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FEATURES OF SOUND GENERATION BY THE JET-DRIVEN HELMHOLTZ OSCILLATOR

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***Abstract**: Experimental studies the model of a jet-driven Helmholtz oscillator has been carried out. The oscillator is a cylindrical chamber, closed on the sides by two covers with inlet and outlet holes. The oscillator was excited by a stream of airflow. The influence of the geometric dimensions of the chamber and the openings in the covers on the amplitude of pressure fluctuations was studied and the optimal channel configuration was determined. Particular attention is paid to the study of the influence on the amplitude of pressure fluctuations of the shape and size of the nozzle - the hole in the front cover. There were measured the following processes: the pressure drop across the nozzle, to calculate the speed of the jet at the chamber entrance, and the parameters of pressure fluctuations in the chamber, to plot the amplitude-frequency spectra. There were made certain observations of a jet tone appearance and acoustic modes excitation at the natural frequency of the chamber-resonator with a smooth increase in the jet velocity. The relationship between the jet tone and the resonant in the chamber is noted. Recommendations for designing a Helmholtz jet oscillator are presented.*

***Keywords:** Jet generation, hole-tone, resonance, acoustic modes*

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1. INTRODUCTION

The acoustic impact on the oil reservoir is known to have a positive effect on oil production [1]. To create long-term exposure hydrodynamic emitters are used that convert part of the dynamic pressure energy of the fluid injected into the formation into the energy of elastic fluctuations due to the shape of the channel [2].

The most suitable hydrodynamic emitter is the jet-driven Helmholtz oscillator (JDHO). This device has no moving elements and is a cylindrical chamber with two side covers that fits well into the well space. All the technical fluid injected into the well is pumped through the JDHO, the fluid flow having gone through acquires regular pressure fluctuations [3]. The possibility of using JDHO for the development of rocks as a part of a hydraulic monitor machine was studied in the work [4]. In their work [5] the authors used a high-speed survey of the jet development in the JDHO chamber, which shot the appearance of cavitation clouds in the jet flowing out of the nozzle. In [6] a tool for stimulating oil production is described, which creates a pulsating jet in the chamber in the interval between the nozzle and the outlet.

In Fig. 1 possible options for installing a Helmholtz resonator in a pipeline are shown. Being voiced by a speaker (Fig. 1a), chamber 2 works as a Helmholtz resonator with two throats, amplifying acoustic fluctuations at the Helmholtz frequency (HF) and absorbing all other frequencies, that do not fall into the resonator gain band. In the frequency response, there is a pronounced single peak at the frequency of the camera's natural frequency (NF). Is possible to excite the chamber with a jet at the HF by pumping liquid through chamber 2 at a certain speed, but in the spectrum, in addition to a powerful peak at the NF, many small peaks are observed at a frequency both higher and lower than the main peak. These peaks are harmonics of the main peak frequency. Chamber 5 (Fig. 1, b), while being sounded with a speaker, works as a reactive muffler at the HF. When pumping liquid through line 4, the chamber is excited by the flow at the HF and returns powerful pressure fluctuations to the flow.

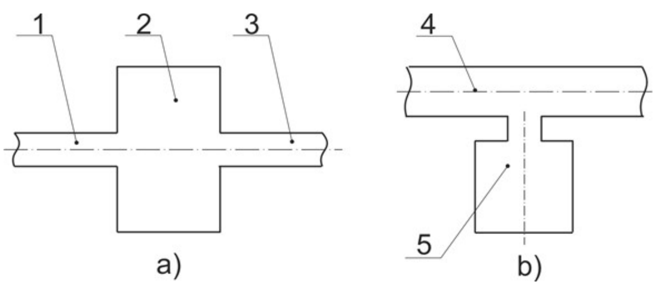

Fig. 1: Installation options for resonators in the pipeline. Placement: a) coaxial, b) lateral

The authors of [7-10] carried out the study of noise damping in the trunk, which is an acoustic waveguide. The authors of these works used a Helmholtz resonator as a reactive silencer. A great number of works [11-13] are devoted to the study of the excitation of a Helmholtz resonator, docked to the side of a line, caused by a flux. A flat version of a Helmholtz oscillator, controlled by a jet flowing through its chamber, represents schematically a flat channel with two side chambers [14]. A number of works are devoted to the study of the influence of the chamber geometry and the oncoming flow parameters on the generation amplitude of pressure oscillations in the chamber, which is a section with sudden expansion and contraction of the channel [15-18].

