Oscillations of a homogeneous gas and drift particles in an external wave field an open tube

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Abstract. The dynamics of a particle and a homogeneous gas in the external wave field open tube by different values of amplitude of piston travel at the first eigenfrequencies in the shock-free mode are experimentally investigated. It is found the velocity distribution of the gas flow in the external the wave field open tube in different cross sections at various amplitudes of piston travel. The dependence of the coordinates of the particle along the axis the outside of the tube at on the time at resonance frequency are obtained. The comparison of velocity flow of the gas and particle drift in the external the wave field open tube is performed.

1. Introduction
At present the study of wave dynamics of dispersed media is an urgent [1]. Such media are often found in modern technology. Therefore, it is important to study the resonance oscillations media in tubes and their influence on the dispersion system, for example, aerosols (a mixture of gas with droplets or solid particles). In the theoretical investigation of nonlinear oscillations of gas in an open tube having significant difficulties caused by different effects of a nonlinear wave field at the exit cross section. An analysis of theoretical and experimental work is shown in detail in review [2]. Discontinuous oscillations of gas near nonlinear resonances were studied [3]. External wave field in the mode of formation of shock waves was investigated in [4, 5]. Various nonlinear effects in the propagation of waves in the tube with the flanges on end are detected [6]. In experiments [7] appearance at the open end tubes of pulsating jet and vortex rings near a linear of the resonance was found.

When modeling the coagulation and deposition of aerosols arising the problem of studying the motion of single particles in a nonlinear wave field of the tube. The results of experimental studies of the motion of particles with different physical and geometrical parameters at nonlinear oscillations of a homogeneous gas along the axis of the open tube near the subharmonic resonances in [8, 9] are given. In these papers the shock wave mode of oscillation of gas at large excitation amplitudes (of the order of 0.1-0.4 bar) is considered. The shock-free mode at low amplitudes of excitation (about 0.01 bar) when the loss to the walls become significant, has not been studied.

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In this connection the aim of this work is to study the dynamics of particle and determination of the velocity distribution of the gas flow in the external the wave field open tube in different cross sections at various amplitudes of piston travel at the first eigenfrequencies in the shock-free mode.

2. Experiment
Experiments carried out on a previously used to study the coagulation and deposition of the aerosol [10], which was upgraded to study the oscillation of a homogeneous gas and particle motion in the external the wave field open tube. Longitudinal oscillations of the gas in a horizontal quartz tube length of 1.06 m and of inner diameter of 0.0365 m are created by a cylindrical piston with a flat surface. Piston is driven by means of the vibration generator TV51075 with a power amplifier VAA 120 firms TIRA. The measurement and control of the sinusoidal oscillations are done by the software module SincVIEW (VR610) installed on the computer by means of a piezoelectric IEPE accelerometer with integrated electronics 4513-001 firm Bruel & Kjaer and controller type VR8500-1 firm Vibration Research Corporation. The values of frequency and of amplitude of piston travel are set with an accuracy of better than 10^{-6} Hz and 10^{-7} m, respectively. Experiments were performed at gas oscillations near the first eigenfrequency \( \nu_1 = 78.6 \) Hz.

For measurement the gas flow velocity with an accurate to 0.01 m/s was used thermoanemometer ATT-1004 firm AKTAKOM with a thermistor placed in a small measuring sensory probe head on a telescopic handle. Telescopic handle attached to a traversing gear that allowed her to move along and perpendicular to the pulsating jet. Data from the hot-wire anemometer are supplied to the computer across RS-232, and are processed by a special program.

For studying of drift of a particle along an axis of a tube the fishing line with a diameter of 0.3·10^{-3} m was stretched. Fishing lines with tension was fixed on the one hand near the piston and the other hand on rack outside of the pipe at a distance of 0.3 m. The particle represented a washer from expanded polystyrene with a diameter of 0.9·10^{-3} m and a thickness of 0.4·10^{-3} m. The cylindrical polyethylene tubule 2.1·10^{-3} m long with an internal diameter of 0.8·10^{-3} m and external diameter of 1.3·10^{-3} m was inserted into an opening of a washer. The weight of the particles is \( m = 4.6 \) mg. Visualization of particle motion was carried with a digital SLR camera Canon EOS 650D with the lens Kit EF-S 18-55mm IS II Black. Particle was placed outside of the tube at a distance of 0.03 m from the open end and oscillations were started. For processing the results of the data transferred from the camera to the computer. Video of by means Virtual Dub 1.5.3 editor broken into frames and each frame correlated with the time from the start of shooting that allows fixing the position of a particle at different times.

3. Results
Figure 1 shows the dependence of the velocity of gas flow on the distance \( r \) from the tube axis for different distances from the open end of the tube. At small distances from the open end of the tube \((x = 5·10^{-3} \) m) accurately expressed stream kernel with constant values of the gas velocity is observed. At a distance \( x = 14·10^{-3} \) m core flow practically disappears. And a smooth change in the distribution of the gas flow velocity to the value \( \nu = 0.2 \) m/s is observed that is connected with dispersion of a kernel. Further increase in distance leads to that the value of the velocity of the gas from maximum its value decreases to \( \nu = 0.1 \) m/s. Thus, the increase of the distance from the open end of the tube more than 14·10^{-3} m leads to the fact that in the dependence velocity of gas on the radial coordinate constant values are not observed. Thus there are a smooth change of velocity values. And already at a distance \( x = 52·10^{-3} \) m are available only insignificant increase in speed of gas from \( \nu = 0.1 \) m/s. Comparison of the results with the mode with the formation of shock waves, in which the core flow is 1.5 to 6 radii of the tube indicates that the core flow in the shock-free mode is less than 0.7 the radius of the tube. This is due to the significant influence of the dissipative losses.

