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A Criterial Assessment of Quality Transformations a Plane Elastic Wave in the Solid-State Resonant Sonotrode

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ABSTRACT: *The criteria are described optimization of the form of solid-state resonant sonotrodes, which allow without full-scale simulation make a complex assessment of the qualitative characteristics of the transformation of the plane elastic waves:*

– the resistance to the bending vibrations at the high value of the coefficient of transformation;
– disposition to the emergence of the bending a vibration modes;
– measure of sharpness of the resonance, which determined by the shape of the profile function.

It is shown that the best is in all respects is sonotrode, the function of the profile of which is described by the equation of the line of the flow path of the wave vector in the canonical stepped sonotrode.

Keywords: *The resonant sonotrode*

I. INTRODUCNION

Optimization of the design of resonant sonotrodes (acoustic waveguide) that are part of the ultrasonic vibrating systems is an important engineering problem. Is correct solution of this problem provides the highest values of energy efficiency in the transmission of elastic waves in the load.

Oscillatory systems operating in devices for the treatment of the solid body (for example, plastic deformation of surfaces metallics details) may be described by characteristics of idling. Optimization of waveguide transformers such systems is carried out by means of quality factor *f* Eisner [1]. Was proposed a universal criterion *q* [2]. That criterion is non-trivial criterion of similarity that allow at the choice of the profile function the sonotrode do minimize mechanical stresses in it by optimizing the cross-section and the curvature of the surface in the plane of the antinodes of oscillatory deformations at obtaining maximum coefficient of transformation. Thus, they provide reliability and reduce the possibility of bending vibrations of the sonotrode, which can dissipate part of the energy. More strong load receives system transmitting oscillations in the substances which not have elasticity of shape (in the liquids). Such systems are used, for example, in apparats for sonochemical processing food liquids and water, which is used in the preparation of foodstuffs [3].

II. FURTHER THEORETICAL STUDIES

If sonotrodes of such systems do not contain the stress raisers – grooves, grooves or holes – near the antinodes of strain, then criterion:

$$\theta = \frac{m}{K \cdot M}\frac{\varepsilon_{\max,0}}{\varepsilon_{\max}} = \frac{\mu}{K}\frac{\varepsilon_{\max,0}}{\varepsilon_{\max}}, \qquad (1)$$

where: K – stress concentration factor; m – the transformation ratio of the optimized sonotrode; M – transformation ratio sonotrode with stepped profile with the same areas ratio on the ends; ε_{max} – the maximum by length of sonotrode value vibrational strain; $\varepsilon_{max,0}$ – the maximum strain along the length of sonotrode with a coefficient of transformation to 1, can be written, as:

$$\theta^* = \mu\frac{\varepsilon_{\max,0}}{\varepsilon_{\max}} \qquad (2)$$

For a comprehensive evaluation of the quality the sonotrodes oscillatory systems operating under high mechanical loads, it is proposed two new criterion - a criterion for passive mass σ (the term "passive mass" introduced E. Kikuchi [4]) and quality factor of form □ = $\partial L/\partial f$. The first of these is given by:

$$\sigma = \frac{v - L\cdot \mathrm{s}(L)}{V - V_0} = 4\frac{m}{\lambda\cdot(1-m)}\int_0^L \frac{\mathrm{s}(L)-\mathrm{s}(x)}{\mathrm{s}(0)}dx, \qquad (3)$$

where: v, V, V_0 – volumes of sonotrode what assessed, the stepwise sonotrode with the same coefficient transformation and a sonotrode with coefficient transformation $m = 1$, the sectional area of which equals the area of the smaller end of stepwise sonotrode, respectively; L – a resonant length of the studied sonotrode; $\mathrm{s}(x)$ – the function of the cross-sectional of studied sonotrode along its length.

Such type of criterion selected from the consideration that the sonotrode with a constant cross-section not has a passive mass, so masses of the sonotrodes from the same material or volumes of sonotrodes from different materials as in this case, must be compared without volumes which equal the length of the waveguides, multiplied by area of its smaller end. Passive masses are responsible for the presence of additional modes of oscillation in the sonotrode (other than main: strictly longitudinal and strictly transverse), hence and for additional uncontrolled energy dissipation at a time when the sonotrode fully immersed in the environment in which it should transfer energy fundamental modes of oscillation.

The second from newly proposed criterions - the criterion "quality factor" of form□□, shows amount by which the hypothetically should be changed the resonant length of sonotrode for a given change of sound velocity in the material of which it is made, or at change frequency of the oscillator.

Analyze sonotrodes with this criterion arises from need to pre-assessment "quality factor" oscillating system without its full-scale simulation. Criterion □□in the form in which it is proposed allows evaluating the resonance of the projected waveguide independently of characteristics scattering of the material from which it is made. Clearly, the larger on magnitude values of this criterion indicate higher sensitivity to changes sonotrode resonance condition, i.e. the sharpness of the peak, and therefore the possibility of obtaining large amplitude values vibrational displacement at resonance.

III. NATURAL AND COMPUTER EXPERIMENTS

Graphics functions of the quality criterion q(*m*) from coefficient transformation *m*, excluding the effect of stress concentrators, constructed from (2) shown in Fig. 1. In the new interpretation criteria q(*m*) its graph for stepped canonical sonotrode will look line gray. In this case *m* = 1, $\frac{\varepsilon_{\max,0}}{\varepsilon_{\max}} = \frac{\xi_{\max,0}}{\xi_{\max}} = \frac{\xi_{\min}}{\xi_{\max}} = \frac{1}{m}$. For correctness of comparison the node of vibrational displacement all sonotrodes is located at a distance of 0,25□□from the end of the larger diameter.

