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ACTION OF A NONHARMONIC ACOUSTIC SIGNAL ON A TURBULENT JET

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The influence of the shape of an acoustic signal acting on a jet on the aerodynamic characteristics of the jet is investigated based on an analysis of experimental data. It is shown that in the considered case of a nonharmonic acoustic signal the attenuation of mixing in high-frequency acoustic excitation turns out to be more substantial than in harmonic excitation.

In generation of a sound of pure tone by various emitters, in addition to the fundamental tone component, the components at harmonic frequencies can also be formed in the spectra of the acoustic signal due to the nonlinearity of the acoustic characteristics of the emitter (dynamic loudspeaker). The relative level of harmonic components of higher orders increases, as a rule, with increase in the level of the exciting signal. In our experiments on acoustic excitation of turbulent jets [1, 2], the level of harmonics was much lower than the level of the fundamental component; therefore, the presence of these harmonics had no substantial effect on the process of action of acoustic vibrations on a jet. At the same time, there are data that indicate that the efficiency of control of the aerodynamic characteristics of a turbulent jet can be improved using acoustic action by multifrequency excitation at the fundamental frequency and its subharmonics with the corresponding shifts of their phases [3, 4]. The shape of the acoustic signal can noticeably differ from a sinusoidal one. A change in the signal shape can lead to a change in the pressure gradient in the sound (acoustic) wave acting on the jet and generating the formation of vortex disturbances (vortex rings).

Below, we present the results of an experimental investigation of the influence of the shape of an acoustic signal acting on a jet on the jet's aerodynamic characteristics. The change in the average velocity and longitudinal velocity pulsations at a fixed point of the axis of the jet ($x/d = 8$) in the case of transverse acoustic irradiation of the jet is investigated experimentally for different frequencies, levels, and shapes of the acoustic signal. The jet under study was flowing out of a nozzle of diameter $d = 0.02$ m; the velocity of outflow was $u_0 = 10$ and 20 m/sec; the corresponding Reynolds numbers were $\mathrm{Re} = u_0 d/\nu = 1.4 \cdot 10^4$ and $2.8 \cdot 10^4$. The initial boundary layer was nearly laminar.

Acoustic excitation ($L_0 \leq 130$ dB) was carried out by an electrodynamic loudspeaker. A harmonic electric signal (to generate harmonic acoustic excitation) or periodic rectangular electric pulses which were tconverted to periodic acoustic signals of a certain shape were fed to the emitter coil. Each rectangular electric pulse fed to the coil of an electrodynamic emitter led to the formation of pressure pulses of different signs in the acoustic field. The change in the shape of these signals was attained by variation of the parameters of periodic rectangular pulses which are characterized by the period T, the corresponding level of electric voltage, and the ratio of the duration of the pulse T_0 to the period $k = T_0/T = 0.1$, 0.3, 0.5, and 0.9.

Figure 1a-c presents oscillograms of pressure pulsations measured using a microphone near the edge of the nozzle for $f_s = 3000$ Hz at $L_0 = 120$ dB; the narrow-band spectra corresponding to them for different values of the parameter $k = T_0/T = 0.1$, 0.5, and 0.9 and in the case of a harmonic electric signal are shown

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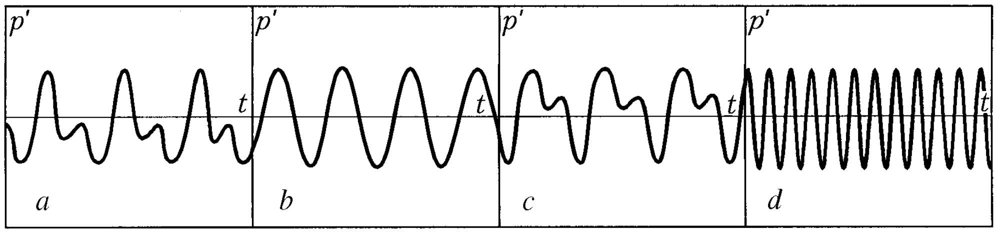


Fig. 1. Oscillograms of pressure pulsations near the nozzle edge: a) f_s = 3000 Hz and k = 0.1; b) 3000 and 0.5; c) 3000 and 0.9; d) 10,000 and 0.1.

