Calculation Features Of The Ultrasonic Vibrating Systems

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***Abstract* – The article is devoted to definition of features of development of ultrasonic vibratory systems, which to affect on accuracy of calculation of resonance frequency. Related with threaded connection between parts of vibratory system the feature of calculation is detected. Comparison of result of researches by FEM and parameter of real constructions is made. This comparisons show that at modeling of parts of vibratory system by FEM the core hole in the model must be muted by pin and pin should be taken with a diameter equal to the minimum diameter of the thread**

***Index Terms* – Ultrasonic vibrating systems, FEM, engineering calculation**

I. INTRODUCTION

AT PRESENT ultrasonic apparatuses are widely applied, such devices are large class of apparatuses used in different spheres of human activity.

Any ultrasonic technological apparatus has a source of energy (the generator of electric oscillations) and an ultrasonic vibrating system.

The ultrasonic vibrating system consists of a transducer, a matching element and a working radiating tool. In the transducer (active element) of vibrating system energy of electric oscillations transforms into energy of elastic vibrations of ultrasonic frequency and alternating mechanical force is generated.

Matching element of the system (passive concentrator) realizes transformation of speeds and provides matching of external load and active internal element.

Working tool generates ultrasonic field in processed object or it can directly influence on it.

The appearance of typical ultrasonic vibrating system is shown in Fig.1.

It consists of radiating cover-plate – 1, piezoelectric elements – 2, pin of the transducer – 3, reflecting cover-plate – 4, joint pin – 5, concentrator – 6, working tool – 7.

At that in the vibrating system there are some joints, which provide acoustic coupling and mechanical link of its elements. The joints can be permanent, however, when it is necessary for changing of working tool they can be made threaded.

The main characteristic of the ultrasonic vibrating systems is a resonance frequency. It can be explained by the fact, that efficiency of technological processes is determined by vibration amplitude (values of vibrational displacement), and maximum values of the amplitudes are achieved by excitation of the ultrasonic vibrating system at resonance frequency. At that the values of resonance frequencies of the ultrasonic vibrating systems should be within allowed ranges (for the ultrasonic apparatuses for dimensional processing these frequencies are 18, 22 and 44 kHz).

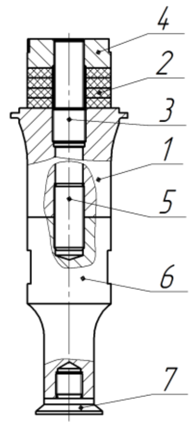

Fig. 1. Appearance of the ultrasonic vibrating system

Preliminary calculations of all units of the ultrasonic vibrating system are carried out by the procedures of engineering computation proposed in [1]–[3]. As a result of step-by-step performance of all stages of calculation main structural dimensions of vibrating system are defined depending on specified resonance frequency and power of ultrasonic action.

For more accurate calculation direct numerical methods are used. The most important method among other methods applied for the calculation of compound piezoelectric transducers is the finite element method (FEM) [4].

At that according to the results of the calculation with the use of FEM it is possible to correct the procedures of engineering calculation for more accurate dimensioning of the elements of the ultrasonic vibrating system before its production. However, even application of FEM does not allow to achieve the accuracy of calculations, when calculated and produced elements of the ultrasonic vibrating system have the same (within the limits of error admissible for matching ±100 Hz) designed resonance frequency.

It can be explained by the fact, that during the calculation of FEM there are some difficult moments, which influence on the accuracy of the calculation:

– the presence of threaded joints at the boundary of elements;

– the application of junctions between cylindrical parts in the production, which differ in form from those used in the procedures of engineering calculation.

Thus the aim of the paper is to determine the features of the calculation of compound units of the ultrasonic vibrating system by finite element method and on the base of their analysis to introduce amendments into the stages of engineering calculation.

II. Study Of The Influence Of Threaded Joints On The Calculations Of The Piezoelctric Transducer

Due to the presence of threaded joints in the boundaries of the elements we set a problem to define optimum dimension values of constituent elements at the calculations by FEM, which have minimum error.

For the calculation by FEM the piezoelectric transducer with four piezoceramic elements having threaded joint of M18x1.5 was taken. For modelling it is necessary, that joint pin 5 (see Fig.1) does not overhang reflecting cover-plate 1, so multiplicity of the piezoelectric transducer to half-length is achieved. The appearance of the model of the piezoelectric transducer is shown in Fig.2.

