Transactions of the **14th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 14), Lyon, France, August 17-22, 1997 **K17/6**

Upgrading of dynamic reliability and life extension of NPP piping by means of HVD technology

Kostarev V.V.(1), Belyanin L.A.(2), Berkovski A.M.(1), Pavlov M.A.(2), Schukin A.J.(1)
(1) CKTI Vibroseism, Russia
(2) Leningrad Nuclear Power Plant, Russia

ABSTRACT

The presented paper contains the evaluation of dynamic impacts influence on fatigue and service life of highly loaded NPP piping. The analysis was performed on the base of on site measurements of piping operational vibration and strength study of phenomena by methods of fatigue and fracture mechanics. The 3D High Viscous Dampers (HVD) were successfully applied for protecting primary loop piping welding from flaw growth due to operational flow induced vibration, hydraulic hammers, seismic excitation and other possible dynamic impacts.

INTRODUCTION

The NPP operational experience in a lot of cases shows that the reliability and service life of NPP are very often essentially limited by dynamic behavior of the main and auxiliary piping systems. In contrast with other plant systems as turbine and different rotating equipment, there are not strict rules in limitation of piping vibration. Only a few recommendations were developed based on the operational experience of safety related piping subjected to vibration loads.

In the R. Gamble and S. Tagart Method [1] on the base of experience and failure analysis of more than 400 US NPP piping it is recommended to protect piping from vibration in case of displacements more than 0,5 mm in frequency range less 10 Hz and 0,25 mm in frequency range 10 - 40 Hz.

The different criteria of piping vibration stability are considered in ANSI/ASME OM3-82 [2] depending on piping responsibility. The values of allowable stresses, vibro-velocities and vibro-displacements may be included in these criteria. The limit value of vibro-velocity is determined by the empirical dependence, which contains several coefficients reflected features of piping weld arrangement, properties of material, lumped masses and so on. When the peak values of vibro-velocity is less than 12.7 mm/sec, it may be assumed that piping has the sufficient vibro-capacity. If vibration exceeds this level the Guide recommends to accumulate additional information on potential reasons of vibration and to improve piping system.

In the ASME BPVC (NB-3622.3) it is indicated that piping vibration has to be in limits that guarantee the safety operation but not pointed out the current limits of allowable vibration [3].

In France the recommended threshold limit of piping root-mean-square (RMS) vibration is defined as 12 mm/s for the NPP 1300 MWt units [4].

* *The authors would like to acknowledge gratefully Mrs. L. Piven and Messrs. V. Alexeev and D.Pavlov for participation in present study*

In distinction with operational vibration seismic and shock input brings exclusively high piping displacements mainly in low frequency range. At the same time the allowable seismic forces and stresses in piping systems are strictly limited by national and international standards. That is why the procedures of seismic design and upgrading of piping are more evident than in design case of piping subjected to potential operational vibration and shock loading.

PIPING VIBRATION SOURCES

The piping operational vibration strongly depends on external and internal sources of dynamic excitation. The external sources include dynamic impact from rotating machines, seismic and kinematics excitation. The internal sources are connected primarily with non-stationary flow in piping and valves, so as with two-phases flow. The main distinguishing feature of piping external and internal excitations is exclusively wide-band frequency spectra. It is the reason of high vibration sensitivity of usually low damped and flexible piping. The world experience shows that the operational vibration of piping can achieve values of 10-1000 mm/sec and can heavy influence on reliability and safety of NP and FP plants [1]. Under seismic and shock impacts the acceleration of piping may be greater than 10g and displacements more than one meter. High level of operational and seismic vibration can lead to flaw and crack growth in base metal and welding materials, failure of piping, fatigue damages of supports and pendulum system, break of attached small bore pipes, malfunction of valves, relays, drives and so on.

