Fortum Head Office, Espoo, Finland.
Seminar: Vibrations in Nuclear Applications
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Vibration protection of NPP's piping from operational vibration matter using 3D high viscous dampers' technology

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Content

- Objectives: Why piping operational vibration is detrimental
- Root Cause of Vibration
- Piping Vibration Criterion and operational practice
- Vibration Measurements and Walkdown
- Dynamic Analysis
- Codes
- 3D High Viscous Dampers Technology
- Elimination of Piping Vibration: practical cases
- Conclusions

Objectives: Why piping operational vibration is detrimental



1. Fatigue/leakage/rupture of pipelines due to a high-frequency excitation or over pressure with possible fatal consequences for human lives.
2. NPP safety concerns and power losses. NPP’s occasional shutdowns due to a piping rupture or leak with significant financial losses.
3. Fatigue and wear of hangers and piping supporting system.
4. Existing of an expensive program for repairing piping and supports.
5. Environmental effects: noise/vibration at working areas including control room area, personnel operation fears.
6. Permanent safety concerns and pressure from Nuclear Authority.
7. Negative general effect on plant’s operation quality

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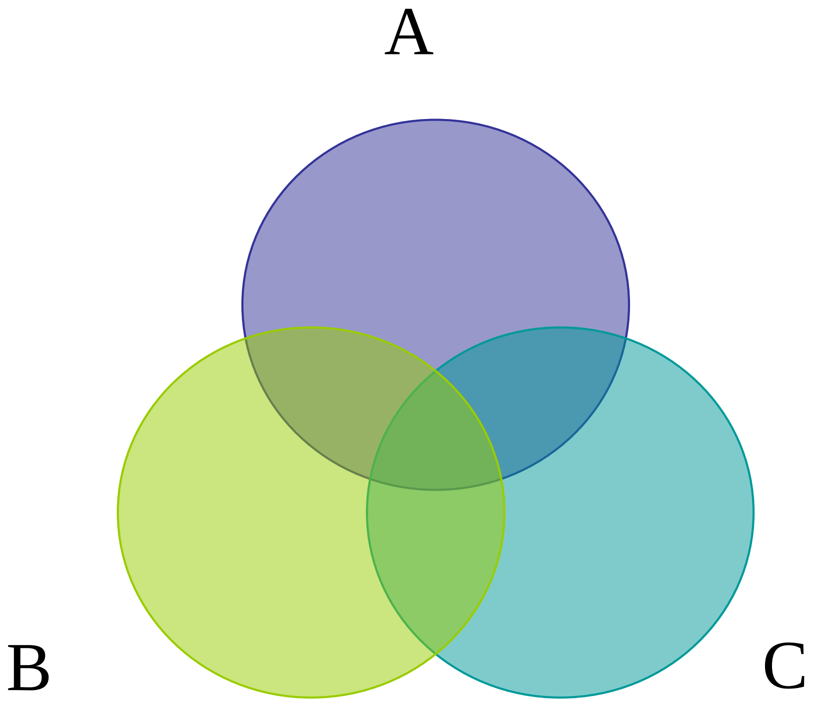
Root cause of piping operational vibration.
Why it happened not at all of similar piping

(probabilistic interpretation of a piping flow induced vibration)



A) Piping mechanical resonance frequencies;

B) Vortex frequencies in pressure restrictions;

C) Acoustic resonance frequencies of piping medium.

.Objectives:

1. **Coincidence of three circles is rather rare**
2. **Explanation why similar piping have different vibration state**
3. **Hard to calculate and predict.**
4. **Not a design case still.**

Root cause of piping operational vibration

- **Rotating** machines, compressors and pumps:

f=N z (N-rotating frequency, z-number of blades)

- **Vortex shedding** in Tees, Valves, orifices, reducers and system's flow resistance points

f=S V/D (S-Strouhal number ~0.2 to 0.5, V-flow velocity, D-restriction/character diameter)

- **Acoustic resonance** in hydraulic tract:

f=n c/2L (closed or open ends) or

f=n c/4L (close-open ends)

- **Hydraulic hammers** (surge by rapid change in flow rate: rapid valve closer, pump start-up/shut down, vapor pocket collapse, safety valve blow down)

F=ΔP A ~= ρ C Δ V A (ρ-density, C-speed of sound in the fluid, Δ V –change in fluid velocity, A-area of impact)

- **Two-phase flow** in feed-water/condensing lines: slug force in elbows

$F= \rho A V^2$

- **Cavitation** (vapor pockets collapse)
- **Environmental effects** (wind, earthquakes, outside vibration)

Root cause of piping operational vibration

A-TYPE: Pressure pulsations with coinciding of several factors at dominant system's frequency (ies)

- Initial pump's + vortex excitation in valves, fittings and tees, then
- Tuning and amplifying it by acoustic resonance of hydraulic tract forming intensive internal pressure waves acting on elbows and walls, then
- Tuning and amplifying above process by mechanical resonance of piping runs/support/hangers system forming mutual stick/shell resonance modes of vibration

Depending on systems' parameters A-TYPE Vibration could be:
Low Frequency (1.0-30 Hz),
Medium Frequency (30-100 Hz) and
High Frequency (100-1000Hz) connected with high acoustic pressure (acoustic fatigue)

B-TYPE: Water Hammers (rapid flow change)

Basically piping responses on a first natural modes with displacements up to 0.1-1.0 meter (Ignalina NPP case)

C-TYPE: Two-Phase Slug's Mode (in subcooled water lines-bubbles and in wet steam lines-condensate)

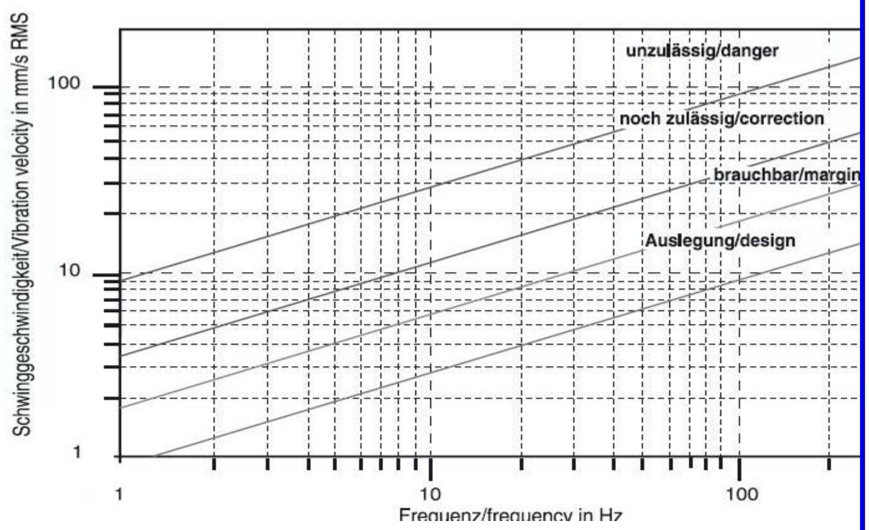
Basically piping responses on a first natural modes with high displacements of a system

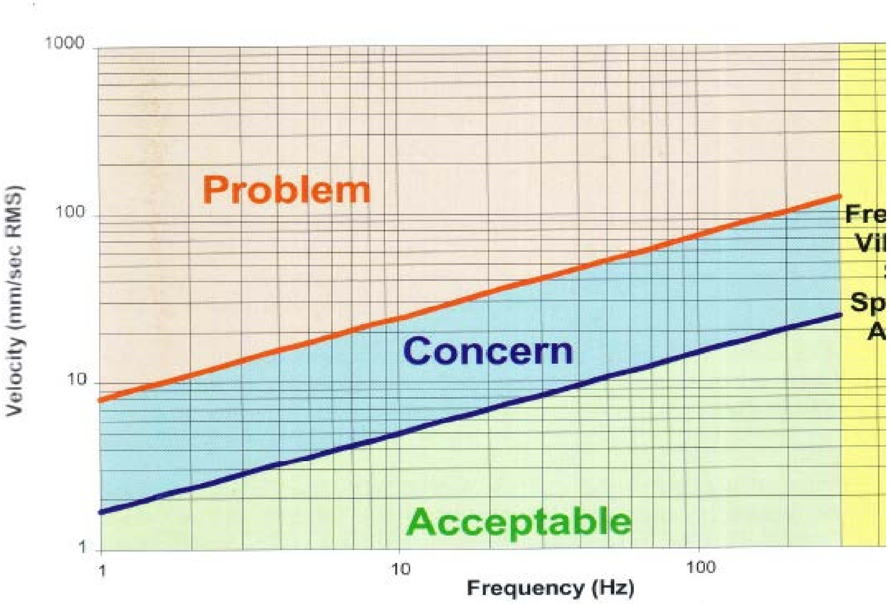
TO REMIND:

