Measurements of acoustic flow parameters in the orifice on non-linear regimes

A Bykov 1,2, A Komkin 1 and V Moskalenko 1

1 Bauman Moscow State Technical University, 5 Second Baumanskaya Street, Moscow, 105005, Russian Federation

2 E-mail: alecksbykov@mail.ru

Abstract. This research presents the results of measurements of the parameters of the acoustic jet from the orifice in the partitions on nonlinear regimes. The resulting dependences of jet velocity on the distance from the measurement point to the partition with the orifice are presented.

1. Introduction

In acoustics, nonlinear waves propagation processes at high sound pressure levels take place starting from certain amplitude of oscillating velocity in the orifice, and it can cause considerable changes in acoustic impedance. These changes can significantly affect the acoustic characteristics of the Helmholtz resonators [1, 2].

The study of the nonlinear properties of the orifice is devoted to a large number of works that are mainly experimental [3 – 12]. In these studies main focus was on the real part of the orifice impedance, defined as the acoustic impedance \( R \).

Additionally to direct measuring of the orifice impedance it is necessary to describe a shape of the gas-dynamic processes when a high-intensity sound passes through orifice in the partition to understand the mechanisms that forms the nonlinear impedance of the orifice. A proper form of jet-vortex motions in the air near the orifice was obtained in [5] by applying smoke particles to the measuring tube. Similar results for jet-vortex motions in a liquid were obtained in [8]. After then the studies of partition velocity in the orifice radius by mean of hot-wire anemometer took place. In [10] the partition velocity in the orifice was measured and it was found that velocity is related to the sound pressure in the chamber by a quadratic dependence. A number of studies on the characteristics of acoustic jets were performed in [13 – 15], it was shown that the process of jet formation with acoustic waves by leading them through an orifice has a complex character. Similar studies were carried out in [16 – 20] in the study of synthetic jets generators. Recently, methods of laser visualization for oscillatory processes were used in experimental studies of jet-vortex motions near the orifice [20 – 23]. At the same time, computer simulation methods for studying acoustic processes in the orifice area [24 – 26] find its application. However, most of these calculations were done with a constant flow. Moreover, with the help of computational methods it has not been possible to identify general properties of the orifice nonlinear impedance formation so far.

2. Problem definition
This study is devoted to obtaining reliable experimental data on the effect of the orifice diameter on the amplitude of the oscillation velocity in the orifice at high levels of sound pressure.

3. Experimental setup

In the measurements, we used an impedance tube with inner diameter $d = 99$ mm. At one end of the impedance tube partition with an orifice of certain diameter, $d_0$, was installed, at the other end – the source of sound, 450-watt loudspeaker. A narrow chirp signal that was formed by a signal generator with a bandwidth of 10 Hz around central frequency of 150 Hz and was applied to the speaker by mean of a power amplifier. The amplitude of the chirp signal varied, so that the sound pressure levels in the impedance tube could vary in the range from 85 dB to 150 dB. The sound pressure in the impedance tube was measured by two 1/4-inch condenser microphones. Signals from microphones after passing a signal amplifier were subjected to spectral analysis. Further on, the obtained spectra were processed in a computer by the method of transfer functions $[27, 28]$ in order to obtain the characteristics of sound pressure directly at the partition with an orifice. Simultaneously with the acoustic measurements and processing, there was performed using the Pitot tube of the oscillatory velocity in the opening of the partition and its vicinity along the longitudinal axis of symmetry.

4. Results

Figure 1a shows the dependences of the axial longitudinal velocity, $V_0$, in the area of 10 mm diameter orifice from distance to the partition expressed in calibers, $\kappa$, at various sound pressure levels. A characteristic feature of the curves presented in this figure is that in the initial section, at distances of up to $\frac{1}{2}$ caliber, there is a gradual increase in the measured speed. At a distance of the caliber, the longitudinal axial velocity reaches its maximum and further on gradually reduces. Additionally, as curves show with the sound pressure level increase in the impedance tube, the values of the longitudinal velocity increases through the entire length of the measuring section. Moreover, the higher sound pressure level, the greater range of changes of the longitudinal velocity on the measuring section.

Figure 1b shows the dependences of the longitudinal axial velocity, $V_0$, on the caliber distance, $\kappa$, to the measurement point from the partition for three orifice diameters of 5, 10 and 15 mm. The curves presented here corresponds with the curves in fig. 1a. With the decrease of orifice diameter, the corresponding curve shifts upward along the ordinate axis. However, the value of the axial velocity in the cross section of the orifice remains approximately constant.

![Figure 1](image_url)
κ - calibers: a – for different sound pressure levels at the partition with an orifice of 10 mm diameter; b – for partitions with different diameters at a sound pressure level of 140 dB.

![Figure 2](image-url)

Figure 2. Experimental results of the effect of sound pressure level, $L_n$, at the orifice on axial longitudinal velocity $V_0$ for different diameters: $\Diamond d=5\text{mm}$, $\triangle d=7\text{mm}$, $\Delta d=10\text{mm}$, $\blacksquare d=12\text{mm}$, $\blacklozenge d=15\text{mm}$.

Figure 2 shows the dependence of the axial longitudinal velocity, $V_0$, in the orifices on the sound pressure level, $L$, at the partition. As expected from data in figure 2, the axial velocity in the cross section of the orifice does not depend on the diameter and is determined only by the sound pressure level. Presented in figure 3 dependence can be approximated by the following function:

$$V = 0.013(L_n - 113)^2 + 2.$$

5. Conclusion

The conducted studies allowed us to establish the characteristics of the oscillatory motion of the medium in the vicinity of a partition with a hole on nonlinear operating regimes. It is shown that the velocity in the hole does not depend on its diameter, but is determined only by the level of sound pressure at the partition.

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