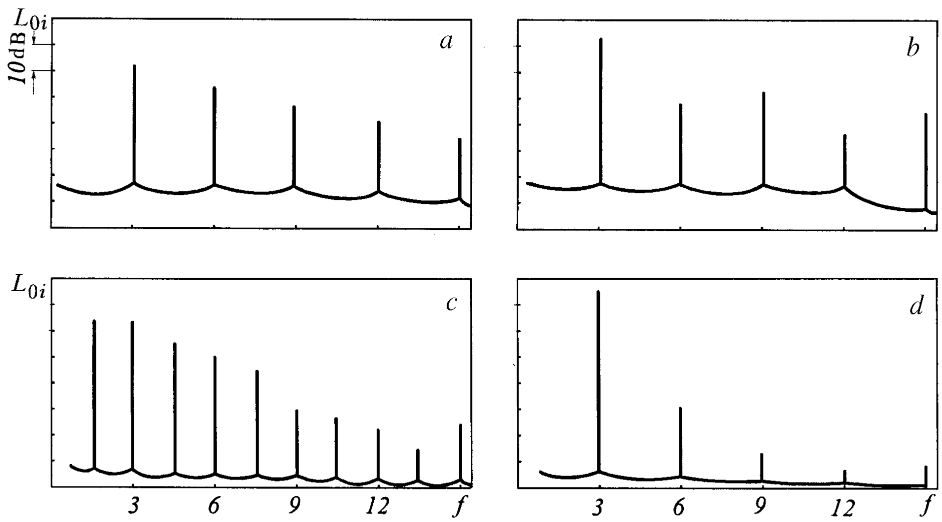
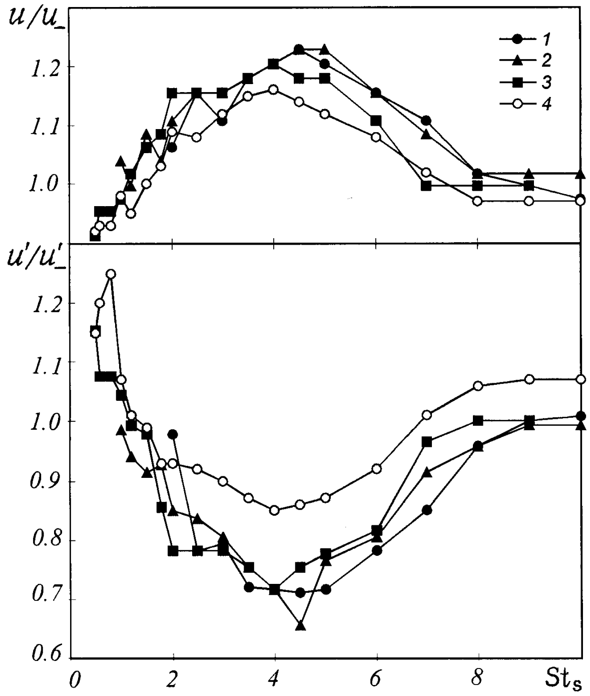


Fig. 2. Narrow-band spectra of pressure pulsations near the nozzle edge for f_s = 3000 Hz: a) k = 0.1; b) 0.5; c) 0.9; d) harmonic electric signal.

in Fig. 2. It should be noted that these spectra are characterized by a great number of comparatively intense harmonics. Hence, a multifrequency acoustic excitation of the jet is essentially realized here. In this case, the frequency of rectangular electric pulses that were fed to the emitter was subsequently used as a characteristic frequency f_s. This choice is due to the fact that at this frequency for all k the level of sound pressure is at least 5–10 dB higher than the level of harmonics. If the shape of the acoustic signal is nearly sinusoidal, the level of the harmonics is quite low (it is 30–50 dB lower than the level of the fundamental tone), as follows from the spectrum (see Fig. 2d). It is of interest to note that, as the frequency f_s increases, irrespective of the values of the parameter k, the oscillograms and the spectra increasingly correspond to harmonic vibrations, in particular when the frequency approaches f_s = 10,000 Hz (Fig. 1d).

Figure 3 gives the dependences $u/u_{-} = F_1(k, \mathrm{St_s})$ and $u'/u'_{-} = F_2(k, \mathrm{St_s})$ at a fixed point on the axis of the jet x/d = 8 for u_0 = 10 m/sec (Re = $1.4 \cdot 10^4$), obtained on the basis of thermoanemometric measurements. The corresponding results for the case of harmonic excitation are also presented there. The most interesting results were obtained in high-frequency excitation ($\mathrm{St_s}$ = 3–8). Here for different values of k the decrease in u'/u'_{-} and the increase in u/u_{-} are more noticeable than in harmonic excitation.