Figure 2 shows the values of the gas flow velocity to the tube axis on the amplitude of piston travel at different distances from the tube end. Obviously, increasing the amplitude of piston travel leads to an increase of the gas velocity for all distances from the open end of the tube. At the same time at a
distance of \( x = 5 \times 10^{-3} \) m from the end of the tube nonlinear character of the increase the gas flow velocity in 4.5 times from \( u = 0.6 \) m/s at an amplitude of \( l = 0.25 \times 10^{-3} \) m to \( u = 2.7 \) m/s at amplitude \( l = 1.75 \times 10^{-3} \) m is observed. Further increase in the distance leads to that an increase in velocity with increasing amplitude of piston travel becomes linear. Figure 3 shows the dependence of the flow velocity along the tube axis of the distance from the open end for different values of amplitude of piston travel. As seen from the figure, there is a sharp decrease in the velocity: for example, for \( l = 1.75 \times 10^{-3} \) m increase in the distance by 10 times (from \( x = 5 \times 10^{-3} \) m to \( x = 52 \times 10^{-3} \) m from the open end of the tube) leads to reduction of the velocity of approximately by 25 times (from \( u = 2.7 \) m/s to \( u = 0.1 \) m/s). The area of the jet is practically not observed at a distance equal to the inner diameter of the tube, as opposed to the regime with the formation of shock waves, where this region occupies the to 5 dimensions of the internal diameter of the tube [11]. It is connected with expansion of a cylindrical jet during removal from an open end already at a distance of \( x = 14 \times 10^{-3} \) m.

![Figure 1](image1.png)

**Figure 1.** The dependence of the velocity of the gas flow on the distance from the axis of the tube at the amplitude of piston travel \( l = 1.75 \times 10^{-3} \) m: 1 – \( x = 5 \times 10^{-3} \) m, 2 – \( x = 14 \times 10^{-3} \) m, 3 – \( x = 28 \times 10^{-3} \) m, 4 – \( x = 42 \times 10^{-3} \) m, 5 – \( x = 45 \times 10^{-3} \) m, 6 – \( x = 52 \times 10^{-3} \) m.

![Figure 2](image2.png)

**Figure 2.** The dependence of velocity of the gas flow on the tube axis on the amplitude of piston travel: 1 – \( x = 5 \times 10^{-3} \) m, 2 – \( x = 14 \times 10^{-3} \) m, 3 – \( x = 28 \times 10^{-3} \) m.

![Figure 3](image3.png)

**Figure 3.** The dependence of velocity of the gas flow on the tube axis on the distance from the open end: 1 – \( l = 1.75 \times 10^{-3} \) m, 2 – \( l = 1.25 \times 10^{-3} \) m, 3 – \( l = 0.75 \times 10^{-3} \) m, 4 – \( l = 0.5 \times 10^{-3} \) m, 5 – \( l = 0.25 \times 10^{-3} \) m.

Now consider the dynamics of the particle. In the external wave field of the tube significant oscillations of the particle was not observed. Figure 4 shows the dependence of the coordinates of the particle with \( m = 4.6 \) mg along the tube axis from the time at the resonance frequency of the amplitude
of piston travel \( l = 1.75 \times 10^{-3} \) m. The points – experimental data, the solid line – approximation. The data allows to determine the drift velocity of the particle from the open end towards the outside of the tube. This velocity was determined as the ratio of a given distance to time of the travel this distance. As a result, for a given amplitude of piston travel have the value \( V_p = 0.36 \) m/s. Measurement of the gas flow velocity in the external the wave field for the conditions of this experiment gave the value of \( V = 0.8 \) m/s. Unlike the velocity due to the presence of friction on the fishing line, and the influence of the hydrodynamic flow around the particle.

![Figure 4. Dependence of the coordinate of the particle along the tube axis on the time near the open end outside of the tube for the amplitude of piston travel \( l = 1.75 \times 10^{-3} \) m. The solid line - approximation.](image)

4. Conclusions

Thus the dynamics of particles and of the gas flow in the external the wave field open tube at of amplitude of piston travel at the first eigenfrequencies in the shock-free mode are experimentally investigated. It was found that the core of the flow in the shock-free current is less than 0.7 the jet radii that is 2-9 times less than in the case of oscillations with the formation of shock waves. Increasing of amplitude of piston travel leads to an increase in the gas flow velocity for all distances from the open end of the tube. It is revealed that near the open end of the tube with increasing of amplitude of piston travel by 7 times velocity of the flow of gas in the resonance increases by 4.5 times, and increasing the distance by 10 times reduces the velocity of approximately 25 times. It is shown that near the open end outside the tube is an increase in the particle velocity with an increase in the piston displacement amplitude. The motion of the particle from the open end along the axis of the pipe takes place practically without hesitation. It is shown that near the open end outside the tube is an increase in the particle velocity with an increase in the amplitude of piston travel. The motion of the particle from the open end along the axis of the tube takes place practically without oscillations.

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