HUGE VIBRATION OF A/B/C TYPES COULD DESTROY PIPING IN DAYS OR MONTHS
HARD/IMPOSSIBLE TO PREDICT AT A DESIGN STAGE

Piping Vibration Criterion and Operational Practice

1. J.C.Wachel, 1990 approved as VDI European Criterion since, 2004





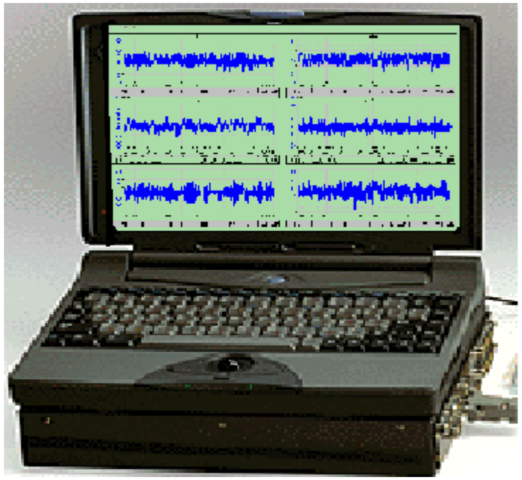
According to the VDI 3842 Guideline

Piping Vibration Criterion and Operational Practice (cntd)

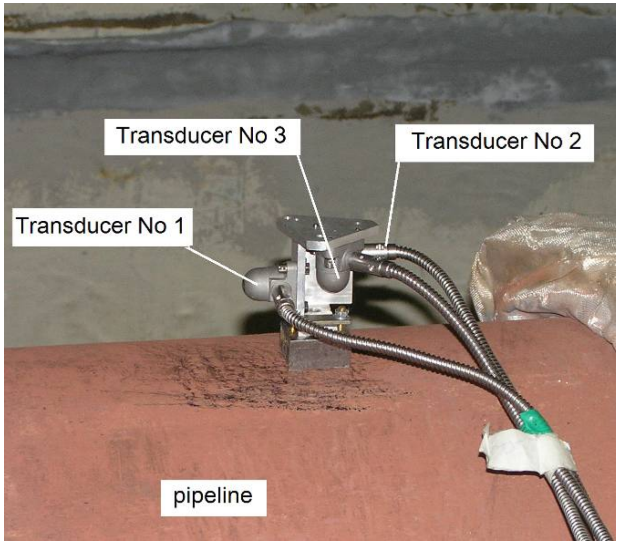
2. ASME OMa S/G Standard. Screening criterion on ½” - 12.7 mm/s of Peak vibrovelocity.
3.French EDF practice: threshold level of piping vibration of 12 mm/s RMS vibrovelocity for the powerful NNP units.
4. A number of petro-chemical codes and guidelines on piping vibration.
5. Russian RD standard installs peak piping vibration grades: less 15.0 – excellent; 15.0-25.0 mm/s required analysis; more than 25 mm/s improving vibration state.
6. Finally the following criterion were installed by CVS practice for NPP piping to protect any detrimental consequences in piping operation (e.g. Loviisa Units 1 and 2 steam and feed water piping application):

RMS vibrovelocity < 7.5 mm/s	**Peak vibrovelocity < 20mm/s**

Vibration Measurements and Walkdown

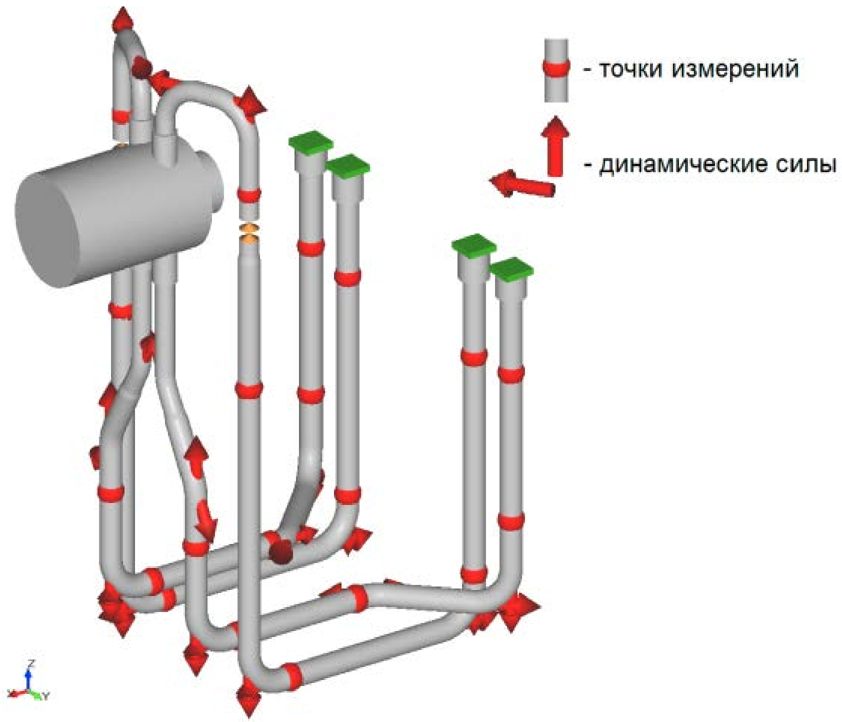


3D vibration measurements at the hot steam piping

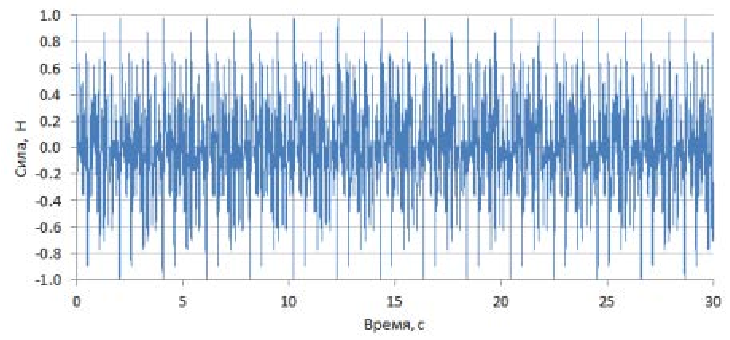


Dynamic Analysis of piping flow induced operational vibration using dPIPE software

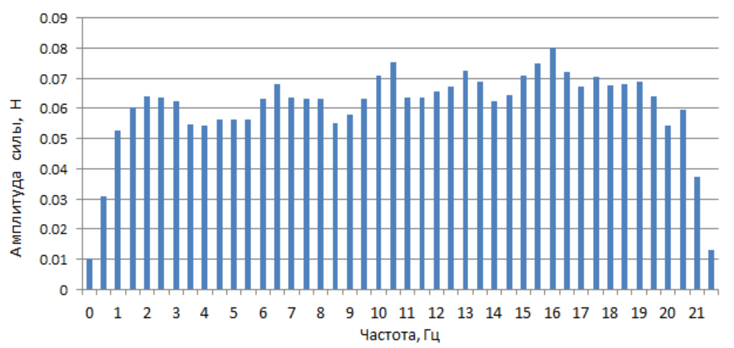
https://www.dpipe.ru/en/



Piping with a system of acoustic excitation forces and control measurement vibration points

