Research Article
Management of the Acoustic Characteristics of Jet Streams

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Abstract: The objects of research are devices, which generate and suppress the acoustic and wave pressure oscillations. Purpose of the study is the classification of oscillations generating devices, description of the physical principles of acoustic waves generation. The schemes of the most common sound generators-whistles are discussed. The gas-jet sound generators are described separately. It is shown that a simple cylindrical head at the supersonic nozzle can both enhance the acoustic emission and serve as an effective silencer. The comparison of acoustic emission of a supersonic jet and a jet, flowing into a cylindrical head is given. The results presented in the study can be recommended by the developers of whistles, sirens, other acoustic generators, installations for thermo-acoustic hardening metals, metallurgical blast devices.

INTRODUCTION

Purpose-Classification of devices for generating oscillations, description of the physical principles of the generation of acoustic waves, study the acoustic characteristics of the resonators. Large amplitude of low-frequency pressure oscillations can lead to undesirable consequences and be hazardous to the structural elements. However, in many technical applications, on the contrary, it is required to generate a powerful acoustic emission of a given spectrum. It is an acoustic generators, whistles and sirens. Very promising is the usage of pulsating flows in thermo-acoustic metal processing (Vorobeva and Uskov, 2012), powder metallurgy (Uskov *et al.*, 2013), dispersion devices (Sizov, 1991), gas metal cutting, as well as in other branches of science and technology.

In metallurgy, there are a number of processes (Yavoysky *et al.*, 1985) associated with the usage of supersonic gas jets. In steel production (Sizov, 1987) they are used in the converter and open-hearth production. The purpose of the jets control in metallurgical plants is in the formation of jet streams with the necessary characteristics for the intensification of heat- and mass transfer processes. Control systems and actions should be as simple and low power-consuming as possible. For management purposes, it is important to have a physically unstable process, with a non-unique state.

The requirements, listed above are satisfied by the propagation of supersonic jets in channels with a sudden expansion of the cross section (Bulat *et al.*, 2010, 2012), which, in a wide range of underlying parameters change, is unsustainable, is accompanied by the pulsations of pressure and the jets wave structure. The task of studying the fluctuations in the cylindrical channel was first formulated by Jungowski (1967).

MATERIALS AND METHODS

Classification of oscillation generating devices: All variety of oscillation generating devices can conventionally be divided into several types.
By the principle of operation:

- Continuous and pulse operation

By the type of working fluid:
- Gas-dynamics
- Hydrodynamic
- Electro-dynamic

By the principle of sonic waves excitation:
- Due to fluctuating flows (sirens, pulsators)
- Due to vortical streams (vortical whistles)
- Due to the presence of resonators and acoustic feedback in the systems (whistles)
- Due to the flexible membrane
- Due to non-stationary shock-wave structures, arisen in the stream
- Due to the consumption mechanism
- Due to the interaction of gas-liquid flows with various obstacles

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- Due to resonance-thermal effects
- Due to different combinations of these principles

By type of environment:

- Air acoustic field
- Hydro-acoustic field

Whistles: The following whistles have gained a widespread use: Havre whistles, Hartmann whistles, Galton whistles, vortical whistles, Levasseur whistles. Whistles are the mechanical devices for converting the kinetic energy of the jet into the energy of the acoustic oscillations. The principle of operation is based on the occurrence of self-oscillatory processes in the jet and the surrounding area during the interaction of the jet with sharp edges or resonant cavity. Mechanism of self-oscillations is based on a combination of jet instability effects and feedback through the acoustic field in the cavity.

At very small velocities of the jet outflow the vortices occurs inside it in the critical layer and the axis of the jet remains straight. At a certain threshold value of the jet velocity the jet loses its stability and its axis bents, the amplitude increases with the increase of distance from the source, until a so-called vortex trail is formed. All this is due to loss of the system's stability under the influence of random perturbations. Vorticity perturbations arising in the jet in the vicinity of the nozzle edge are amplified and transferred to the jet downstream, forming localized vortices. Vortices interact with the edges of the resonator and (or) the wedge generate sound perturbations, which are amplified by the resonator and interact with the jet. Thus, the feedback closes. Let's consider some types of gas sonic generators.

