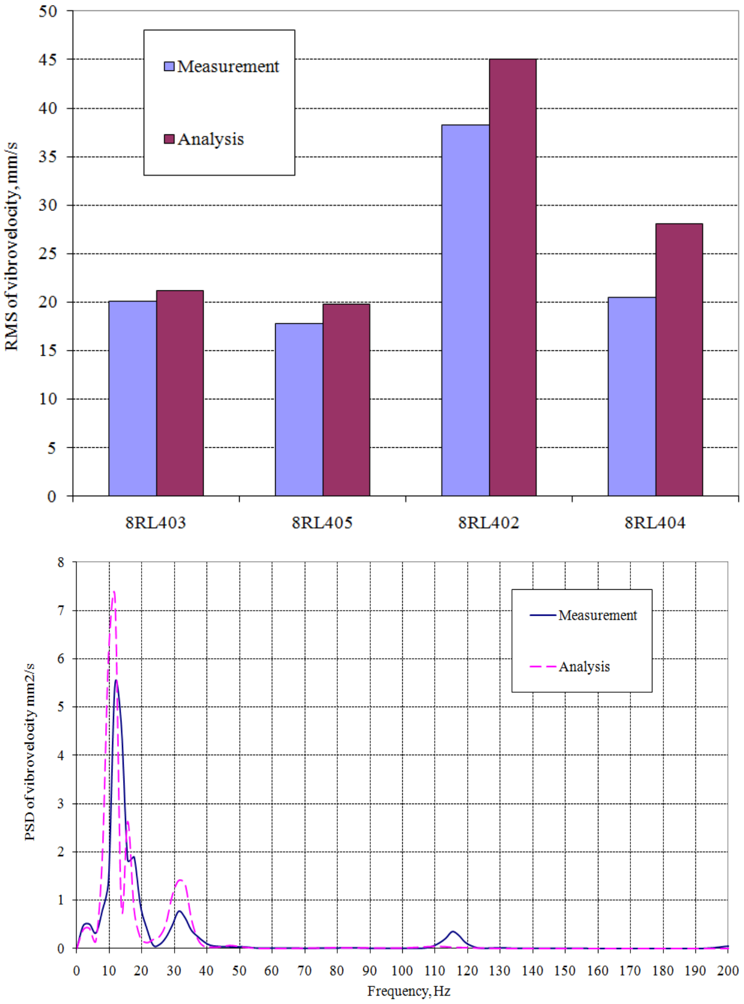


Figure 35 Experimental and analysis results of piping vibration: vibration distribution along the piping (a) and PSD spectra in the control point (b).

After piping vibration analysis has been carried out in the initial state, the same analysis with VDs was carried out. These analytical results showed the potential damper influence on the vibration state. In this analysis the mathematical model and damper characteristics were used. Figure 36 demonstrates the analysis results of RL74 pipeline, in Unit 4, without and with HVDs.

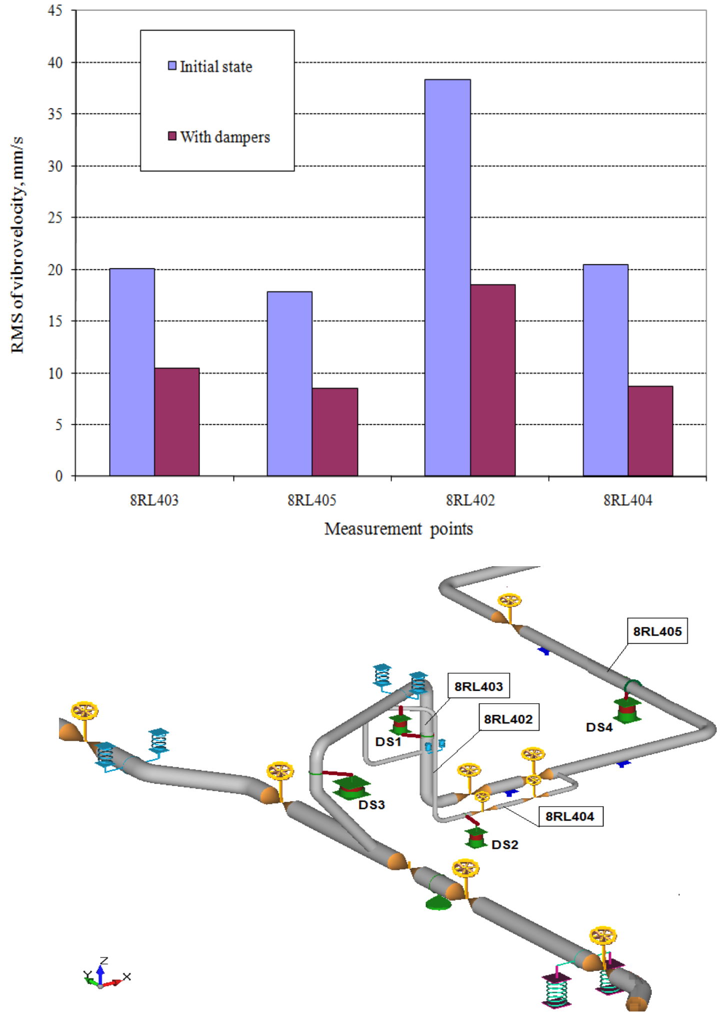


Figure 36. Top: Analytically predicted influence of dampers on the RL74 pipeline (Unit 4) vibration. Bottom: Layout of piping with measurement points, shown in frames, and dampers, numbered DS1-DS4.

Dampers of different types were used to reduce vibration of RL pipelines. The choice of damper type usually depends upon various factors including piping thermal expansion displacements. Therefore, thermal expansion analysis was carried out for RL systems.

7.1.4 Elimination of piping vibration

As the result of vibration analysis, 23 VD units were recommended to be installed at RL systems of Unit 3 and 4, respectively 10 and 13 VD units. Figure 37 shows the location layout of dampers at RL pipelines of Unit 4.

Dampers were installed at Kola NPP in two ways:

- damper piston attached to the piping, housing attached to the rigid structure, see Figure 38 a, b, d, e).
- damper piston attached to one piping, housing attached to another piping with different dynamic properties, see Figure 38 c, f. This makes it possible to damp two piping with one damper.

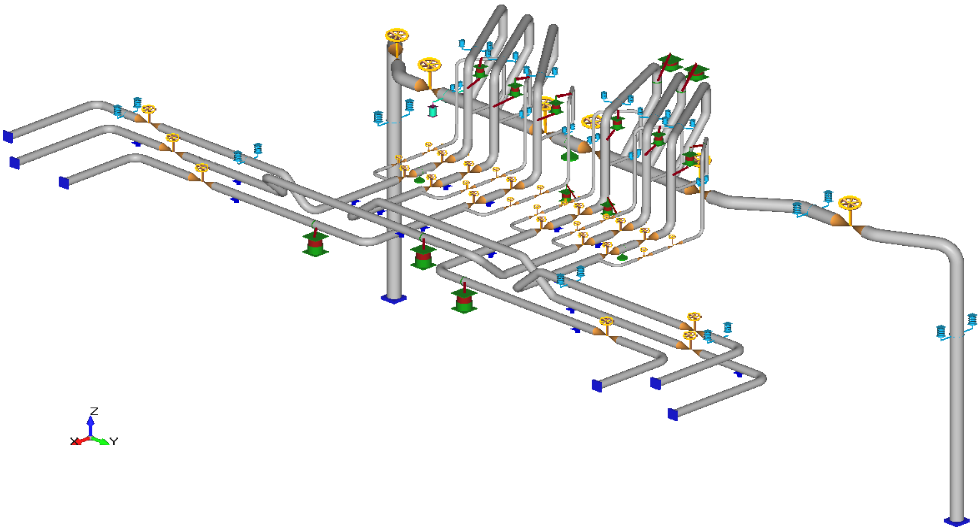


Figure 37. 13 dampers were installed on RL pipelines of Unit 4.

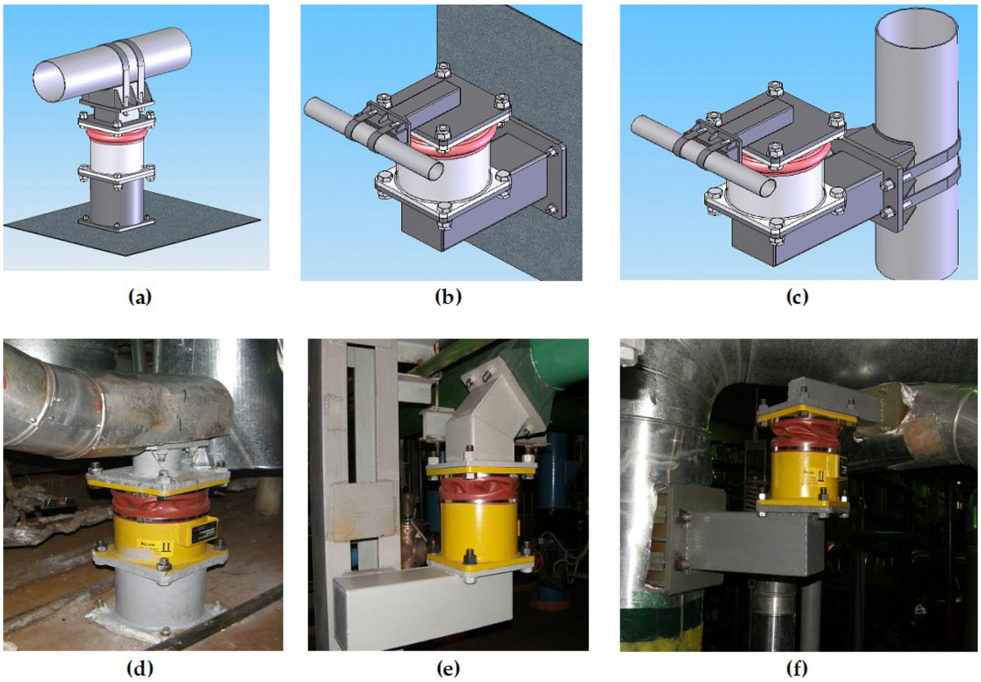


Figure 38. (a), (b), (c) – typical schemes of damper attachment; (d), (e), (f) – examples of damper installation on RL piping; (a), (d) – piping & floor; (b), (e) –piping & building structures; (c), (f) – piping & piping.

The results of vibration measurements where dampers were installed are shown in Table 5.

Table 5. Values of piping vibration at points for damper installation, same points as Table 4.

Unit 3				Unit 4			
Point No.	Location	RMS of vibrovelocity, (mm/s)		Point No.	Location	RMS of vibrovelocity, (mm/s)	
		Initial state	With dampers			Initial state	With dampers
5RL125	RL31	46.4	11.9	7RL102	RL31	19.7	13.8
5RL128	RL33	34.8	12.3	7RL302	RL33	37.4	12.1
5RL127	RL35	47.3	14.0	7RL502	RL35	20.0	11.7
6RL137	RL74	17.3	8.6	8RL202	RL72	41.8	11.0
6RL143	RL76	16.7	11.2	8RL402	RL74	38.3	15.1
				8RL602	RL76	32.0	14.1

The reduction of RL pipelines vibration varies from 3.9, in the 5RL125 measurement point, to 1.4, at 7RL102. The average vibration reduction rate for all the points where dampers were installed is 2.6 times. It should be underlined that vibration measurements after damper installation were performed after increasing Units power up to 107% which makes obtained results more valuable.

