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An investigation of the effect of flow charasteristic on maximal level of ultrasonic oscillations at the time of pipeline valve closing

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Introduction

The present article discusses the relationship of the amplitudes of the vessel pipelines' oscillations to turbulence of a flow. The main factors exiting mechanical oscillations of the walls of pipelines' elements in the presence of a turbulent fluid flow are pulsation of a pressure on the inner surfaces of walls, whose values in a specific point are integral characteristics of the field of turbulent pulsation of the speed. Pressure pulsations on the pipe walls are characterized by a wide frequency spectrum, while the intensity of a specific frequency is related to the characteristics of turbulent vortexes of the corresponding scale. Low scale vortexes favouring generation of pressure pulsation at ultrasonic frequencies occur with dissipation of the big ones; also they are created in the pre-wall area by a lateral shift. The field of speeds and pressures in a turbulent flow in general case is described by the Reynolds equations, which are open even for the elemental cases of the turbulent flow (free isotropy turbulence, axisymmetrical flows, etc.). However on their basis the main factors determining the intensity of a pressure pulsation on the pipe walls can be identified. These are in the first place the physical properties of the fluid (density, viscosity, sound speed), average flow speeds, specific dimensions (which is a diameter of the pipe-line), etc. At the same time they are not expected to depend on the averaged values of a static pressure in the flow in the absence of cavitation. Characteristics of vibrations of the surface of the pipelines' elements will be influenced, apart from intensity of turbulent pulsation, by additional factors, such as:

- material quality and density;
- speed of sound;
- length of the element and type of connection with the next one;
- diameter, thickness of the wall or other specific dimensions of a pipeline;
- configuration and structure of the flowing part of the element and its body.

Experimental investigation

The aim of the discussed work was an experimental study of the influence of different factors on the amplitude of ultrasonic vibrations of the walls of specific elements of the vessel pipelines in the frequency spectrum 40-120 kHz. The choice of frequency spectrum is conditioned by the wish to exclude possible influence of the low frequency periodic oscillations in the volume of fluid and pipelines' walls, caused by the work of pumps, as well as other interference, occurring while performing measurements in the industrial conditions.

Vibration characteristics caused by turbulent pulsations were investigated in the hydraulic stand, equipped with the device for damping pressure pulsation from the pump and flow rate, pressure and temperature measuring devices. An indicator of ultrasonic oscillations for testing industrial hydraulic pipelines was used in the experiment. Fig.1 shows the scheme of measuring noise vibration characteristics of the pipelines. The use of fresh water as the main medium for the experiment was stipulated by the primary practical interest in the pipelines of the by-board and fresh water and their density and viscosity being measured in comparatively small ranges. To avoid the filling of the volume with the air bulbs, each run of tests lasted not longer than 50 minutes, after which the air was removed. Check-up of the interference was performed by measuring ultrasonic vibrations of the walls of the pipelines' elements in the chosen spectrum without a flow (zero speed), but all working details being in operation.

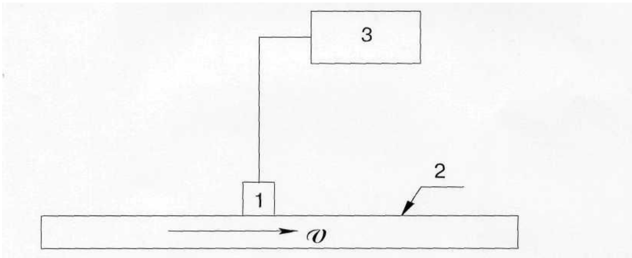

Fig. 1 **. 1 - sensor; 2 - pipelines elements; 3 – measuring device**

The following elements were tested:

- standard fixtures (straight-way stop and none-reverse stop valves with different diameters);
- straight parts of the pipes;
- lead ways;
- triple valves;
- diaphragms.

The influence of the main factors, such as the speed (rate) of a flow in the range 1-7 m/s, the pressure within the range 0.1-0.4 mPa, the diameter of the diaphragm cross-section, different units of the same type of fixtures, lengths of the straight pipes between flange connections were investigated. The chosen ranges of speeds and pressures correspond to the operational characteristics of the main vessel systems. In most of the cases a full experiment, accounting for all factors, was conducted with randomized factors levels, using diversion and regression analysis for data processing. Fig. 2 shows an example of relation of changing of the values of ultrasonic oscillations on the surface of the valve to the Re number in a pipeline.

