High Intensity Ultrasonic Transducers for Gas Media

Igor I. Savin, Sergey N. Tsyganok, Andrey N. Lebedev, Student member, IEEE, Denis S. Abramenko, Student Member, IEEE

Biysk Technological Institute (branch) of Altai State Technical University after I.I. Polzunov, Biysk, Russia

Abstract—In article is devoted to different type piezoelectric stepped-plate radiators for gas media.

Index Terms—Ultrasonic; ultrasonic oscillations in gas media; stepped-plate radiators.

I. INTRODUCTION

Widely used technologies frequently cannot satisfy growing inquiries of the industry on increase in speed and quality of let out production. Therefore for the decision of arising problems it is necessary to use earlier not applied technologies. As example: using of ultrasonic oscillations of high intensity. The ultrasound finds the increasing application in the industry in current of last 20 years.

The big prospect is using of ultrasonic oscillations of high intensity in gas environments.

The first researches lead on research of high-intensity ultrasonic oscillations at influence on substances through gas intervals has shown their high efficiency. For example, use ultrasonic oscillations have allowed to increase efficiency of smokecatching installations and to lead their efficiency to 93-96 %. [1]

Basic deterrent of a wide spreading of ultrasonic radiators for gas environments was their low efficiency.

Until recently the basic sources of ultrasonic oscillations in gas environments were aerodynamic radiators. Their distinctive feature is the low efficiency (39% at the best samples), a high level of permanent noise and complexity in operation.

Progress in the field of piezoceramic elements has allowed to develop on it basis radiators for influence on gas environments. [2] Structurally it represents ultrasonic oscillatory system with a radiator having the form of a disk and creating acoustic oscillations in the gas environment. The basic complexity consists in a choice of the form of a disk radiator. Further functionalities of disk radiators of the various forms are analyzed.

II. STEPPED-PLATE RADIATORS

A. Phased focusing disk

Operation principal of phased focusing disk is shown on Fig 1.

The solid surface (plate or disk) bending vibrating, they allocation to diameter is given by stationary flexural waves. The each point of vibrating surface radiate to air medium the acoustic wave. If using the form factor of disk allocate the “positive” maxima of stationary waves at distance from disk center as

\[ Y_+ = \sqrt{naL + \frac{n^2a^2}{4}} \]

where \( n=0,2,4,\ldots \), \( a \) - sound wave-length in air medium, \( L \) - distance, between plate (disk) center and focus point, and “negative” maxima at distance

\[ Y_- = \sqrt{naL + \frac{n^2a^2}{4}} \]

where \( n=1,3,5,\ldots \) then waves are irradiated form each point would be arrive to focus point in equally phase. In the case the acoustic waves intensity level (AIL) in focus reach the 200 dB value and higher and focus be surrounded by
High Intensity Ultrasonic Transducers for Gas Media

concentric spherical equal phase surfaces where AIL reach 130-150 dB. In more detail designing and use is described in [3,4].

B. Disk with preferred radiation in one phase

Application of focusing radiator is a expedient only in a small volume. Therefore there radiators that provides an acoustic wave close to flat wave.

As well know, in condition of central exciting of thin flat disk, with radius divisible on integer numbers of flexural half waves (in disk material), along radius of disk the wave pattern in disk will be has a view of stationary waves.

The oscillation amplitude of disk surface point at distance \( r \) from center may be determined as:

\[
A(r) = A_0 \cdot \cos \left( \frac{2\pi \cdot k \cdot r}{R} \right),
\]

where \( A_0 \) - oscillations amplitude at disk center, \( k \) - integer number of flexural half-waves along disk radius, \( R \) - radius of disk.

The approximate view of distribution flexural waves on thin flat disk surface and acoustic radiation (AR) from some points of surface are shown on fig. 2

![Fig. 2 - The approximate view of distribution flexural waves on thin flat disk surface and AR from some points of surface](image)

As it see from the picture, the different points of disk oscillate in opposite phases, therefore at some distance from surface acoustic radiation cancellation by means mutual interference.

For the exclusion unwanted interference it is need to specially reducing oscillation amplitude at “negative” phase zones. It may be realized if thickness of disk in that zones will be increased. As result in will be step-plate disk like schematically shown on fig. 3 (conditionally shown with half-wave SET). At that picture also shown distribution of flexural oscillations waves.

![Fig. 3 – Step-plate disk with preferred radiation in one phase](image)

As see from distribution, the oscillation amplitude of “negative” zones is significantly reduces in comparison with amplitude of “positive” zones. Therefore in this case full cancellation of AR is impossible.

The radiation performances of this disk are characterized by effective radiating area. The effective area it is a area of hypothetic piston that creates in far-field region same radiation as a flexural oscillating disk.

Effective area defines use formula:

\[
S_{\text{eff}} = \frac{1}{A_0} \int_0^r [2\pi \cdot r \cdot A(r)] \cdot dr
\]

where \( A(r) \) - oscillation amplitude of disk points at radius \( r \) - from center.

The appearance of one radiator is shown on fig. 4.

