Longitudinally oscillating ultrasonic emitter for influencing gas-dispersed systems

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Abstract. The article describes the design of an ultrasonic emitter for exposure to gas-dispersed media. A longitudinally oscillating cylindrical body of half-wave length, connected to a piezoelectric transducer, serves as the basis for the design of an ultrasonic emitter. The optimization of the geometric dimensions of the radiator made it possible to ensure the uniformity of the distribution of the vibration amplitudes of the radiating end surfaces. The execution of the connecting plane for excitation of vibrations, deepened relative to the end radiating surface, made it possible to increase the amplitude of vibrations by 2 times. Optimization of the design using the finite method made it possible to create a longitudinally oscillating ultrasonic emitter capable of providing exposure to gaseous media with an intensity of at least 145 dB at a power consumption of no more than 90 W.

1. Introduction
Currently ultrasonic technology is widely used in various industries. Exposure to high-intensity ultrasonic oscillation provides an improvement in the properties of known substances and materials, and makes it possible to intensify various technological processes [1-3].

Recently, ultrasonic exposure is beginning to be used to intensify processes in gaseous media. Such an exposure makes it possible to increase the capture efficiency of highly dispersed materials [4-5] and to ensure gas purification due to coagulation of solid and liquid particles, to remove foams during the production and packaging of foaming products [2, 6]. In addition, ultrasonic treatment through gaseous gaps (non-contactly) accelerates the drying process of food and medicinal, easily oxidizable substances, provides spraying of liquids in the production of highly dispersed materials and applying a variety of coatings, and even heals a human [7-8].

2. Problem statement
However, despite its high efficiency and demand, the ultrasonic intensifying effect in gaseous media has not found wide practical distribution yet. This is due to the fact that available sources of ultrasonic exposure (gas-jet radiators, dynamic sirens, electro-acoustic transducers of the piezoelectric type) do not provide the required sound pressure level, frequency and direction of radiation.

Ultrasonic oscillatory systems (USOS) created in recent years on the basis of a piezoelectric transducer, with radiators in the form of flexurally oscillating disks [9] Figure 1 are not widely used due to their high cost, manufacturing complexity, and low radiation efficiency, high probability of
destruction and the impossibility of manufacturing such radiators with a diameter of more than 300...400 mm.

The lack of suitable and efficient radiators, the high need for the practical implementation of technological processes in gaseous media necessitate the creation of highly efficient ultrasonic radiators for gaseous media.

3. The design of the experimental stand
Since the effect on the radiator from the in medium being processed is minimal when radiating into gaseous media, it is necessary to use radiators with the highest possible resonance properties.

The basis of the design of such radiator can be a cylindrical body of resonant (half-wave) length, connected to an electro-acoustic transducer. A sketch of the proposed radiator is presented in Figure 2.

A distinctive feature of the radiator proposed, which allows increasing the amplitude of its resonant vibrations, the implementation of the connecting plane to excite oscillation (pos. 3), deepened relative to the end surface (pos. 1) by a distance (H). Wherein the end face of the concentrator of the ultrasonic oscillation system is attached to the plane (pos. 3).

A sketch of an ultrasonic radiator along with an attached ultrasonic oscillatory system is presented in figure 3.

With such a design pattern of the radiator, the transformation coefficient is defined as the ratio of the amplitude of the oscillations of the radiating surface (pos. 1) to the amplitude of the oscillation of the connecting plane (pos. 3)
\[ K_{Tr} = \frac{A_{\text{Long}}}{A_{\text{in}}} \]  

(1)

Figure 3. Sketch of the ultrasonic radiator along with an ultrasonic oscillatory system: 1 - ultrasonic radiator; 2 - a piezoelectric transducer concentrator; 3 - piezoceramic elements; 4 - reflective pad; 5 - case; 6 - a flange; 7 is hairpin.

The study of the emitter proposed and optimization of its parameters was carried out using the finite element method.

Figure 4, curve 1 shows the calculated dependence of the transformation coefficient on the relative depth of the hole (H / L, pos. 3, figure 2). Curve 2 of Figure 4 shows the dependence of the frequency of natural oscillations on the ratio (H / L).

The calculations were carried out with the radiator diameter \( D = 0.1 \text{ m} \); \( D_{\text{in}} = 0.015 \text{ m} \); \( L = 0.1 \text{ m} \). An aluminum alloy B95 was used as the material of the emitter (\( E = 7.1 \times 10^{10} \text{ Pa} \); \( \rho = 2800 \text{ kg/m}^3 \); \( \mu = 0.31 \)).

As follows from the dependences presented, with the ratio \( H / L = 0.4 \), the transformation coefficient tends to infinity. This is caused by the fact that, for a given ratio, the connecting plane is in the zone of minimal longitudinal oscillation.

Figure 4. Dependence of the transformation coefficient (curve 1) and the frequency of natural oscillations (curve 2) on the ratio (H / L).
Figure 5 shows the oscillation mode of the piston-type radiator.

