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EXPERIMENTAL RESEARCH AND REDUCTION OF VIBRATION OF PUMPS PLANTS

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Abstract: *Vibration generating during pumps operation is a serious problem both for the human health and for operational characteristic of pumps and joining mechanical systems. The reasons of generation of vibration in pumps are considered. Analysis of the methods of experimental research of vibration of pumps plants is discussed. Results of experimental research of vibration during operation of pump plants on the example of «KuibyshevAzot» public joint stock company of Togliatti city of Russia are described. In total analysis of results of experimental research of vibration characteristic of pumps plants is showing that values of vibration acceleration levels are especially high in low frequency range and in some points of measurements are exceeding maximal permissible norms. Approaches to reduction of vibration of pumps plants are suggested. The results described in this paper may be useful for further development and application of constructions of pumps plants with reduced vibration levels.*

Keywords: *vibration, pumps, industrial enterprises, research, reduction*

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1. INTRODUCTION

During pumps operation intensive vibrations are generated, which may significantly reduce productivity, durability and reliability of pumps operation and may cause significant damage of personnel health [1-4]. As a serious danger accident caused from pumps vibration may be considered [2-3, 5-7].

Vibration in pumps is generated due to the several reasons. One of them is inhomogeneity of the pumped liquids [1]. Cavitation may occur in the impeller of centrifugal pumps and in discharge device. Qualitative change in the flow structure caused by cavitation causes a change in the operation of the pump. Instability of the cavitation zone and the resulting secondary fluid flow lead to significant pressure oscillations in the flow causing dynamic effects and intensive vibration. Presence of rotating parts leads to vibration due to imbalance. Mechanically balanced rotor of pump during operation of pump may become hydrodynamically unbalanced, when the pump impeller is not made accurately enough and differs in pitch, angle between the blades, by the length, thickness and pitch angles of the blades. At the same time, the forces acting on the individual blades of the impeller are not balanced and create a vibration with the frequency f_0.

As result hydrodynamic and mechanical imbalance are occurs on the frequency f_0 and on its harmonics. The forces that cause it are significantly less than the forces from mechanical imbalance and may be determined when the rotor is balanced with a high degree of precision.

Sources of vibration of the pump itself without a drive there are first of all the phenomena associated with the flow around its elements, formation of vortices on the blades and discs, on the walls of the pump housing and the outlet pipe leading to the appearance of pseudo-sound as the source of vibration of pump body [1, 5, 8].

During pumps and the other power plants operation low--frequency gas dynamic pressure oscillations (pulsations) are generating [2-3, 5]. Such pulsations are especially significant for low-frequency vibration generation and may cause negative impact to the power plants operation, reliability and durability.

This paper is devoted to discussion of Russian approaches to experimental research and reduction of vibration of pump plants, especially in low frequency range.

2. DISCUSSION OF THE METHODS OF EXPERIMENTAL RESEARCH OF VIBRATION OF PUMPS PLANTS

Requirements of Russian State Standard 12.1.012-2004 "Occupational safety standards system. Vibration safety. General requirements" were taken into consideration. The standard determines general requirements to provision of vibration safety in industry, transport, construction, mining and other works connected with negative impact of vibration to the man. This standard is also determines the structure of complex of standards in the field of vibration safety and requirements to these standards.

Standards of group questions of vibration safety were also studied, which are determining methods of measurement and estimation of vibration in concrete conditions of it impact or for large groups of products as well as separate private aspects of vibration safety. This type of standards is including

Russian standards 31192.2, 31319, 31191.4, 16519, 31193, ISO 10326-1 etc.

Concerning research of vibration of machines of separate kinds it should be noted that the standards in this field may be completely devoted to the questions of vibration safety or include some separate questions of vibration safety. Vibration of machines may be measured in points where vibration is transmitted to support or connecting structures.