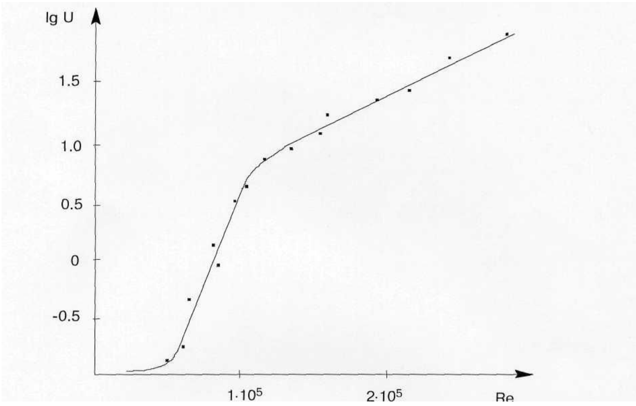

Fig. 2**. Relationship of Ig U (level of vibration) to Re number**

Results and conclusions

1. In all the cases the amplitude of vibrations of vessel pipelines is essentially related to the rate of a flow.
2. Relationship of Ig U (level of vibration) to the Re number (Fig. 2) allows to identify 3 intervals of change of lg U:
   - the first interval (Re < 0.5-10^5) is characterized by comparatively high gradient of the values lg U and minimum value of the vibration level;
   - the second interval ($0{,}5 \cdot 10^5$ < Re < $1{,}2 \cdot 10^5$) is characterized by abrupt increase of the vibration level;
   - the third interval (Re > $1{,}2 \cdot 10^5$) shows reduction of the gradient lg U at high vibration levels.

The change of lg U for other tested elements of pipelines has a similar character but with different boundaries of characteristic intervals;

3. The effect of a pressure on change of ultrasonic vibration levels, as it had to be expected, can be ignored in the tested range of pressures.
4. Vibration levels on the surface of straight pipes, leadways and triple valves are much lower than on the surface of the fixtures.
5. Installation of different units of the fixtures of the same type leads to certain scattering of the vibration levels, and the results of the dispersion analysis show the necessity of accounting for it.
6. There is no virtual relationship of the levels of oscillations on the surface of the fixtures to presence of other pipelines elements earlier in the flow, which can not be applied to the other tested objects.
7. Vibration level on the surfaces of straight pipes is increased with the increase of the pipe's length between flanges.
8. Correlation has been established between the level of ultrasonic oscillations on the surface of pipelines elements and coefficient of local resistance, characterizing the losses of the flow energy, which is indicative of the interconnection between the characteristics of the low-scale turbulent vortexes in whose domain dissipation of the main part of the turbulent flow energy occurs and intensity of the pulsation pressure on inner surfaces of pipelines' elements.
9. In all the experiments when the flow speed is lower than 1 m/s the vibration levels on the walls of pipelines' elements are quite low.

The empirical function

When a fluid flow through a pipeline is being cut off with a shutoff valve, increased flow pulsations and vibration of the pipeline's walls and the valve's body are observed at a certain degree of the valve closure. A special experimental investigation has been conducted for the study of this effect in the Ship Systems Laboratory. The Du 50 valve was used as a shutoff valve on a branch line running parallel to the trunk line of the experimental manifold of the Laboratory's hydraulic test bench. Evaluation of the vibration level of the valve body was performed with the IKU-1 Ultrasonic Vibration Indicator, detecting ultrasound vibrations at a frequency of about 40 KHz. Some of the experimental results are shown in Table 1.