Havre whistle: During a flow of the flat stream around the resonator throat (Fig. 1) some of the gas, due to ejection and inertial properties, falls into the resonator. Inside the resonator the complex vortical flows are occurs. Perturbations of the mass influx propagate inside the resonator in the form of compression waves. Reflected from the resonator's walls, wave perturbations reach its throat, causing a deflection of the flow from the throat, thereby providing an outflow of some air mass from the resonator. Mass ejection from the resonator causes perturbations and, reflecting off the walls in various ways, as a result affects the flow in the resonator throat, deflecting it again into the resonator cavity. The cycle repeats.

Galton whistle: During interaction of annular jet with the resonator edges (Fig. 2) self-oscillations are excited in the stream-resonator system. During this the part of the stationary gas flow energy is converted to acoustic emission and in the resonator cavity intense pressure pulsations are excited. The generation process will be supported, if the energy in the oscillatory system will exceed the losses due to emission and friction.
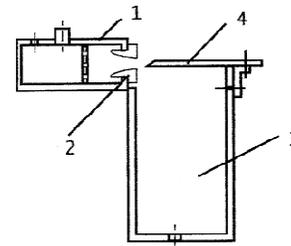

Fig. 1: Havre whistle
  1: Receiver; 2: Nozzle unit; 3: Rectangular resonator;
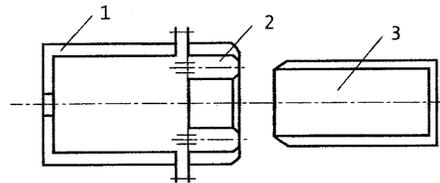 4: Flexible wedge

Fig. 2: Galton whistle
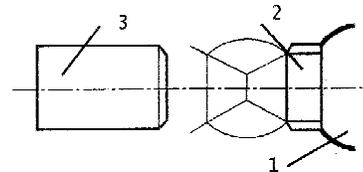 1: Receiver; 2: Nozzle unit; 3: Resonator

Fig. 3: Hartmann whistle
  1: Receiver; 2: Round nozzle; 3: Cylindrical resonator

Hartmann whistle: Hartmann whistle (Fig. 3) is a sound source with a supersonic jet. During the outflow of a supersonic jet, a system of shocks occurs, the jet pulsates, interacting with the resonator, spatial pressure oscillations is observed in it.

Gas-jet generators: Gas-jet pressure pulsations generators-are mechanical generators of pressure waves (shock and acoustic), which have no moving parts and a source of energy in which is the kinetic energy of the jet. Analysis of the processes that accompany the spread of supersonic jets in channels of various shapes, peculiarities of the wave structure of flows in the channels, revealed connection of acoustic field characteristics with the regimes of jets interaction with each other and with the walls of the channels, suggests the possibility of controlling the geometric, gas-dynamic and the acoustic parameters of the jets. Performing a discrete or continuous geometric, consumable, acoustic, thermal influence, or a combination thereof in various forms on the gas flow in the paths, it is possible change the flow regime or the wave structure of the jets, to control the distribution of gas-dynamic parameters in the jets. The geometric influence should be understood as the impact of the flow by the channel configuration, the consumable-as blowing gas into the canal or extraction of gas from the

boundary layer on the canal walls, varying the gas consumption rate through the nozzle.

For fixed parameters of the jet at the nozzle exit the following the flow regimes can be obtained by applying the nozzle heads of different diameters (Bulat *et al.*, 2012):

- High flexural-torsional oscillation of the jet
- Low frequency self-oscillations of the jet wave structure
- Stationary regime with the formation of the central shock, occupying the entire cross-section of the jet, behind which the gas velocity becomes subsonic
- Stationary regime with the formation of a peripheral supersonic annual jet and axial supersonic flow
- Stationary regime with the formation of oblique shocks system in the jet

With the high frequency oscillations it is possible to increase the opening angle of the boundary layer. Low-frequency oscillations stabilize the supersonic jet core, increase its range. Organization of high-frequency oscillations, modulated by low-frequency ones, can simultaneously increase the range of supersonic core.