Vibration levels in industry in Russia are evaluated according to hygiene requirements, stated by valid sanitary norms (Sanitary Norms 2.2.4/2.1.8.562-96), Russian State Standards and Building Norms and Rules. Hygienic vibration estimation parameters are vibration velocity $\boldsymbol{v}$ and it logarithm levels $\boldsymbol{L_v}$ and vibration accelerations in octave and 1/3 octave frequency bands. It is also admitted integral vibration estimation for all frequency range of vibration and estimation of vibration dose $\boldsymbol{D}$ according to the time of vibration impact. For estimation of vibration levels of technological equipment also vibration displacements and it amplitudes are using as normative parameters.

In paper [6] the results of vibroacoustic characteristic research of the gas pipeline with discrete throttle valve are described. The levels of vibration acceleration in different parts of the main gas pipeline were measured. On the basis of experimental data the possible causes of the acoustic-induced vibration are described, the measures of reduction of vibration loading of a gas pipeline were proposed.

Analysis is showing that existing methods and recommendation on research of vibration characteristic of bodies, pipelines and the other elements of power plants are not allowing take into consideration characteristic and specific features of low frequency pulsations impact, e.g. measurements range, vibration load of the elements of power plants etc. Therefore it is necessary to develop the methods of research of vibration characteristic of gas guides of power plants, including specific of low frequency gas dynamic pulsations impact.

One of the most dangerous sequences of impact of vibration on the pump body is destruction of pipeline system of pump, which may cause accidents with the most serious consequences.

Analysis of power plants pipelines destructions is showing that they, as a rule, occur due to fatigue of pipes material, therefore for the criteria of safe operation of pipeline it should be select the value of admissible tension in the most dangerous section.

Pipeline system of power plants may be considered as elastic construction from the elements of different rigidity: straight sections of pipes, turns of pipes, armature, small technological devices and means of securing pipelines. Such system it is possible to consider as made up of separate sections because in it there are always present elements (device supports, compressors etc.), rigidity of which is infinitely large and which are dividing the system on the separate independent sections dynamically isolated from each other. The character of oscillations of pipelines of these sections is different: straight-line pipelines under the influence of disturbing forces make bending oscillations, in a meantime flat and spatial – bending, torsion and longitudinal oscillations.

Concerning the selection of points of measurement of pipelines vibration, it should be noted that here it is necessary to pay attention to the points of attachment of flanges of supports to the pipeline, because fatigue rupture of pipelines is occurring, as a rule, directly in pipeline in the place of the flanges attachment.

It is also necessary to take into consideration that pipelines vibration is transmitting through the supports to the foundation and to the connecting aggregates (cooler, moisture and oil separator etc.), therefore during the measurements it is necessary to include all above mentioned objects.

For measurements of pumps plants vibration characteristic it is reasonable to investigate first of all one-third octave and octave low frequency range, beginning from the octave 2 Hz.

3. RESULTS OF EXPERIMENTAL RESEARCH OF VIBRATION OF PUMPS PLANTS

Experimental research of vibration during operation of pump plants on the example of «KuibyshevAzot» public joint stock company of Togliatti city of Russia were carried out with the purposes to determine the spectral and equivalent values of vibration acceleration levels for estimation of the reasons of increased vibration levels generation, the influence of pumps vibration to the personnel and for the diagnostic purposes of pumps plants.

Vibration of two kinds of pumps was investigated: pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company and high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company.

Modern measuring equipment was used: precise vibration level meter «OCTAVE 101M» allowing us to measure root-mean-square, equivalent and peak values of vibration acceleration levels, and precise sound level meter, vibration level meter, spectrum analyzer «ACCISTANT TOTAL» allowing us to measure sound and sound pressure levels, vibration acceleration levels, to carry out frequency analysis in sound, infrasound and ultrasound ranges, in ranges of general and local vibration in three channels simultaneously.

Measurements of vibration levels were carried out in the characteristic points of the pipelines, on the supports, on the foundation of shop where the pump is installed and in the upper part of pumps housing in three mutually perpendicular directions:

- $\boldsymbol{z}$ – vertical direction, perpendicular to the axis of pipeline and body of pump;
- $\boldsymbol{y}$ – horizontal direction, parallel to the axis of pipeline and body of pump;
- $\boldsymbol{x}$ – perpendicular direction to the axes z and y.