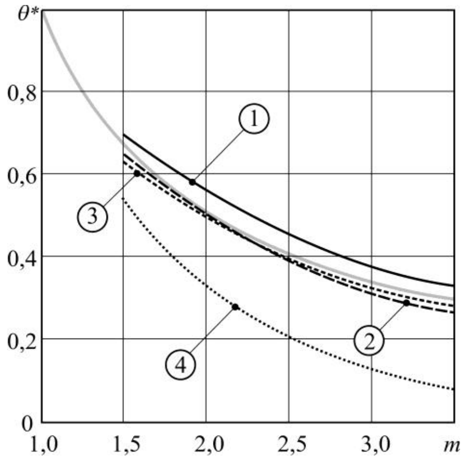

Figure 1. Functions of the quality criterion □ from coefficient transformation m, excluding the effect of stress concentrators.

1 - equilinear sonotrode [5,6], the profile of which is described by lines of the flow path of the wave vector in the stepped sonotrode at the height of the canonical conformal invariant □ = 0,95;

2 - sonotrode, the profile of which is composed of line parallel to the axis x, fillets, chamfer and another line parallel to the axis of x, which conjugate (congruent) together;

3 - hollow chamfer sonotrode;

4 - cylindrical-conical sonotrode.

In Fig. 2 shown sizes of all sonotrodes with transformation ratio equal 4.

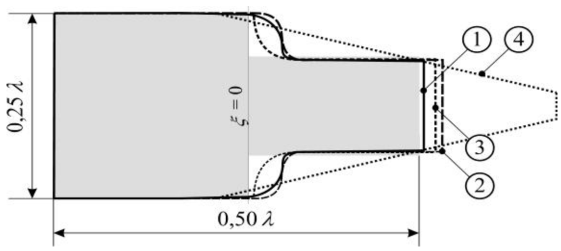

Figure 2. Profiles of sonotrodes with *m* = 4.

The graphical comparison profiles of sonotrodes, which were considered by availability a passive mass shown in Fig. 3.

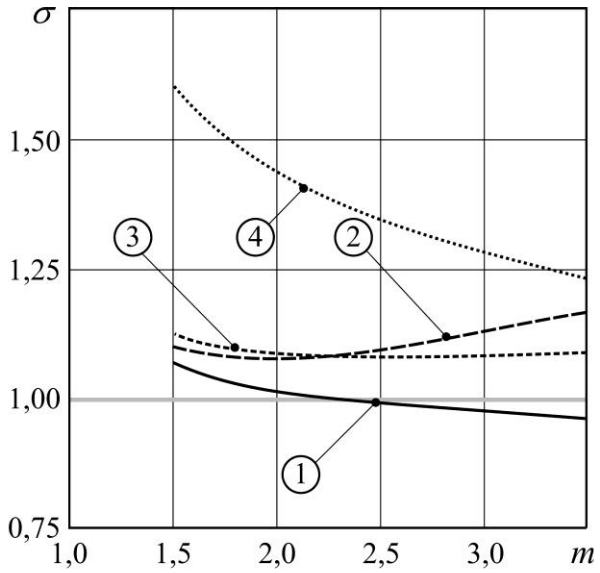

Figure 3. Functions of the criterion of passive masses *s* from transformation ratio *m*.

In table 1 shows the values of the criterion "quality factor" of form the considered above sonotrodes at a constant value of *m* and the position node of the vibrational displacement x_{node}/L. The values were obtained as the average in the range of variation of frequency.

Table 1

Criterion	Value
$\square_{\text{canonical}}$	1,00
$\square_{1}$	1,10
$\square_{2}$	0,86
$\square_{3}$	0,89
$\square_{4}$	0,91

IV. CONCLUSION

In Fig. 1 clearly shows that in the range of transformation ratios, which provide condition for the preservation of a flat wave front, the worst is sonotrode with cylindrical-conical shape, and the best - with equilinear profil. The rest almost do not differ from each other and from the stepped sonotrode.

Sonotrode equilinear profile, only one may have a volume of passive mass smaller than in the stepped transformer, where it is equal to 1 (solid gray line). The waveguide 2 with increasing m the criterion is increases, so as the ratio of the radius of chamfer and internal rounding (fillet) constantly, whereas, for example, the radius of curvature equilines flux of the field of wave vector at the canonical sonotrode in the wide portion more than in the narrow (see Fig. 2).

In Fig. 3 Larger values criterion □□at the waveguide with cylindric-conical profile has the strong difference from waveguide with profile the type equilines of flow in a stepped transformer with the same ratio of the area of input and output ends. But such a stepped transformer will have the transformation coefficient in 8 times more. Criterion □ and the criterion □ show that the advantages of the waveguide 3 before hollow chamfer transformer in given conditions occur only in the field of transformation ratios below 2.3.

Passive masses are responsible for the presence of additional modes of oscillation in the sonotrode (other than main: strictly longitudinal and strictly transverse), hence and for additional uncontrolled energy dissipation at a time when the sonotrode fully immersed in the environment in which it should transfer energy fundamental modes of oscillation.

Therefore, smaller value of the criterion □ (especially the smaller then 1) point to the possibility of obtaining high efficiencies of sonotrode. It is essential for the acoustic transformers on which are based work, for example, the sonochemical reactors cylindrical wave [7].

Here, as in all previous cases, the qualitative benefits remain with the equilinear sonotrode. It has the smallest value of □ and □ criteria in a wide range of transformation ratios, what determines its use, for example in equipment for handling liquids having different values of acoustic impedance, as in the food sonochemistry [8].

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