THE INFLUENCE OF OPERATIONAL VIBRATION ON PIPING RELIABILITY

The influence of operational vibration on a piping reliability can be shown on example of the NPP primary loop system with 800 mm diameter. This system has a number of micro-cracks and flaws in on site fabricated weld joints of piping that is quite usual in practice. In several weld joints the cumulating of flaw growth was observed in relatively short period of operation. Many of improvements of welding technology was implemented into system before operational vibration became one of the actual sources of damage cumulating to be considered.

The fatigue analysis of piping weld material has been undertaken according to Russian Code PNAE that is rather close to methodology of ASME BPVC, Section III. Additionally more accurate flaw growth analysis has been carried out according to ASME BPVC. As input data for these analyses the experimental piping vibration obtained by direct multi-channel measurements along the piping were used. By means of CVS computer code dPIPE the results of vibration measurements were converted to stresses distribution in piping and welding zones.

For more reliable and demonstrative representation of results the wide range of static and dynamic factors of piping loading that influence on fatigue were taken into account. The analytical fatigue curves with different asymmetric ratios are shown on figure 1. It should be noted that essential decreasing of allowable number of loading cycles under permanent vibration amplitude is observed only for asymmetric ratio more than 0.6. This value is quite usual for high pressure hot piping. The influence of service and residual stresses on Cumulative Usage Factor of piping is illustrated by figure 2. Obviously that even in case of slight residual and Normal Operating Loading (NOL) stresses for in site made welded zone of piping the Cumulative Usage Factor exceeds the allowable limit. The results on figure 3 show the outstanding influence of piping vibration on Cumulative Usage Factor under NOL stresses that are usual for energetic piping. The performed analysis of different factors influence on Cumulative Usage Factor allows to create the Generic Vibration Usage Curves (GVUC), figure 4. These results obviously identify that decreasing of operational vibration is very effective source of piping life extension. For example, reduction of RMS vibration from 30 up to 4 mm/sec may lead to essential increasing of piping service life.

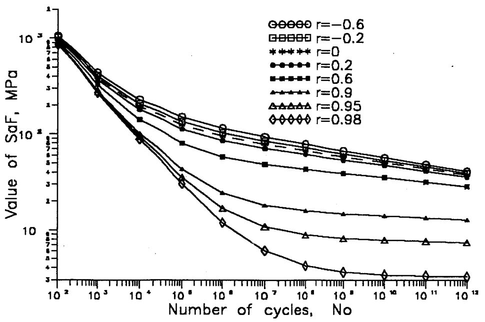


Figure 1. Analytical Fatigue Curves calculated with different asymmetry ratios r (r = $\sigma_{min}/\sigma_{max}$)

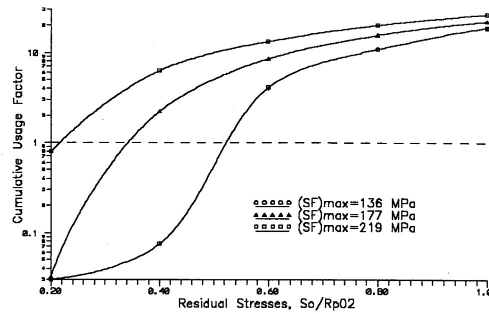


Figure 2. Cumulative Usage Factor of the welded joint zone due to different levels of operational and residual stresses. (Calculations were made for 3 years operational period with value of root-mean-square velocity Vrms=15 mm/sec)

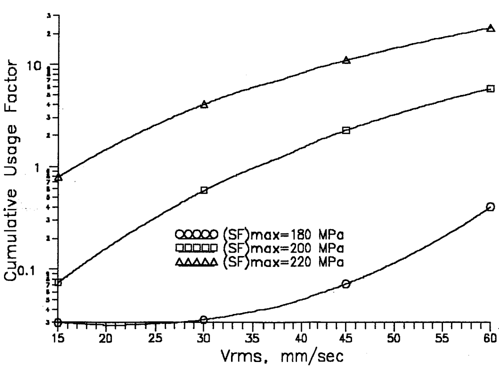


Figure 3. Cumulative Usage Factor of the welded joint zone (pipeline ∅ 800mm) as function of root-mean-square velocity. (Calculations were made for 3 years operational period. Residual stresses were assumed as So = 0.2•Rp02)