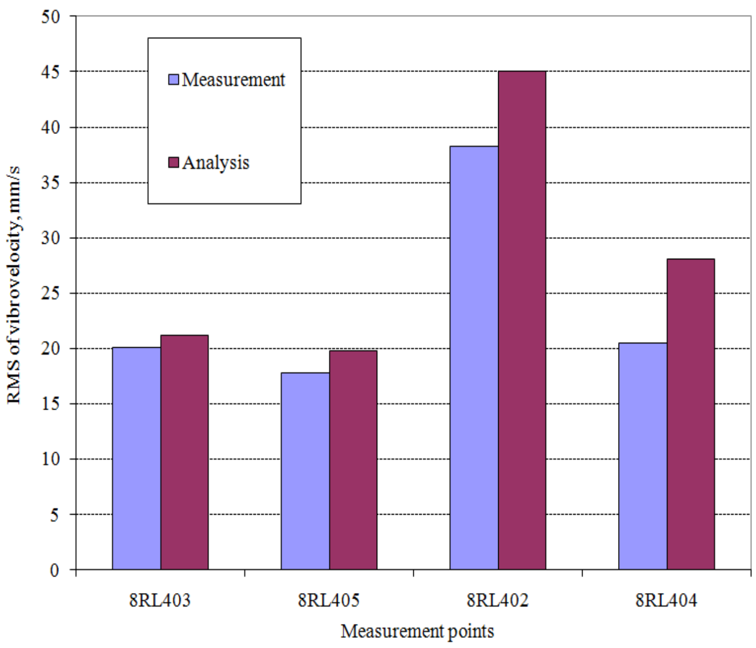


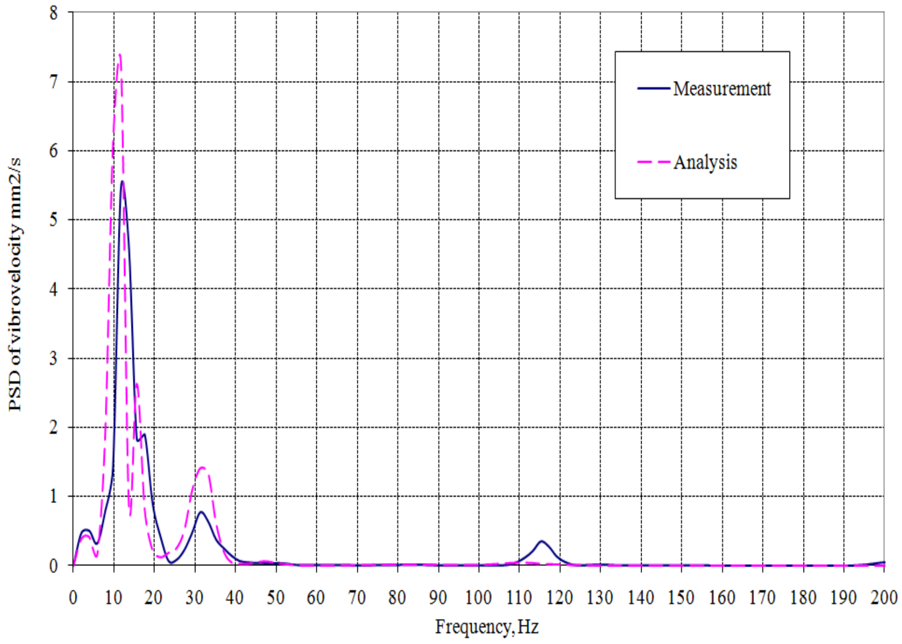
Dynamic acoustic force in the elbow



Amplitude – frequency characteristic of the acoustic force in the elbow.

Modeling of Piping Operational Vibration by dPIPE Software Package (www.dPipe.ru)





(a) **(b)**

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

3D High Viscous Dampers Technology. Why damping?

Viscoelastic Pipework dampers have been used successfully for many years for seismic upgrading and vibration control of piping systems and components in different installations:

- Nuclear and conventional power plants
- Chemical, petrochemical and industrial plants
- Offshore facilities
- More that 10 000 viscodampers are installed worldwide

As a dynamic restraint Pipework dampers work in a softer manner than snubbers and stoppers providing essential additional damping to the system.

Excitations are critical if they contain frequencies that are close to natural frequencies of the piping system (resonance effects).

- Increase of damping = Increase of energy dissipation

➢ Reduction of resonance amplification

➢ Reduction of shock response

➢ Faster decay of shock excited vibrations

Nuclear Codes

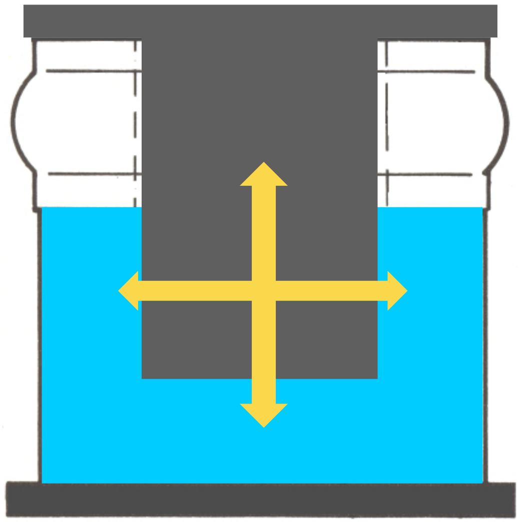
- Pipework dampers have been added to the types of dynamic restraints (November 2007) covered by ASME B&PVC Section III - Subsection NF. Hence, they are an acceptable type of dynamic restraint for NPP piping in accordance with ASME B&PVC Section III.

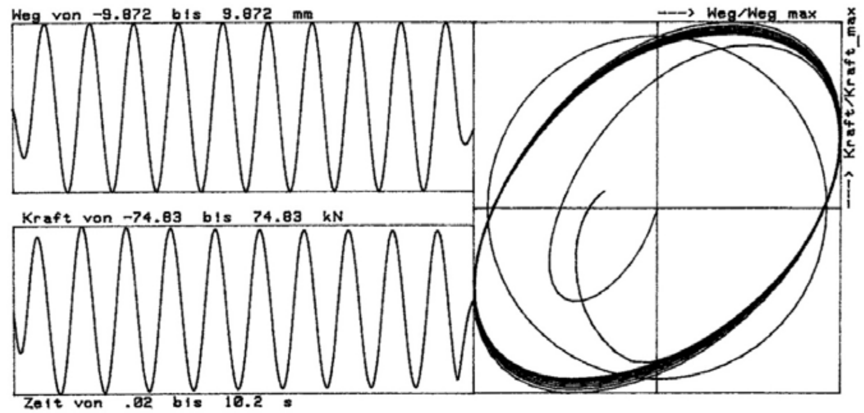
- Pipework dampers are covered by German Nuclear Code KTA and European Nuclear Code for Light Water Reactors.

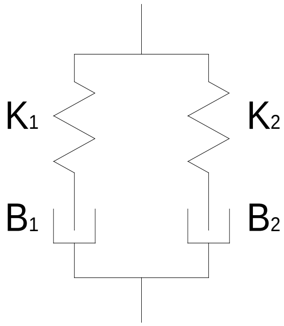
- Pipework dampers are accepted by Nuclear Authorities of all Nuclear States in Europe, including Russia, as well as in Japan, China,Turkey, India, etc.

