RESOLVING OF VIBRATION MATTER ON FEED-WATER PIPING OF KOLA NPP

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ABSTRACT

This paper describes resolving an operational vibration problem of a feed-water (RL) piping located in the Turbine Hall of Kola Nuclear Power Plant (Units 3 and 4) with the help of high viscous dampers technology. Intensive vibration of these lines raised concerns in actual operation state of the plant and piping safety especially prior to power capacity upgrading of the Kola 3 and 4. Power upgrading is associated with an increase of working media flow in piping and corresponding increase of piping vibration might lead to exceeding recommended and threshold levels.

The investigation covers the following items:

- 3D vibration measurement and walkdown of all vibrating RL-lines;
- Piping finite element models development;
- Simulation of dynamic excitation causing piping vibration close to measured one;
- Development and implementation of protective measures.

As a result of this work the minimal optimum number of high viscous dampers and their location along the lines were determined and the dampers were installed at the piping. VD type dampers of different size and construction were used.

Finally, the substantial reduction of RL piping vibration has been achieved providing more safety and extending service life for pipelines and their support systems.

INTRODUCTION

Kola NPP consists of four Units with VVER-440 type pressurized water reactors. The first Unit started its operation in 1973, the forth – in 1984. In 1991-2005 the 1st and 2nd Units systems, components and equipment were seriously modernized that brought them in accordance with new nuclear safety requirements and extended service life of the pant. Since 2007 the reconstruction of Units 3 and 4 has been carried out including the increase of power capacity up to 107% to initial one. It is known that power upgrading leads to corresponding increase of flow velocity in feed water and steam piping and usually has a negative consequence such as increase of existing pipelines vibration.

NPP 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 pipelines vibration can lead to wall piping fatigue, essential wear and even failure of piping supports. In addition to piping and supports fatigue problem a serious deterioration of plant operation conditions could take place due to environmental noise covering all the plant areas including control room.

Considering all the possible negative effects of vibration it was decided to resolve vibration matter of Units 3 and 4 feed-water pipelines in the view of upcoming reconstruction. 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.

High viscous damper technology had been chosen for this purpose [1-4], based on a positive experience in vibration elimination.

PIPING VIBRATION CRITERION AND OPERATIONAL PRACTICE

At the moment recognized international practice in piping vibration limitation does not exist in contrast with turbines and other rotating equipment. It is mainly connected with the diversity of piping operation conditions, layouts, diameters, materials etc. Only a few national recommendations and guidelines were developed based on operation experience of safety related piping subjected to vibration loads.

ASME OM S/G-2000 [5] Standard Part 3 imposes limits for piping vibrovelocities and vibrodisplacements based on piping fatigue stress analysis according to the ASME Code, [6]. ASME OM piping screening criterion is 12.7 mm/sec of peak vibrovelocity and seems to be very conservative piping vibration safety margin with guaranteed fatigue capacity independently on a piping features. If vibration exceeds this level the Guide recommends to perform additional stress analysis or to improve piping vibration state.

In France a recommended threshold RMS vibration limit for NPP piping is defined as 12 mm/s [7]. These data correlates to a French standard in gas industry.

Russian Boiler Standard RD 10-249-98 recommends to control piping peak vibrovelocities according to the following criteria: less than 15.0 mm/s is excellent; 15.0-25.0 mm/s – additional measurements and analysis to confirm safety is recommended; more than 25.0 mm/s – vibration state needs improvement [8].

The most comprehensive European standard for piping vibration is VDI [9] that provides some screening criteria for piping vibrovelocities against frequency of vibration based on rearranged Wachel allowable, [10]. The vibrovelocity in the frequency range 3.0 – 30.0 Hz with corresponding values more than 6 - 20 mm/s RMS is recognized as requiring corrections and 16 - 50 mm/s RMS as dangerous for piping safety.

Based on all available documentation, NPP pipeline operation practice and data on vibration characteristics the following threshold for piping vibration at Kola NPP has been approved: RMS vibrovelocity ≤ 15 mm/s.

FLOW CHART OF WORK

The main stages of work for resolving vibration matter of feed water pipelines of Units 3 and 4 of Kola NPP and their interaction are schematically presented on Figure 1.