Table 1**. Evaluation of sample characteristics of the studied values**

Characteristics		*P*, MPa		
		0,4	0,5	0,6
Sample averages	q_{cp}	93,5	105,0	119,0
	U_{cp}	1,65	3,51	7,26
	$(1+\lg U)_{cp}$	0,89	1,16	1,44
	$((1+\lg U)/q)_{cp}$	0,013	0,017	0,02
Sample mean-square deviations	S_q	94,9	108,4	119,0
	S_u	2,39	5,86	13,8
	$S_{1+\lg U}$	0,53	0,59	0,53
	$S_{(1+\lg U)/q}$	0,008	0,011	0,013
Correlation coefficients	$r_{q,U}$	0,06	0,03	0,02
	$r_{q,1+\lg U}$	0,12	0,11	0,1
Relative mean-square deviations	S_q/q_{cp}	1,02	1,03	1,0
	S_U/U_{cp}	1,45	1,67	1,9
	$S_{1+\lg U}/(1+\lg U)_{cp}$	0,60	0,51	0,41
	$S_{(1+\lg U)/q}/((1+\lg U)/q)_{cp}$	0,65	0,65	0,65

As Table 1 indicates and as one would expect, an increase in pressure causes an increase in values of leakage averages and ultrasonic vibrations intensities. However, small values of the correlation coefficients and large values of mean-square deviations are the evidence of the large variation of the experimental results and absence of unique dependence between the leakage and indications of the detector. This can be explained by significance of shape and size of the fluid path, which was set randomly as indicated above, and influence on the intensity of ultrasonic vibrations.

It is much more informative to represent the experimental results as conditional distributions of the leakage '*q*' in different indication ranges of the detector IKU-1. The empirical function of the conditional distribution is shown in Fig. 3 for the pressure 0.6MPascal.

During the studies a relationship between hydraulic resistances of the trunk line and of the parallel line with the shutoff valve was measured. In every experiment smooth shutting off of the shutoff valve was performed and for the position of the maximum level of ultrasonic vibrations the following data were recorded: the pressure before and after the shutoff valve and the water discharge for the trunk line and for the branch with the shutoff valve. Besides, the same data were measured for the fully closed and the fully opened positions of the valve.

For pressure measurements standard pressure gauges with scale interval of 0.06 kilogram-force/sm^2 were used. Water discharge for the trunk line was measured by a mass flowmeter. For the branch line with the shutoff valve a water discharge was measured by the orifice flowmeter. The schematic diagram of the experimental pipe installation is shown in Fig. 4.

As a result of the investigation it was concluded that the following characteristics somehow depend on each other: the ratio between hydraulic resistances of the parallel pipe lines, the difference between the pressure, when the shutoff valve is fully closed, and the pressure, when the shutoff valve is in the position where the ultrasonic vibrations are maximal, the maximum value of the vibrations displayed by the IKU-1 and the water discharge when the shutoff valve is fully opened (i.e. initial discharge).

This dependence in the final analysis is described as a correlation between the initial flow velocity V_o (when the shutoff valve is fully opened) and the maximum value of the intensity of the ultrasonic vibrations (USV) U_{max}.

Fig. 5 shows the experimental values of V_o and lg(U_{max})+l. As can be seen from Fig. 5, there is a relationship between the above mentioned values, and the coefficient of a linear correlation r is equal to 0.779. Fig. 5 shows also the straight line, which approximates the experimental data. The equation of the straight line with the coefficients, defined by the least squares method, is

$$V_o = 0.286 + 0.151\ (\lg U_{max}) + 1).$$

The minimal value of the initial water discharge, which resulted in occurrence of a maximum of ultrasonic vibrations, was about 1.0 m^3/h.