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

Design and Function of 3D VD

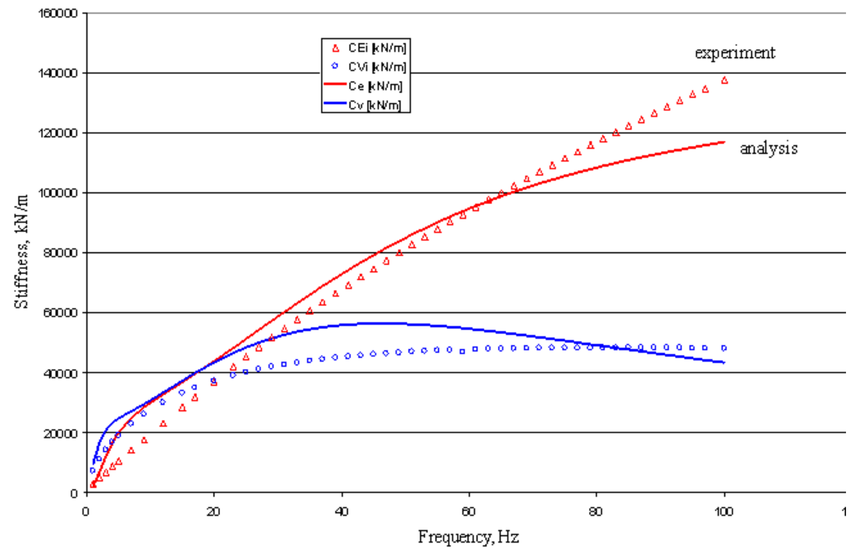




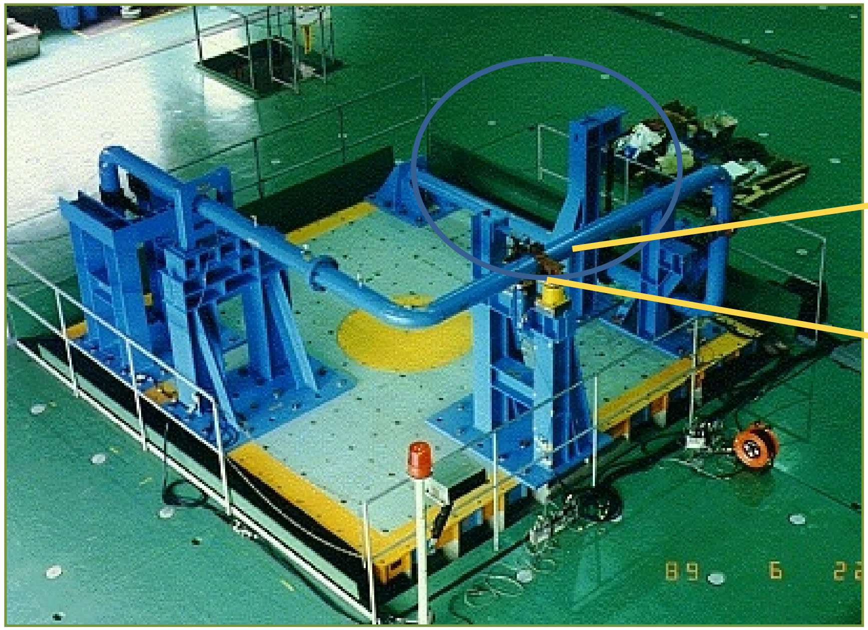


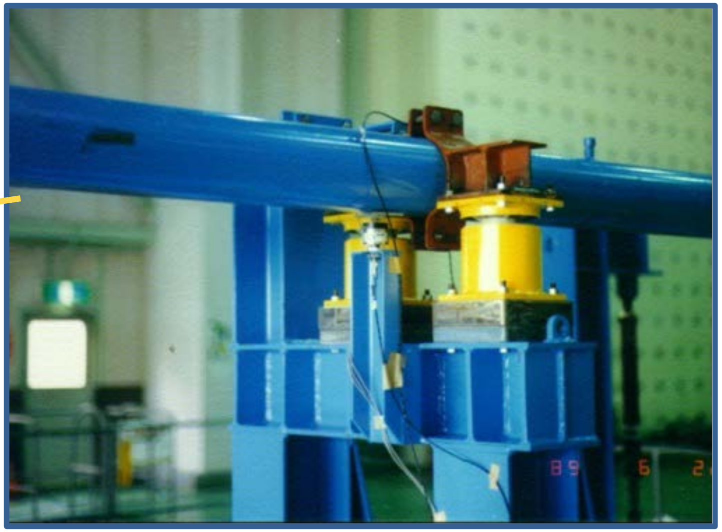
Modelling by 4 parameters Maxwell Model

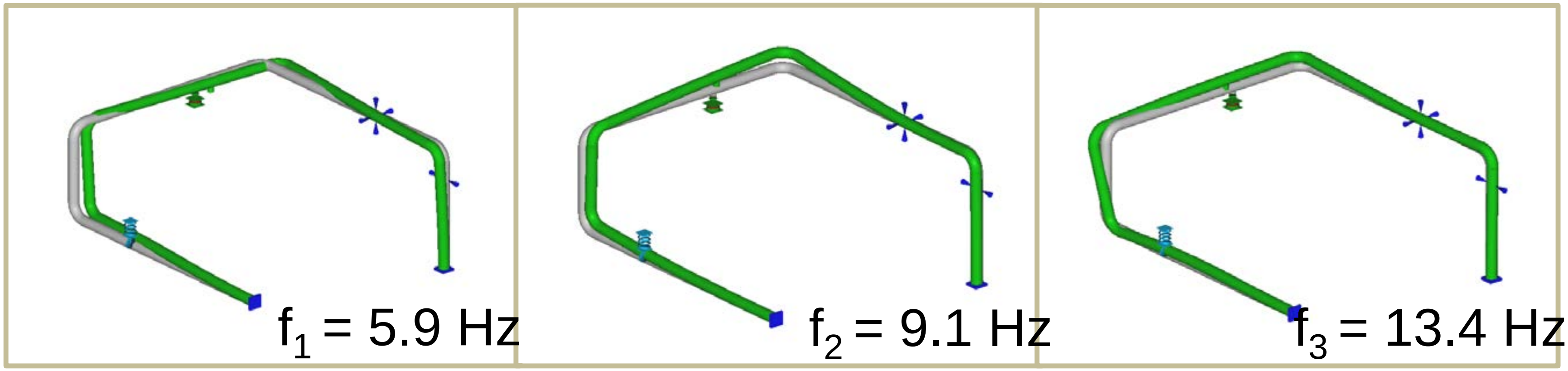
- Damping forces are generated by shearing and displacing of highly viscous fluids.
- Forces are approximately velocity proportional.
  - ➢ High forces in case of high impact velocities
  - ➢ Small forces in case of thermal expansions
  - ➢ No support of static loads



The earliest and the latest confirmation of VD efficiency
IHI Co. Iokohama 35 Tons Shaking Table, Japan, 1989







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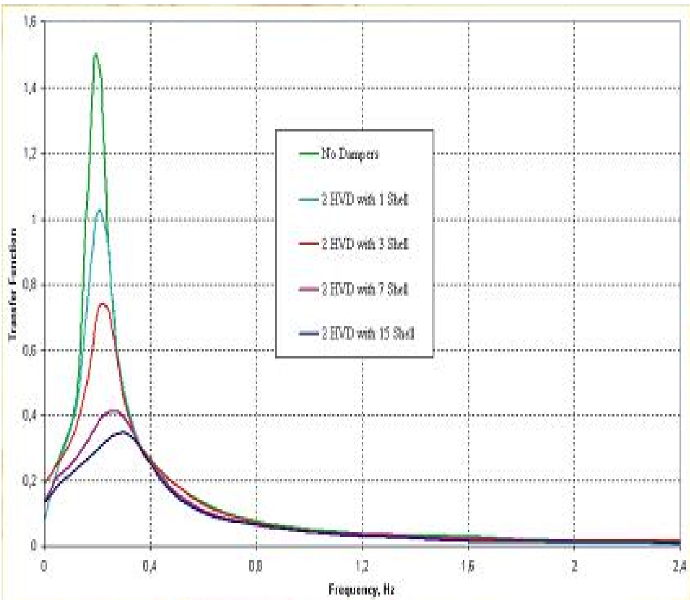
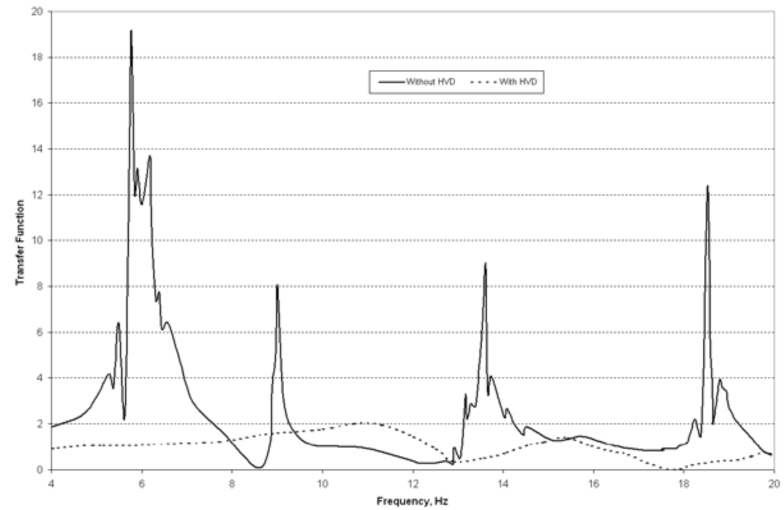
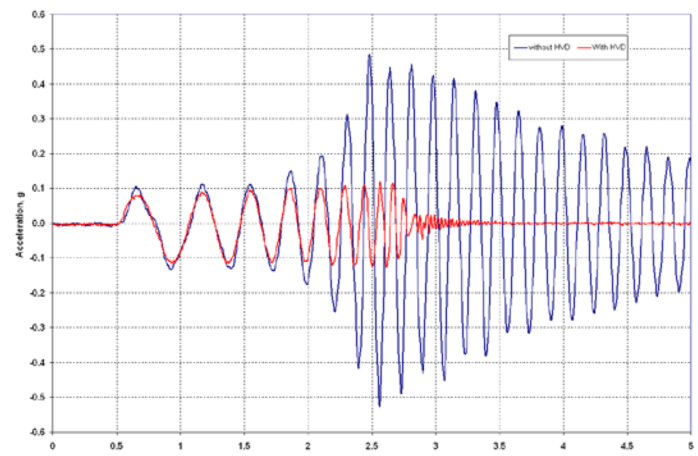


Damping Regulation in the same VD Unit



Sinusoidal Sweep Excitation

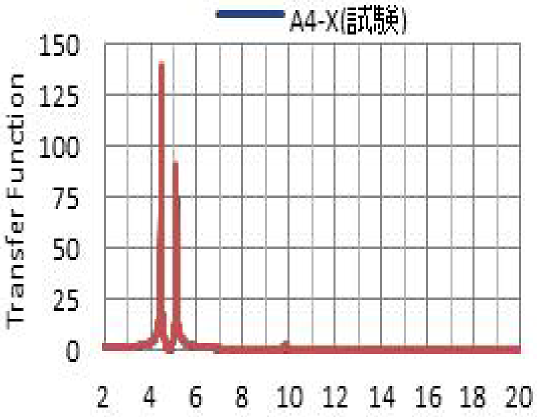


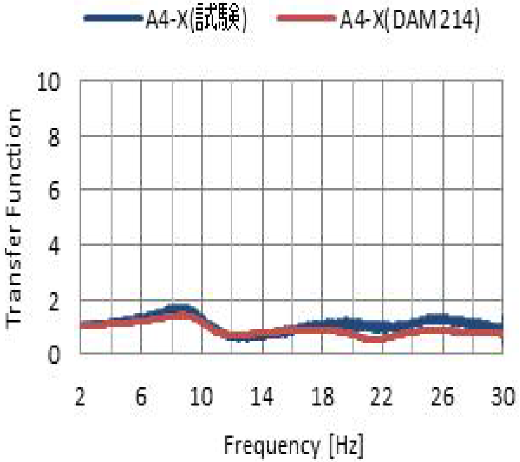
Shock Mode

The latest confirmation of VD efficiency.
Tsukuba Lab, Shaking Table, Japan, 2014. Program for rehabilitation and restart of Japanese NPPs

Beyond Design Basis Tests

A_{Hor}=2.0g; A_{Vert}=1.0g.