It should be noted that for the same value of the level of sound pressure near the edge of the nozzle L_0 = 130 dB as the velocity u_0 increased from 10 to 20 m/sec the efficiency of high-frequency excitation of the jet by a nonharmonic signal decreased in our experiments. Thus, for u_0 = 10 m/sec at the point x/d = 8 on the jet axis the minimum of u'/u'_{-}, when $\mathrm{St_s}$ = 4, for a harmonic and a nonharmonic signal was equal to 0.9 and 0.7 respectively, whereas for u_0 = 20 m/sec these values were equal to 0.92 and 0.82. This appears to be due to the fact that in both cases the values of u'_s/u_0, which are equal to 1.5 and 0.75% respectively,



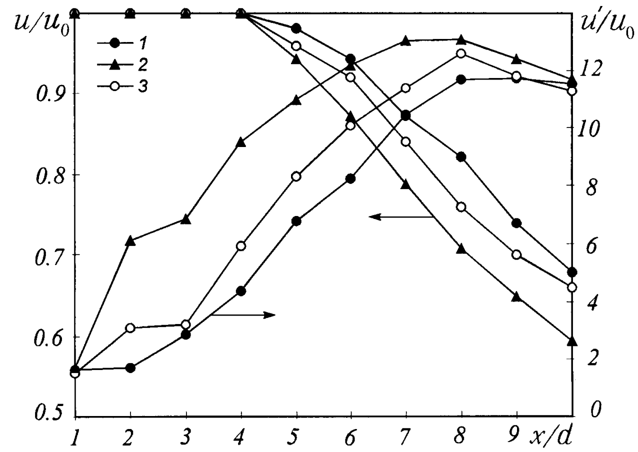


Fig. 3. Dependences $u/u_{-} = F_1(k, \mathrm{St_s})$ and $u'/u_{-} = F_2(k, \mathrm{St_s})$ at the point $x/d = 8$ on the jet axis for $u_0 = 10$ m/sec, $L_0 = 130$ dB, and $u'_s/u_0 = 1.5\%$: 1) $k = 0.9$; 2) 0.5; 3) 0.1; 4) harmonic electric signal.

Fig. 4. Change in the average velocity u/u_0 and in the root-mean-square values of the velocity pulsations u'/u_0 along the jet axis in the case of transverse acoustic excitation $\mathrm{St_s} = 6$, $u_0 = 10$ m/sec, $L_0 = 130$ dB, and $u'_s/u_0 = 1.5\%$: 1) $k = 0.9$; 2) nonirradiated jet; 3) harmonic excitation.

differ. The values of u'_s were found from the relation $u'_s = p'_s/\rho a$. Since the level of sound pressure is determined by the known dependence $L_0 = 20 \log (p'_s/p_0)$, to preserve the ratio u'_s/u_0 constant as the velocity of outflow of the jet increases twofold (from 10 to 20 m/sec), one should increase L_0 by 6 dB (i.e., to attain a substantial effect for $u_0 = 20$ m/sec, it is necessary to ensure the level of sound pressure $L_0 = 136$ dB).

Figure 4 shows the dependences of u/u_0 and u'/u_0 on the longitudinal coordinate for a turbulent jet ($u_0 = 10$ m/sec) in harmonic and nonharmonic ($k = 0.9$) acoustic excitation ($\mathrm{St_s}$ = b, $u'_s/u_0 = 1.5\%$) and in the absence of excitation. These dependences, just as the data of Fig. 3, illustrate a higher efficiency of nonharmonic excitation in comparison to the harmonic one for realization of the effect of attenuation of turbulence.

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NOTATION

x, longitudinal coordinate; d, diameter of the exit cross section of the nozzle, m; u_0, velocity of outflow of the jet, m/sec; u, average velocity on the jet axis, m/sec; u_{-}, average velocity on the jet axis in the absence of acoustic excitation, m/sec; u', root-mean-square value of the velocity pulsations, m/sec; u'_{-}, root-mean-square value of the velocity pulsations in the absence of acoustic excitation, m/sec; f_s, acoustic-excitation frequency, Hz; L_0, total level of sound pressure, dB; L_{0i}, level of sound pressure in the frequency band with a width of 8 Hz, dB; f, average frequency in the band with a width of 8 Hz; p', pressure pulsations, Pa;

p'_s, root-mean-square value of the sound pressure acting on the jet, Pa; $p_0 = 2\cdot10^{-5}$ Pa, threshold value of the sound pressure; u'_s, root-mean-square values of the vibrational velocity in the sound wave which excites the jet in the direction of its propagation near the nozzle edge, m/sec; a, velocity of sound, m/sec; ρ, density of the escaping gas, kg/m^3; $St_s = f_s d / u_0$; ν, kinematic coefficient of viscosity; T, period of rectangular electric pulses, sec; T_0, pulse duration, sec; k, parameter of periodic rectangular electric pulses.

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