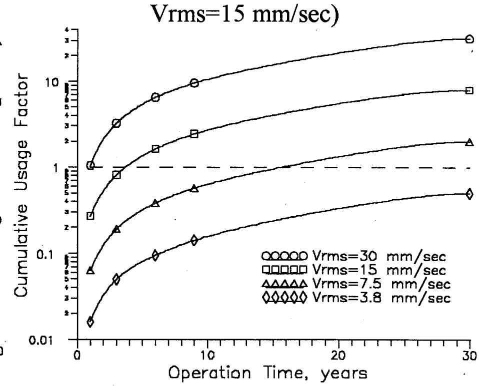


Figure 4. Cumulative Usage Factor of the welded joint zone (pipeline - collector nozzle) as function of Operational Period Time for different levels of operational vibration. (Calculations were made for Residual Stresses So=0.2•Rp02, (SF)max = 219 Mpa)

Approximately the same conclusion was obtained in evaluation of crack growth by methods of Fracture Mechanics according to ASME BPVC, Sec XI, C-3000. In the present analysis the largest hypothetical flaw of on site welding was under consideration. The criteria for flaw growth was assumed as crack propagation up to nearest external surface of welding joint. The results of analysis show big influence of operational vibration on service life of high loaded piping (by pressure, weight, thermal expansion and residual stresses), figures 5 and 6.

Thus, in many practical situations the piping life extension can be achieved by essential decreasing of piping operational vibration level. Obtained results demonstrate that level of RMS piping vibration less than 10 mm/s seems to be the appropriate limit for safety operation under wide range of sustained loads. The best way to protect piping from vibration, shocks, hammer and seismic impacts is installation of special damping devices that provide dynamic safety for all piping service conditions and at the same time do not resist to thermal expansions of piping.

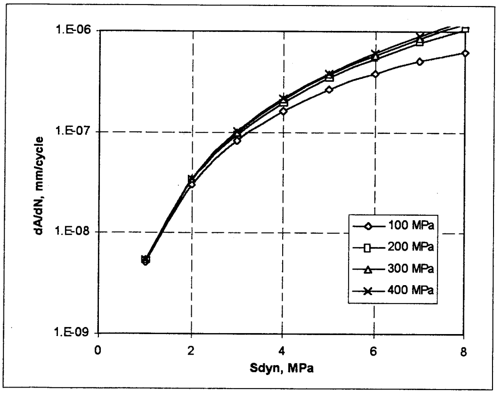


Figure 5. Influence of Flaw Growth Rate due to Cyclic Fatigue from Level of Sustain Load

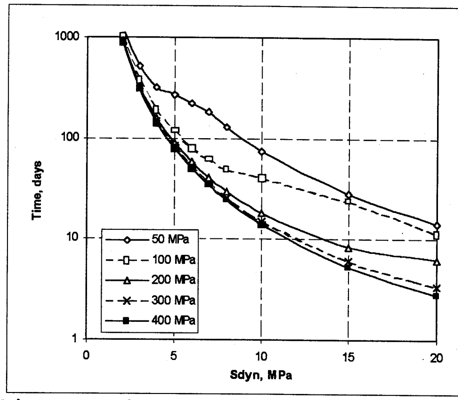


Figure 6. "Time -- Dynamic Stresses" Fatigue Flaw Growth Dependencies for Different Level of Sustained Load

MODERN DEVICES FOR DYNAMIC PROTECTION OF PIPING

In energetic and petro-chemical industry are widely dispersed: mechanical and hydraulic snubbers; axial high-viscous dampers; elasto-plastic absorbers; stoppers; magnetic liquid dampers; resonance absorbers; multi-component high-viscous GERB dampers or CVS-HVD [5-11].