The scheme of points of measurements during operation of pumps of «Grundfos» company in the shop 78 of

«KuibyshevAzot» public joint stock company (three-dimensional image) is shown in Fig. 1.

Values of vibration acceleration levels measurements in low frequency octave bands during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (point 1, axes X, Y, Z) are shown in Tabs. 1-3.

Vibration acceleration spectra in low frequency octave bands during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (point 1, axes X, Y, Z) are shown in Figs. 2-4.

Photo of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company is shown in figure 5.

Values of vibration acceleration levels measurements in low frequency octave bands during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (axes X, Y, Z) are shown in tables 4-6.

Vibration acceleration spectra in low frequency octave bands during operation of high pressure ammonia pump «URACA» in the shop 4of «KuibyshevAzot» public joint stock company (engine body, educing plant, pipeline, axes X, Y, Z) are shown in Figs. 6-11.

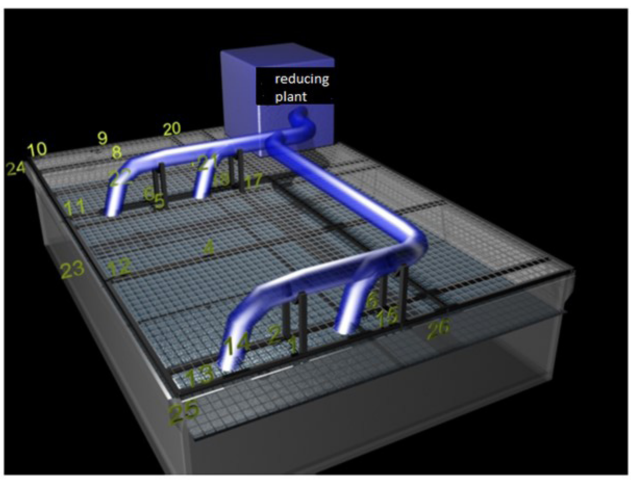

Fig. 1: The scheme of points of measurements during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (three-dimensional image).

Axis X								
F, Hz	1.0	2.0	4.0	8.0	16.0	31.5	63.0	125
L10 s max	80.64	60.77	61.71	65.97	78.21	97.45	128.32	105.55
Leq	65.16	59.62	60.68	65.09	77.53	97.07	126.40	103.73

Tab. 1: Values of vibration acceleration levels measurements in low frequency octave bands during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (point 1, axis X).

Axis Y								
F, Hz	1.0	2.0	4.0	8.0	16.0	31.5	63.0	125
L10 s max	80.16	57.90	57.56	59.99	69.38	82.79	109.05	98.75
Leq	63.45	56.73	56.37	59.32	67.90	82.38	108.04	97.98

Tab. 2: Vibration acceleration spectrum in low frequency octave bands during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (point 1, axis Y).

Axis Z								
F, Hz	1.0	2.0	4.0	8.0	16.0	31.5	63.0	125
L10 s max	79.18	59.09	59.91	64.70	76.34	91.67	121.52	105.70
Leq	79.18	59.09	59.91	64.70	76.34	91.67	121.52	105.70

Tab. 3: Vibration acceleration spectrum in low frequency octave bands during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (point 1, axis Z).

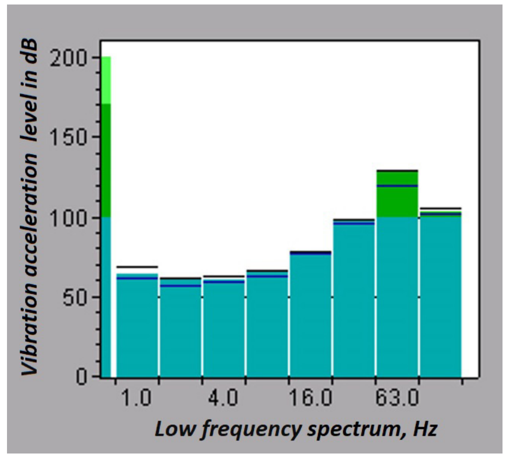

Fig. 2: Vibration acceleration spectrum in low frequency octave bands during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (point 1, axis X).