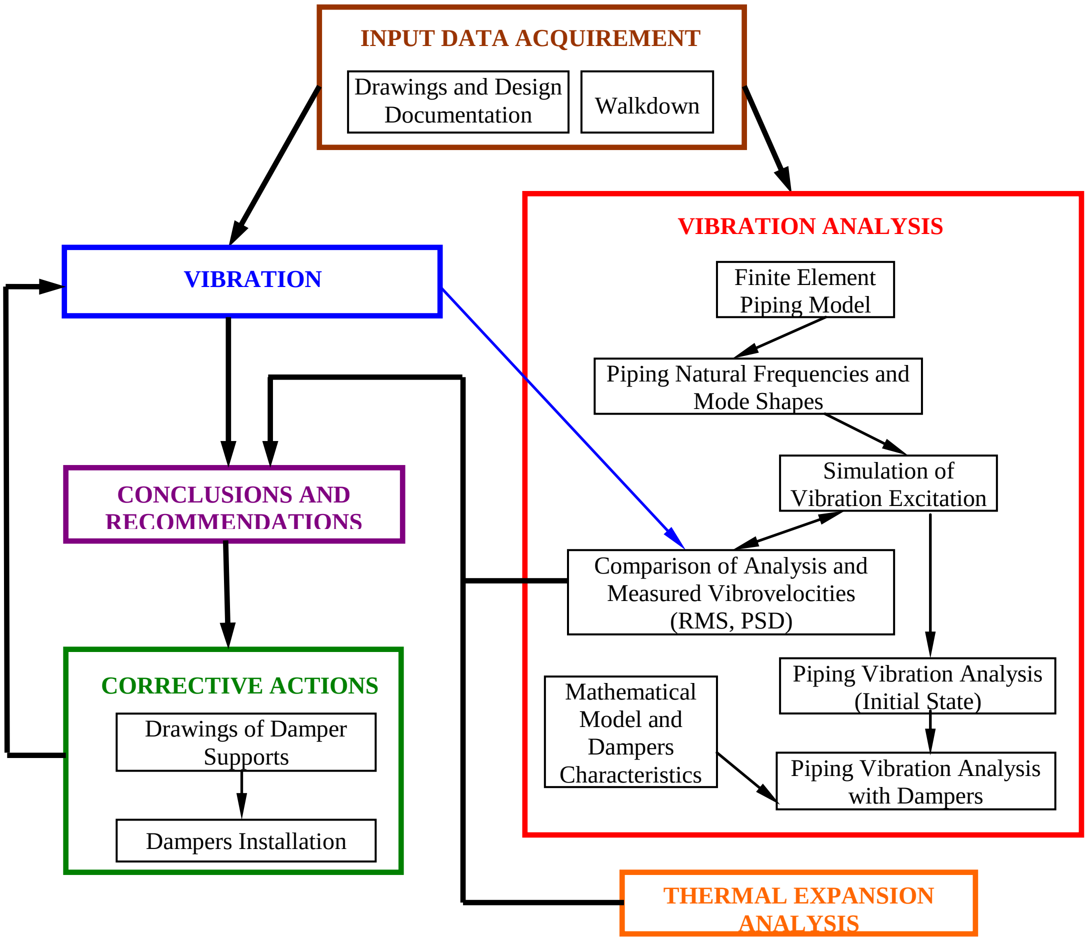


Fig. 1 Flow chart of work

INPUT DATA ACQUIREMENT

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 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 choose measurement points and to create a general measurement scheme.

VIBRATION MEASUREMENTS

The vibration measurements were performed by several multi-channels portable signal analyzers MIC-200 (manufactured by Mera Co., Russia), Fig. 2.

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, Fig.3. Measurements were carried out simultaneously at two points along pipeline.