70-times decreasing of vibration power

VIDEO

Some relevant cases on essential reduction of severe piping operational vibration

- Kostroma FPP, 1200 MWt, P=24MPa, T-565C, 1986
- Paks NPP, Hungary
- PWR/VVER Cola NPP, Russia
- BWR Cooper NPP Unit, 900 Mwt, USA
- PWR/VVER Loviisa NPP, Finland
- Shimane BWR NPP, Japan, 2019

Kostroma FPP, 1200 MWt Unit, Russia, 1986
Severe vibration of the Main Steam Piping: P=24MPa, T=565C
First case of VD dampers application in Russia

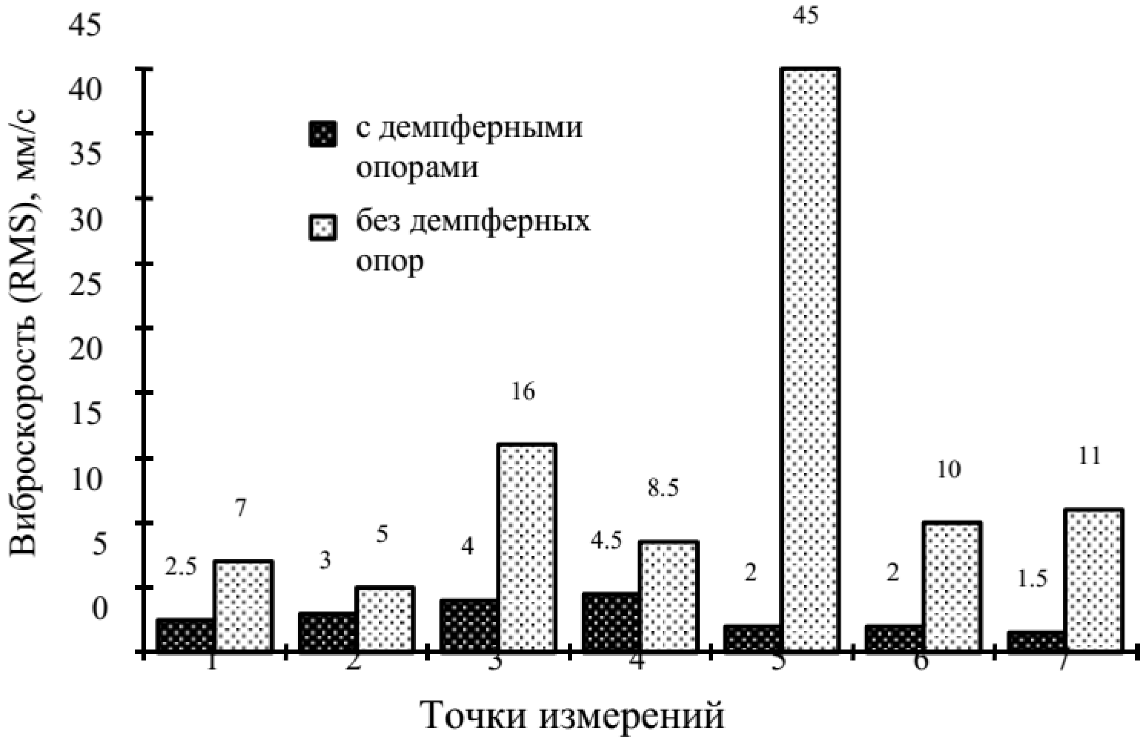
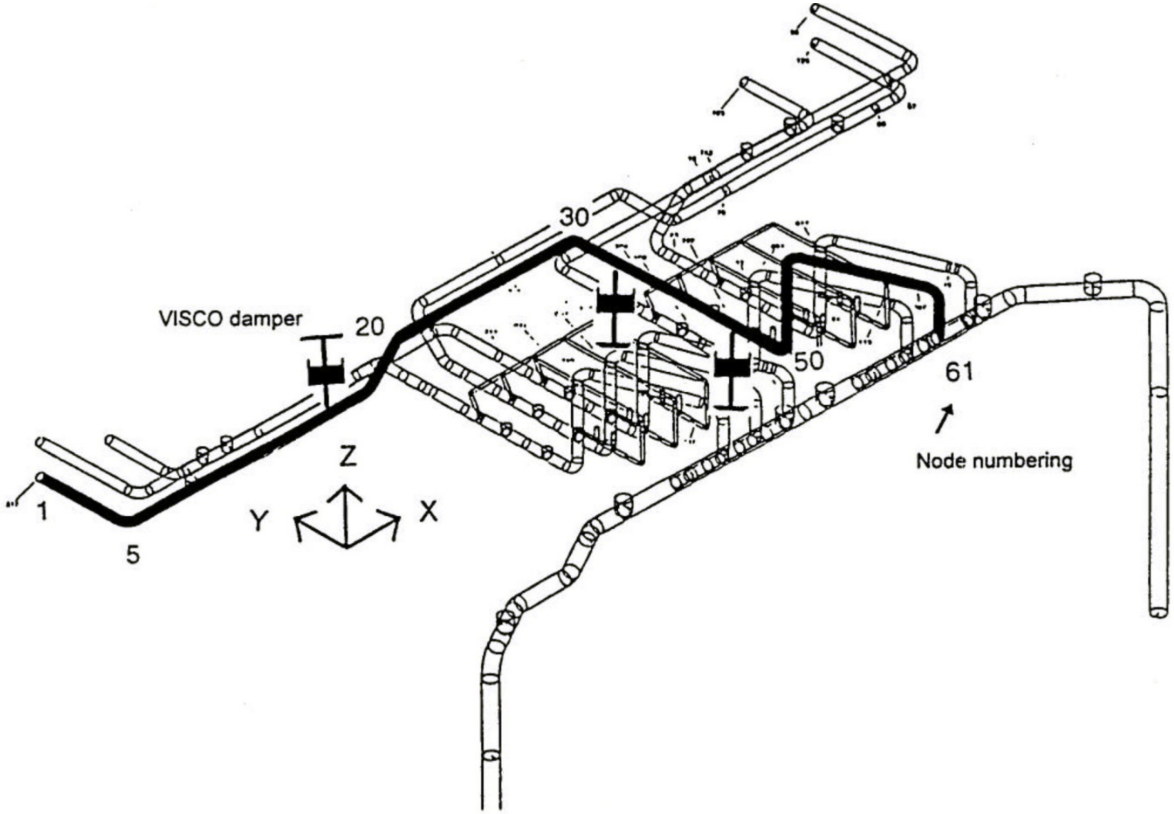


Рис. 11. Влияние установки демпферных опор на вибрацию системы паропроводов Dy 630 мм. Костромская ГРЭС, блок мощностью 1200 МВт.