The general requirements for energetic and industry plant damping devices can be postulated as follows: high damping ability for operational vibration, shock and seismic impacts; long service life without repairing; radioactive and thermal resistance; high compensation ability to piping thermal expansions; lack of time delay and collisions of internal elements under dynamic load; ability for overloading without loosing of device integrity; ability for regulation and controlling of damping and tuning on current dynamic system; low primary, inspection and maintenance cost. The snubbers, axial high viscous dampers, stoppers and multi-component high-viscous dampers (HVD) have the most wide circulation among other devices.

EXPERIMENTAL CONFIRMATION OF HVD EFFICIENCY

The comparative analysis has shown that High Viscous Damper Technology (HVDT) has outstanding advantages practically for all scope of above pointed general requirements to damping devices. There are a lot of experimental data that confirm damping efficiency and cost benefits of HVDT due to several thousands cases of installation on NPP's and FPP's all over the world. To illustrate the positive features of HVD some actual examples of damper application are presented below.

The figures 8 and 9 show the HVD installation on PCLS of RBMK-type NPP for damping of operational vibration. In this actual case using of HVD essentially decreased level of vibration and extended piping service life for several times, figures 4,7.

Using of HVD for dynamic protection of 630 mm hot (560 C) steam piping system (1200 MWt Unit of Kostroma FPP) reduced the level of flow-induced operational vibration more than for 20 times, figure 10.

The results of special vibration and seismic accurate testing of large-scale piping model (∅165 mm, 15 m length) on 35 tons IHI Shaking Table are illustrated by figures 11-13, [5]. Attaching to the system only one unit of HVD excludes practically all resonance of piping due to multi-component features of this damper, figure 12. The testing of piping system under seismic excitation demonstrates the radical reducing of resonant amplification for dynamic response which provides full seismic protection of piping, figure 13.

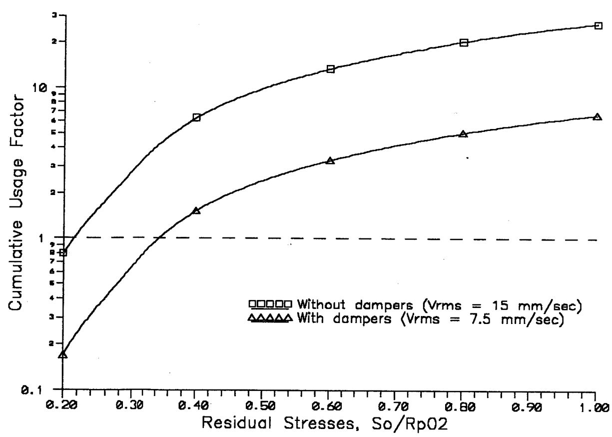
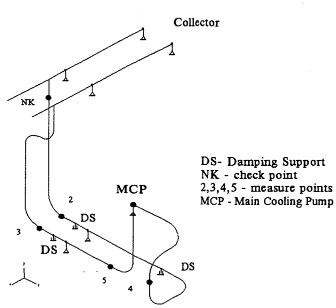


Figure 7. Cumulative Usage Factor of the welded joint zone (pipeline - collector nozzle). Influence of the damping support installation.



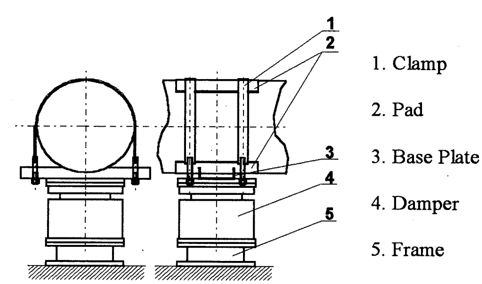


Figure 8. Sketch of Pipeline ∅ 800mm (Primary Loop System of RBMK-type NPP)

Figure 9. Damping Support (Mounting Scheme).