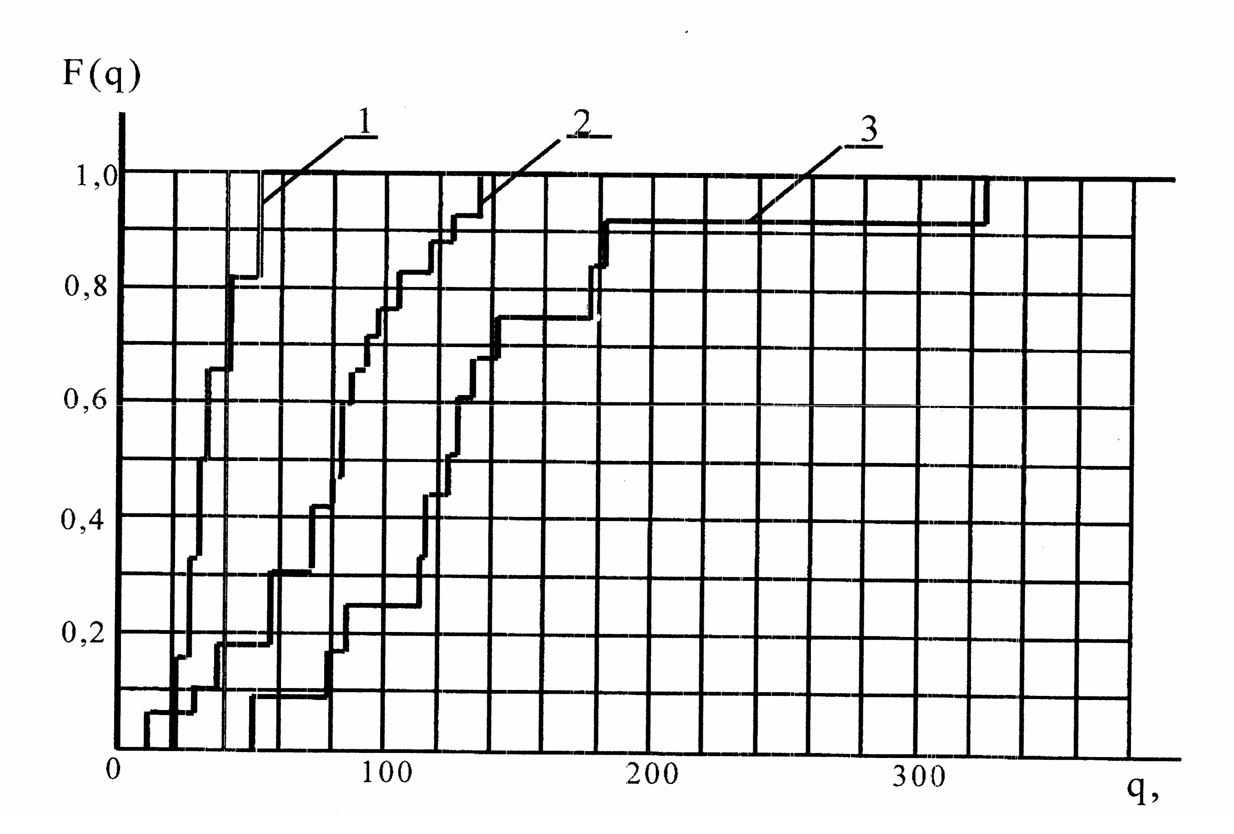

Fig. 3. **The empirical function of conditional distribution of the value of q, when P = 0.6: MPa: 1 - 0,5<U <1; 2 - 1<U<3; 3 - 3< U< 10**