Damper efficiency obviously depends on the installation of several dampers installed along the pipeline. Presented results have been achieved with a minimal number of dampers on the basis of a cost-effective decision development.

Table 6 shows overall damper influence on the vibration state of RL pipelines of Unit 3 and 4 in relation to approved criterion.

Table 6. Influence of dampers installation on the vibration state of Kola NPP RL systems.

Total number of measurement points (Units 3, 4)	182	
Approved thresholds vibration criteria	RMS of vibrovelocity <15 mm/s	
Number of measurement points and percentage with vibration over threshold values	Points	%
Initial state (without dampers)	35	19
With dampers	1*)	0.6

*) RMS of vibrovelocity in this point is 15.1 mm/s.

Results show that HVD technology has successfully resolved the operational vibration matter of feed water piping at Kola NPP Units 3 and 4.

Dampers have reduced the vibration of pipelines on average by 2.6 times with maximum factor of 5.0 and have decreased the values of vibration to the accepted limit even in conditions of increased power capacity of the Units up to 107%.

Dampers provide protection from different dynamic loads: mechanical induced pulsation induced, liquid or mixed phase flow excited, pressure surge and hydraulic hammer, seismic, etc. and that way increase piping safety and extend its service life.

> High viscous damper technology has successfully resolved the operational vibration matter of feed water piping at Kola NPP Units 3 and 4.
>
> Dampers have reduced the vibration of pipelines on average by 2.6 times with maximum factor of 5.0 and have decreased the values of vibration to the accepted limit even in conditions of increased power capacity of the Units up to 107%Dampers provide protection from different dynamic loads: mechanical induced pulsation induced, liquid or mixed phase flow excited, pressure surge and hydraulic hammer, seismic, etc. and that way increase piping safety and extend its service life.

7.2 LOVIISA NPP (LOVIISA, FINLAND) [40]

Loviisa NPP has two units. The first started its operation in February 1977 and the second in November 1980. The units are Russian designed VVER (PWR)-440 type pressurized water reactors as well as the turbines, generators, and other main components. Safety systems, control systems and automation systems are of western origin. The steel containment and its related ice condensers were manufactured using Westinghouse licenses.

The operation experience of the power plant is very positive. Key figures measuring reliability and efficiency, load factors, are remarkably above the international average.

7.2.1 Steam and feed-water piping vibration matter at Loviisa NPP

The present electric power capacity of Loviisa NPP is approximately 10 % larger than it was originally. The electric power increase of each unit from 440 to 488 MWt was a result of the upgrading project that took place in 1997-2002. The primary and secondary systems water and steam pressure and temperature parameters remained the same. Thus, power upgrading of the units had been achieved by increasing of reactor, steam generator and other plant systems capacities in steam and feed-water mass flow generation. It resulted in corresponding increasing of flow velocity of feed-water piping and steam piping with some negative consequence such as piping vibration.

Several attempts were carried out to decrease vibration prior turning to VD technology. Re-designing of piping support system, its strengthening, and in some cases installation of additional elastic supports was arranged. All these measures had not provided a positive effect, in some cases only transferring system vibration frequency and did not significantly influence the degree of vibration.

7.2.2 Piping vibration criterion

Based on all available documentation and good NPP operational practice the following thresholds for piping vibration at Loviisa NPP was approved: RMS vibrovelocity less than 7.5 mm/s and Peak vibrovelocity less than 20 mm/s. The criterion of RMS piping vibration was considered to be as the primary limit, of peak value, as the secondary one.

RMS vibrovelocity threshold was not so conservative, as it seemed first, because it limited vibrovelocities in piping axial direction and in cross-section piping direction separately.

For each measurement point maximum values of RMS ($V_{\max}^{RMS}$) and peak vibrovelocity ($V_{\max}^{Peak}$) were defined according to the following correlations:

$V_{max}^{RMS} = \max\{V_a^{RMS};\ V_{cs}^{RMS}\}$ and $V_{max}^{Peak} = \max\{V_1^{Peak};\ V_2^{Peak};\ V_3^{Peak}\}$,

where

$V_a{}^{RMS}$– piping axial RMS or peak velocity;

$V_{cs}{}^{RMS}$ - cross section RMS velocity: $V_{cs}^{RMS} = \sqrt{{V_2^{RMS}}^2 + {V_3^{RMS}}^2}$;

$V_{1,2,3}{}^{Peak}$ - peak velocity along one of three directions 1, 2 or 3;

1, 2, 3 – directions of transducers measurements: usually transducer No 1, along the pipe axis, transducer No 2, along the tangent to the pipe cross section, transducer No 3, along the radius of the pipe cross section.

7.2.3 Vibration measurements and walkdown

Considering concerns connected to increased piping vibration comprehensive measurements had been carried out at all main steam and feed-water piping at Loviisa NPP Unit 1 and 2 in the turbine hall, in the reactor building containments' area, and in the middle area between turbine hall and reactor building. The total number of measurement points along piping, its supports, and building structures were near two hundred.

At the same time walkdowns were performed in order to get information concerning actual state of piping and supports. The walkdown procedure showed evidence of piping vibration, see Figure 39.

a) wear of the rod hanger.　　b) fatigue collapse of elastic support.

Figure 39. Example of piping supports degradation due to vibration.

The vibration measurements in turbine hall was performed by two multi-channel portable signal analysers MIC- 200, see section 6 above, with its usual settings, in containment area, and MIC- 200 combined with Bruel&Kjer, Denmark, measuring equipment.

Vibration measurements found that in an essential number of measurement points on the RA and RL piping the RMS and Peak values of vibrovelocities exceed approved criteria of 7.5 mm/s RMS and 20 mm/s Peak vibration.

The most dynamically loaded zones of the RA and RL piping of Loviisa NPP in terms of RMS and Peak vibrovelocities is shown in Table 7.

Table 7. Maximal values of piping vibration of RA and RL in turbine hall (TH), reactor buildings (RB) LO1 and LO2 and deaerator room (DR).

Point No	Location	$V_{\max}^{RMS}$, mm/s	$V_{\max}^{Peak}$, mm/s
2540	RA small bypasses in TH, turbine No 2, RA54	14.6	47.9
4512	RA turbine inlet, turbine No 4, RA 13	9.7	33.4
3542	RA vertical runs in TH, turbine No3	8.8	36.3
2568	RA in DR (big bypasses)	7.4	25.2
2576	RA50, turbine No 2	15.9	55.5
4222	RL vertical runs in TH, turbine No 4, RL70	9.3	32.5
3202	RL low elevation TH, turbine No 3, RL30	9.6	30.2
13	RL31 in DR, turbine No 1	11.8	42.3
N07	RL76 in RB, LO2	19.8	81.0
1F14	Turbine No 1 bearing No 1, floor	3.2	11.9

7.2.4 Dynamic and thermal expansion analysis

The following actions were carried out for piping vibration analysis and thermal expansion analysis:

- generation of finite-element models of piping.
- solving of eigenvalue problem to define the natural frequencies and mode shapes.
- modal time-history analysis of piping system.
- post-processing of results in time domain, defining of RMS and Peak values of vibrovelocities, and in frequency domain, creation of PSD Spectra for selected points.
- thermal expansion analysis to define thermal displacements for possible damper installation places.

PIPE software code was used for piping analysis. The examples of Loviisa NPP piping calculation models are shown in Figure 40 and Figure 41. These are the models of RL76 piping inside containment of Unit 2 and RA50, 52, 54, 56 piping in turbine hall of Unit 1.

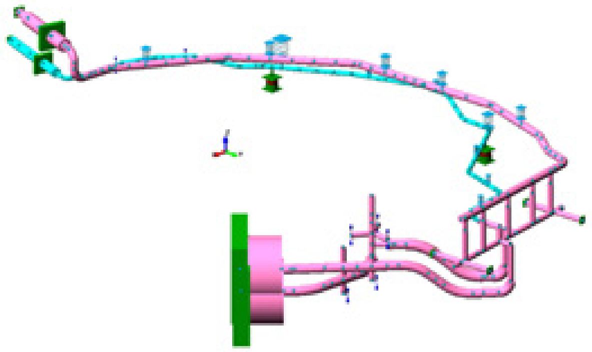


Figure 40. Left: Calculation model of RL76 piping inside containment of LO2.

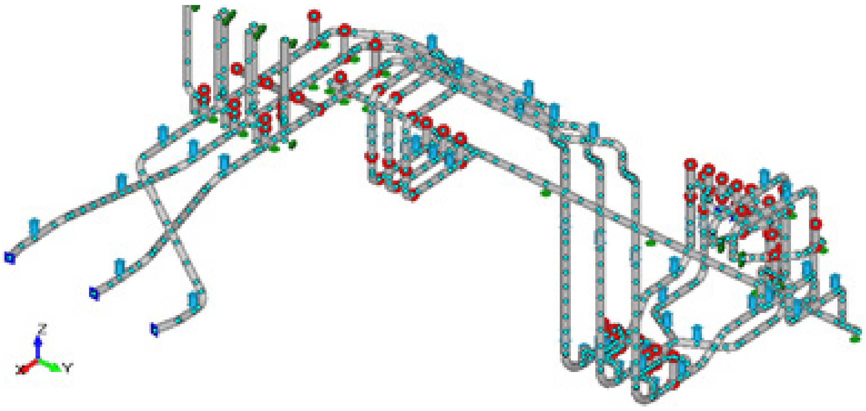


Figure 41. Right: Calculation model of RA50, RA52-54 piping in turbine hall of LO1.

The input vibration excitation was generated using analysis results, piping natural frequencies and modes, and experimental results obtained in piping vibration measurements. Excitation was defined as a set of multi-harmonic modal forces at piping resonance frequencies with random phase angles and amplitudes fit by iterative procedure.

The analytically produced modal forces generated piping vibration that was the same as the measured vibrations. Obtained from analysis PSD spectra and RMS values of vibrovelocities corresponded with experimental values. The results for main steam piping RA52-54 of LO1 is given in Figure 42 and Figure 43.