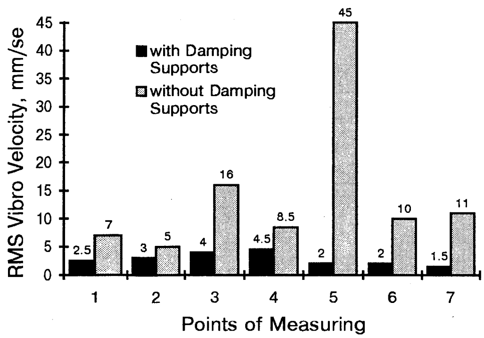


Figure 10. Flow induced Vibration of the steam piping system (∅ 630 mm). 1200 MWt Unit, Kostroma FPP.

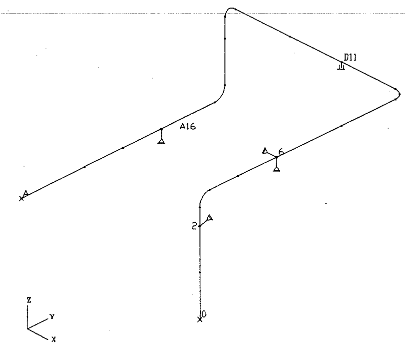


Figure 11. Piping Test Model (IHI Co. 35 tons Shaking Table)

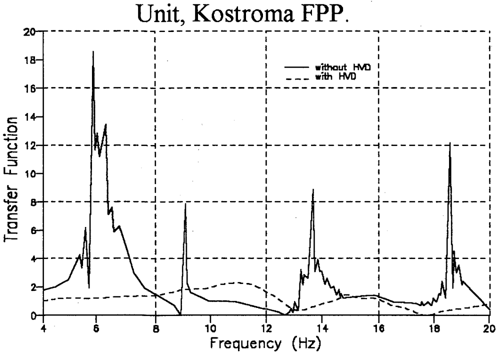


Figure 12. Transfer Function of Piping under Sinusoidal Sweep Excitation (IHI Co. 35 tons Shaking Table)

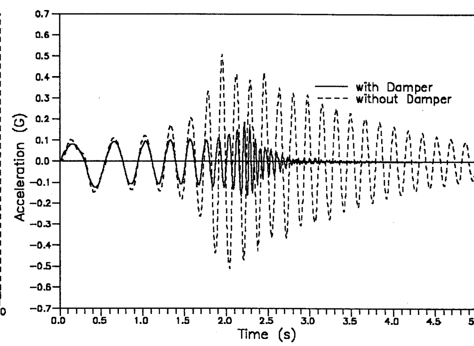
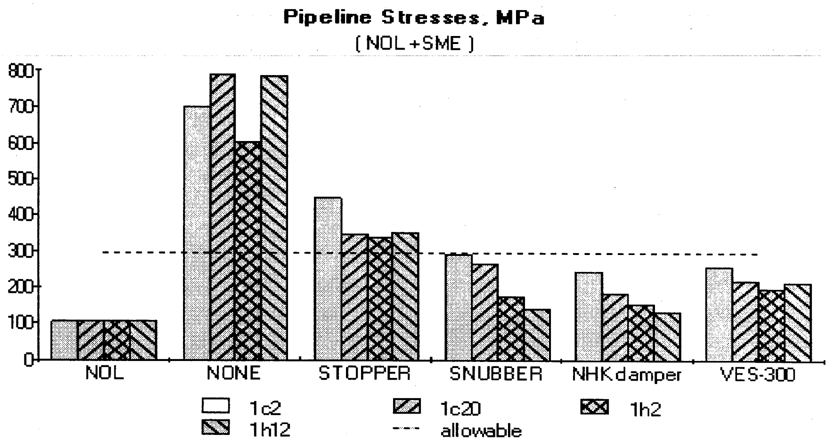
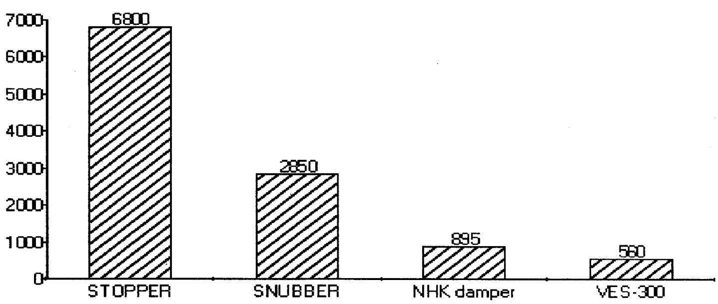