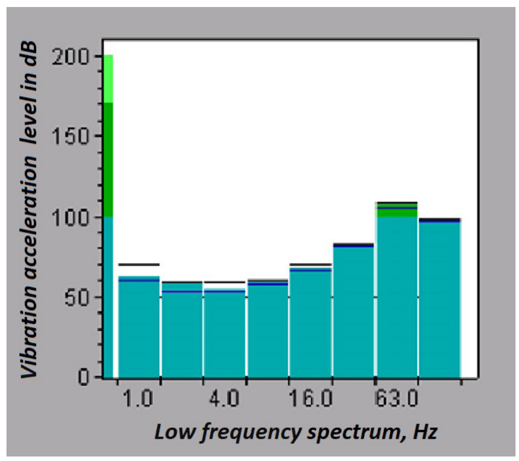

Fig. 3: Vibration acceleration spectrum in octave bands during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (point 1, axis y).

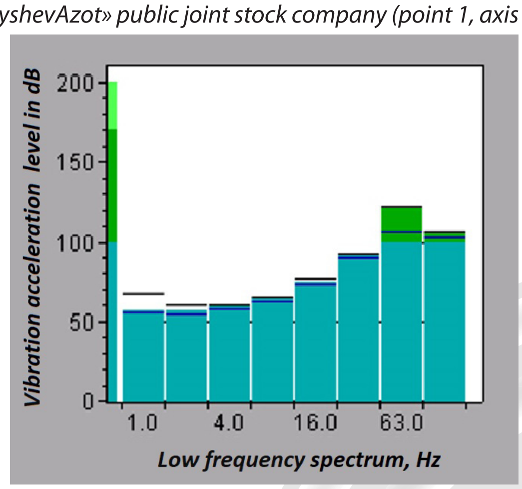

Fig. 4: Vibration acceleration spectrum in octave bands during operation of pumps of «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company (point 1, axis y).

Fig. 5: Photo of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company.

Axis	Kind of value	Vibration levels, dB, in octave frequency ranges, Hz						Corrected levels Wk, dB
		2	4	8	16	31.5	63	
X	Leq	140.8	139.7	137.6	132.7	130.6	127.2	-
Y	Leq	141.3	140.1	138.1	133.2	130.6	127.8	-
Z	Leq	140.9	139.8	137.7	132.9	130.1	121.1	143.6

Tab. 4: Vibration acceleration spectrum in low frequency octave bands during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (reducing plant, measurement 1, axes X, Y, Z).

Axis	Kind of value	Vibration levels, dB, in octave frequency ranges, Hz						Corrected levels Wk, dB
		2	4	8	16	31.5	63	
X	Leq	129.6	125.2	121.9	118.4	115.8	120.8	-
Y	Leq	130.0	125.7	122.4	118.8	115.9	122.1	-
Z	Leq	129.7	125.4	122.1	118.5	115.7	120.0	131.2

Tab. 5: Vibration acceleration spectrum in low frequency octave bands during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (engine body, measurement 1, axes X, Y, Z).

Axis	Kind of value	Vibration levels, dB, in octave frequency ranges, Hz						Corrected levels Wk, dB
		2	4	8	16	31.5	63	
X	Leq	152.7	149.4	144.3	141.0	136.3	141.4	-
Y	Leq	153.1	149.9	144.8	141.4	136.7	141.8	-
Z	Leq	152.8	149.6	144.4	141.1	136.4	141.5	153.3

Tab. 6: Vibration acceleration spectrum in low frequency octave bands during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (pipeline, measurement 1, axes X, Y, Z).

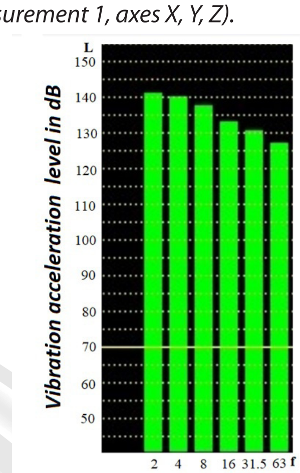

Fig. 6: Vibration acceleration spectrum in octave band during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (reducing plant, measurement 1, axis X).