The article [19] considers a jet-driven Helmholtz oscillator with an annular nozzle and a ring with a sharp edge, installed opposite the nozzle in front of the resonator chamber. The most useful material for the design of the JDHO is contained in the work of Morel [20], who determined that with a smooth increase in the velocity $\boldsymbol{W}$ of the air jet the mode in the chamber passes through a sequence of periods of oscillations – modes, separated by periods of rest. The frequency of pressure fluctuations f in each mode was close to the natural frequency (NF) of the chamber. Morel determined experimentally that the optimum chamber diameter $\boldsymbol{D}$ is 8, related to the nozzle diameter $\boldsymbol{d_1}$ ($\boldsymbol{D/d_1 = 8}$). He believed that a smooth nozzle inlet slightly increases the amplitude of generation of pressure fluctuations while the rounding of the outlet decreases it. The nozzle can have a small cover overhang inside the chamber, while it is desirable to make the boundary layer thin at the exit from the nozzle. Morel patented a jet-driven Helmholtz fluid oscillator with a constant inlet flow and an oscillating outlet flow.

In this work, we continue to study the influence of the geometric dimensions of the channel on the amplitude of the generation of pressure fluctuations in the JDHO.

2. TECHNIQUE AND EXPERIMENT

The JDHO model was a plastic tube 1 (Fig. 2), which was closed by covers 2 and 4. In the center of the front cover 2 there was a through opening 3 - a cylindrical nozzle with sharp edges to accelerate air before it was fed into the resonator chamber, and in the center of the back cover 4 – an outlet with sharp edges 5 for emission of exhausted air from the resonator chamber. A measuring microphone (6) and a fitting (7) for measuring the static pressure inside the chamber were mounted in the front cover.

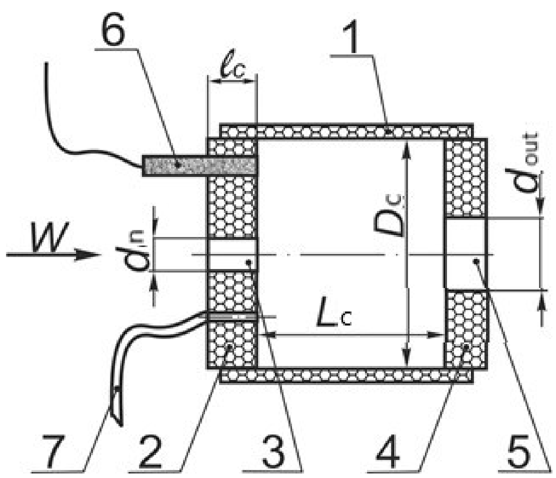

Fig. 2: Longitudinal section of the JDHO

The layout of the experimental stand is shown in Fig. 3. Model JDHO 1 was installed in the cover of the vacuum chamber 2 in such a way that the air was sucked into the nozzle from the laboratory room and flowed from the outlet into the vacuum chamber, the volume of which was three orders of magnitude larger than the volume of the resonator chamber. Thus, the chamber volume was isolated (in the acoustic sense) from other volumes. The pressure drop across the nozzle $\boldsymbol{\Delta P}$ (slowly varying pressure component in the chamber) was measured with a differential pressure transducer 6, the signal was digitized 8 and processed by the Power Graph program. Pressure fluctuations (a rapidly changing component of pressure in the chamber) were measured with microphone 4, amplified with 7, digitized with 8, and also fed to a personal computer 9 for processing.