The highest vibration dropped down 10 times from 45.mm/s to 4.5 mm/s RMS

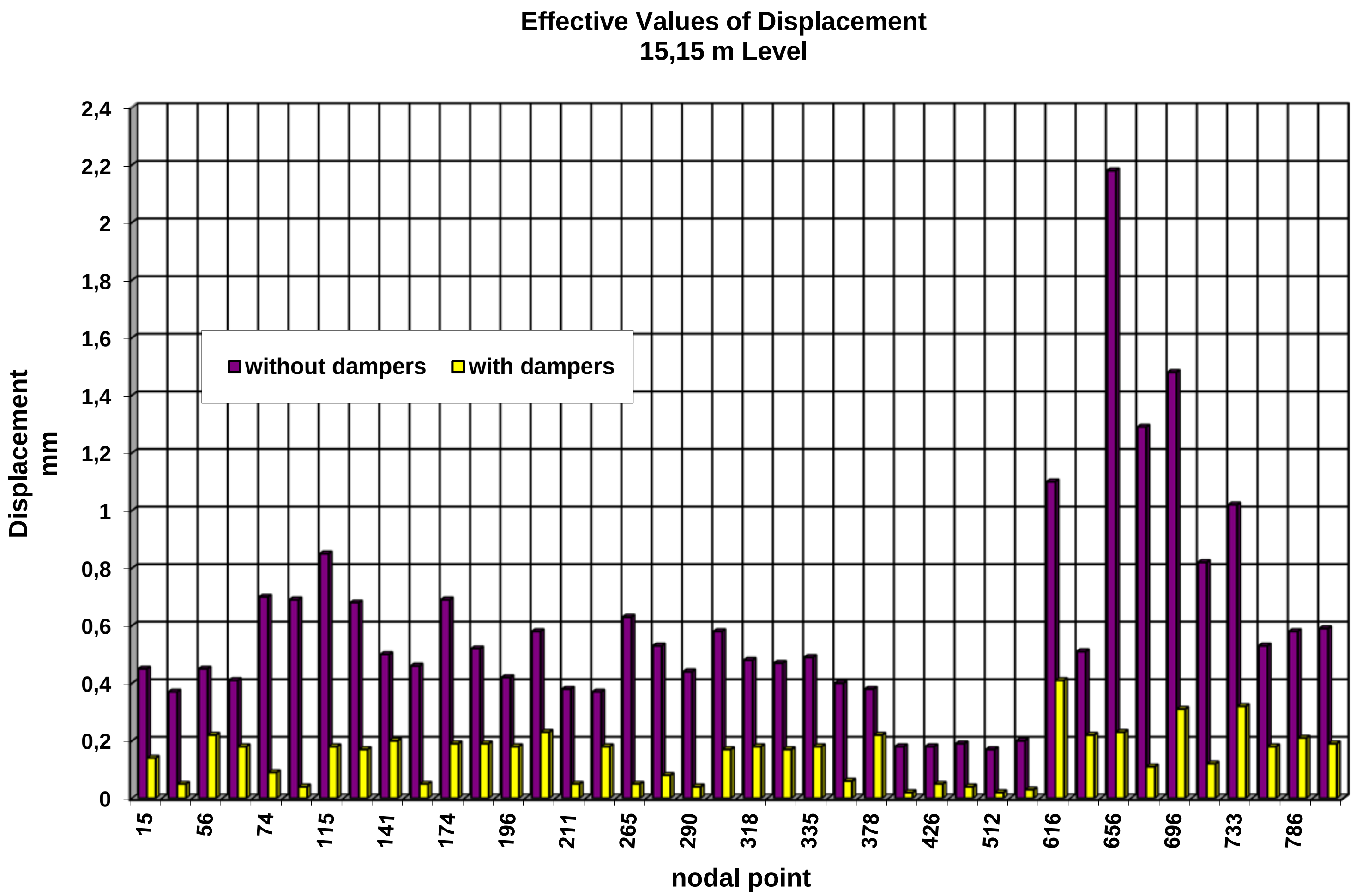
NPP Paks, Hungary, Feed-water pipeline case

Reduction of operational vibrations

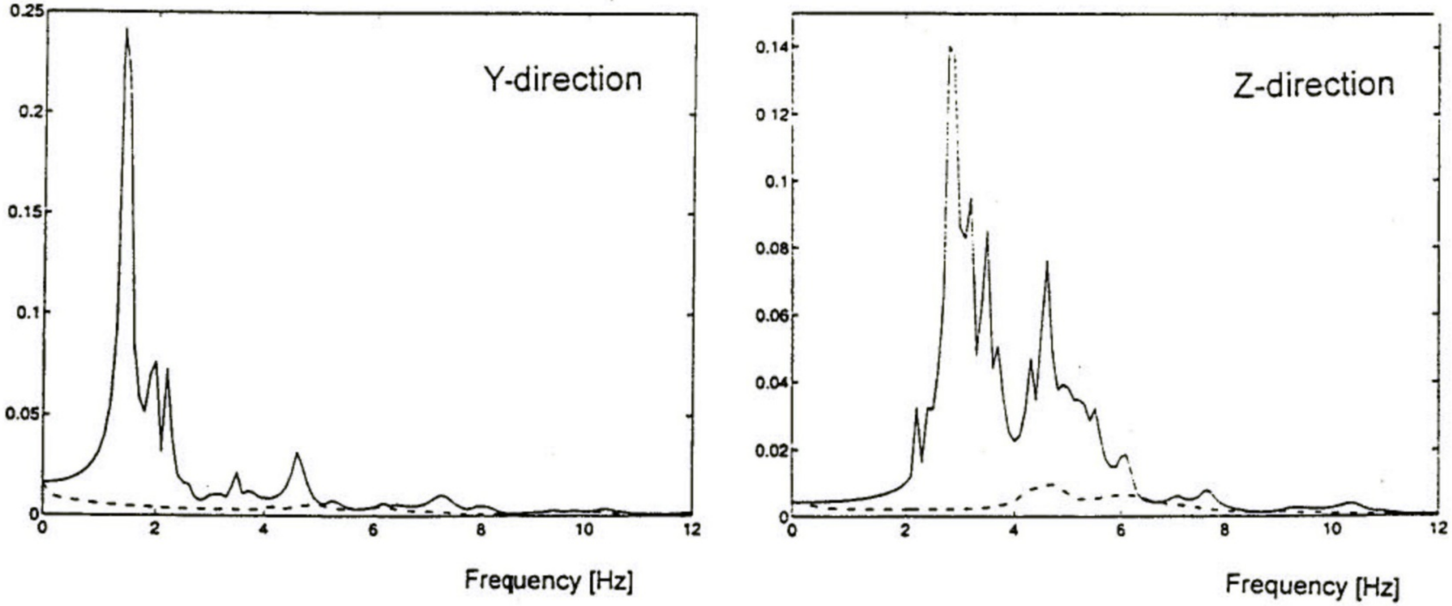


Feed-water piping system (the part presented is bold marked)

Reduction of operational vibration of feed-water piping in terms of displacements