Usually, the jet generator of a pulsating pressure consists of the working chamber, connected to a source of compressed gas and the flow interrupting device, made in a form of a kinematically connected plates, which covers the inlet opening in the working chamber and the valve, which closes the outlet opening.

The disadvantage of such devices is the limitation in amplitude-frequency characteristics of the sonic oscillations, determined by the interruption of the flow, as well as low oscillation frequency.

We can formulate the task of creating the oscillations excitation generator, which have an extended range of sound oscillations parameters. Figure 4 shows a possible scheme for such a device.

It consists of a Laval nozzle 1, the gas duct 2 connected with a source of compressed gas. Nozzle 1 is coaxial and is tightly fixed at one end of the pipe 3 and on the opposite end thereof diaphragm 4 with a central opening 5 with a diameter greater than the diameter of the Laval nozzle 1 critical section and lesser that the diameter of its output cross section. For hermetic sealing there are the packing rings 7 installed on the nozzle block 6. Nozzle is mounted in the tube 3 with the possibility of relative movement for regulating the distance of its section from the diaphragm.

Expansion of the acoustic range is achieved by the including a diaphragm in the device. Pipe is movable along with the diaphragm relative to the Laval nozzle cross-section. Device for sonic oscillations excitation operates in the self-oscillatory regime.

Figure 5 shows the moment when the mixing layer of the jet interacts with the diaphragm and is turned into
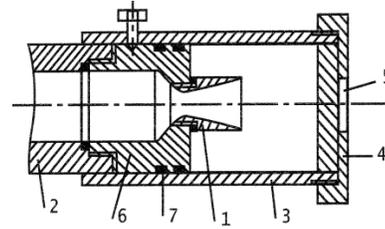

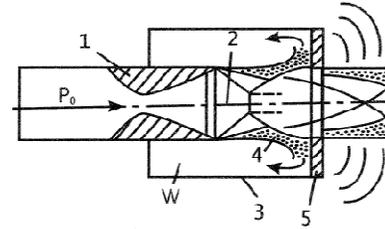Fig. 4: Diagram of the device for excitation of acoustic oscillations

Fig. 5: Scheme of the gas flow in the generator at the regime of filling the bottom volume
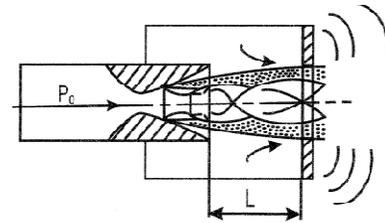

Fig. 6: Scheme of gas flow in the pipe volume at the regime of the gas outflow from the volume of the pipe

the bottom area, causing an increase in bottom pressure. Legend is the same as in Fig. 4.

The gas pressure in the cavity of the pipe begins to rise, the degree of jet nonisobarity at the bottom area W decreases; the opening angle of the jet's mixing layer increases. Increase of the opening angle leads to an increase in the mass of gas being sliced by the diaphragm, which returns to the cavity. Flow separates from the nozzle wall due to the increase of the pressure W. The pressure tube cavity 3 continues to rise, the cross-section of jet separation from the nozzle wall is moved upstream, closer the nozzle throat. And, although the opening angle of the jet increases, the absolute size of the jet decreases, its diameter at the diaphragm section 4, i.e., diameter of the jet with the mixing layer becomes equal to the diameter of the hole in the diaphragm. Therefore occurs the uncorking of tube 3 with the formation of a shock wave in the surrounding space (Fig. 6).

