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ABOUT EFFECTS OF RECTIFICATION OF ACOUSTIC WAVES

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The work is concerned to effects of steady flows formation under action of acoustical waves near by orifices and solid bodies. The theories of acoustical streaming and "quartz wind" have been developed but these effects are different from the effect of acoustical rectification. The main difference is characteristic value of the effect. According to the theory of acoustic streaming steady flows appear in second approximation with respect to wave amplitude but under certain conditions steady flows amplitude could be comparable to oscillation velocity of sound wave. Three experiments on acoustical rectification are considered in current work. In one of those experiments the formation of signal corresponded to wave envelop near by the outlet of conical concentrator was observed. Also qualitative analysis of the effect was conducted. It was shown that the effect of acoustical rectification can be described by two dimensionless hydrodynamic numbers. According to experimental data qualitative correspondence between those criterions and effect's structure has been determined.

It is well known that secondary streams are formed nearby oscillating bodies. A number of works deal with such effects, for example classical ones are [1], [2]. Also it is known that period-averaged force acts on the oscillating body and, therefore, on the medium [3], which leads to stationary flows formation. The same phenomenon occurs in case of immovable body placed into acoustic field with wavelength mach larger than characteristic size of the body. Under certain conditions flow velocity could be comparable to oscillating velocity amplitude. If incoming wave is amplitude modulated the presence of asymmetrical body would lead to formation of spectral component corresponded to envelop frequency. On the analogy of electro engineering this phenomenon could be called an acoustical rectification.

Experimentally the acoustical rectification was observed nearby an outlet of conical concentrator. The conical horn with square cross-section was used as the concentrator. The size of the inlet was 15mm, and the size of the outlet was approximately 0.2-0.4mm. Due to the nonlinear properties of the outlet the jet was formed near by the outlet. The observation of jets in such small scale is hard challenge due to this reason two ultrasonic waves with frequencies close to each other were used and the sound pressure on difference frequency was measured near the outlet. The jet of variable velocity is assumed to behave as monopole sound source. According to known relation for monopole source it is possible to estimate the velocity amplitude of the jet.

The sketch of the experiment is shown on Fig. 1. Ultrasonic transducers 1 radiated ultrasonic waves with close frequencies into the horn 3. Incoming sound pressure level of ultrasound was measured by microphone 2. The horn was fixed in the isolating screen 4. The low-frequency microphone 5 was used for measurement of sound level of difference frequency on the distance of 2 cm from the outlet. Taking into account small size of the outlet the low frequency microphone can be considered to be placed into the far field of the monopole sound source.

The dependence of the low-frequency pressure amplitude versus envelop frequency (difference frequency in this specific case) was experimentally obtained. To calculate the jet velocity amplitude the following expression for monopole source was used:

$p = \frac{\pi\rho_0 F d^2}{8R} u$, where ρ_0 – density of the air, F – difference frequency, d – outlet diameter, R – distance between outlet and low-frequency microphone, u – jet velocity amplitude. The dependence of the relation $\frac{U_0}{u}$ (where U_0 is the amplitude of the ultrasonic wave oscillating velocity) versus difference frequency is presented on the Fig 2. The maximum value of the jet velocity is equal to 2.5% of ultrasonic oscillation velocity. But this estimation is understated. The reflection of ultrasonic wave from the inlet was neglected. Also the reflections of the ultrasonic wave from the different cross-sections of the horn were not considered.