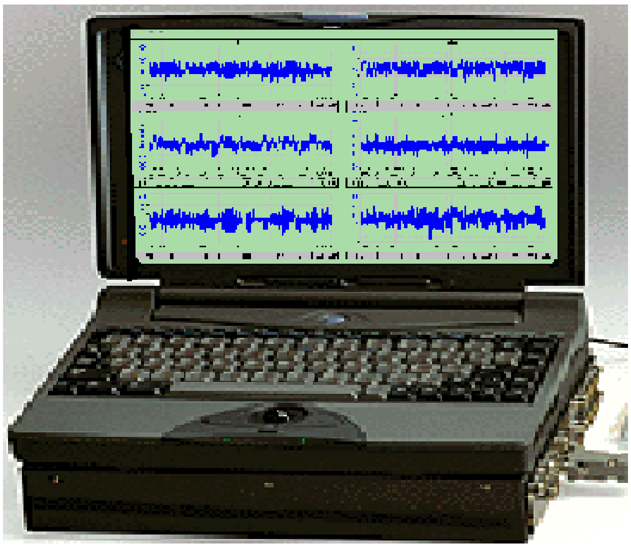


Fig. 2 Multi-channels portable signal analyzers MIC-200

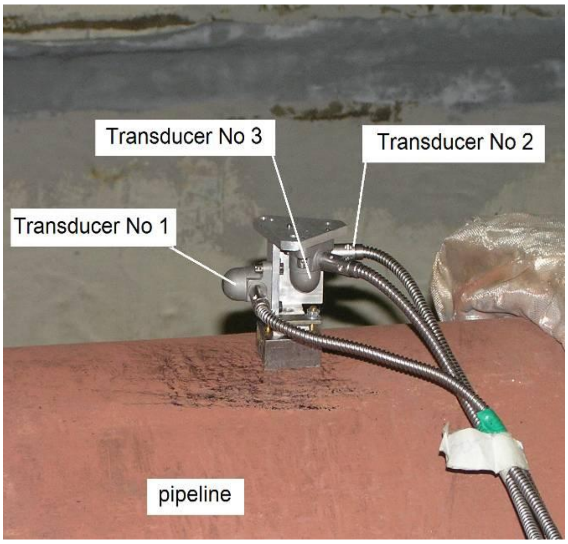


Fig. 3 Magnetic platform with transducers on the pipe

The acceleration signals from transducers passed through the charge preamplifier, main amplifier and the analog low-pass filter. Then the signals were processed by analog-digital converter and recorded as files. Further processing of signals were carried out by a special program and resulted in 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 was 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.

The main technical parameters of vibration measurements:

- Frequency measurement range: 2.0 to 1000 Hz;
- The duration of measurement: 60 seconds;
- Sampling frequency: 2000 Hz;
- Low pass filter cut-off frequency 200 Hz.

The vibration measurements on RL piping systems of Units 3 and 4 were fulfilled in 94 and 88 points respectively. The RL system of each Unit consists of RL31, RL33, RL35, RL72, RL74, RL76 pipelines, main feed water collector, feed water electric pumps pipelines and their collector, feed water heaters pipelines. The maximal values of piping vibration of these sections are shown in Table 1in item of full RMS of vibrovelocity.

Table 1 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

Table 1 (Cont'd)

Unit 3				Unit 4		
Point No.	Location	RMS of vibrovelocity, mm/s		Point No.	Location	RMS of vibrovelocity, mm/s
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

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

VIBRATION ANALYSIS. THERMAL EXPANSION ANALYSIS

For piping vibration analysis of above-mentioned RL piping systems of Unit 3 and 4 a basic analytical procedures have been applied as it shown at chart on Fig.1. The computer software code for piping dynamic analysis dPIPE 5 was used [11].

The complex calculation models of the examined piping systems have been developed on the basis of design documentation and walkdowns performed for this purpose. One of them (for Unit 4) is shown on Fig. 4.