![Fig. 4 – The appearance of radiator with preferred radiation in one phase](image)

At the picture 5 the distribution (obtained from experiment) of flexural waves on disk surface is shown.

For the disk with 340 mm diameter total area of radiating surface for this disk is 0,091 m\(^2\). At that the 56\% (0,05 m\(^2\)) of total area is oscillates in “positive” phase (like at on disk
High Intensity Ultrasonic Transducers for Gas Media

axel) while 44% (0.041 m²) of disk area are oscillates in “negative” phase. Because of “negative” zones are more thick, its oscillations amplitude is low and in “positive” phase disk radiates 70% of total radiation while in “negative” phase – only 30%. Effective area of disk is 0.036 m².

![Fig. 5 – The distribution of flexural oscillations on disk surface](image1)

Key performances of disk with 340 mm diameter shown in table 1.

<table>
<thead>
<tr>
<th><strong>KEY PERFORMANCES OF RADIATOR WITH DIAMETER 340 MM</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiating surface diameter, mm</td>
</tr>
<tr>
<td>Material of radiating element</td>
</tr>
<tr>
<td>AIL at distance 0.2 – 1 m, dB</td>
</tr>
<tr>
<td>Resonant frequency, kHz</td>
</tr>
<tr>
<td>Number of half-waves distributed along disk radius</td>
</tr>
<tr>
<td>Effective radiating area, m²</td>
</tr>
<tr>
<td>Radiating disk mass, kg</td>
</tr>
</tbody>
</table>

C. Non-focusing disk with phase equalizing elements

If the height of ledge allocated in “negative” zones of step-plate disk will be equal with half-wave of radiation in air medium, then the radiation of “negative” and “positive” zones will be as early as not subtraction but summing. Thus the phases of radiation from all points of disk are equalizing. The scheme of this radiator is shown on fig. 6.

![Fig. 6 – Radiating disk with phase-equalizing elements](image2)

How it seen from picture, ledges allocates not on back surface but on radiating surface. As long as the radiation from opposite zones in this case are summing, reducing of oscillation amplitude in ledges zones is undesirable. Therefore at back side of disk, opposite ledges is a hollow that compensates reducing the oscillation amplitude at ledges. Effective radiating area of this disk determinates as:

\[ S_y = 0.7S \]

where \( S \) - total area of radiating disk.

The appearance of radiator with phase-equalizing elements is shown on fig. 7.

![Fig. 7 – The appearance of radiator with phase-equalizing elements](image3)

Its performances are shown in table 2.

<table>
<thead>
<tr>
<th><strong>THE PERFORMANCES OF RADIATORS WITH PHASE EQUALIZING ELEMENTS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiating surface diameter, mm</td>
</tr>
<tr>
<td>Optimal radiating frequency, kHz</td>
</tr>
<tr>
<td>Number of half-waves distributed along disk radius</td>
</tr>
<tr>
<td>Phase equalizing ledges height, mm</td>
</tr>
<tr>
<td>AIL at distance 0.2 – 1 m, dB</td>
</tr>
<tr>
<td>Deepness of hollows, mm</td>
</tr>
<tr>
<td>Disk mass, kg</td>
</tr>
</tbody>
</table>

The result of theoretical investigations and environmental tests this type of radiator potentially may be provides greater
characteristics of acoustic field in comparison with other radiators. Unfortunately, the structure of radiator, viz very thick metal at place of connection to concentrator, the strength of bolt connection is insufficient – break of bolt are have a place after few minutes work.

III. PRACTICAL USING OF THE STEPPED — PLATE RADIATORS

Designed and made 2 different types of radiating disks. Its construction practically approved and optimized. The obtained results allows to draw follow conclusions

The focusing radiator allows create high-intensity acoustic field in small zone of focus. Lack of construction is maintenance complexity of uniform distribution of acoustic oscillations with intensity 150 - 170 dB in great volume. Construction of radiator with preferred radiation in one phase may be recommended for serial production already now. The construction may be improved, due to installation behind radiator of reflector which will allow increasing efficiency of radiation.

Construction of radiators with phase equalizing elements now still needs design tweaking, although potentially have a best performance in comparison with other construction. At current stage there is necessity of revision of strengthening of disk radiator to ultrasonic oscillation system.

REFERENCES


Sergey N. Tsyganok was born in Biysk, Russia, 1975. Now he is Ph.D (Machinery), he received degree on information measuring engineering and technologies from Altay State Technical University, key specialist of electronics. Laureate of Russian Government premium for achievements in science and engineering. His main research interest are development of high -effective multifunctional oscillators for ultrasonic technological devices.

Andrey N. Lebedev (S’03) was born in Kiselevsk, Russia in 1983. He received degree on information measuring engineering and technologies from Biysk Technological Institute of AltSTU. He is post-graduate student of Biysk Technological Institute.. His research interests is finite-element modeling.

Denis S. Abramenko – post graduated student of BTI. He is received engineer’s degree from BTI AltSTU at 2005. IEEE Student Member.