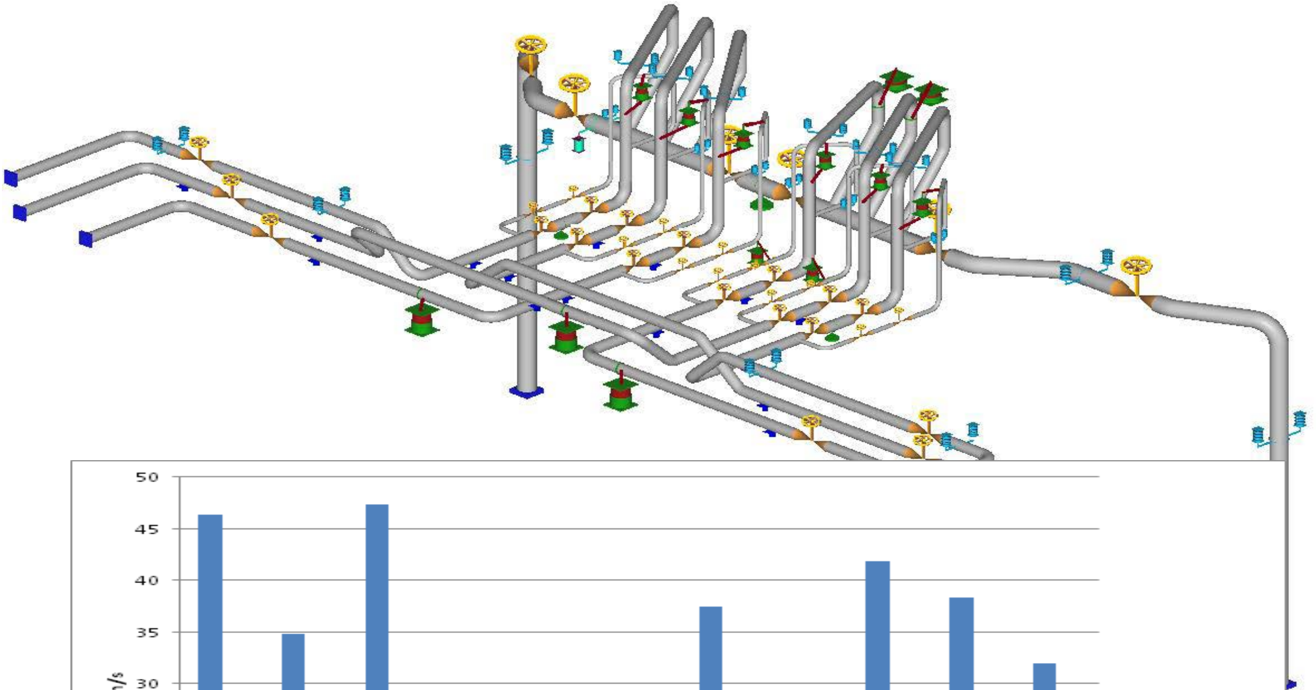


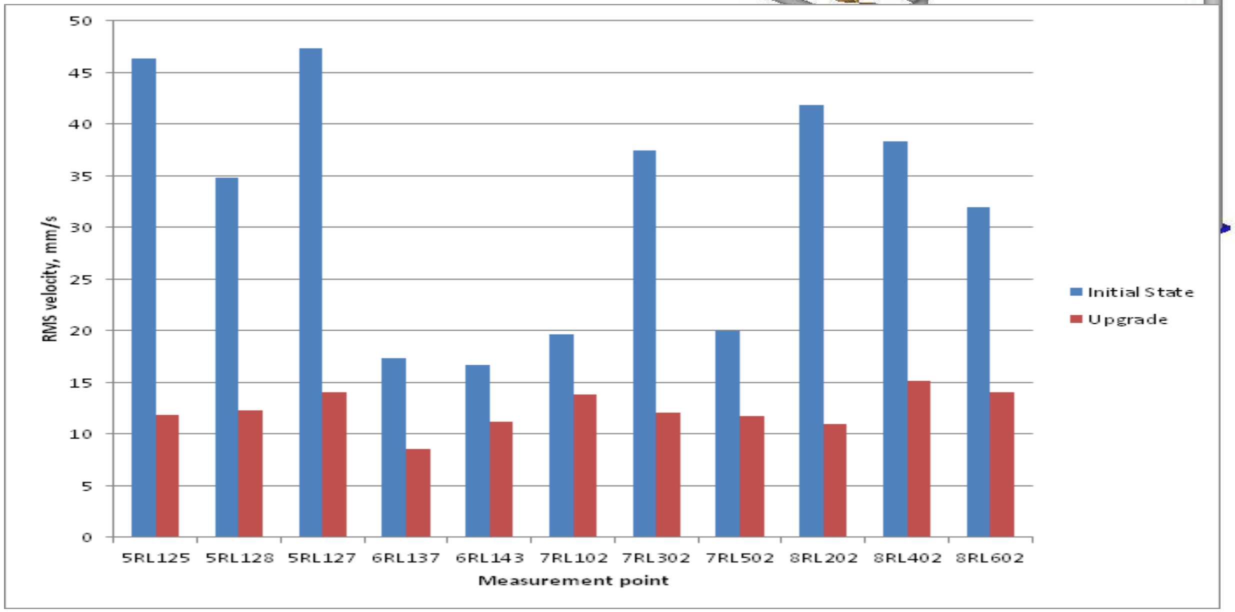
Reduction of operational vibration of feed-water piping in terms of transfer function, Paks NPP



MAX-norm of transfer functions:
Original undamped (full line) vs. upgraded damped piping (dashed line)

Feed-Water System FE Model
with Viscodampers (PWR/VVER Cola NPP)





Different Approaches for Viscodampers Clamp Installation (Cola NPP)

To the floor

To the structural element

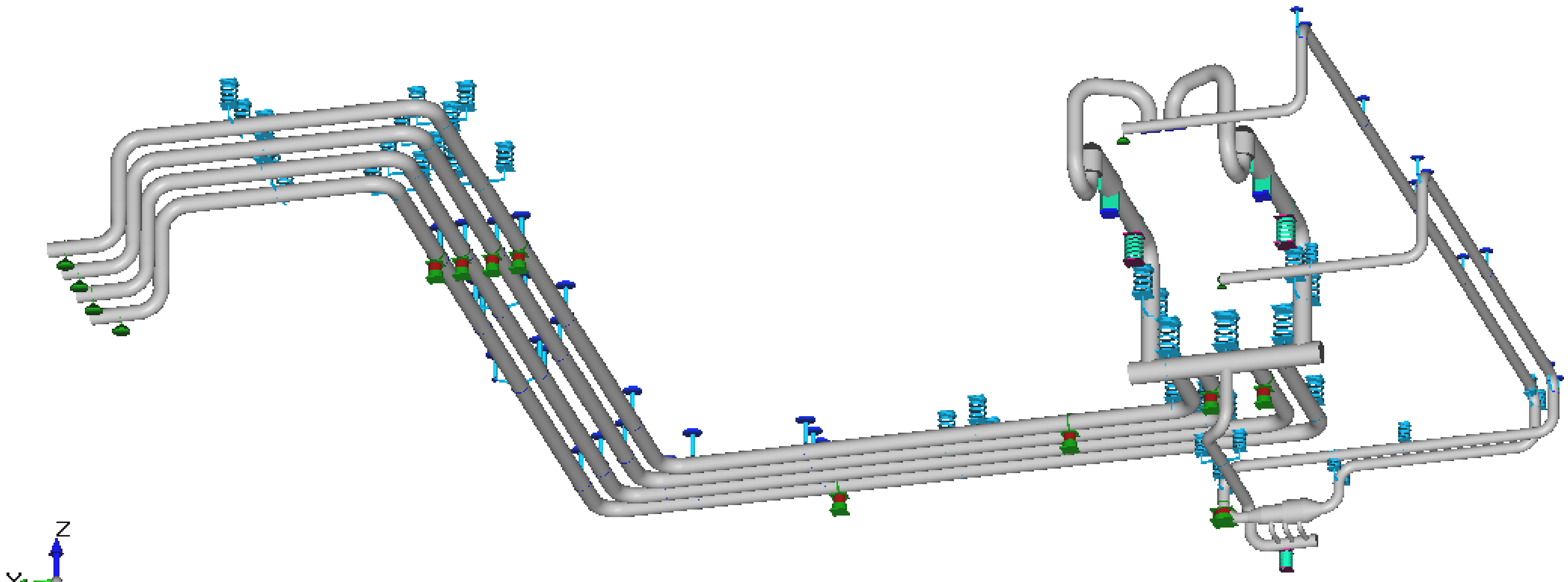
Pipe to Pipe

Vibration Reduction due to viscodampers installation at feed-water lines, Cola NPP

Unit 3			
Point No.	Location	RMS of vibrovelocity, mm/s	
		Initial State	With dampers
5RL125	RL31	<u>46.4</u>	<u>11.9</u>
5RL128	RL33	34.8	12.3
5RL127	RL35	<u>47.3</u>	<u>14.0</u>
6RL137	RL74	17.3	8.6
6RL143	RL76	16.7	11.2

Unit 4			
Point No.	Location	RMS of vibrovelocity, mm/s	
		Initial state	With dampers
7RL102	RL31	19.7	13.8
7RL302	RL33	37.4	12.1
7RL502	RL35	20.0	11.7
8RL202	RL72	<u>41.8</u>	<u>11.0</u>
8RL402	RL74	38.3	15.1
8RL602	RL76	32.0	14.1

Viscodampers Installation at BWR NPP, Cooper NPP, USA
Main Steam Lines. Severe vibration case with multi-failure of piping supports due to fatigue.
Limitation in NPP Power Capacity by USNRC



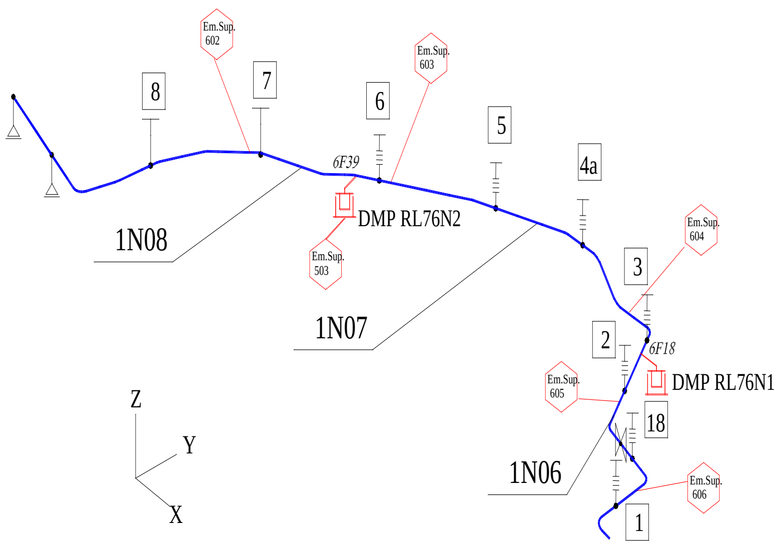
Viscodampers Installation at BWR NPP Main Steam Lines for Elimination of Operational Vibration

Loviisa Case

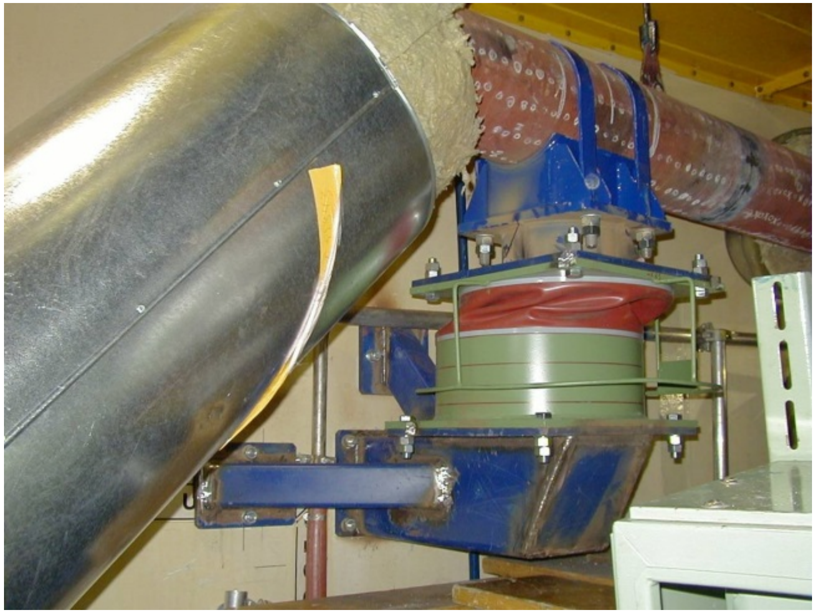
- Loviisa NPP is the first nuclear power plant in Finland. The power plant has two units operate since February 1977 and November 1980.
- The units are Russian designed VVER-440 type pressurized water reactors, turbines, generators and other main components. Safety systems, control systems and automation systems are of western origin. The steel containment and its related ice condensers were manufactured using Westinghouse licenses.
- The present electric power capacity of Loviisa NPP is approximately 10 % larger than it was originally. The net electric power increase of each unit from 440 to 488 MWt is a result of the upgrading project in 1997-2002. The primary and secondary systems water and steam pressure and temperature parameters remain the same.
- Upgrading of the Units has been achieved by increasing of reactor, steam generator and other systems' capacities in steam and feed water mass flow generation and thus flow velocity in the same diameters feed and steam piping.
- An extensive vibration of the lines appeared after upgrading.
- A number of attempts were carried out to decrease vibration prior turning to High Viscous Dampers Technology (HVD). Redesigning of piping support system with its strengthening and installation of additional elastic supports in some cases has been arranged.
- All these measures did not provide positive effect shifting in some cases system's vibration frequency and not much influence on its vibration level. At the same time transferring of vibration and noise to environmental structures has been increased.