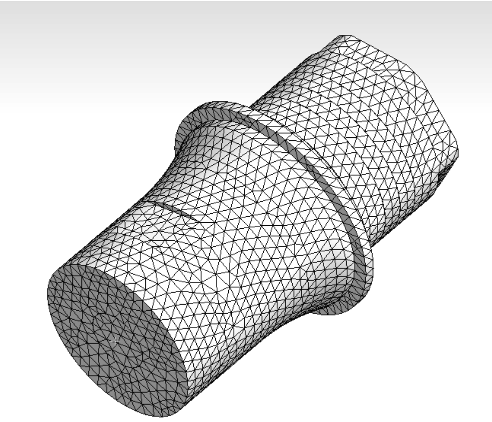

Fig. 2. Appearance of the model of the piezoelectric transducer

Maximum value of the diameter of shortened pin was 18 mm, that corresponded to maximum diameter of jointing thread. Minimum value of the diameter of the pin was 16.5 mm, that corresponded to minimum diameter of the thread. The value of the diameter was changed with the step of 0.5 mm. The calculations were made by finite element method. The number of the elements in every calculation was the same and it amounted to 6000±100.

As a material of the pin titanium alloy was chosen. The calculation are given in Tab. I.

TABLE I
Calculation Of Frequency Of The Compound Piezoelectric Transducer

Diameter of shortened pin, mm	Frequency, Hz
16.5	19052
17	19044
17.5	19020
18	18530

By analogy frequencies of the compound piezoelectric transducer with the pin made of steel were calculated. The calculations are given in Tab. II.

TABLE II
Calculation Of Frequency Of The Compound Piezoelectric Transducer With The Pin Made Of Steel

Diameter of shortened pin, mm	Frequency, Hz
16.5	18879
17	18835
17.5	18796
18	18750

To determine accurate values we compared the results of the frequency values obtained by FEM and the values of proper resonance frequencies measured at produced and assembled piezoelectric transducers.

For measurements of the values of proper resonance frequencies the sample from 10 produced and assembled piezoelectric transducers was taken. Measurements of proper resonance frequency were made by the piezoelectric probe with dry point contact connected to the oscillograph at the power supply of the piezoelectric transducer from the low-voltage generator. Resonance frequency was defined by maximum value of vibration amplitude observed at the screen of the oscillograph.

According to the results of measurements the values of resonance frequency of the piezoelectric transducers are 19070±90 Hz for the transducers with titanium pin and 18950±80 Hz for the transducers with steel pin. The difference in frequency between the transducers can be explained by the presence of errors at the production of single components of the piezoelectric transducer.

As it is evident from the comparison of the results of FEM calculations with the results of measurements, minimal difference between the values of resonance frequency can be obtained, when the diameter of the pin equals to the diameter of the thread.

According to obtained results it can be concluded, that at the FEM calculation of the units of the ultrasonic vibrating system containing threaded joints tap holes in the model should be plugged by the pin, which does not exceed dimensions of the unit, and the diameter of the pin should equal to minimum diameter of the thread.

III. Studies Of Influence Of Radial Junctions On The Parameters Of The Concentrators Of Vibrating Systems

The concentrators of ultrasonic vibrations are obligatory parts of vibrating systems in different ultrasonic installations. Their main purpose is to increase displacement amplitude of ultrasonic vibrations obtained by the transducers. In paper [5] it was shown, that compound concentrators have more perfect constructive form. Stepped concentrators with gradient junctions (e.g. exponential or radial zone) are the most perspective among them.

The appearance of the compound stepped radial concentrator is shown in Fig.3.

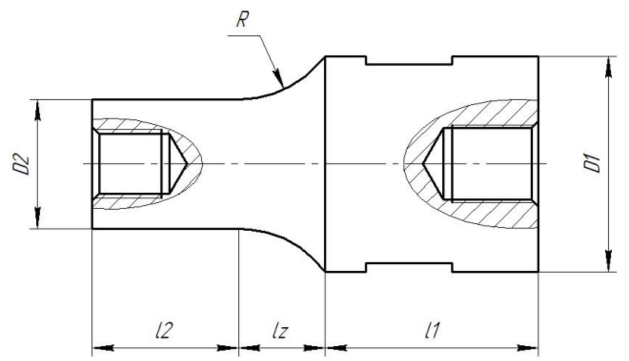

Fig. 3. Appearance of the compound stepped radial concentrator

For the calculations of stepped concentrators N.S. Noskov [5] offers design procedure with the application of graphic dependences and nomograms, which is based on the following design formulas:

In the calculations it was taken c=4950 m/sec (for titanium alloy), design resonance frequency f=22000 Hz.

