Experimental investigation of highly non-linear fluctuations of gas of an open pipe in the vicinity resonances

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Abstract. Non-linear oscillations of gas in an open pipe were researched experimentally. Dependencies of the pressure oscillation amplitude were obtained for various frequencies of the gas excitation near the first proper frequency to the approach to the shock-wave oscillation mode.

Introduction
The development of modern technology brings a number of challenges, among which is one of the actual study of the resonant vibrations of the medium in different apparatuses of power engineering, chemical technology. Of particular interest is the systems of a resonator-pipe type, which a widely used in technics, where one end of the pipe communicates with the environment. Highly non-linear pressure waves emerge in pipe systems near the resonance and non-linear effects are observed [1, 2], such as turbulence in the flow, the occurrence of secondary flows and acoustothermal processes, generation of higher harmonics. The results of theoretical and experimental studies of these environments are analyzed in reviews [3, 4], where he studied modes of unstressed wave currents at small amplitudes of excitation of gas [5-7], and with the formation of shock waves with large amplitudes.

In this new series of studies on the based company vibration generator TIRAvib 5220 / LS with digitally processing were considered different gas dynamic characteristics of highly nonlinear oscillations of gas, which have been little studied.

1. Experimental setup
The research was performed in an installation based on a vibration generator 1 of TIRAvib S 5220/LS make with a power amplifier 15 of BAA 1000-ET model by TIRA firm (Figure 1). Into the vibration table 3 was screwed piston pin flat piston 5 and the diameter d = 100 mm; the total weight is 250 g.

The piston enters the cylinder 6 and oscillates according to the harmonic law with the set frequency ν in Hz. In order to prevent the transition of the stand vibration to the floor, the installation was placed on pneumatic spring cushions 20. Four short clamp bands 2 were fixed on metal angles 19 screwed to the base of the vibration installation. The clamp bands hold a support 11 with a special lower head 8.

Ends of a glass pipe 9 with the length \( L = 918 \) mm, the inner diameter of \( d = 10.05 \) mm and the wall thickness of 2 mm were glued hermetically in an opening of the upper head 10 and the lower head 7. The pipe was held vertical with long clamp bands 8 fixed on the lower head 7 and the upper head 10.
The vibration table was controlled via a computer 16 by means of a piezoelectric IEPE accelerometer 4 of 4513 model by Bruel & Kjaer firm and a feedback controller 13 of VR9500 type by Vibration Research Corporation firm using a specialized VibrationVIEW software. The positioning controller TMS-2 14 was used to adjust the table of the vibration generator. A pressure sensor 12 of 8530С-15 model by Bruel & Kjaer firm was screwed into an opening of the head 7, and the signal from the sensor was fed through a three-channel bridge voltage amplifier 18 of ENDEVCO model 136 by Brue & Kjaer firm to a digital oscilloscope 17 of DSO 3062A model by Agilent Technologies firm, and then via an RS-232 interface to the computer, where the data for the gas pressure p in bar can be observed and saved using a specialized DSO3000 software. A cooling fan 21 was used to prevent overheating of the vibration coil and the field excitation coil.

Sine oscillation of the piston near the first proper frequency \( f_1 \) was set with the controller 13. Upon achieving the frequency and span of the piston oscillation \( 2l \) (where \( l \) is the span amplitude) with a certain value, a record of the pressure oscillogram was performed on the computer monitor. The voltage value \( \Delta U \) in mV with the accuracy of 0.3 mV was converted into the value of the pressure oscillation span in bar using the conversion ratio \( \Delta P (\text{bar}) = 0.00025 \text{(bar/mV)} \times \Delta U (\text{mV}) \).

2. Experimental results
The Figure 2 represents oscillograms with records of the gas pressure oscillations in time at different dimensionless excitation frequencies \( \bar{v} = v / v_1 \) and the piston span amplitude \( l = 0.75 \text{ mm} \). The transition through the resonance near the observed first proper frequency \( v_1 = 90.3 \text{ Hz} \) was observed. It is obvious that away from the resonance (\( \bar{v} = 0.89 \)), the gas oscillates according to the harmonic law. Along with further increase of the frequency (\( \bar{v} = 0.98, 0.99 \)), a distortion is formed and the
amplitude increases in the discharge area. An increase of the steepness of the rising edge of the pressure wave is observed. At the resonance ($\tilde{\nu} = 1$), the amplitude becomes maximum. After the resonance ($\tilde{\nu} = 1.01$), the amplitude decreases, a further increase in the frequency ($\tilde{\nu} = 1.06, 1.1$) leads to the fact that the gas oscillation once again assume a harmonic nature.

Figure 2. Oscillograms of the gas pressure oscillation at the amplitude of the piston shift $l = 0.75$ mm at different dimensionless excitation frequencies $\tilde{\nu}$ near the first proper frequency $\nu_1 = 90.3$ Hz.

Quantitative results for the specified case are represented in Figure 3, where the amplitude-frequency curve is presented in the dimensionless form $\Delta \tilde{p} = 10^2 \cdot \Delta p / p_0$ ($p_0$ – atmospheric pressure, $\Delta p = p_2 - p_1$ and $p_1$ are maximum and minimum values for the period of the piston oscillation). Notably, the value of the gas pressure amplitude at the resonance frequency is 4 times as high as away from the resonance. The theoretical resonance frequency is calculated according to the following formula

$$\nu_1^* = \frac{c_0}{2L(1+\beta')}$$

where $\beta' = \frac{1}{2} \left(1 + \frac{\kappa - 1}{\sqrt{Pr}} \frac{\delta}{R}\right)$

(1)

where $c_0$ is equilibrium sound velocity, and $\beta'$ is absorption factor, $\kappa$ is the adiabatic index, $Pr$ is Prandtl number, $\delta$ is the acoustic interface thickness, $R$ is the pipe radius, $L$ is the pipe length.

The solid line marks the ratio of the excitation frequency to the first of the observed proper frequency, the dashed line marks the ratio of the excitation frequency to the proper frequency, calculated in consideration of the absorption according to the formula (1).
Figure 3. Dependency of the dimensionless span of the gas pressure oscillation on the dimensionless excitation frequency at the dimensionless amplitude of the piston shift $l = 0.75$ mm. Dots mark the experimental results.

4. Conclusion.

Peculiarities of process non-linear gas pressure oscillation in an open pipe in a wide range of frequencies. The deformation of the wave form observed: the steepness of the front rising edge becomes greater than that of the back one when approaching the resonant frequency. Pressure fluctuations have a continuous character. These new data on the characteristics of nonlinear oscillations of gas can be a good basis for increasing the efficiency of existing and to create new and promising applications. Since the nonlinear oscillations of gas may be a shock wave, the average flow vortex structures. Insufficient consideration of these effects in the development of technical devices can lead to a sharp reduction in the timing of their operation or an emergency.

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