Experimental studies for flow velocities of oscillations gas when transiting through resonance in the area of an open end of pipe

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Abstract. Mean velocities of gas in the area on an open end of pipe while gas oscillated in a non-linear way near its first eigenfrequency were researched experimentally. A non-monotonic character of the change of the mean velocity in the radial direction was identified.

Introduction

Researches of features of non-linear oscillations of gas in pipes near resonance points are important today both to improve efficiency of existing applications and to develop new prospective ones: in the vibration engineering, pipeline systems, vibration-based cleaning of reservoirs. In case of such oscillations, shockwaves, middle streams, eddy structures, thermo-acoustic effects occur, etc. [1-4]. Lack of consideration of such effects when developing technical devices may result in a dramatic decrease of their service life or to occurrence of emergency situations. In the course of research of resonance oscillations of gas in an open pipe, in terms of theory [2], significant difficulties arise caused with various effects of the non-linear wave field at the outflow section. In research papers [5, 6], the field of instantaneous velocities in the axial and the radial directions were researched in detail in the area of the open end of a pipe. Motions of a flat particle in the external wave field were also studied [7]. It seems necessary to continue the works [5, 6, 8] for experimental studies of the field of medium velocities of oscillating gas near its first eigenfrequency in the area of the open end of a pipe.

Experimental conditions

The research was performed in an installation based on a vibration generator 1 of TIRA vib S 5220/LS make with a power amplifier 8 model BAA 1000-ET firm of the TIRA (fig. 1). Into the table of the vibration generator, a flat piston 3 with the diameter of \( d = 100 \) mm was screwed. A rod was oscillating inside the piston linked with a nozzle with a glass pipe 3 glued with epoxy resin Dimensions of the pipe were as follows: the length of \( L = 918 \) mm, the internal diameter \( d_o = 10,05 \) mm, and the wall thickness of 2 mm.

The vibration installation was controlled and monitored with a computer 11 by means of a piezoelectric IEPE accelerometer 2 of 4513 model by Bruel & Kjaer firm and a controller 8 of VR9500 type by Vibration Research Corporation firm via the specialized software VibrationVIEW.
The positioning controller 9 of TMC-2 model was used to adjust the table to the vibration generator. A cooling fan 14 was applied to prevent overheating of the vibration coil and the field excitation coil.

Gas pressure was measured with a piezoelectric gauge 4 of 8530C-15 model by Bruel & Kjaer firm, and the signal from the gauge was transferred to a three-channel voltage bridge amplifier 13 of ENDEVCO brand of 136 model by Bruel & Kjaer firm to be further registered with a digital oscilloscope 12 of DSO 3062A model by Agilent Technologies firm. The oscilloscope was connected to the computer via the RS-232 interface to process the data. The pressure gauge was screwed in the lower nozzle of the pipe.

![Figure 1. Basic diagram of the experimental installation.](image)

1 – vibration generator, 2 – piezoelectric IEPE accelerometer, 3 – flat piston, 4 – pressure sensor, 5 – glass pipe, 6 – thermal mass flow meter, 7 – traversing probe, 8 – controller, 9 – positioning controller TMS-2, 10 – power amplifier, 11 – control computer, 12 – oscilloscope, 13 – three-channel bridge voltage amplifier, 14 – cooling fan.

Mean velocities of gas $v$ were measured with a thermal mass flow meter 6 of ATT-1004 model by AKTAKOM firm in the radial and the axial directions using the traversing probe 7 by DICA firm that measured the distance in mm in the non-linear wave field near the open end of the pipe. The range of measurements for the mean gas velocity varied from 0.1 m/s to 25.0 m/s. The definition was 0.01 m/s, the allowable measurement error was ±5% of the measured value or ±1% of the range. The traversing probe was fixed in a stand placed next to the vibration installation which enabled to shift it vertically for a set distance (the value of $x = 0$ corresponded to the edge of the pipe).

**Experimental results**

The experiments resulted in oscilloscope charts of gas pressure for different excitation frequencies when transiting through resonance for the piston displacement amplitude equal to $l = 0.75$ mm.

The experimental data showed that oscillations of gas at the resonance are of non-linear character as the steepness of the leading edge is greater than that of the training edge. However, the shape of the
wave remains continuous. At the same time, the range of oscillation of the pressure at the resonance reaches 0.04 bar.

Figure 2 shows dependencies of the mean velocity of gas in the area of the open end of the pipe in the axial \( x \) and the radial \( r \) directions (\( r = 0 \) corresponds to the axis of the pipe) at the resonance frequency of \( \nu = 90.3 \) Hz at the amplitude of the piston displacement of \( l = 1.5 \) mm for the respective distances to the open end: \( x = 5 \) mm; 60 mm; 100 mm; 200 mm. At the distance of 5 mm, 60 mm from the open end of the pipe, structure of the gas stream contains an area of constant value of the gas velocity near the symmetry axis – the core of the stream corresponding to the velocity of 15 m/s, 7.5 m/s, further in the directions of edges of the pipe, there are areas of increase and then of an abrupt fall in the flow velocity with the corresponding velocities of 22.5 m/s, 15 m/s.

![Figure 2. Distribution of the mean velocity of gas in the radial direction in different sections of the external wave field of the pipe at the resonance frequency.](image)

At the same time, the maximum value of the velocity is near the edges of the pipe. Along with the recession from the end of the pipe to the external wave field, the difference of the velocities decreases, and the maximum value of the velocity is placed near the symmetry axis and equals to 14.5 m/s, while at the edges, an area of monotonous decrease of the velocity is observed. The occurrence of the velocity maximum near the edges is explained with a formation of an eddy motion when gas flows out of the pipe. A similar phenomenon was observed for the field of instantaneous gas velocities [5, 6]. At the distance of 200 mm, the mean velocity at the axis of the pipe equals to 13 m/s, which is less than the velocity near the open end at \( x = 5 \) mm. This is due to the expansion of the cylindrical stream along with recession from the open end.
Figure 3 shows values of the gas velocity depending on the excitation frequency at the axis of the pipe for \( x = 5 \text{ mm} \) at \( l = 1.5 \text{ mm} \).

![Figure 3. Values of the gas velocity depending on the excitation frequency at the axis of the pipe for \( x = 5 \text{ mm} \) at \( l = 1.5 \text{ mm} \). Dots mark the experimental results, and the solid line is Gauss approximation.](image)

Along with an increase of the frequency from a pre-resonance oscillation mode, a rapid increase of the mean velocity is observed, with the maximum value equal to 14.5 m/s at the resonance. After the resonance, along with a further increase of the frequency, the values of the velocity are decreased just as rapidly.

**Conclusion**

Mean velocities of gas in the area of the open end of the pipe were studied experimentally with non-linear oscillations of gas near its first eigenfrequency. The non-monotone character was identified for distribution of velocities related to the vortex motions at the outflow of oscillating gas from the pipe. Away from the open end, the structure of the flow similar to that of the stationary outflow from the pipe is observed.

**References**

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