This design procedure was used for construction of solid-state models, which were calculated by finite element method. In one experiment exponential junction was constructed with the help of formula 3, in the other experiment the exponential junction was replaced by the radial. For threaded joint we used the approaches and values obtained earlier.

Obtained values are given in Tab. III.

TABLE III
THE RESULTS OF MODELLING FOR EXPONENTIAL AND RADIAL FORM OF JUNCTION

Diameter ratio	Frequency (exponential form, kHz)	Frequency (radial form, kHz)
1.5	21939	21105
1.7	21864	21096
2	21813	20863
2.5	21815	20584

According to obtained data it can be concluded, that exponential form of the junction gives the results of resonance frequency, which are close to formula calculations. The error in calculations can be caused by the fact, that at the construction of solid-state model the exponential junction was taken with some approximation to the real form.

At the application of the radial form of the junction miscalculation was about 900 Hz and it increased, as amplification coefficient rose.

However in practice the nomenclature of used concentrators is big, and the application of exponential junction requires great production costs due to the necessity of accurate production of junction profile. That is why, for solving different industrial tasks the use of exponential junctions is unfounded.

Thus it is practical to apply radial junctions. On the base of the analysis of model data it is necessary to introduce amendments in the form of coefficients into the design procedure of the concentrators with exponential junction.

For solving this problem we carried out studies on the search of required coefficients to the sizes l_1 and l_2 for each of amplification coefficient. The size l_z remains unchanged, as its change influences on amplification coefficient.

TABLE IV
CALCULATION OF FREQUENCY AT RADIAL FORM OF JUNCTION

Diameter ratio	Coefficient	Frequency (radial form, kHz)
1.5	0.993	22017
1.7	0.926	22000
2	0.916	22009
2.5	0.898	21902

The formula with the correction coefficient will be following:

where, k is the correction coefficient.

Using obtained formula for different amplification coefficients we designed pilot batches of the concentrators made of titanium alloy. The measurements of proper resonance frequency were carried out by piezoelectric probe with dry point contact at the connection of the concentrator to the piezoelectric transducer.

The results of measurements are given in Tab. V.

TABLE V
MEASUREMENTS OF FREQUENCY OF THE CONCENTRATORS

Diameter ratio	Resonance frequency Transducer+concentrator
1.5	21950
1.7	21980
2	22060
2.5	21895

The appearance of the concentrators with the radial junction developed with the help of completed procedure of engineering calculation is shown in Fig.4.

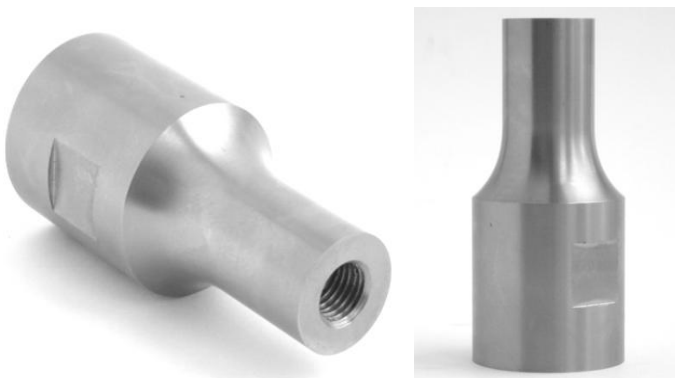

Fig. 4. Appearance of the concentrator with the radial junction

The error between FEM calculations and pilot results is caused by difference of prescribed and real speed in the material and mistake at the production of the concentrators.

Thus it can be concluded, that at the development of the concentrators of ultrasonic vibrations with radial junction existing procedure for exponential junction can be used applying obtained correction coefficients.

IV. CONCLUSION

As a result of carried out researches we revealed main calculation features of the compound units of the ultrasonic vibrating systems by finite element method and on the base of their analysis necessary amendments were introduced into the stages of engineering calculation.

At the calculation of FEM elements of the ultrasonic vibrating systems contained threaded joints it was ascertained, that for more accurate calculation the diameter of joint pin should be equal to internal diameter of the thread.

At the study of the concentrators with radial junction necessary corection coefficients for the design procedure of the concentrators with exponential junction were obtained.

Carried out research allowed to obtain required values of frequency of produced elements of the ultrasonic vibrating system, that in turn reduced time expenditures and production costs for modification and fitting of the elements.

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