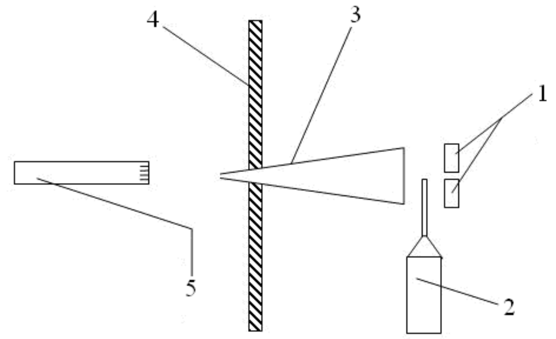

Fig. 1. Skecth of the experiment

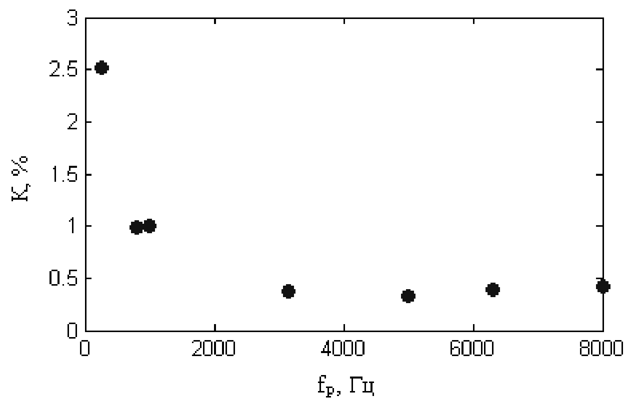

Fig. 2. Conversion coefficient versus difference frequency

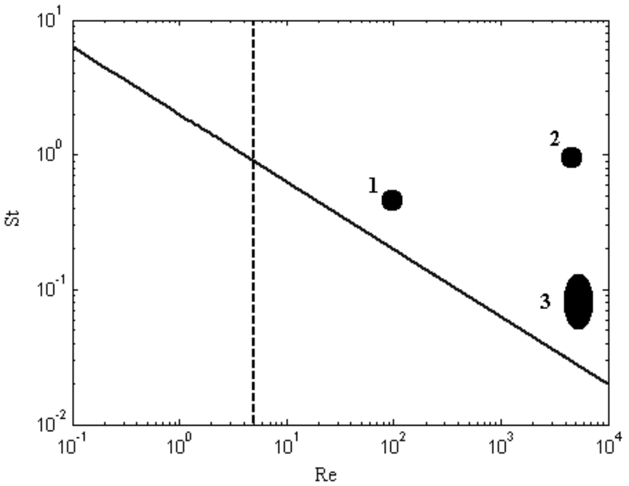

Fig. 3. Re-St Domain

If the low frequency sound is assumed to be the result of parametric interaction then according to [4] its amplitude should be one order less.

I.V. Lebedeva has conducted a number of experiments dedicated to jet formation at the open end of a waveguide [5]. The jet velocities in her experiments were very close to oscillation velocity amplitude of sound wave.

Let us consider a qualitative picture of the effect. It was shown in [6] that the problem of oscillating body in viscous liquid can be fully described by two dimensionless hydrodynamic numbers, i.e. the Reynolds number and the Stroukhal number. Obviously the problem of jet formation nearby the outlet can be fully described by the same parameters. Thus it is natural to consider the phenomenon on the domain of these numbers. Let us determine the region where the phenomenon of acoustical rectification could take place. At first, the laminar streaming is symmetrical, thus period-averaged velocity field does not contain constant component. In this way the first condition of acoustical rectification is at least slightly turbulized streaming, i.e. relatively high Reynolds numbers. The exact determination of this value is complicated but in reviewed experiments the phenomenon takes place under $\mathrm{Re} \approx 5 \div 10$. The dashed line on the Fig. 3 corresponds to value Re = 5. Also the displacement amplitude shall be higher than boundary layer size, in other words the following relation shall be met:

$$\sqrt{\frac{St \cdot Re}{4}} > 1$$

Here as the Stroukhal number the relation $St = \frac{2a}{L}$ is considered, where a – displacement amplitude, L – characteristic size of a body or an orifice. The Reynolds number has form: $Re = \frac{uL}{\nu}$, where u – oscillation velocity amplitude ν – cinematic viscosity of the medium.

The solid line on Fig. 3 represents the number of points where displacement amplitude is equal to boundary layer thickness. Finally, the Re-St domain is divided into four regions, the effect of the jet formation (acoustical rectification) can take place only in the region which is above the solid line and is left from the dashed one. On the figure the regions corresponded to the described experiment of rectification of ultrasonic wave (region 1), experiments conducted by I.V. Lebedeva (region 2) and experiments by E.D. Sorokodum (region 3) are marked.

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