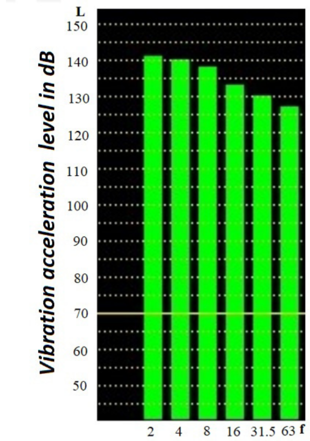

Fig. 7: Vibration acceleration spectrum in octave band during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (reducing plant, measurement 1, axis Z).

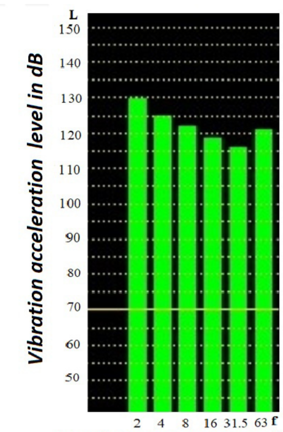

Fig. 8: Vibration acceleration spectrum in octave band during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (engine body, measurement 1, axis X).

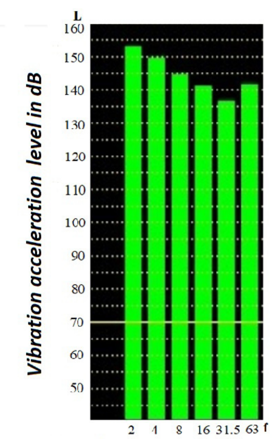

Fig. 9: Vibration acceleration spectrum in octave band during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (pipeline, measurement 1, axis X).

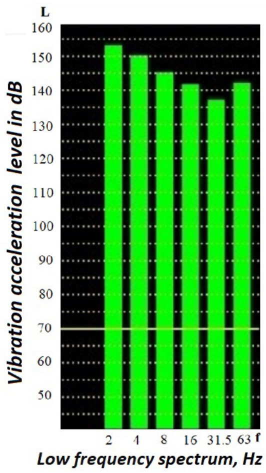

Fig. 10: Vibration acceleration spectrum in octave band during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (pipeline, measurement 1, axis Y).

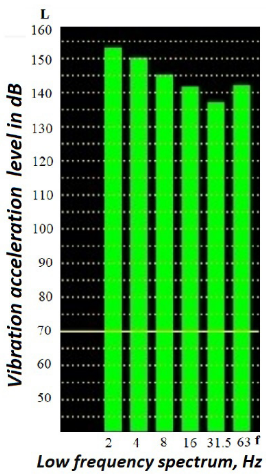

Fig. 11: Vibration acceleration spectrum in octave band during operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company (pipeline, measurement 1, axis Z).

The analysis of measurements results allows us to draw the following conclusions.

Results of measurements of vibration acceleration levels during the operation of pumps «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company are showing the following.

1. Maximal levels of vibration acceleration for all coordinate directions are observed for measurements points on the pump mounting beams and on the pump supports.
2. The most high values of vibration acceleration levels are determined on the frequencies 50 Hz and100 Hz for the pump mounting beams and 50 Hz for the pump supports.
3. On pump supports in points of measurements 1 and 2 the values of vibration acceleration levels on the frequency 50 Hz are significantly exceeding the values of vibration acceleration levels for the other frequency ranges of all directions of measurements.
4. In supports in points 5 and 6 increased values of vibration acceleration levels are determined in very low frequency range (from 0,8 up 3,15 Hz) and on the frequency 50 Hz.
5. In supports in points 15, 16, 17 and 18 increased values of vibration acceleration levels are determined in low frequency range (from 0,8 up 6,3 Hz) and on the frequency 50 Hz.
6. Main source of vibration are rotating pars of pumps, hydrodynamic imbalance of pumps, gas pressure oscillations and dynamic components of radial and axial forces, arising during the operation of pumps.
7. Significant reduction of vibration acceleration levels was determined directly on the concrete tank frame.