When developing the radiator, the depth of the connecting hole is calculated taking into account the required transformation ratio using expression (1). In this case, for example, the amplitude of longitudinal vibrations (A Long) at an oscillation frequency of 22 kHz should be no more than 80 μm for aluminum alloys. Exceeding the oscillation amplitude can lead to the destruction of the radiator. After the transformation coefficient is set, the depth of the connecting hole is determined using the obtained dependence (curve 1 in Figure 4). For example, for a given transformation coefficient of the developed radiator equal 2, the hole depth is 25 mm.

An analysis of the oscillatory processes of the radiator made it possible to establish that with variable compression and tension of the material in the radial direction, its cross section increases and decreases, respectively, i.e. the diameter of the working surface changes. Also, the length of the converter changes due to longitudinal oscillation. The distribution of oscillation shows, that a cylindrical body of half-wave length, performing longitudinal oscillation, also oscillates in the radial direction. A number of model calculations were performed in order to obtain numerical values of the uniformity of the distribution of the amplitudes of oscillation on the end surfaces depending on the diameter / length ratio (D / L). To simplify the calculations, the ratio of the amplitude of longitudinal oscillation in the center to the amplitude of oscillation at the periphery, (ALong / APer) was used as a uniformity criterion. This made it possible to obtain the dependences of the ratio of the amplitude of radial vibrations to the amplitude of longitudinal vibrations (ARad / ALong) on the ratio diameter / length (D / L) presented in figure 6.

The analysis of the dependences made it possible to establish that with the ratio D / L = 1.56, the ratio (A Long / A Per) - (Figure 6, curve 1) reaches its maximum value, while ensuring maximum uneven
distribution of the amplitude of the oscillations on the end surface of the radiator. A further increase in
the ratio \(D/L\) does not lead to a significant change in the uniformity of the distribution of the amplitude
of oscillations on the end plane. At the same time, the analysis of the dependence (Figure 6, curve 2)
showed that the radiator begins to oscillate mainly in the radial direction.

Thus, it was found that the maximum uniformity on the end surface of the radiator is achieved with
a minimum diameter of the radiator, which is not acceptable when creating practical designs of radiators.

In order to ensure uniform distribution of the amplitude of oscillations with a large diameter of the
radiator, it is proposed to constructively change the cylindrical surface of the radiator, in particular, to
make an annular groove near the radiating surface. Figure 7 shows a sketch of a modified radiator with
a groove.

Next, a series of model calculations was carried out, which allowed obtaining data on the uniformity
of oscillation depending on the depth of the annular groove \(G\), with \(L_1 = 0.15L\).

![Figure 7. A sketch of a piston-type radiator with a groove: 1 is end radiating surfaces; 2 is cylindrical radiating surface; D is the
cylinder diameter; L is the length of the cylinder; A Rad is the amplitude of radial
oscillation; Along is the amplitude of longitudinal oscillation; A Per is the
amplitude of oscillations of the cylinder edge; L1 is the distance from the radiating
end plane to the groove; G - groove depth.]

Figure 8 shows the waveforms of the surface of the radiator for different values of the depth of the
groove.

As a criterion for the uniformity of the amplitude of the oscillations, the root mean square (standard)
deviation of the amplitude of oscillations of the points of the end surface was used.

![Figure 8. Distribution of oscillation along the diameter of the radiator.]
Further, the dependences of the standard deviation of the relative oscillation amplitudes (Figure 9, curve 1) and the natural oscillation frequencies (Figure 9, curve 2) on the relative groove depth ($2G / D$) were obtained.

An analysis of the results made it possible to determine the optimal depth ($G = 0.13D$) of the annular groove at which the maximum uniformity of the distribution of oscillations of the surface of the radiator is ensured. It was also found that increasing the depth of the groove reduces the frequency of natural vibrations by reducing the rigidity of the oscillation system.

![Figure 9: The dependence of the standard deviation of the relative amplitudes of oscillations (curve 1) and the frequency of natural oscillation (curve 2) on the relative depth of the groove ($2G / D$).](image)

Two annular grooves were proposed to be made in order to ensure maximum uniformity of oscillation of both end surfaces. Figure 10 shows a sketch of such an ultrasonic oscillation system with a radiator for piston-type gaseous media.

![Figure 10: Sketch of a modified ultrasonic emitter with an ultrasonic oscillation system: 1 is ultrasonic radiator; 2 is hub; 3 is piezoelectric elements; 4 is reflective pad; 5 is case; 6 is a flange; 7 is hairpin.](image)

Figure 11 shows the waveform and photo of the optimized radiator.
4. Experiment results
An ultrasonic oscillatory system was manufactured and measurements were made to study the functionality of the developed piston-type emitter. Figure 12 shows a photo of an ultrasonic oscillatory system with a piston-type radiator.

5. Conclusion
The need to solve practical problems of ultrasonic impact on technological processes in gaseous media and the lack of suitable radiator allowed us to propose and develop a new type of radiator excited by a piezoelectric oscillatory system.

As a result of the research, a piston-type ultrasonic emitter was created, capable of providing effects on gas media with an intensity of at least 145 dB and a power consumption of no more than 90 watts.

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