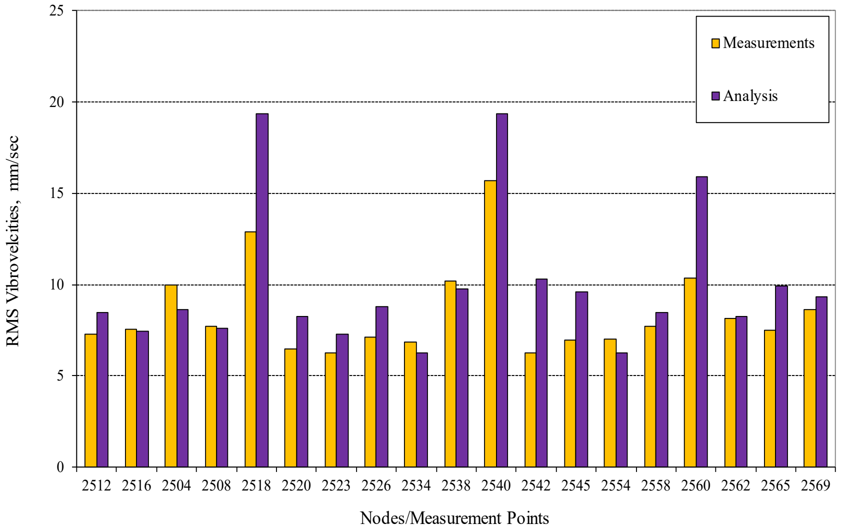


Figure 42. Experimental and analysis results of piping vibration. Vibration distribution along the RA52-54 piping of LO1

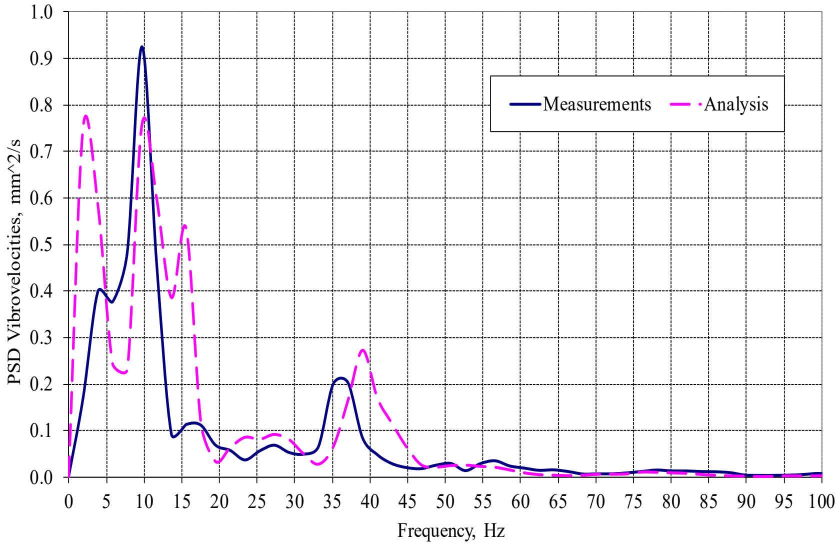


Figure 43. Experimental and analysis results of piping vibration. PSD spectra in the point 2538 of RA52 piping of LO1

Piping vibration analysis showed that the most effective solution for vibration reduction of Loviisa NPP piping is installation of high viscous dampers.

Figure 44 and Figure 45 depicts preliminary analysis results and later obtained real results of feed-water piping RL of LO2 inside containment subjected to flow induced excitation without and with high viscous dampers.

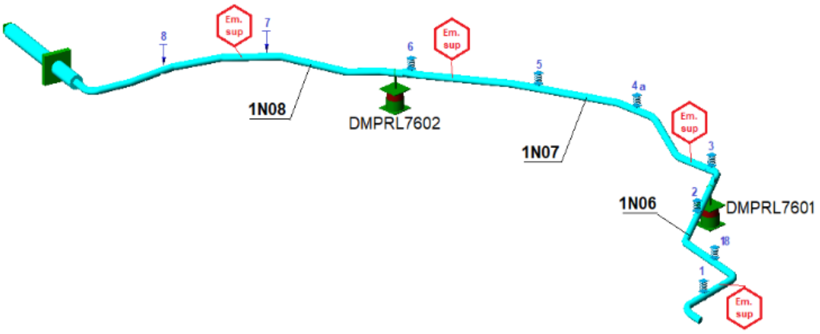


Figure 44. Layout of the feed-water RL76 piping in the containment LO2 with dampers location.

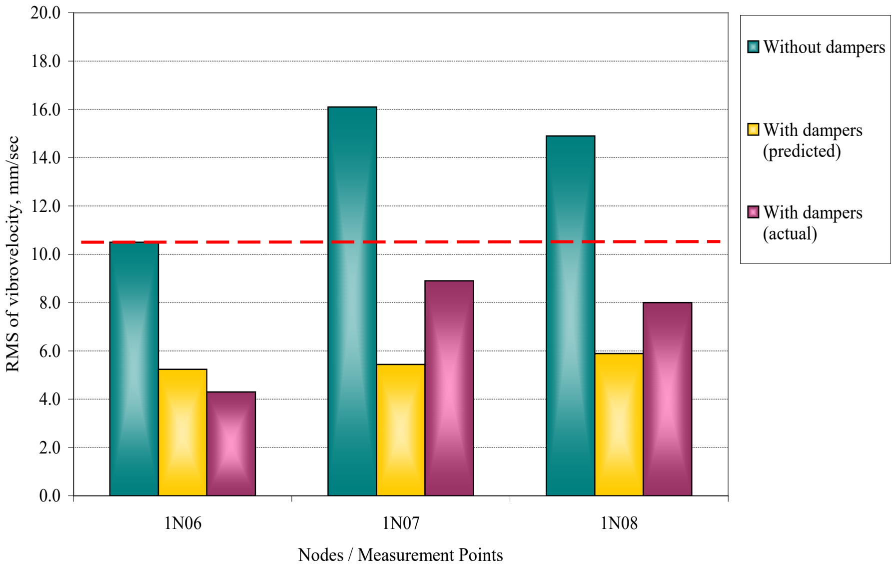


Figure 45. Analytically predicted and actual influence of dampers on the piping vibration.

The vibrovelocity threshold, shown in this diagram, is equal to 10 mm/s because it is for the sum of axial and cross-section values of vibrovelocity.

7.2.5 Elimination of piping vibration

Two types of high viscous dampers were used for reducing the vibration of steam and feed-water piping: VD and VES type, manufactured by GERB GmbH, Berlin.

Dampers were installed at Loviisa NPP in three ways:

- damper piston was attached to the piping and housing to the rigid structure.
- damper piston was attached to the rigid structure and housing to the piping.
- piston attached to one piping and housing to another, using different dynamic properties of these piping.

Mounted dampers are shown in Figure 46 - Figure 49 below.

Figure 46. VES damper at the RL76 in RB LO2 during installation. Damper's piston attached to the piping, housing – to the RB wall.

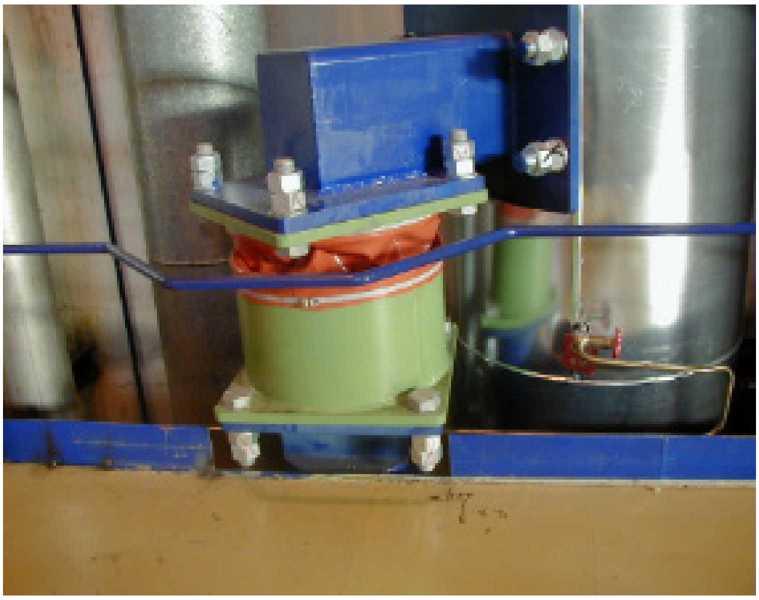


Figure 47. VD damper at the RA11 in turbine hall. Damper's piston attached to the piping, housing to the TH gallery floor.

Figure 48. Connection of two RA piping with different dynamic properties by VD damper

Figure 49. VES damper at RA10 piping in deaerator room. Damper's housing attached to the piping, piston – to the wall.

Dampers installation provides the following reduction in piping vibration: see Table 8 to compare RMS of vibrovelocities before and after dampers installation.

Table 8. Values of final piping vibration and dampers efficiency at the lines where dampers have been installed, same points as Table 7.

Point No	Location	$V_{\max}^{RMS}$, mm/s		$V_{\max}^{Peak}$, mm/s	
		Without dampers	With dampers	Without dampers	With dampers
2540	RA small bypasses in TH, Turbine 2, RA54	14.6	4.2	47.9	14.0
4512	RA turbine inlet, Turbine 4, RA 13	9.7	6.4	33.4	18.7
3542	RA vertical runs in TH, Turbine 3	8.8	4.5	36.3	12.5
2568	RA in DB (big bypasses)	7.4	3.5	25.2	11.8
2576	RA50, Turbine 2	15.9	4.6	55.5	19.3
4222	RL vertical runs in TH, Turbine 4, RL70	9.3	4.9	32.5	13.9
3202	RL low elevation TH, Turbine 3, RL30	9.6	2.5	30.2	8.5
13	RL31 in DB, Turbine 1	11.8	8.4	42.3	30.4
N07	RL76 in RB, LO2	19.8	8.0	81.0	30.9
1F14	Turbine 1 Bearing No 1 Floor	3.2	2.6	11.9	9.8

As result of dynamic analysis and cost analysis, the optimal number of 97 dampers was installed at Loviisa NPP. 73 dampers at RA steam piping and 24 dampers at RL feed-water piping. Among 97 dampers 58 were VES and 39 VD type. In the most problematic points along all RA and RL piping of Unit 1 and 2 in turbine hall and deaerator room the vibration reduction factor varies from 3.8, maximal value, to 1.5, minimal value, with the average factor approximately 2.5. In the points of RL feed-water piping in the containment area of Unit 1 and 2 the vibration reduction factor is 2.1.

The operational vibration matter of steam and feed-water piping at Loviisa NPP Units 1 and 2 was successfully resolved using viscodamper technology.

Total number of measurement points in the TH, DR and RB (LO1 and LO2):			204	
Approved thresholds vibration criteria:	Vrms <7.5 mm/s		Vpeak < 20 mm/s	
Vibration over threshold values:	Point	%	Points	%
Without dampers:	87	43	153	75
With dampers:	6	3	34	17

Dampers provide to the systems protection from different potential excitation sources as mechanical induced, pulsation induced, steam flow excited, liquid or mixed phase flow excited, pressure surge and hydraulic hammer, as well as seismic and other extreme dynamic loads.

It is also necessary to put attention to the specific point 1F14 located at TH floor near turbine No 1 bearing No 1, see Table 8. The results showed that dampers connection to the building structure decreases vibration of the floor in spite of some predictions. More-over, dampers installation not only dropped down vibration at the piping but also reduced noise in attended rooms.