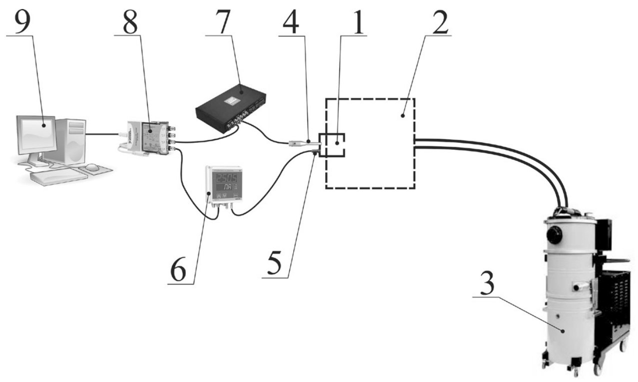

Fig. 3: Block - diagram of the experimental stand

The Strouhal ($\boldsymbol{Sh_L = f- L/W}$) and Reynolds numbers ($\boldsymbol{Re_L = L-W/v}$), where $\boldsymbol{v}$ is the kinematic viscosity of air, were calculated in this work from the ideal jet velocity $\boldsymbol{W^2 = 2\Delta P/\rho}$, where $\boldsymbol{\rho}$ is the air density [21]. The total error of the acoustic measuring system when registering the frequency of the calibrated signal was about 0.4%. Model mounting, measuring equipment and the algorithm for processing measurement results are described in detail in [22, 23].

There was studied the influence of the length of a cylindrical nozzle $\boldsymbol{\ell_1}$ with sharp edges on the generation amplitude of pressure fluctuations in the resonator chamber, as well as the effect of rounding the input edge along an arc of a circle with a radius of $\boldsymbol{R=d_1/2}$ and $\boldsymbol{R=d_1}$. In addition there was investigated the influence of the overhang presence $\boldsymbol{d_1/2}$ length protruding from the front cover towards the flow in one case and inside the chamber in the other case. The effect of the cavity chamber diameter $\boldsymbol{D}$ and the outlet diameter $\boldsymbol{d_2}$ was also studied. The length of the outlet did not change and was 10 mm. To study the resonance frequency effect on the jet tone frequency the resonator chamber volume $\boldsymbol{V}$ was changed at a constant jet length $\boldsymbol{\ell_1}$, and the jet length was also changed at a constant chamber volume. In this work the generation amplitude means the amplitude of pressure fluctuations measured inside the chamber using a microphone.

3. RESULTS AND ANALYSIS

Initially, the signals from the pressure transducer and microphone were briefly recorded without flow rate to set the zero. With a smooth increase in the jet velocity to ~ 2 m/s, jet generation began at a frequency of several tens of Hz. This frequency is much less than the NF of the camera and no resonance occurred. Alongside, one of the peaks excelled - a jet tone at the feedback frequency in the jet. With a smooth increase in the jet velocity the frequency of one of the peaks with high ***Sh*** increased to a value corresponding to the NF of the resonator chamber, causing the resonator respond. The first acoustic mode appeared - a stable excited state of the resonator, characterized by a complex of geometrical and operating parameters. Pressure fluctuations in the cavity chamber at all other resonance frequencies practically disappeared.

With a further increase in the jet velocity the first mode gradually decayed, but the next mode appeared almost immediately with a larger amplitude of pressure fluctuations. The modes exist in the gain band of the resonator and, as a rule, their frequency varies smoothly near the NF of the resonator chamber. Suddenly the generation disappeared after reaching some Re, unique for each specific device configuration.

3.1. Influence of nozzle configuration

The main results of the experiments are shown in Fig. 4. The figure shows that the short nozzle ($\ell/d_1=0.3$) worked best in combination with the short chamber ($L/d_1=0.5$).

The curves in Fig. 4, corresponding to nozzles 9 and 16.5 mm long ($\ell/d_1=0.75$ and **1.375**) demonstrate the same behavior, but the overall generation level has decreased. A nozzle of two calibers length (the ratio of the nozzle length to its diameter) did not work in combination with a short chamber. Meanwhile the optimum of the chamber length was observed, at about $1.5d_1$. A further increase in the nozzle length to $\ell/d_1= 2.9$ led to a decrease in the generation amplitude with a gradual shift of the upper extremum in the direction of increasing the chamber length.

As it can be seen in the figure, a slight rounding of the leading edge led to a noticeable increase in the generation amplitude at a chamber length of about two calibers.

3.2. Jet tone and acoustic modes, resonance

In the process of processing the experiments graphs were built, as in [24, 25], one of which is shown in Fig. 5.