The described above feature of the jet mixing layer that acts as a positive feedback begins to play ithe role of negative feedback. With uncorking of pipe cavity outflow of gas begins and the pressure in it decreases, which leads to a decrease in the opening angle of the jet
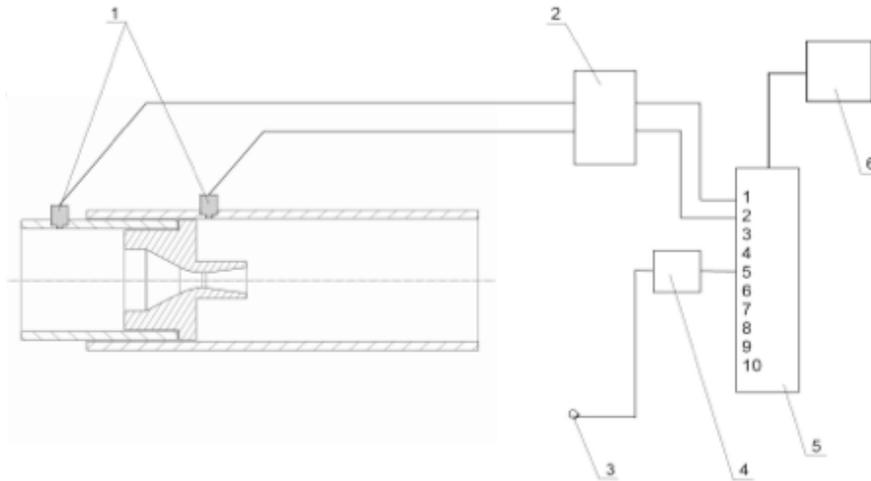
Fig. 7: The scheme of experimental installation for the study of non-stationary processes in canals with a sudden expansion
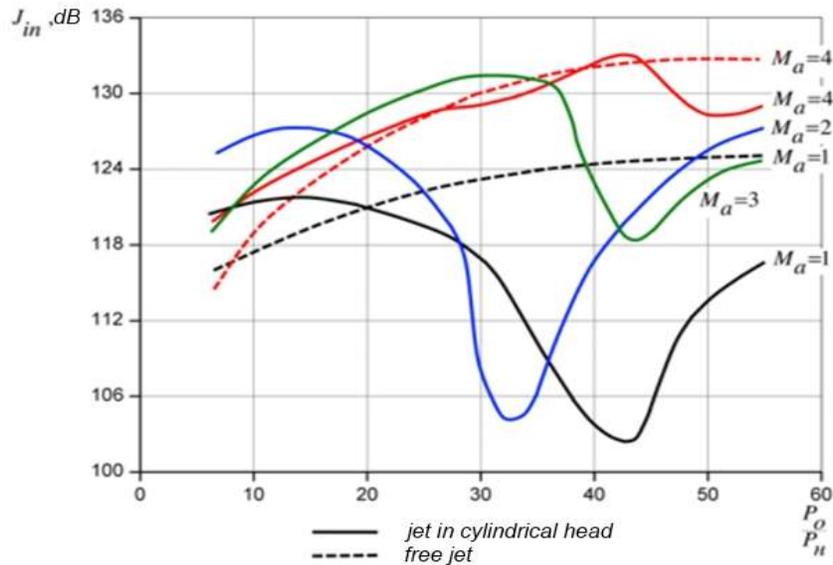

Fig. 8: Integral level of acoustic emission of a free jet and jet in cylindrical head

mixing layer, the displacement of the cross-section of the jet separation cross-section in the diaphragm cut and blocking of the hole in the diaphragm 4 by the jet mixing layer. The filling of the pipe cavity with the gas begins.

Change in the total gas pressure upstream of the nozzle leads to the increase of the pressure oscillations amplitude at the diaphragm, i.e., the uncorking pressure of the pipe and the sonic pressure level in the surrounding area. At the same time, the oscillation frequency does not change as much. Using the drive, causing the displacement of the diaphragm 4 relative to the nozzle exit, you can manage the frequency parameters of the sonic oscillations.

The analyzed device provides a stable excitation of oscillations in the surrounding area, as well as a significant increase in sonic pressure.

Amplification and noise reduction of supersonic jet by a cylindrical head: Outflow of compressed gas from the nozzle is accompanied by emission of noise into the surroundings.