7.3 NARVA POWER PLANTS. EESTI POWER PLANT (NARVA, ESTONIA)

The Narva Power Plants are a power generation complex in and near Narva in Estonia. The complex consists of the world's two largest oil shale-fired thermal power plants, Eesti Power Plant and Balti Power Plant. The Eesti Power Plant is located roughly 20 km west-south-west of Narva. It was built between 1963 and 1973. As of the end of 2005, Eesti Power Plant had installed capacity of 1,615 MW. The Eesti Power Plant initially had sixteen TP-101 type boilers and eight 200 MW steam turbines. Fourteen boilers and seven turbines are currently in service. In 2003, Unit 8 was reconstructed to use the circulating fluidized bed boiler technology.

Figure 50. Eesti fossil power plant, Estonia.

Modernisation work was also carried out for turbines, in particular the oil piping to bearings of turbine No 8 in Eesti Power Plant were reconstructed. After the modernisation an increased vibration of some sections of the oil piping was observed at normal operating conditions. Preliminary measurements of vibration by specialists of Eesti Power Plant and CVS confirmed the presence of piping sections with high vibration, RMS values of vibrovelocity equal to 60-70 mm/s. This level of vibration was deemed unacceptable and required the development of measures to reduce vibration.

For the period from 2004 to 2006, additional measures were taken to modernise the piping layout and supports. For example, the anchor support was removed; the layout of oil piping to turbine bearings 3 and 4 was changed; the modification of several sliding supports was carried out. These measures led to some, but not sufficient, reduction of vibration in the oil piping.

In 2006 an agreement was signed between Narva Power Plant and CVS to conduct research and design work to reduce the vibration of oil piping to bearings of turbine No 8 of the Eesti Power Plant.

Vibration measurements of oil piping in the initial state from oil coolers to turbine bearings were carried out. The measurement results showed that many oil piping sections had rather high vibration. In some points RMS of vibrovelocities reached 66 mm/s, and measures to reduce vibration was required. Measurement points are depicted in Figure 51. The result of vibration measurements can be seen in Table 9.

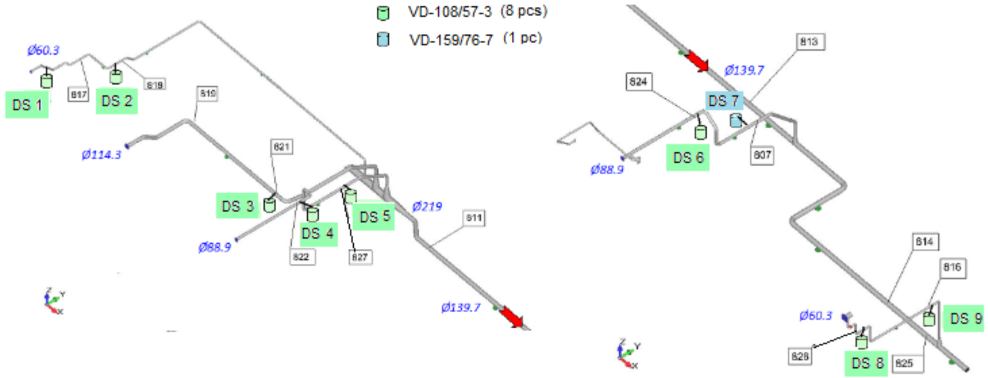


Figure 51. Turbine No 8 oil piping: header and bearing oil piping. Measurement points and damper supports layout.

The walkdown of the oil piping to bearings of turbine No 8 and its support system was carried out and all necessary data for preparing the calculation models and further analysis of the vibrational state was obtained.

Table 9. Vibration measurements of oil piping in initial state.

Measur. point	Piping section	Dxt, mm	RMS of vibrovelocity, mm/s
807	Supply piping to bearings No 5 and No 6	88.9x1.5	66.0
811	Oil header	139.7x2	51.8
813	Oil header	139.7x2	44.8
814	Oil header	139.7x2	21.1
816	Supply piping to bearing No 7	60.3x1.6	31.7
817	Supply piping to bearing No 1	60.3x1.6	33.4
818	Supply piping to bearing No 1	60.3x1.6	32.6
819	Supply piping to bearing No 2	114.3x2	18.4
821	Supply piping to bearing No 2	114.3x2	27.7
822	Supply piping to bearings No 3 and No 4	88.9x1.5	40.6
824	Supply piping to bearings No 5 and No 6	88.9x1.5	52.7
825	Supply piping to bearing No 7	60.3x1.6	17.3
826	Supply piping to bearing No 7	60.3x1.6	24.9
827	Supply piping to bearings No 3 and No 4	88.9x1.5	63.1

Based on vibration measurements, the vibration calculations with different types of vibration excitations of oil piping were carried out. The possibility and effectiveness of reducing vibration in various ways was determined: installing additional supports, increasing the wall thickness of the piping, installing damper supports, installing dynamic absorbers. A comparative vibration analysis of turbine No 8 oil piping and turbine No 7 oil piping was also carried out.

A technical solution to reduce vibration of oil piping was developed and agreed. It proposed to consider, as the main measure to reduce the vibration of the turbine No. 8 oil piping, its modernisation from analogy of turbine No. 7 project. Since the oil piping replacement is a labour-intensive work and requires a long shutdown, it was proposed at this stage to install damper supports.

It was decided to install nine damper supports: eight with VD-159/76-7 damper and one with VD-108/57-3 damper. Design of damper supports was carried out. Assembly drawings and detail drawings for nine damper supports were developed. Places of damper supports installation are shown in Figure 51. They were chosen in vibration analysis and in-site walkdown. Figure 52 gives several pairs of photos of the same places for dampers installation on the stages of designing and after dampers installation.

Figure 52. Places for dampers installation before and after dampers installation. The speckled yellow box is a mockup of damper.

The vibration measurements of oil piping after damper installation were carried out at normal operating condition of turbine No 8. The measurement results and a comparison with the initial state are given in Table 10. Results show that vibrovelocities were lowered, but in some points not enough. So, it was decided to estimate vibration stress intensity before and after dampers installation.

Table 10. Results of vibration measurements of oil piping to turbine No 8 bearings.

Measurement point	RMS of vibrovelocity, mm/s		Reduction factor
	Without dampers	With dampers	
807	66.0	23.8	2.8
811	51.8	15.8	3.3
813	44.8	13.7	3.3
814	21.1	15.3	1.4
816	31.7	22.1	1.4
817	33.4	16.6	2.0
818	32.6	18.0	1.8
819	18.4	13.3	1.4
821	27.7	12.1	2.3
822	40.6	27.5	1.5
824	52.7	22.5	2.3
825	17.3	13.6	1.3
826	24.9	8.6	2.9
827	63.1	34.0	1.9
Piping average			2.1

To calculate the vibration stresses the oil piping to bearings No 3 and 4 of turbine No 8 and the oil collector section, to which it is connected, were selected. The reason for this choice is a high level of vibration in this area, measurement points 822 and 827. A fragment of the calculation model is shown in Figure 53.

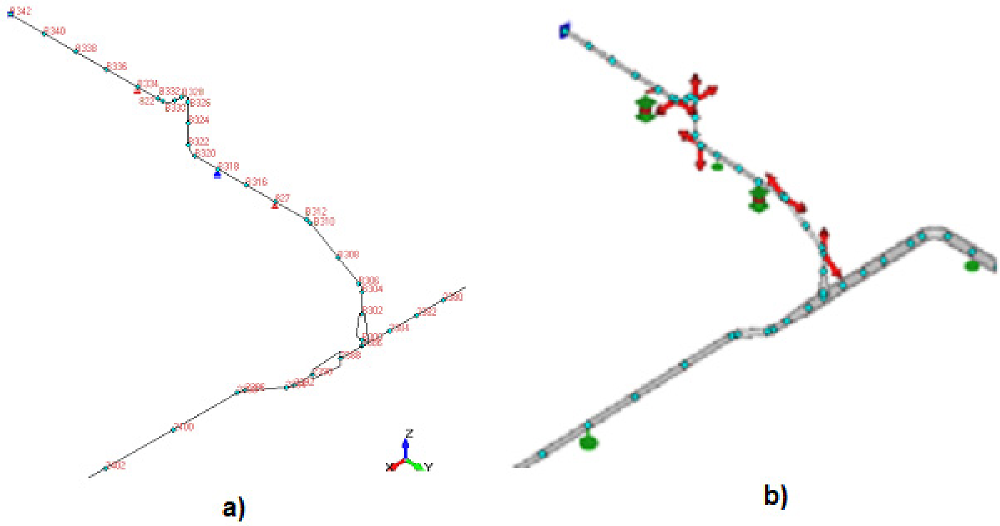


Figure 53. Calculation model of oil piping to bearings No 3, 4 of turbine 8: (a) number of nodes (b) modelling of forces

The calculation was carried out by method for the time integration of the modal response.

The process of matching the vibrational excitation was iterative and was controlled by comparing the calculated and measured vibration values. The vibrational impact was modelled by harmonic forces applied in the bends of the piping Figure 53b. The forces frequency was 50 Hz, because this frequency is fundamental in the spectrum of vibrovelocities measured in a given section of the piping, points 822 and 827.

The calculation was carried out in order to determine the vibration stresses in the piping in the initial state, before damper installation, and after damper installation in accordance with the Part 3 of ASME OMa-S/G-2000 [31].

For steady-state vibration the maximum calculated alternating stress intensity S_{alt} should be limited:

$$S_{alt} = \frac{C_2 K_2}{Z} M \leq \frac{S_{el}}{\alpha};$$

where

$C_2K_2 = 2i$

i = stress intensification factor, as defined in Subsections NC and ND of ASME BPV Code [32].

α = allowable stress reduction factor: equal to 1.0 for stainless steels (Fig. 1-9.2.2 of ASME BPV Code [32]).

M = maximum zero to peak dynamic moment loading due to vibration only, or in combination with other loads as required by the system Design Specification, summarized according to SRSS rule [32]. Moments have been acquired as results of vibration analysis carried out by dPIPE program.

S_{el} = 0.8 Sa, where Sa is the alternating stress at 1011 cycles from Fig. 1-9.2.2 of ASME BPV Code [32]. Sa = 93.8 MPa, Sel = 75.0 MPa.

Z = section modulus of the pipe.

Table 11 shows the above-mentioned data necessary for calculating vibration stresses and the results of calculating vibration stresses for the initial state of the oil piping and after installing dampers.

The calculation results are given for fifteen nodes of the oil piping model, in which the highest values of vibration stresses were obtained. It can be seen, that after damper installation the vibration stresses decreased by an average of 2.1 times along the piping; in node B326, where before dampers installation, the vibration stress exceeded the allowable one, it decreased 2.2 times.

After dampers installation the vibration stresses in all points of the oil piping to bearings No 3 and 4 of turbine No 8 did not exceed the allowable value, shown by a red dashed line in Figure 54.

Table 11. The results of vibration stresses calculations.