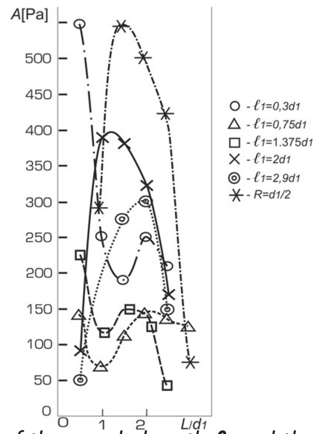

Fig. 4: Influence of the nozzle length ***ℓ*** *and the rounding of the entrance R on the generation amplitude A for different chamber lengths* L/d_1 *and* $d_2/d_1=1.33$

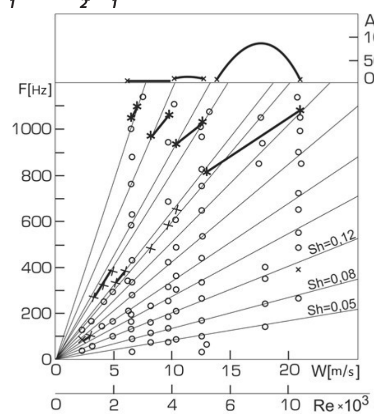

Fig. 5: Jet tone and acoustic modes on the reference characteristics ***Sh - const.***
$d_1=12\times25$ ***mm,*** $d_2=16\times10$ ***mm, L=18 mm.***
*o - generation frequency, x - jet-tone frequency, *- acoustic mode frequency.*

The figure shows a jet tone depicted by crosses in the lower left corner, at first its frequency smoothly increases with a smooth increase in the jet speed [26-27], but then its frequency changes abruptly to the lower characteristic. It can be assumed that the formation frequency of primary pressure perturbations at a sharp edge of the outlet, $f=Sh_L\text{-}W/L$, is ahead of the feedback frequency, which is described with the following expression,

$$T=\frac{1}{f_T}=\frac{L}{W_{conv}}+\frac{L}{c}+t \qquad (1)$$

according to the Kruger jet amplification mechanism [28], where c is the sound speed, W_{conv} is the convective speed, ***L*** is the jet length (which corresponds to the length of the chamber ***L***). Due to the need for internal coordination, the process jumps to a lower characteristic with a lower Strouhal number. A further increase in the jet velocity leads to the fact that one of the higher components of the spectrum increases to the NF of the resonator - the first weak acoustic resonance mode appears. Inside the chamber, at resonance, pressure fluctuations at all other frequencies are suppressed except for those that correspond to the NF of the resonator. Pressure fluctuations are also suppressed at the tone frequency f_T, which is much less than NF. Higher modes have a larger extent according to the velocity scale in Fig. 5, because they rely on flatter characteristics.

The experiments with nozzles supplemented with overhangs have shown that a overhang protruding from the front cover towards the flow has no noticeable effect on the generation amplitude. The nozzle with a overhang protruding into the chamber from the front cover showed a lower generation amplitude.

4. CONCLUSION

The experimental data obtained make it possible to assert that there is effect of the acoustic resonance frequency on the jet tone frequency in the "nozzle - jet – hole" system.

The optimal nozzle length is of the order of two calibers (***$1</d_1< 2$***). In combination with the chamber length (***L/d_1~1.5***) and the outlet diameter (***d_2/d_1~1.33***) the generation highest amplitude of pressure fluctuations in the chamber with a cylindrical nozzle was observed. Rounding the leading edge along a circular arc with a small radius ***$R=d_1/2$*** significantly increases the amplitude of generation.

The largest amplitude of pressure fluctuations in the experiments was observed in the JDHO with a short cylindrical nozzle (***ℓ/d_1~0.5***) in combination with a short chamber (***L/d_1~0.5***) and an outlet (***d_2/d_1~1.33***). In this case the optimal chamber diameter was (***D/d_1~4***). The existence of a overhang in front of the nozzle had no noticeable effect on the generation amplitude. The existence of a overhang extended towards the chamber somewhat reduced the generation amplitude.

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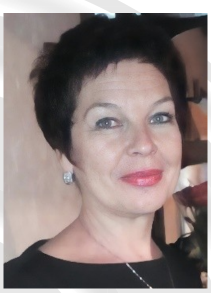

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