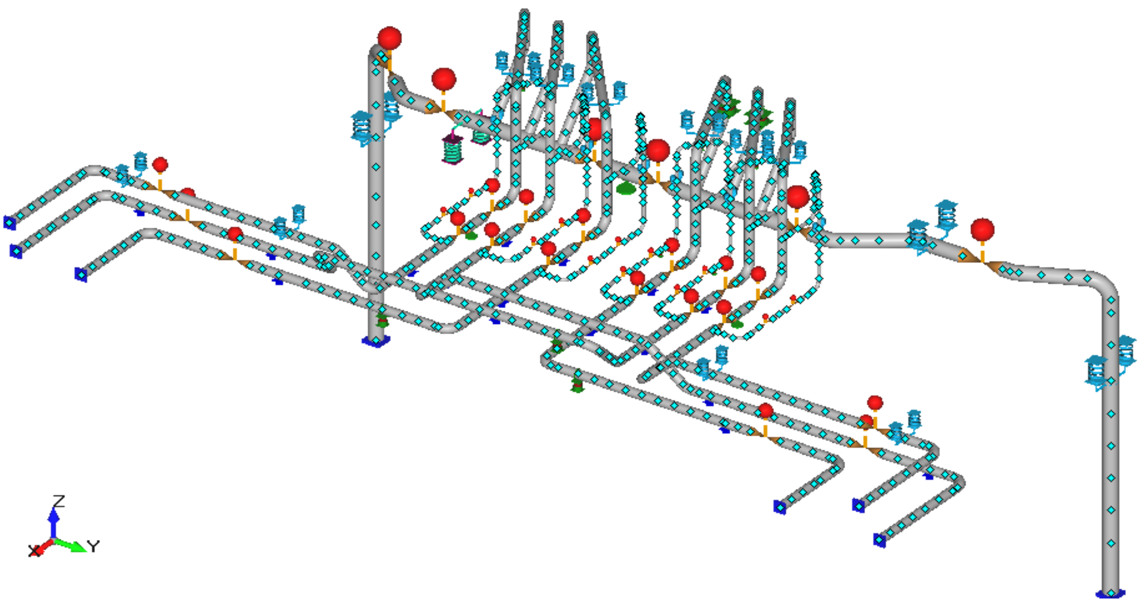
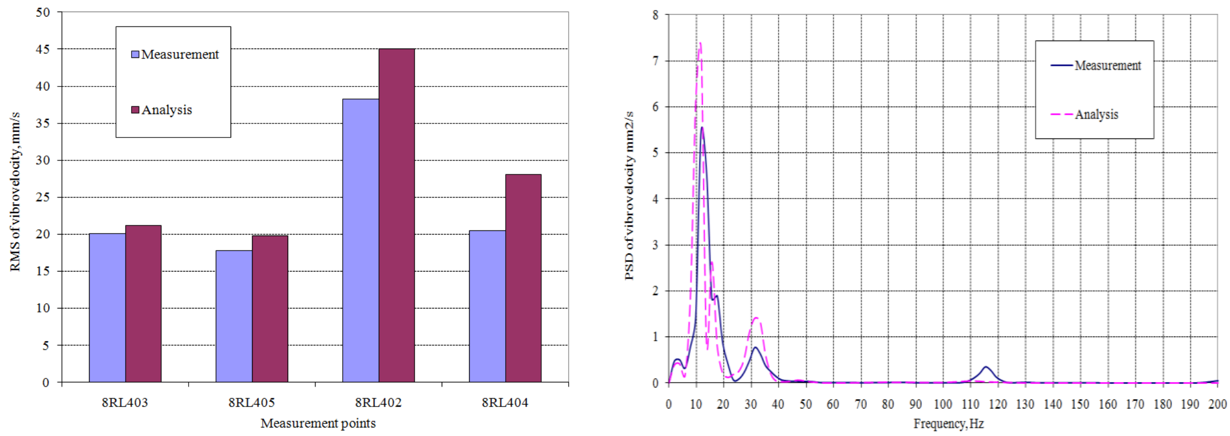


Fig.4 Complex calculation model of RL system of Unit 4

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 modeling of dynamic behavior of the piping systems. All pipes were modeled by the straight (run) and also by means of the curved (bend) pipe elements. The modeling of equipment was performed by means of rigid beam elements with lumped masses located in the center of gravity. Boundary conditions for piping systems (piping supports and anchorage) were modeled by the boundary and spring elements.