Node	Piping element type	Stress intensif. factor (i)	Section modulus of the pipe (Z), mm^3	MAX dynamic moment (M), N·mm		Vibration stresses (S_{alt}), MPa	
				Without dampers	With dampers	Without dampers	With dampers
B302	Reducer	1.27	8.85E+03	9.86E+04	5.88E+04	28.3	16.9
B304	Bend	4.5	8.85E+03	4.74E+04	2.21E+04	48.2	22.5
B306	Bend	4.5	8.85E+03	4.81E+04	1.95E+04	48.9	19.9
B310	Bend	4.5	8.85E+03	6.33E+04	3.13E+04	64.3	31.8
B312	Bend	4.5	8.85E+03	5.61E+04	2.82E+04	57.0	28.6
B316	Run	1	8.85E+03	1.13E+05	5.64E+04	25.5	12.7
B320	Bend	4.5	8.85E+03	3.44E+04	1.10E+04	35.0	11.2
B322	Bend	4.5	8.85E+03	3.93E+04	2.50E+04	40.0	25.4
B326	Bend	4.5	8.85E+03	7.62E+04	3.54E+04	77.5	36.0
B328	Bend	4.5	8.85E+03	5.06E+04	2.21E+04	51.5	22.4
B330	Bend	4.5	8.85E+03	2.93E+04	1.63E+04	29.8	16.6
B332	Bend	4.5	8.85E+03	5.43E+04	2.40E+04	55.3	24.4
B336	Run	1	8.85E+03	1.08E+05	5.62E+04	24.4	12.7
B342	Run	1	8.85E+03	1.84E+05	6.38E+04	41.5	14.4
Piping average						43.6	20.7

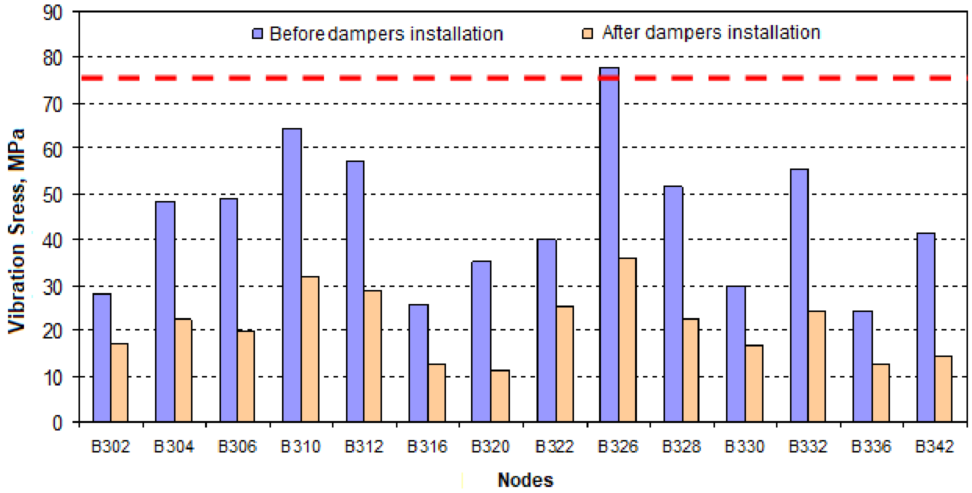


Figure 54. The results of vibration stresses calculations.

The vibration state of the oil piping to bearings of turbine No 8 of Eesti Power Plant significantly improved after nine damper supports installation: eight with VD-159/76-7 dampers and one with VD-108/57-3 damper. RMS of vibrovelocity decreased by an average of 2.1 times.

Calculation of the vibration stresses of the oil piping to bearings No 3 and No 4 before and after the dampers installation showed, that the vibration stresses decreased by an average of 2.1 times in the piping and do not exceed the allowable value in any node.

According to [31] maximal value of vibrovelocity in piping branch is in direct proportion to maximal vibration stress in this branch. This was confirmed by dynamic calculations performed for the oil piping to bearings No. 3 and No. 4 of turbine No 8.

Vibration stress calculations were performed for a piping that after dampers installation had a vibration level higher than others. Since after damper installation in no single node of this piping, the vibration stresses did not exceed the allowable value, it was assumed that the vibration stresses in the whole examined oil piping to bearing of turbine No 8 were lower than allowable.

7.4 PAO ACRON CHEMICAL PRODUCTION FACILITY (VELIKY NOVGOROD, RUSSIA)

Acron Group is a major global producer of mineral fertilizer. PAO Acron chemical production facility is part of it. PAO Acron was established in 1961 as Novgorod chemical factory. The company in its current form exists since 2002.

Figure 55. Piping at PAO Acron Chemical production facility.

7.4.1 Reducing vibration of down comers and raisers of waste heat boiler

In 2002 Acron faced a need to reduce vibration of down comers and raisers for the waste heat boiler of the methane conversion unit. Vibration measurements of waste heat boiler piping were carried out at maximal, inter-mediate, and minimal flow rates of conventional gas.

Measurement points were chosen during walkdown in such a way as to obtain the necessary amount of information to assess the vibrational state of the entire system. Vibration measurements were carried out at 14 points located on the down comers, raisers, and on the supports of the waste heat boiler, see Figure 56. Measurement points are marked in red. More measurement points were selected at raisers because of their higher vibration.

The results of vibration measurements showed that vibration of raisers was higher than approved threshold, 25 mm/s Peak vibrovelocity, at all flow rates of conventional gas. The average levels of Peak vibrovelocity were as follows: at minimal flow rate of conventional gas, 32.5 mm/s, at intermediate flow rate, 45.2 mm/s, at maximal flow rate, 71.4 mm/s. The vibration levels of down comers were lower than threshold, but at maximal flow rate of conventional gas close to it – 24.8 mm/s.

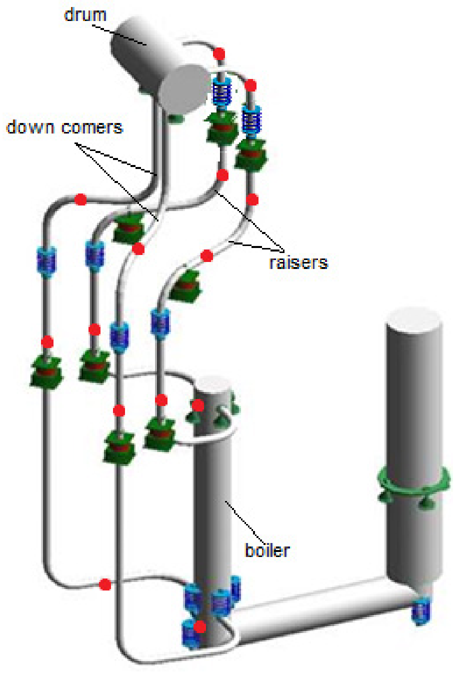


Figure 56. Down comers and raisers of waste heat boiler. Red markers indicate the measurement points.

To reduce vibration eight dampers of VD -219/108-7 type was recommended to be installed: six on the raisers and two on the down comers. The drawings of damper supports were issued, and dampers were installed. Dampers were installed outdoors, see Figure 57.

Figure 57. Dampers installed on the piping of waste heat boiler.

The vibration measurements were fulfilled also at three flow rates of conventional gas after damper installation. They showed that on the raisers the average levels of Peak vibrovelocity at minimal flow rate had become 3.4 mm/s, at intermediate flow rate, 4.1 mm/s, at maximal flow rate, 4.3 mm/s. On the down comers maximal value of Peak vibrovelocity was 8 mm/s.

> The vibration state of the raisers and down comers of waste heat boiler of methane conversion unit was successfully improved by installing eight VD -219/108-7 dampers. Peak values of vibrovelocity was lowered by 9–16 times for raisers and at 3 times for down comers.
>
> All Peak values of vibrovelocity had become lower than threshold of 25 mm/s.

7.4.2 The elimination of interstage piping vibration of compressors No 1, 2, 3 of methanol workshop

The operation of reciprocating compressors No 1, 2 and 3 in the methanol workshop was accompanied by increased vibration of the interstage piping. RMS of vibrovelocity were higher than threshold of 20 mm/s in nearly half of measured points.

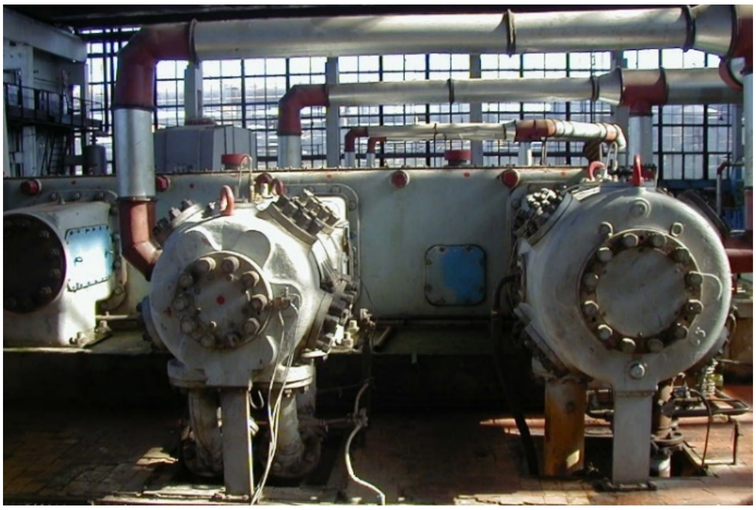


Figure 58. Piping of compressors at methanol workshop.

Interstage compressor piping is a complex system, which includes piping buffer tanks, filters, heat exchangers, coolers. Efficiency of buffer tanks as pressure snubbers for reciprocating compressor is achieved by accurate selection of volumes and designs of these devices for specific parameters of the power fluid.

The compressors of the methanol workshop underwent reconstruction, in which the number of rows and stages, the compression ratio and the characteristics of the working medium were changed. At the same time, buffer capacities remained the same, and their effectiveness could be reduced. The support system was also reconstructed in the “working” order, part of the supports and hangers were eliminated, some types of supports were changed, new supports were installed, etc. Under these conditions the compressor interstage piping is influenced by internal pressure pulsations, the vibration of the sur-rounding structures and attached equipment.

During the compressor operation period, measures were taken to reduce vibration, aimed at installing additional rigid supports or stay rods in places of increased vibration. In some cases, these measures led to a local reduction of vibration, but new areas with high vibration were detected, on which new restrains were necessary to install.

Measures to install additional supports, stops and other anti-vibration devices were not of a sequential nature, their mutual influence was not always considered.

In this work measures were taken to reduce vibration by adding additional damping into the system, i.e. using viscodamper’s technology.

The work was carried out according to usual plan, see Fig. 20. The work was fulfilled for interstage piping of compressors No 1, 2 and 3 of methanol workshop. The work is de-scribed on the example of compressor No 2. The end results of the work are given for all compressors.

The first stage of the work included checking the support system of interstage piping and equipment, a preliminary assessment of the vibrational state, and also collecting design and operational documentation.

When examining the supports system of interstage piping and equipment the types of supports were determined and the features of their operation were specified. Some deficiencies were identified and recommendations were given for their elimination.

Next a measurement program was developed and agreed upon, measurement schemes were drawn up, compressor operation modes were determined during measurements, and measuring equipment was prepared. Measurement scheme for compressor No 2 interstage piping is depicted in Figure 59.