Figure 13. Response of Piping System under Seismic Wave Excitation with/without 1 HVD-159 (IHI Co. 35 tons Shaking Table).

In case of seismic protection of NPP Primary Loop System application of HVD provides optimal restraining of the system that means minimal number of devices, minimal reaction force to the building structure and minimum primary and maintenance cost, figure 14, [10, 11].



a)



b)

Figure 14 Seismic Response of PCLS:
a) Pipeline Stresses, MPa, b) Summary Load to Reactor Building, kN.

CONCLUSIONS

1. The analysis and testing of NPP piping subjected to operational vibration show that RMS level less than 10 mm/s provides the safety of piping operation. In the range of 10-20 mm/s it is recommended to investigate the reasons and to evaluate potential dangerous of fatigue damage of piping due to vibration. In cases of piping vibration more than 20 mm/s RMS the special measures have to be implemented to improve piping and reduce vibration. This approach is proposed like initial standardization background for guide and code developing.

2. Actual study confirms the essential advantages of HVD technology in protecting of NPP and FPP piping systems from operational vibration, seismic and shock impacts and from

flaw growth. Thus application of HVD is recommended for upgrading of piping dynamic reliability and life extension purposes.

REFERENCES

1. Gamble, S.W. Tagart. A Method to Assign Failure Rates for Piping Reliability Assessments. *PVP-Vol. 215, Fatigue, Fracture, and Risk, ASME* 1991.
2. Requirements for Pre-operational and Initial Start-up Vibration Testing of Nuclear Power Plant Piping Systems. *ANSI/ASME OM3-82.*
3. *American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, Division I, Nuclear Power Plant Components, Subsection NB, NB-3600*, 1992.
4. D. Seligman, J. Guillou. Flow induced vibration in a PWR piping system. *Transactions of the 13th SMIRT*, Porto Alegre, Brazil, August 13-18, 1995.
5. Y. Ochi, A. Kashiwazaki, V. Kostarev. Application of HVD on piping system and Isolation Floor System. *Proc. of 9th EAEE,* Vol. 3, 1990, Moscow, Russia.
6. V.V.Kostarev, D.J.Pavlov. Application of CKTI Damper for Protecting Piping Systems, Equipment and Structures Against Dynamic and Seismic Response. *SMIRT 11 Transactions*, Vol. K, Tokyo, Japan, 1991, p.p. 505-510.
7. T.Katona, S.Ratkai, K.Delinic, W.Zeitner. Reduction of operational vibration of feed-water piping sistem of VVER-440/213 at PAKS. *Proc. of 10th European Conf. on Earthquake Engineering*. p.p. 2847-2852.
8. R. Masopust, G. Hueffmann, J. Podrouzek. GERB Viscous dampers in applications for pipelines and other components in Czechoslovak nuclear power plants. *ASME PVP-Vol.237-2, Seismic Engineering*, p.p.17-22.
9. V. Kostarev, A. Berkovski, et. al.. Application of mathematical model for high viscous damper to dynamic analysis of NPP piping. *Proc. of 10th ECEE,* 1994, Vienna, Austria.
10. A. Berkovski, V. Kostarev, et. al.. Seismic Analysis of VVER NPP primary coolant loop with different aseismic devices. *Transactions of SMIRT 13*, Porto Alegre, Brazil, 1995.
11. A. Berkovski, et. al. Seismic analysis of the safety related piping and PCLS of the WWER-440 NPP. *Transactions of the 14th SMIRT*, Lyon, France, August 1997.