Results of measurements of vibration acceleration levels during the operation of high pressure ammonia pump «URACA» in the shop 4 of «KuibyshevAzot» public joint stock company are proving that vibration acceleration levels in low frequency range are very high. Maximal values of vibration acceleration levels are determined in low frequencies 2, 4, 8 Hz, exceeding the value 150 dB. It was alse determined that octave values of measured vibration acceleration levels in different axes are not having significant differencies.

In total analysis of results of experimental research of vibration characteristic of pumps plants is showing that values of vibration acceleration levels are especially high in low frequency range and in some points of measurements are exceeding maximal permissible norms.

4. APPROACHES TO REDUCTION OF VIBRATION OF PUMPS PLANTS

Classification of methods of vibration reduction of power plants, including pumps plants, may be based on the different principles. Widely the means of protection from noise and vibration it is possible to divide on means of collective and individual protection. Firstly it is necessary to use collective methods and means which may be classified as following:

1. Architect-planning methods:
 - rational vibration and acoustical solutions of planning of industrial buildings and of general plans of objects;
 - rational displacement of technological equipment;
 - rational displacement of working places;
 - creation of noise and vibration protective zones.
2. Vibration and acoustical means:
 - means of noise and vibration isolation (including vibration isolating supports);
 - means of noise and vibration damping;
 - pulsation damping etc.
3. Organization-technical means:
 - application of technological processes with low level of vibration;
 - equipage of vibration dangerous power plants by means of distant and automatic control;
 - perfection of technology of energetic plants repair and service;
 - using of power plants with low level of noise and vibration, variation of constructive parameters of power plants;
 - using of rational regimes of labor and rest.

The ways of different kinds of pumps plants vibration reduction (including pumps body, engine, connecting elements and pipelines) in general may be the following:

1. Installation of the different types of pipelines fixtures, strengthening of pipelines bearings (supports). There are different types of supports: moving and fixed, slipping, roller, suspended etc. Despite on different well-known sophisticated measures of vibration reduction for the number of cases using of supports of pipelines remains the most simple and efficient decision.
2. Reducing of a number of pipeline bends.
3. Installation of the damping packings.
4. Alteration of pipeline mass and rigidity, increasing of pipelines geometrical dimensions.
5. Installation of throttle washers in pipeline flange connections.
6. Installation of narrowing diaphragms for pulsations reduction.
7. Vibration damping methods using (e.g. dynamic dampers).
8. Installation of low-frequency pulsations dampers.
9. Using of resonant pulsations dampers. Such dampers are efficient only for very restricted frequency range, but for some cases such constructions are reasonable to use. Resonant damper have significantly lesser volume comparing with usual empty dampers.
10. Using of accelerated oscillator dampers. Accelerated oscillator damper (AOD) has been proposed in paper [9]. The AOD system included oscillator mass, transmission, spring, and viscous damper. The oscillatory motion of primary structure is transferred by a geared transmission to enlarge the velocity of secondary oscillator mass.
11. Using of active and active-adaptive pulsations compensators. Active noise and vibration control method has a lot of practical usage opportunities in the different branches of industry. Active methods are assuming using of additional energy and bringing it into the system. For operation of systems of active compensation source of energy and electronic unit of transforming of characteristic of active source are required. In modern practice of reduction of vibration it is assumed that using of active compensation is reasonable only when passive methods are insufficiently efficient [10-11].

5. CONCLUSIONS

Among of the reasons of vibration generation during pumps plants operation significant importance are having low-frequency gas dynamic pressure oscillations (pulsations). Such pulsations are especially significant for low-frequency vibration generation and may cause negative impact to the power plants operation, reliability and durability.

Results of measurements of vibration acceleration levels during the operation of pumps «Grundfos» company in the shop 78 of «KuibyshevAzot» public joint stock company are showing the following.

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In total analysis of results of experimental research of vibration characteristic of pumps plants is showing that values of vibration acceleration levels are especially high in low frequency range and in some points of measurements are exceeding maximal permissible norms.

Classification of methods of vibration reduction of power plants, including pumps plants, may be based on the different principles. Approaches to reduction of vibration of pumps plants are suggested. The results described in this paper may be useful for further development and application of constructions of pumps plants with reduced vibration levels.

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