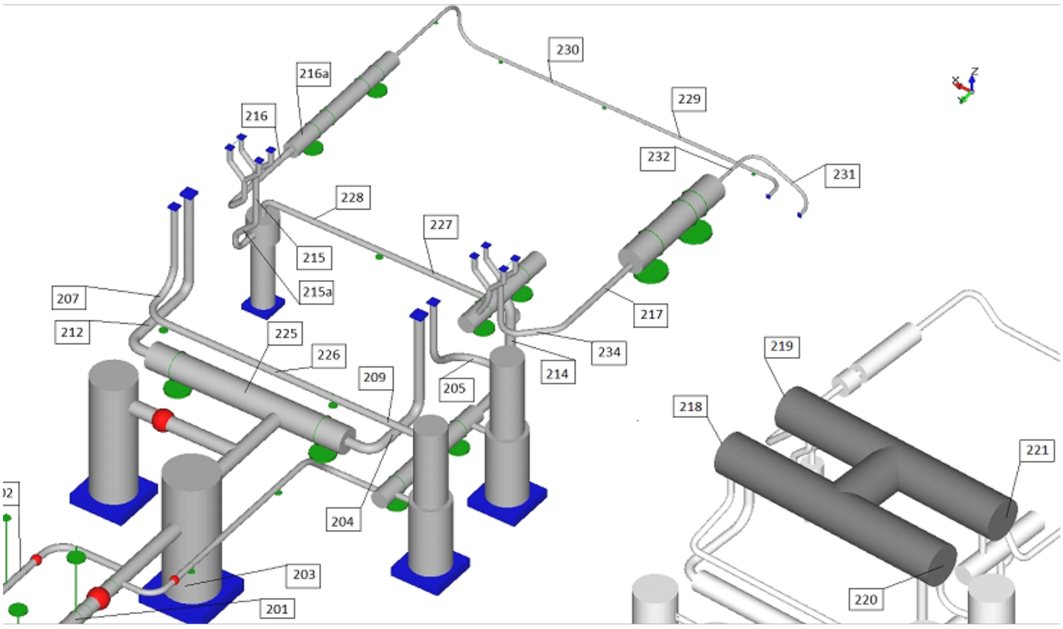


Figure 59. Measurement scheme for compressor No 2 interstage piping.

Vibration measurements were fulfilled and processed for interstage piping and equipment. Nearly in the half points of measurements the vibration level was higher, than acceptable limit of RMS vibrovelocity equal to 20 mm/s. This result was approximately the same for all compressors.

The RMS of vibrovelocity of interstage piping of compressor No 2 for sections with high vibration is shown in Table 12.

The vibration reduction was recommended to the following piping sections of compressor No 2:

- 1st stage suction piping.
- 1st stage 2nd row discharge piping.
- 2nd stage suction piping.
- 2nd stage 3rd row discharge piping.
- 2nd stage 4th row discharge piping.

Vibration analysis were carried out based on vibration measurements. Example of calculation model can be seen in Figure 60.

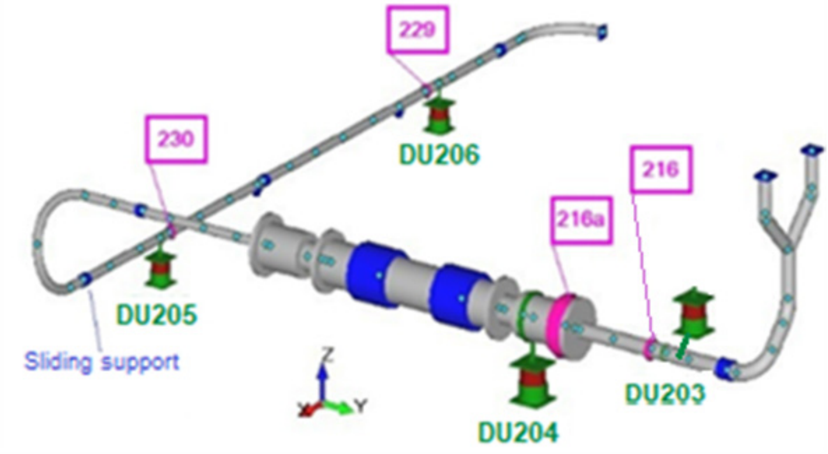


Figure 60. Calculation model of 2nd stage 4th row discharge piping of compressor No 2.

Based on analysis results it was proposed to install 12 damper supports with VD-219/108-7 type dampers, see Figure 61. The dampers were installed on the following interstage piping of compressor No 2:

- 1st stage suction piping - 1 damper support.
- 1st stage 2nd row discharge piping - 1 damper support.
- 2nd stage suction piping - 2 damper supports.
- 2nd stage 3rd row discharge piping - 4 damper supports.
- 2nd stage 4th row discharge piping - 4 damper supports.

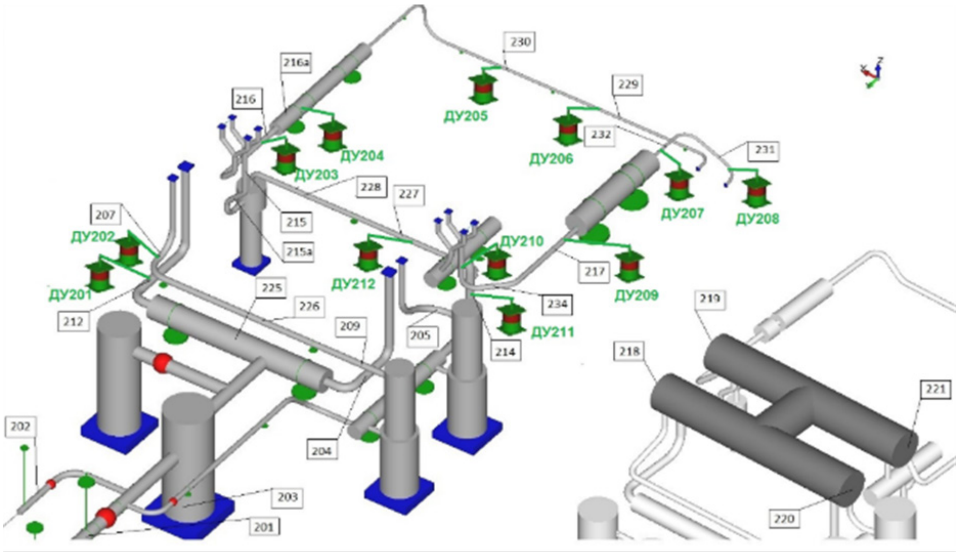


Figure 61. Scheme of dampers installation on interstage piping of compressor No 2.

The results of vibration analysis had predicted two times reduction of vibrovelocity average per all system.

After the development and approval of the technical solution for the damper installation, a set of damper supports drawings was released. Figure 62 shows the damper's path from vibration analysis to end result.

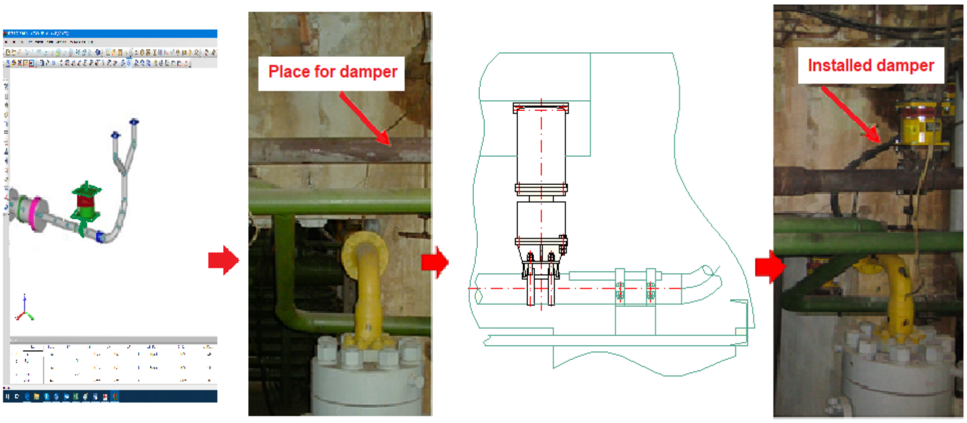


Figure 62. Damper development path from analysis work to end result.

CVS carried out supervision of the damper supports installation. Several installed damper supports are given in Fig. 57.

Figure 63. Examples of damper supports installed on interstage piping of compressor No 2.

The vibration measurements were made after dampers installation. Measurement points, their positions on compressor No 2 interstage piping and RMS of vibrovelocity before and after dampers installation are listed in Table 12. Results are given for piping sections with high vibration level in initial state, where dampers were installed.

Table 12. Results of vibration measurements of compressor No 2 interstage piping.

Measure point	Location	RMS of vibrovelocity, mm/s		Reduction factor
		Without dampers	Without dampers	
207	1st stage 2nd row discharge piping to cooler	25.1	14.8	1.7
212	1st stage 2nd row suction piping	22.4	14.3	1.6
214	Piping from 1st stage discharge buffer to 2nd stage suction buffer	29.4	9.5	3.1
216	2nd stage 4th row discharge piping	51.6	24.7	2.1
216a	2nd stage 4th row discharge buffer	41.5	17.3	2.4
217	2nd stage 3rd row discharge piping	57.9	60.5	1.0
227	Piping from 1st stage discharge buffer to 2nd stage 4th row suction buffer	25	10.9	2.3
228	Piping from 1st stage discharge buffer to 2nd stage 4th row suction buffer	23.3	13.1	1.8
229	Piping from 2nd stage 4th row discharge buffer to cooler	38.1	12.9	3.0
230	Piping from 2nd stage 4th row discharge buffer to cooler	76.5	16.1	4.8
231	Piping from 2nd stage 3rd row discharge buffer to cooler	108	26.7	4.0
232	Piping from 2nd stage 3rd row discharge buffer to cooler	51	42.1	1.2
234	2nd stage 3rd row discharge piping	85.8	38.2	2.2
	Piping average			2.4

In general, the results of vibration reduction were rather good and even a little bit better than in the vibration analysis. But in two points, 217 and 232, the vibration was not improved as predicted by vibration analysis. During the inspection it was noticed that some dampers' bolt joints were not properly tightened. It was recommended to correct bolts tightening. Unfortunately, no measurements were made after that, but according to staff, the situation has improved.

33 dampers of VD-219/108-7 were installed on interstage piping of compressors No 1, 2, and 3 of methanol workshop to reduce vibration:

- 11 dampers – on compressor No 1.
- 12 dampers – on compressor No 2.
- 10 dampers – on compressor No 3.

Maximal values of vibration (RMS of vibrovelocity) were significantly reduced:

- from 50 mm/s to 13.1 mm/s – on compressor No 1.
- from 108 mm/s to 26.7 mm/s – on compressor No 2.
- from 113 mm/s to 22.4 mm/s – on compressor No 3.

Average reduction factors for each compressor interstage piping are as follows:

- 2.1 for compressor No 1.
- 2.4 for compressor No 2.
- 2.3 for compressor No 3.