Studies of the acoustic properties of the processes were carried using the experimental stand (scheme shown in Fig. 7), consisting of inertia-free pressure sensors 1, signal processing devices 2 and 4, microphones 3, visualization systems 6 and data collection 5. The following was measured:

P_0 = Total pressure in the receiver
P_d = The pressure in the base region
L = The noise level

In the range of large nonisobarities for under expanded free jets the increase of total pressure in the receiver is associated with a monotonic increase in the

level of acoustic emission. The existence of cylindrical head with hermetically sealed bottom area behind the nozzle cut causes a significant transformation of general regularities of changes in the integral noise level of the flow behind the cross-section of the canal at the same values of the total pressure (Fig. 8).

RESULTS AND DISCUSSION

The integral level of acoustic emission from the section of the canal may be lesser than of the one from a free flooded supersonic jet, as well as greater. For example, at the regime with the open bottom area the cylindrical head enhances the jet's acoustic field due to the bottom area acting as resonator. Considering the frequency spectrum of bottom pressure pulsation in supersonic separated flows (with fixed separation point), the following specific types of pulsations can be noted:

- Turbulent and acoustic pulsations
- Vortical pulsations (large vortices)
- Quasi-stationary consumption pulsations

The integral noise level depends not only on the Mach number (Fig. 8), but also on the diameter of the nozzle throat (Fig. 9). The larger the nozzle is the higher is the noise level. If the gas consumption through the nozzle is used as a parameter, then the dependences become universal (Fig. 10).

It is evident that there is a minimum integral acoustic emission. A comparison with the experimental graphs Rd (P_0) have shown that this minimum corresponds to the regime o f limiting nonisobarity

when entire canal section is blocked by a powerful direct shock wave, the flow behind which is completely subsonic.

At a part of flow with open bottom area the jet, which does not touch the walls of the canal generates acoustic emission, amplified by an annular cavity. During the outflow of a supersonic stream from the canal cut, a monotonic increase in emitted noise is observed with the increase of P_0. Acoustic emission at self-oscillatory regime and at a flow regime with an open bottom area has a frequency of discrete tones, vastly superior by amplitude than broadband component. All of this creates a great opportunity for the practical use of self-oscillation phenomenon, management of its characteristics and the acoustic characteristics of supersonic jets.

The presence of quasi-stationary bottom pressure pulsations indicates the ambiguity of the stationary flow, which can occur either in the inviscid flow, or in the viscous layer. Different types of such ambiguity and the hysteresis and low-frequency pulsations associated with it, found during experimental studies of flat annular nozzles models (Gogish, 1969), are inherent as well for axisymmetric flows in the canals. A number of studies in which the pulsations in different types of nozzle compositions were researched, confirm the foregoing. Cyclic rearrangement of the wave structure is accompanied by the generation of external acoustic field, whose frequency control is accomplished by changing the total pressure P_0, the Mach number at the nozzle exit and the canal length l_{tr}.

In the flows with open bottom area the spectrum is distinguished by the presence of 3-4 harmonics substantially above the background level.
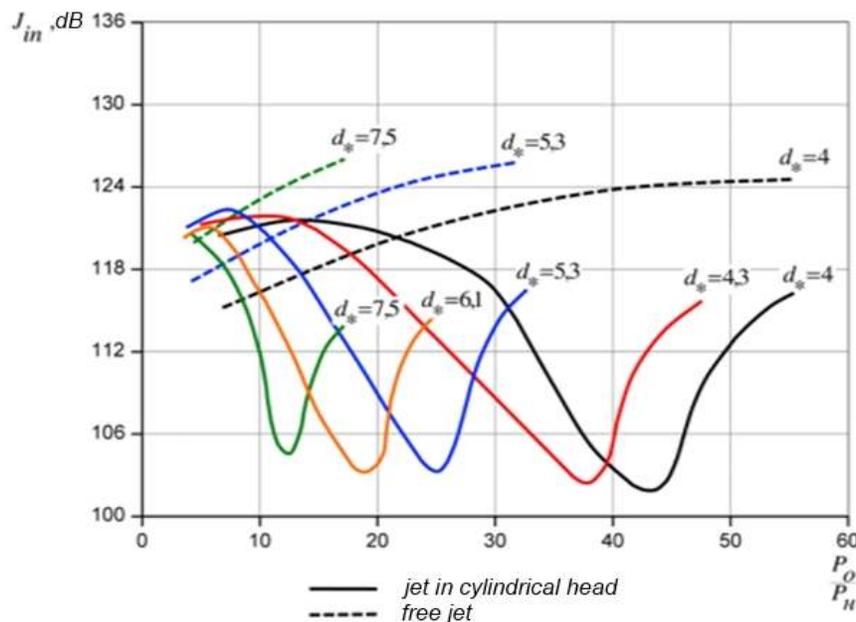