Loviisa PWR NPP Operational Vibration Case.
Feed-water Line in the Containment.

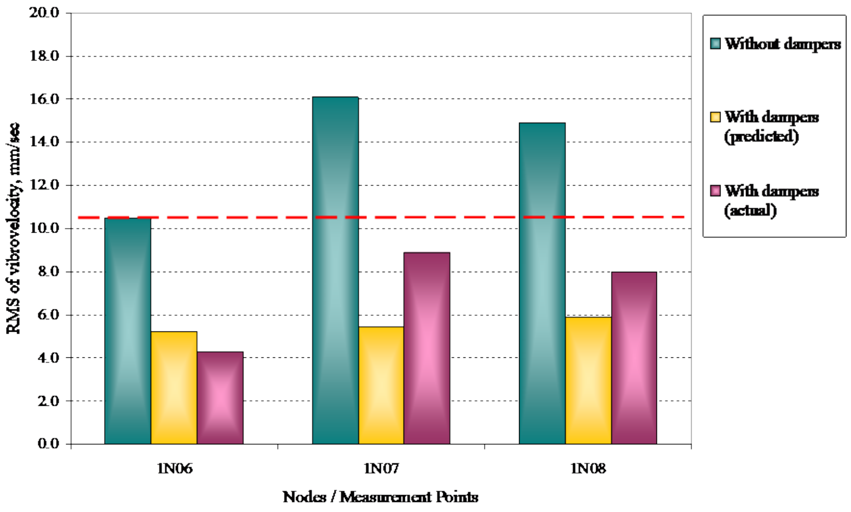
Feed-Water Line Layout



Line in Outage



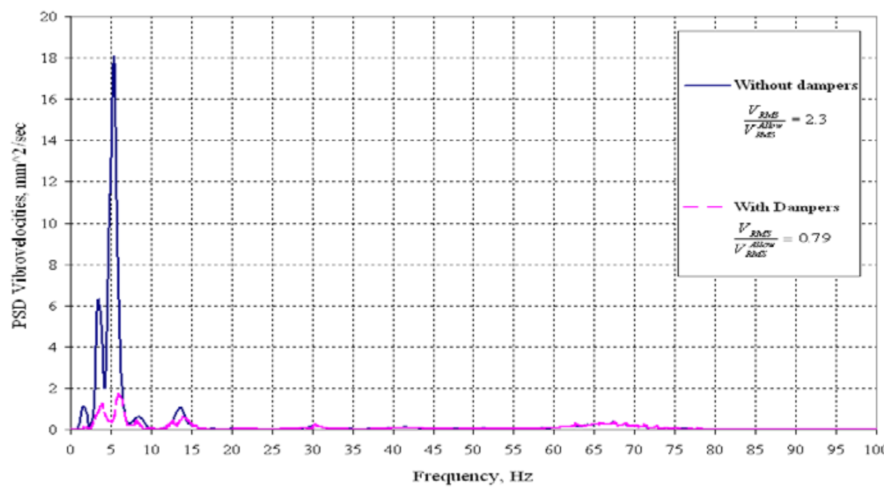
Loviisa PWR NPP Operational Vibration Case.
Feed-water Line in the Containment.



Operational vibration reduction along the line in terms of Vrms:
Blue: Experimental measurements without DMP
Orange: Advanced predicted DMP efficiency by dPIPE software
Purple: Experimental measurements with DMP

Experiment:

Operational vibration reduction in terms of PSD spectra with/without dampers

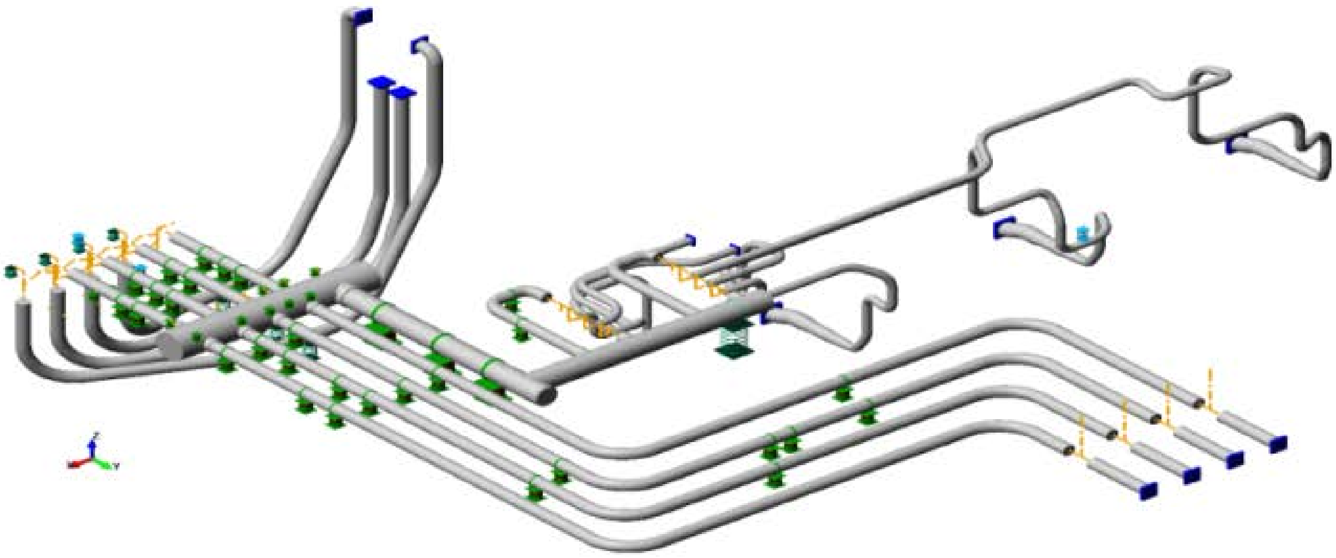


Loviisa PWR NPP Operational Vibration Case. Dampers Installation

Elimination of Piping Vibration (viscodampers efficiency)

Point No.	Location	Vrms, mm/s Without dampers	Vrms, mm/s With dampers	Vpeak, mm/s Without dampers	Vpeak, mm/s With dampers	Vrms/ Vpeak Reduction factors
2540	RA small bypasses	14.6	4.2	47.9	14.0	3.5/3.4
4512	RA turbine inlet	9.7	6.4	33.4	18.7	1.5/1.8
3542	RA vertical run in TH	8.8	4.5	36.3	12.5	2.0/2.9
2568	RA big bypasses	7.4	3.5	25.2	11.8	2.1/2.1
2576	RA50	15.9	4.6	55.5	19.3	3.5/2.9
4222	RL vertical runs in TH	9.3	4.9	32.5	13.9	1.9/2.3
3202	RL low elevation TH	9.6	2.5	30.2	8.5	3.8/3.6
13	RL31	11.8	8.4	42.3	30.4	1.4/1.4
N07	RL76	19.8	8.0	81.0	30.9	2.5/2.6
1F14	Turbine 1 Floor	3.2	2.6	11.9	9.8	1.23/1.21

Program for rehabilitation and restart of Japanese NPPs. Shimane BWR NPP, 900 Mwt. Replacing of snubbers and struts by VD dampers for increasing seismic and dynamic capacity of distribution systems



Conclusions

- **High Viscous Dampers Technology provides to piping, distribution systems and components extended service life and protection from different potential excitation sources as seismic, mechanical induced, pulsation induced, steam flow excited, liquid or mixed phase flow excited, pressure surge and hydraulic hammer, as well as extreme dynamic loads.**