It was not possible to reduce vibration to the recommended values at several points on the interstage piping of each compressor. This is due to the limited choice of optimal locations for damper supports, due to the configuration of the interstage piping and their position relative to the compressors’ seats.

8 Some specific cases of piping vibration mitigation by HVD application at power plants and industrial facilities[7]

VRF – Maximum Vibration Reduction Factor achieved at the facilities' systems.

No	Facility	Country	Year	Number and type of HVD		Systems	VRF	Notes
				VD	VES			
1	Kostroma FPP 1200 Mwt Unit Conventional Power Plant	USSR/ Russia	1988-1990	96		Main Steam Line, 24 MPa, 565 C	22.5 10.0 !	1
2	Ignalina NPP RBMK (BWR) 1500 MWt	Lithuania	1991-1994	34		Main steam piping in the Turbine hall and Confinement	6.0	
3	Lenenergo FPP No. 14	Russia, St. Petersburg	1992	11		Condensate drain water piping	7.0	
4	Leningrad NPP (LAES-1) RBMK (BWR) 1000 MWt	Russia	1993-1994	38		Drain water and Recirculation turbines piping	4.0	
5	Lenenergo, Yuzhnaya FPP UTMZ 300 MWt	Russia, Saint Petersburg	1993	4		Main steam lines to the HP turbine inlet, 24MPa, 560 C	3.0	
6	Lenenergo, FPP No. 15	Russia, St. Petersburg	1993	2		Deaerator manifold. Drain line	7.0	
7	Kola NPP VVER (PWR)-440	Russia	1993-1995	20		TQ, TH coolant injection lines	3.0	
8	WNP-2 (WAPP) BWR	USA, WA	1994	8		Heater Bay Area Feed&Drain lines	Good	2
9	Kola NPP VVER (PWR)-440	Russia	1994	6		Coolant makeup system	5.0	
10	Leningrad NPP (LAES-1) RBMK (BWR) 1000 MWt	Russia	1995	24		Primary loop in the Confinement	Good	3
11	Temelin NPP	Czech Republic	1995-2006		62	Primary and secondary systems	Good	
12	Kozloduy NPP VVER (PWR)-1000	Bulgaria	1997	5		Main steam line. Emergency loops	1.1-3.0	4
13	Loviisa NPP VVER (PWR)-440	Finland	1999-2002	39	58	Main steam lines, Feed-water lines in the Turbine hall and the Containment	3.8	5
14	Mochovze NPP	Slovakia	1999-2002		27	Primary and secondary systems	Good	

---

[7] Aside from seismic upgrading by HVD's

No	Facility	Country	Year	Number and type of HVD		Systems	VRF	Notes
				VD	VES			
15	Angra NPP	Brazil	1999-2003		39	Primary and secondary systems	Good	
16	Balakovo NPP VVER (PWR)-1000	Russia	2000-2002	12	11	Main steam line. Emergency valves loops	1.2-2.0	See Note 4
17	Chernobyl NPP RBMK (BWR) 1000 MWt	Ukraine	2000		6	Main steam line. SEBIB safety valves.	3.0	6
18	RAO Acron Chemical Plant	Russia	2002	8		Waste heat boiler lines of methanol workshop	up to 16.0	
19	Ignalina NPP RBMK (BWR) 1500 MWt	Lithuania	2005	6		Condenser line to the condenser pump	1.2	7
20	Temelin NPP VVER (PWR) 1000	Czech	2006-2007	4		Main steam line. Emergency loops	1.5	See Note 4
21	RAO Acron Chemical Plant	Russia	2007-2012	33		Compressors inter-stage piping of methanol workshop	2.4	
22	Kola NPP VVER (PWR)-440	Russia	2008-2012	24		Recirculation lines of high and low pressure injection	2.0	
23	Narva Power Plant, EEsti PP	Estonia	2008	9		Oil piping lines to turbine's bearing	3.3	8
24	Kola NPP VVER (PWR)-440	Russia	2008	8		Main steam lines inside Confinement	3.7	
25	Kola NPP VVER (PWR)-440	Russia	2009	42		Feed-water and mix- flow condensate manifold lines	2.6	
26	Kola NPP VVER (PWR)-440	Russia	2010	4		Main steam lines' bypasses	3.9	
27	Kola NPP VVER (PWR)-440	Russia	2011	14		Emergency feed-water lines	1.7	
28	Cooper NPS BWR 950Mwt	USA, NB	2010-2012	18		Main Steam Lines Heater Bay Area	Full Power	9
29	Brown Ferry NPP BWR 1300 MWt	USA, AL	2019-2020 Ongoing Project	16		Main Steam Lines Heater Bay Area		See Notes 9, 10

*Vibration Reduction Factor (VRF) is the ratio of an initial system's maximum vibration to the system's maximum state with HVD (times drop)

8.1 NOTE 1, KOSTROMA FPP

Kostroma FPP 1200 MWt Unit is the most powerful supercritical high speed 3000 rpm turbine in Europe. This was an extremely severe vibration case of the main steam elongated piping with total length over 120 meters with supercritical steam parameters of 24 MPa and 565 C with maximum vibration Vrms = 45 mm/s. Operational staff refused to service the system due to a danger of piping rupture. The problem was completely resolved by VD dampers installation and in the point of highest system's vibration the VRF achieved 22.5. But for the complete piping system VRF was 45/4.5 = 10.0 as is shown in Figure 64. This good result was due to an optimal placing of necessary types and number of VD dampers.

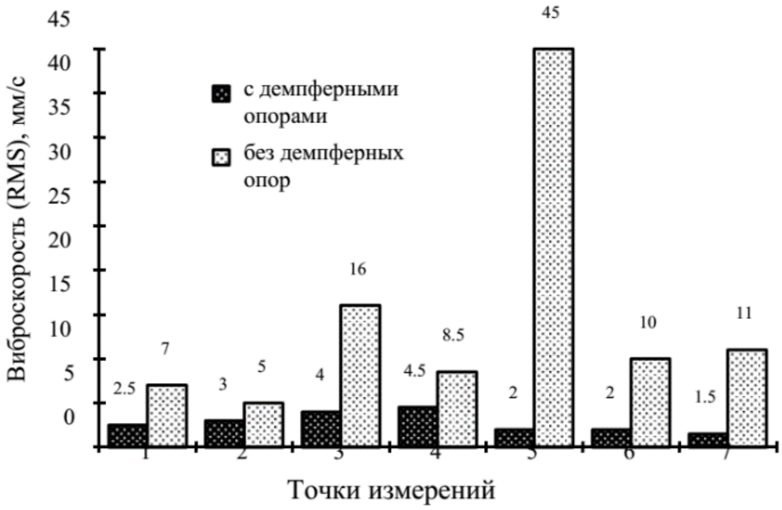


Figure 64. Resolving of vibration matter at Kostroma 1200 Mwt FPP Unit. Grey columns: before HVD installation. Black columns: with HVDs.

8.2 NOTE 2, FIRST EVER APPLICATION IN USA

The first application of VD dampers in the US. Extremely high vibration limited power capacity of the Unit. After dampers installation all concerns were removed.

8.3 NOTE 3, FIRST EVER APPLICATION AT NPP PRIMARY CIRCUIT

The first application of VDs at the nuclear power plant primary circuit, loop, in a very high radiation zone in reactor's proximity with an ambient temperature range 50C to 150C and humidity up to 100%. Cases of fatigue in 820 mm piping welding joints were prevented and no more fatigue cracking appeared since damper installation.

8.4 NOTE 4, RARE CASE OF FLUID INDUCED PHENOMENON

Vibration of several Emergency Valves Loops of the Main Steam Lines in the VVER-1000 NPPs is a very specific and rare case of fluid induced phenomenon. In these closed loops a stable, extensive, and sharp acoustic resonance exists often in the frequency range 40 - 50Hz. As known HVDs damping efficiency drops down after 30 Hz vibration and higher and the damper itself becomes dramatically stiffer. Beside that a critical point for these loops' vibration is the location of the acoustic resonance peak, either at a rising branch of mechanical resonance curve of the system or at a falling branch. In the first case the efficiency of HVDs could be very low while additional elastic stiffness of dampers could bring co-incidence of acoustic and mechanical resonances of the system. On the other hand, if we are at falling branch then this additional elastic stiffness will bring the system to a full detuning from the resonance. This is why the system's VRF for these lines could essentially fluctuate from 1.1 to a quite high 3.0.

8.5 NOTE 5, UPGRADING OF REACTOR POWER

Upgrading of Reactor Power capacity by 15% resulted in high vibration of all steam and feed-water lines due to increasing of flow velocity and flow induced vibration effects. All known anti vibration measures implemented had brought no effect and only after HVD installation the vibration matter was resolved on both Units 1 and 2 and power plant can work safe on a full upgraded power

8.6 NOTE 6, CHERNOBYL SEBIM SAFETY VALVES

Chernobyl vibration case is also a very specific story. After the huge nuclear accident in 1986 only Unit 3 returned to operation. However, its power capacity was limited to 80%, 800 MWt, only due to a high vibration of SEBIM safety valves and a permanent fatigue failure of valve's manifold small bore piping and several case of Unit's occasional shut-down. Installation of VES dampers completely resolved the problem and Unit 3 power capacity returned to 100%. Dampers behaved well in an extremely high radiation environment and 100% humidity until final shutdown of the station.

Figure 65. Vibration protection of the MSL safety valves at Chernobyl NPP, unit 3.

8.7 NOTE 7, ACOUSTIC RESOINANCE

The case with a low HVDs efficiency that is connected with a) an extremely high frequency of vibration due to acoustic resonance initiated by pump blade excitation number (NxZ=over 300Hz) and b) thin piping shell mode of vibration dominated over piping beam vibration mode. For such cases the most efficient way of vibration elimination is tuning out of resonance.

8.8 NOTE 8, FATIGUE CRACKS

High vibration of oil-bearing turbine’s manifold pipelines, initiated fatigue cracks and increased fire hazard. The problem has been resolved by installation of the smallest type of VD dampers along the system.

8.9 NOTE 9, HIGH FLOW INDUCED VIBRATION OF MSL

Cooper is a one Unit BWR NPP located in the state of Nebraska just in the centre of the US. Extremely high flow induced vibration of MSL on a full length from Dry Well through Heater Bay Area to the Turbine Hall penetration led to multi cases of fatigue and failure of the piping supports, supports of the Steam Drum, and elastic steel frame anti-vibration supports caused their permanent rewelding during outages. All improvements by additional system’s restraining by rods, frames and snubbers provided no effect or increased vibration. Under pressure of Nuclear Authority, US NRC, and risk of forced limitation of power output, that would be catastrophic for the one Unit station from operational and costs perspective, it was decided to install VD dampers which completely resolved the vibration issue and permitted the station to work on full power.

Figure 66. Installations of VDs at the MSL in heater bay area Cooper NPS.

8.10 CONCLUDING REMARKS AND LIMITATIONS

At the moment according to the gained worldwide experience it could be concluded that HVD technology is one of the best in piping and structural operational vibration mitigation, dampening, beside its advantages in seismic and extreme dynamic load protection. On the other hand, as any other technology, HVD has its own and quite natural limitations in application.