Fig. 9: Integral level of acoustic emission of a free jet and jet with cylindrical head. $M_a = 3$, half-opening nozzle angle-15
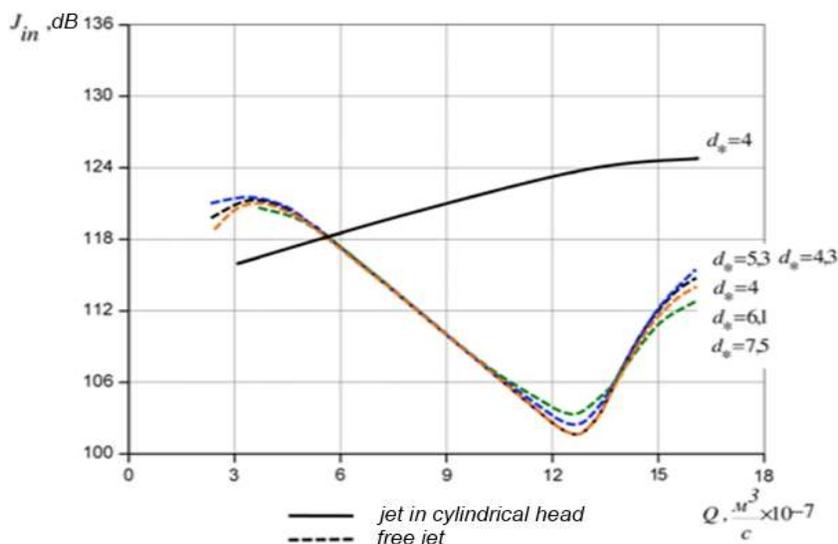
Fig. 10: Integral level of acoustic radiation of a free jet and jet with a cylindrical head depending on the consumption through the nozzle. $M_a = 3$, half-opening angle of a nozzle 15

During oscillatory regimes of the bottom pressure changes there are one or two dominant frequencies, located in the low-frequency part of the spectrum and the first harmonic is corresponded by the rearrangement frequency of the jet's first wave structure (frequency range 45-450 Hz) in the bottom region of the canal.

CONCLUSION

The main types of sound generators: whistles, sirens, gas-jet generators are discussed. Various schemes of the heads for annular Laval nozzle are presented, which, depending on their geometry and operating conditions can serve as generators and silencers of acoustic emission. The experimental data on the regime, at which there is a significant reduction of jet noise are given. This effect has previously been used in several noise suppression devices (Ginsburg *et al.*, 1977). A device, similar by geometry, on the other regimes can be operated as a generator of acoustic emission (Ginsburg *et al.*, 1980).

Supersonic jet, flowing from annual Laval nozzle, at which a cylindrical head is installed, is convenient in its control. The various regimes of jet's mixing layer interaction with the nozzle walls, sharp diaphragm edges, if it is installed on a head section is characterized by significantly different jet opening angles, the level of acoustic emission, nonisobarity parameters, jet range. This makes the usage of such devices attractive in various technological processes. Indeed, the same device at different levels of the total pressure in the receiver before the nozzle can serve as a noise generator, as a silencer and can create both subsonic jet and a pulsating shock wave structure at the cross-section of the head.

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