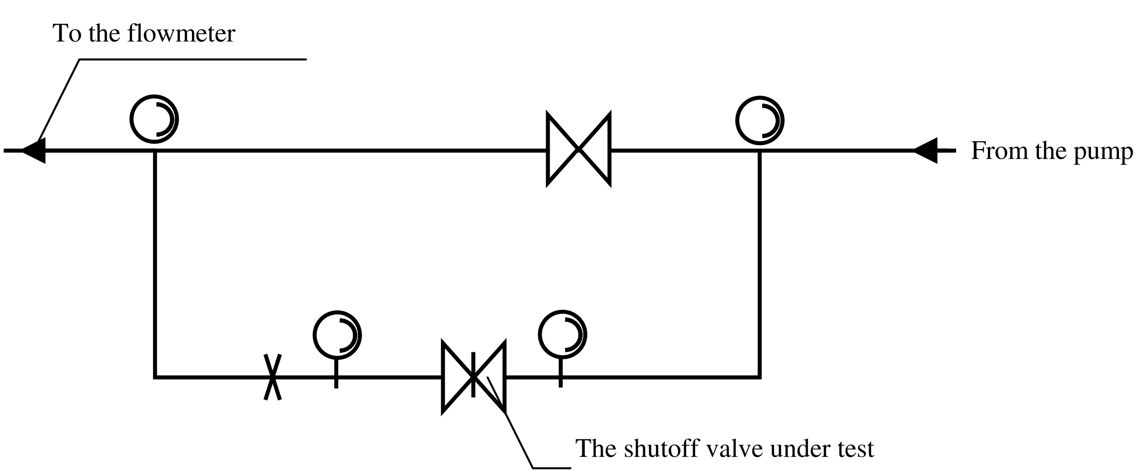

Fig. 4. **Schematic diagram of the experimental pipe installation**

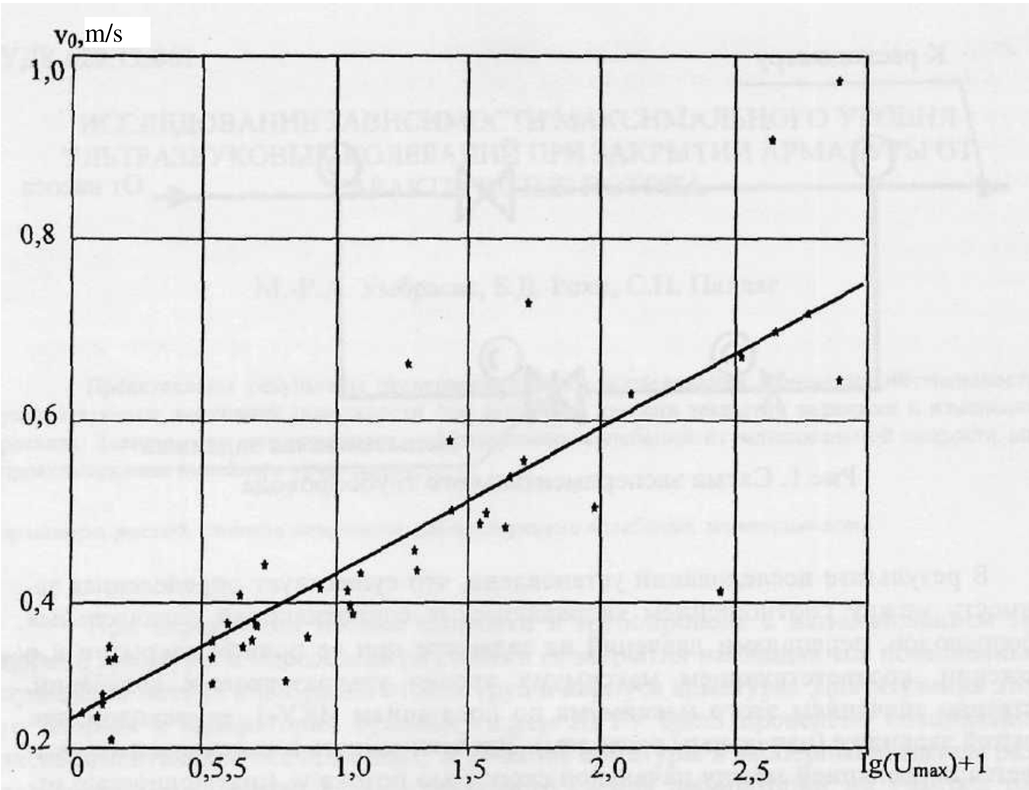

Fig. 5. **The dependence between the USV level and the initial flow velocity**

Conclusions

Empirical formulas have been drawn on the basis of the experimental data, which allow to evaluate expected levels of ultrasonic vibrations on the surface of different pipelines elements, accounting for the Re number and coefficients of a local resistance. These formulas will allow to find practical solutions in operating vessel pipelines.

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Srauto charakteristikų įtakos maksimaliam ultragarsinių vibracijų lygiui tyrimas vamzdyno sklendės uždarymo metu

Reziumė

Rezervuarų vamzdynų sienelių elementų triukšmo ir vibracijų tyrimas yra svarbus eksploatacijos požiūriu. Vamzdynuose buvo nustatyti trys triukšmo šaltiniai: kavitacijos ir dujų nuotėkio žemo slėgio sąlygomis; transportuojamo skysčio greičio ir slėgio svyravimai, sukelti iš esmės mechanizmų darbo; slėgio pulsacijos turbulentiniame sraute.

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