Among them to be aware of are:

- HVD works with resonance phenomenon and is not helpful in forced motions not connected with resonance amplifications.

- The best operating frequency range for HVD application is 0-40Hz. Damping ability in higher than mentioned range will reduce HVD efficiency.
- Ambient temperature range of HVD application is extremely wide but it is not recommended to use HVDs in less than minus -50C and more than +200C environmental situation.
- If HVD will be placed in a close proximity of the PWR/BWR reactor in a very high radiation zone it would be necessary to replace damper or its working liquid after 10 or more years of operation in outage period of the plant.
- Stiffness of dampers supports should be 5 times higher than damper’s dynamic stiffness at the dominant vibration frequency. Otherwise damper will get some motion from vibrated object decreasing its efficiency.

For each vibration case some optimum number and type of HVDs exist to get the best estimate result. To achieve this optimum engineering support of experts in performing vibration measurements and dynamic analysis is highly recommended.

9 References

[1] Y. Ochi, A. Kashiwazaki, V. Kostarev (1990). *Application of High Viscous Damper on Piping System and Isolation Floor System*. Proc. of 9 EAEE, Vol. 3, EAEE, (September 1990), Moscow, Russia.

[2] V.V.Kostarev, D.J.Pavlov. (1991). *Application of CKTI Damper for Protecting Piping Systems, Equipment and Structures Against Dynamic and Seismic Response*. SMIRT 11 Transactions. Vol. K, pp. 505-510. Tokyo, Japan.

[3] V.Kostarev, et.al. (1992). *CKTI Visco-Elastic Dampers for Seismic and Vibration Isolation of Piping*. "Transactions of CKTI", Vol. 272, pp. 81-87.

[4] T.Katona, S.Ratkai, K.Delinic, W.Zeitner. (1994). *Reduction of Operational Vibration of Feed-Water Piping System of VVER-440/213 at PAKS*. Proc. of 10th European Conf. on Earthquake Engineering. pp. 2847-2852, Austria, Vienna.

[5] V. Kostarev, A. Berkovski, et. al. (1994). *Application of mathematical model for high viscous damper to dynamic analysis of NPP piping*. Proc. of 10th ECEE, Vienna, Austria.

[6] Berkovski, V. Kostarev, et. al. (1995). *Seismic Analysis of VVER NPP primary coolant loop with different aseismic devices*. Transactions of SMIRT 13, Porto Alegre, Brazil.

[7] V.Kostarev, et.al. (1997). *Upgrading of Dynamic Reliability and Life Extension of NPP Piping by means of HVD Technology*. (K634-1). Transactions of 14th SMIRT Conference, Lyon, France.

[8] Berkovski A., Kostarev V., Schukin A., Kostov M., Boiadjiev A., Boiadjiev Z. (1997). *Seismic analysis of the safety related piping and PCLS of the WWER-440 NPP*. Transactions of the 14th SMiRT, Lyon.

[9] Masopust, G. Hueffmann, J. Podrouzek. (1999). *GERB Viscous dampers in applications for pipelines and other components in Czechoslovak nuclear power plants*. ASME PVP-Vol.237-2, Seismic Engineering, pp. 17-22.

[10] V. Kostarev, A. Berkovski, A. Schukin. (1999). *Aseismic Design and Analysis of the Primary Coolant Loop and Safety Related Piping Systems of Russian Design NPP WWER-440*. Transactions of PVP ASME Conference, Boston.

[11] V. Kostarev, A. Berkovski, A. Schukin. (1999). *Upgrading of dynamic reliability and life extension of piping by means of high viscous damper technology*. Transactions of PVP ASME Conference, Boston.

[12] Костарев В.В. и др. Повышение динамической надежности и продление службы трубопроводов при использовании технологии высоковязкого демпфера, «Тяже-лое машиностроение» №8, август 2000. (V.Kostarev, et.al. (August, 2000). *Upgrading of dynamic capacity and life extension by HVD application*, “Heavy Industry”, Moscow, No. 8.

[13] J.Stevenson A.Berkovski, O.Kireev, V.Kostarev. (2000). *Analysis of non-classically dampened structures, methodology and practical results*. Transactions of PVP ASME Conference, Seattle.

[14] Fomin V., Kostarev V., Reinsch K-H. (August 2001). *Elimination of Chernobyl NPP Unit 3 Power Out-put Limitation Associated with High Main Steam Piping Flow Induced Vibration*, Transactions of the 16th SMIRT, Washington, USA.

[15] Frank P. Barutzki. (September 2002). *Extending the Service Life of Piping Systems through the Application of Viscous Fluid Dampers*. ENERGY-TECH.

[16] Малов М.Ю., Берковский А.М. и др., Верификация программных комплексов для анализа прочности и сейсмостойкости технологических трубопроводов АЭС, Тру-ды ЦКТИ, 2002, вып.282, с.236-240. (M.Malov, A.Berkovskiy. *Software verification for strength and seismic analysis of nuclear piping*, Transactions of CKTI, Vol/282).

[17] Petr Zeman. (2003). *Reduction of Operational Vibration of Turbine Steam Inlet Piping at Temelin NPP*. SMiRT 17, August 17-22..

[18] Frank Barutzki. (2003). *Improving the Reliability and Life Expectancy of Piping Systems through the use of Viscous Dampers*. Plim + Plex, New Orleans, USA.

[19] Peter Vasilyev, Leonid Fromzel. (2003). *Analytical Study of Piping Flow-Induced Vibration. Ex-ample of Implementation*. SMIRT 17, Prague, Czech Republic, August 17-22, Paper N J280, accessed from, https://www.cvs.spb.su/ru/?option=com_content&view=article&id=86.

[20] P.Vasilyev. Engineering approach for medium modeling in piping dynamic analysis. 18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18) Beijing, China, August 7-12, 2005.

[21] Victor V. Kostarev and Alexander V. Sudakov. (2009). Some Aspects of Russian Regulation and Codes in Nuclear Power. 3rd ed. Chapter 66, *Companion Guide to the ASME Boiler & Pressure Vessel Code*. ASME Press, New York. 30.

[22] Frank Barutzki. (2009). Reduzierung von Rohrleitungsschwingungen mittels Schwingungsdämpfern. FDBR-Fachtagung Rohrleitungstechnik, 24-25 March , Magdeburg, Germany.

[23] Alexey Berkovskiy, Peter Vasilyev, Oleg Kireev. (2009). *Different Approaches for the Modelling of High Viscous Dampers in Piping Dynamic Analysis*. Acceptable Limits for Simplifications. SMiRT-20, Espoo Finland. Paper-1833, accessed from, https://www.cvs.spb.su/ru/?option=com_content&view=article&id=102.

[24] Frank Barutzki. (2014). Dämpfung von Rohrleitungsschwingungen; Handbuch Rohrleitungsbau, Band II: Berechnung; Vulkan Verlag.

[25] Frank Barutzki, Daniel van Wickeren. (2006). *Reduction of Piping Vibrations by Means of Viscoelastic Fluid Dampers*. TINCE-2006, September 05-09.

[26] I. Tamura, et.al. (2016). *Dynamic Analysis of NPP Piping System and Components with Viscoelastic Dampers Subjected to Severe Earthquake Motions.* PVP 2016-64029, ASME PVP Conference, Vancouver, Canada.

[27] V. Kostarev, I. Tamura et al. (2016). *Shaking Table Test of a Piping System with Viscoelastic Dampers Subjected to Severe Earthquake Motions*. ASME PVP2016-64004, Vancouver, Canada.

[28] KIWA INSPECTA GERB, GmbH&Co. KG, Inspection Certificate NO. 6237 VISCO Dampfer VES, Quality Class 1-4, Date of authorization: 20th December 2016, Giltig till / Valid until: 31st December 2021.

[29] TÜV NORD EnSys GmbH & Co. KG, Performance Test Certificate T08-91-12, Rev. 7. Viscodampers® of the model series VES-2.5 up to VES-100, Manufactured by GERB Schwingungsisolierungen GmbH & Co. KG, Berlin, Rev.7, 2017.

[30] CKTI-VIBROSEISM Co. Ltd. Viscoelastic Dampers VD Series. SPECIFICATIONS TU 4192-001-20503039-01, 2018.

[31] ASME OM-S/G-2000. (2000). *Standards and Guides for Operation and Maintenance of Nuclear Power Plants – Part 3 Requirements for Pre-operational and Initial Start-up Vibration Testing of Nuclear Power Plant Piping Systems*. American Society of Mechanical Engineers, New York, NY.

[32] ASME Boiler and Pressure Vessel Code. (2004). *Nuclear Components Class I, Subsection NB*. American Society of Mechanical Engineers, New York, NY.

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

[34] Russian Boiler Standard RD 10-249-98, 1998.

[35] VDI 3842. (2004). *Vibration in Piping Systems*.

[36] J.C. Wachel, et.al. (1990). *Piping Vibration Analysis*. Proceedings of the 19th Turbomachinery Symposium. Texas, pp. 119-134.

[37] ASME BPVC, Section III, Subsection NF Nuclear Supports, 2007-2020.

[38] KTA 3205.1. (2002). *Release 6/02 Component Support Structures with Non-integral Connections*. Nuclear Safety Standard Commission, Germany.

[39] dPIPE 5. (2007). *Computer Software Code for Piping Analysis*, Verification Report, VR01-07, CKTI-Vibroseism.

[40] Victor Kostarev, Aimo Tuomas, Karl-Heinz Reinsch. (2007). *Resolving of Steam and Feed-Water Piping Vibration Matter at Loviisa NPP*, Transactions of SMiRT-19th Conference, Toron-to, Canada.

[41] Reinsch, K..H.; Barutzki, F. (1994). *Dämpfung von Schwingungen in Rohrleitungssystemen. Handbuch „Rohrleitungstechnik"*, 6th ed. Pp. 142-147. Vulkan-Verlag Essen.

[42] Irina Evzikova, Dmitriy Pavlov, Victor Kostarev, Igor Shedogub. (2011). Resolving of Vibration Matter on Feed-Water Piping of Kola NPP. Transactions of the SMiRT-21 Conference, New-Delhi, India.

VIBRATION ELIMINATION USING 3D VISCODAMPER TECHNOLOGY

Pipe vibration experts spend a lot of time analysing the causes of vibrations and implementing different mitigation methods for eliminating them. Viscous dampers have proven to be an interesting solution in many cases to address pipe vibrations in nuclear-, conventional-, and chemical plants.

This report provides description of the damper design and describes the efficiency of high viscous dampers in piping vibration reduction based on the application of the technology in several power plants and industrial facilities.

In accordance with experiences gained worldwide this report concludes that high viscous damper technology is one of the best solutions for vibration mitigation for piping and structural operational vibrations.

Energiforsk is the Swedish Energy Research Centre – an industrially owned body dedicated to meeting the common energy challenges faced by industries, authorities and society. Our vision is to be hub of Swedish energy research and our mission is to make the world of energy smarter!

Energiforsk