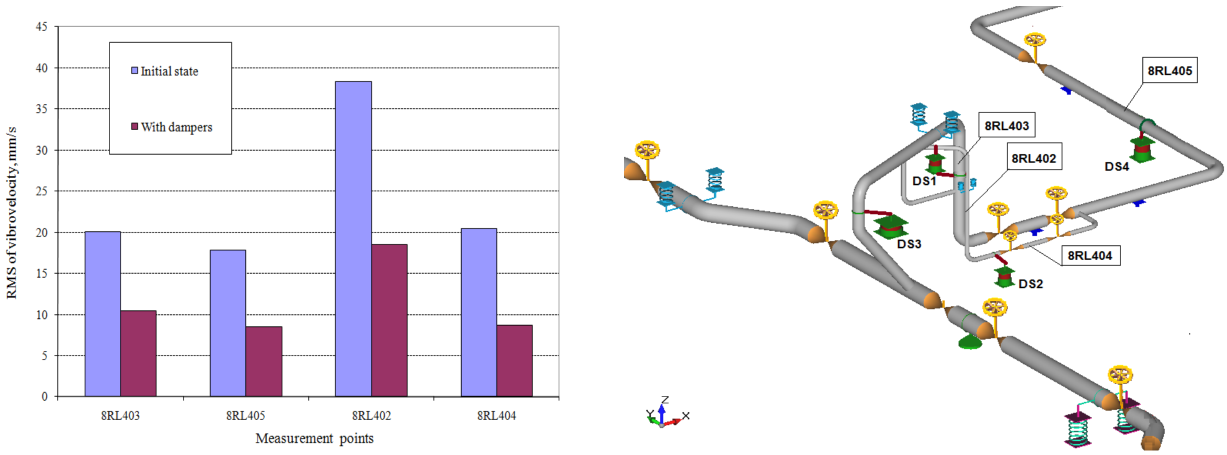
The input vibration excitation was generated using analysis results (piping natural frequencies and mode shapes) and experimental results obtained in piping vibration measurements. Excitation was defined as a set of multi-harmonic modal forces at piping natural frequencies with random phase angles and amplitudes developed by 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. The Figure 5 illustrates this procedure for RL 74 pipeline of Unit 4.

After piping vibration analysis in initial state the same analysis with Viscous Dampers (VD) was carried out. These analytical results had shown the potential dampers influence at vibration state. In this analysis the mathematical model and dampers characteristics were used. Fig. 6 demonstrates the analysis results of RL74 pipeline (Unit 4) without and with high viscous dampers.



(**a**) (**b**)

Fig. 5 Experimental and analysis results of piping vibration: vibration distribution along the piping (**a**) and PSD spectra in the control point (**b**)



(**a**) (**b**)

Fig. 6 Analytically predicted influence of dampers on the RL74 pipeline (Unit 4) vibration (**a**) and layout of this piping with measurement points (shown in frames) and dampers (numbered DS1-DS4) (**b**).

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 made for RL systems.

ELIMINATION OF PIPING VIBRATION

As the result of vibration analysis 23 VD dampers' units were recommended to install at RL systems of Unit 3and 4 (10 and 13 respectively). Fig. 7 shows the layout of dampers location at RL pipelines of Unit 4.

In general dampers do not care static load and respond on dynamically applied loads only using shear effects in special high viscous liquid. Dampers are manufactured by GERB Co. (Berlin) according to Technical Specification 4192-001-20503039-01 under jurisdiction of German Nuclear Safety Standard KTA 3205.3 [12] and German TUF. In 2007 dampers were approved by Nuclear Section III ASME B&PV Code as a dynamic restraint in addition to snubber and gap devices.

High viscous dampers have some essential advantages against other devices. Some of the advantages are: non-stuck soft operation with high damping ability; damping of any dynamic impact including operational vibration, water hammers, seismic and other extreme dynamic loads; six degree of freedom damping ability in one unit; low maintenance and inspection costs; high temperature and radiation stability, [13-17]. VD type damper has low temperature influence on its characteristics.

Damper consists of housing filled with working viscous liquid, piston and internal elements, placed in working liquid. Damper operates as a part of damper support, which consists of one or several dampers and attachment joints connecting damper with building structures and equipment. As a rule, damper's housing is connected to building structures, while piston is linked to a component should be protected.

Dampers were installed at Kola NPP in a two ways:

- damper's piston attached to the piping, housing attached to the rigid structure (Fig.8 a, b, d, e);
- damper's piston attached to one piping, housing attached to another piping with different dynamic properties (Fig.8 c, f). It makes possible to damp two pipelines by one damper.

