5aSA9. Ultrasonic transducers with directional converters of vibration of longitudinal-longitudinal (L-L) type and longitudinal-longitudinal-longitudinal (L-L-L) type intended to work in gaseous media

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The study presents a realised concept of an ultrasonic transducer intended to work in a gaseous medium, that radiates a focused ultrasonic beam in many directions simultaneously. The use of a L-L type vibration direction converter makes it possible to radiate ultrasonic energy in a required direction without changing the location of the activation source. The transducer consists of 4 resonant elements: an ultrasonic sandwich type transducer, vibration amplitude transformer, L-L type converter and axisymmetrical radiating plates. It is also acceptable to use a L-L-L type vibration direction converter. The benefit of such a solution is that it is possible to use one ultrasound source for simultaneous activation of several radiating plates. The study presents conductance and susceptance characteristics of a complex resonance system, amplitude frequency characteristics of the level of acoustic pressure and sample characteristics of the directivity of a transducer with two independent radiating plates. The suggested solution creates new possibilities for applications of this type of resonance systems.

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INTRODUCTION

In case of conventional ultrasonic transducers the use of longitudinal waves is usually limited to constructing simple one-dimensional vibrating setups. Resonators with directional conversion of vibration of the L-L and L-L-L type are constructed of two or three same size half-wave rods, connected to one another at oscillation nodes (as designed by K. Itoh and E. Mori [1,2]), make it possible to change the direction of vibrations in relation to activation source of vibration. Transmission of energy from one element to another occurs as a result of Poisson’s ratio at the spot, where the separate rods are connected together. The lateral dimensions of the rods are small in comparison to their length. By connecting several vibration directional converters in series it is possible to increase vibration amplitude for a selected vibration direction [3] and transmit vibrations from one source in multiple directions simultaneously.

A resonator with L-L type conversion has two resonance frequencies. The converter's vibrations can be symmetric (in-phase-mode resonance) or antisymmetric (anti-phase-mode resonance). Resonance frequency of a converter vibrating in in-phase-mode is higher than resonance frequency of a converter vibrating in anti-phase mode.

A resonator with L-L-L type conversion has four resonance frequencies; one for in-phase-mode vibration and three adjacent ones for three different combinations of anti-phase vibration modes: two linearly independent anti-phase vibration modes and a linear combination of anti-phase modes of vibrations [4]. Fig.1 shows basic vibrations of L-L and L-L-L type converters.

![Converter vibration modes: in-phase-mode and anti-phase-mode of a L-L type converter, one in-phase-mode and three anti-phase-modes of a L-L-L type converter.](image_url)

For two linearly independent anti-phase-mode vibrations, one of the rod resonators is inactive, which results from Poisson's ratio compensation at the intersection of the resonance system. As the length of the inactive rod does not affect the vibrations of the resonance system, such vibrations exist for any length of the inactive rod [4].

COMPUTER SIMULATED VIBRATIONS OF A L-L TYPE CONVERTER

Fig.2 shows the results of a simulation of a L-L type converter vibrating in antisymmetric and symmetric mode obtained using ANSYS Mechanical type software. Vibration frequency in the symmetric mode is \( f = 21.991 \) kHz and in antisymmetric mode \( f = 20.757 \) kHz.

**FIGURE 1.** Converter vibration modes: in-phase-mode and anti-phase-mode of a L-L type converter, one in-phase-mode and three anti-phase-modes of a L-L-L type converter.

For two linearly independent anti-phase-mode vibrations, one of the rod resonators is inactive, which results from Poisson's ratio compensation at the intersection of the resonance system. As the length of the inactive rod does not affect the vibrations of the resonance system, such vibrations exist for any length of the inactive rod [4].
In case of ultrasonic transducers intended for operation in gaseous environments, generation of ultrasonic waves in such media can be guaranteed by using a rectangular plate that operates in striped vibration mode and is activated on one of its edges [5] or an axisymmetric plate that is activated at its centre and operates in transverse symmetric vibration mode [6,7]. The latter solution secures axisymmetric radiation characteristics, the width of which can be additionally controlled using plates profiled on one or both sides [8,9]. Fig.3 shows a result of computer simulated vibrations of an axisymmetric plate made of PA11 aluminium with the thickness of $h = 5$ mm, radius of $r = 67.5$ mm and a hole in the centre that is $d = 5$ mm in radius. The frequency of free vibrations of the plate was $f = 21.994$ kHz and was consistent with the frequency of free vibrations of the converter.
STRUCTURE OF ULTRASONIC TRANSDUCERS WITH DIRECTIONAL CONVERSION OF VIBRATION INTENDED FOR OPERATION IN A GASEOUS MEDIUM

Fig. 4 shows a solution for ultrasonic transducers with a directional converter of vibrations that makes it possible to divide vibration energy generated by a single source in the form of a sandwich type power transducer in a gaseous medium. The sandwich type transducer, equipped with a vibration amplitude transformer, activates axisymmetric plates via an L-L or L-L-L type converter; the plates radiate energy in various directions.

FIGURE 4. The design of transducer with plates radiating in various directions.

MEASUREMENT OF THE PARAMETERS OF A MODEL TRANSDUCER WITH A TYPE L-L CONVERTER

Fig. 5 shows conductance and susceptance characteristics in the function of frequency of a transducer with two radiating plates. The base frequency of the whole setup was \( f = 22.256 \text{ kHz} \).

FIGURE 5. Conductance (a) and susceptance (b) characteristics of a transducer with two radiating plates.

The directivity characteristics of the discussed transducer may be seen in Fig. 6. Distributions and levels of acoustic pressure in all directions were almost identical, which means that the energy was distributed symmetrically in the individual directions.
FIGURE 6. The directivity characteristics of a transducer: a) with two radiating plates (L-L type converter), b) with four radiating plates (L-L-L type converter).

Three-dimensional imaging of the vibrating plate obtained by means of laser vibrometry resulting from the measurement of the acoustic velocity of the vibrating plate is shown in Fig.7. The way the plate vibrates is consistent with the results of computer simulated vibrations of an axisymmetric plate presented in Fig.3.

FIGURE 7. Three-dimensional imaging of a vibrating plate obtained by means of laser vibrometry.

CONCLUSIONS

The presented solution for an ultrasonic transducer intended to work in a gases makes it possible to use one source to radiate ultrasonic wave in various directions. This can have in many practical applications, where ultrasonic sources with omni-directional radiation characteristics (close to spherical characteristics) are required. Such sources can work in continuous or pulse modes.
REFERENCES