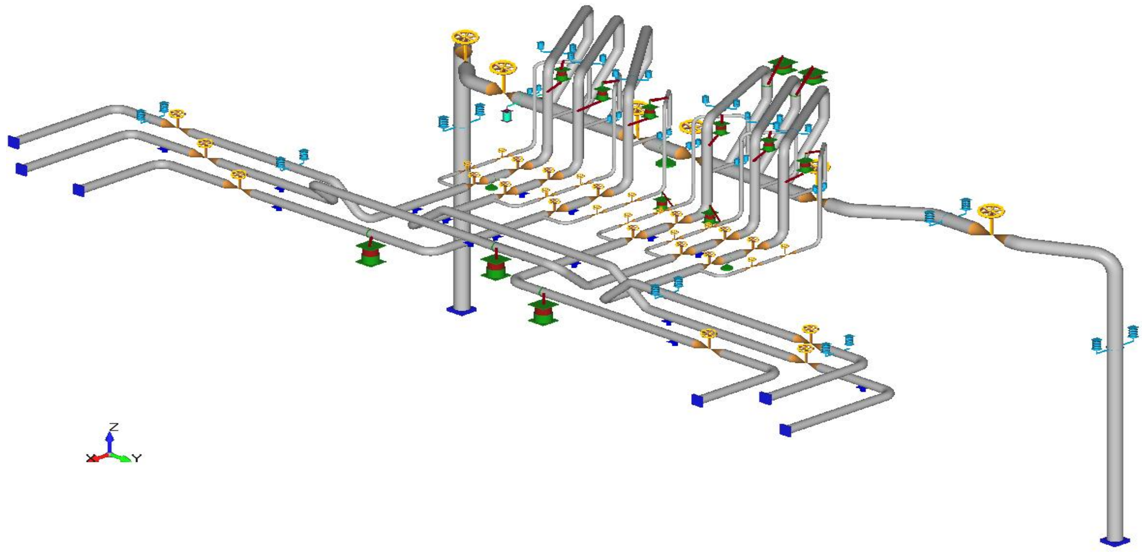
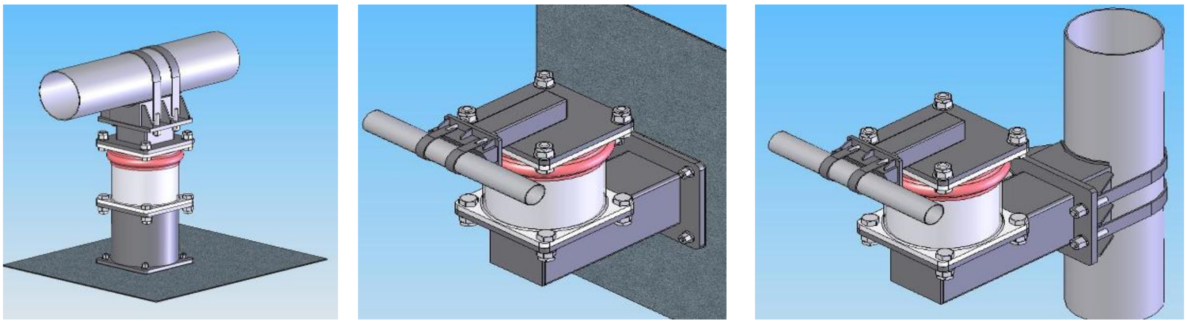


Fig. 7 13 dampers were installed on RL pipelines of Unit 4



(a) **(b)** **(c)**

(d) **(e)** **(f)**

Fig. 8

(a), (b), (c) – typical schemes of dampers attachment; **(d), (e), (f)** – examples of dampers installation on RL pipelines; **(a), (d)** – pipeline & floor; **(b), (e)** – pipeline & building structures; **(c), (f)** – pipeline & pipeline.

Focusing on the maximum vibration of RL systems of Unit 3 and 4 of Kola NPP in initial state (Table 1) dampers installation has provided the following system's reduction of piping vibration, Table 2.

Table 2 Values of piping vibration (at the lines where dampers were installed, same points to Table 1)

Unit 3			
Point No.	Location	RMS of vibrovelocity, mm/s	
		Initial state	With dampers
5RL125	RL31	46.4	11.9
5RL128	RL33	34.8	12.3
5RL127	RL35	47.3	14.0
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	41.8	11.0
8RL402	RL74	38.3	15.1
8RL602	RL76	32.0	14.1

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

Dampers efficiency obviously depends on a number of dampers installed at the pipeline: presented results have been achieved with a minimal number of dampers on the basis of cost effective decision development.

Table 3 shows an overall dampers influence on vibration state of RL pipelines of Unit 3 and 4 versus approved criterion.

Table 3 Influence of dampers installation on the vibration state of Kola NPP RL systems (Unit 3, 4)

Total number of measurement points (Units 3 and 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.

CONCLUSION

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 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.

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