Specific Features of Finite-Element Modeling of Ultrasonic Vibrating Systems and Their Constitutive Parts

Vladimir N. Khmelev, Sergey S. Khmelev, Galina A. Bobrova, Ksenija A. Karzakova
Biysk Technological Institute (branch) of Altay State Technical University named after I.I. Polzunov, Biysk, Russia
Center of Ultrasonic Technologies, Biysk, Russia

Abstract – **The article is devoted to the study of necessity to use computer modeling of the ultrasonic vibrating systems by the finite-element method. There is a need to determine the influence of specified parameters of finite elements on the calculated resonance characteristics.**

Index Terms – **Ultrasound, ultrasonic vibrating system, modeling, finite-element method.**

I. Introduction

RUSH DEVELOPMENT of modern society requires reduction of time spent on mastering of new technologies and new products in industrial conditions. Physical modeling of the technological objects demands significant material and financial expenditures. Modern development level of computer technologies helps to realize computer modeling of the objects for the optimization of their parameters and characteristics, accelerate construction process, avoid possible errors at the stage of design and decrease financial costs for the production [1].

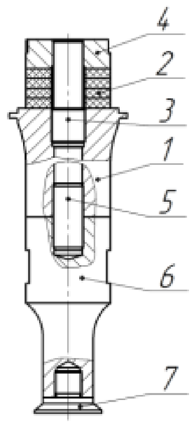
At present in industry the technologies based on the application of ultrasonic vibrations generated by the ultrasonic vibrating systems are widely used. The ultrasonic vibrating systems being a part of the ultrasonic technological apparatuses are complex technological objects consisting of different elements [2].

The scheme of the ultrasonic vibrating system uniting the piezoelectric transducer, the waveguide – the concentrator and changeable working tool is shown in Fig.1 [3].

Analytical calculations of such systems are impossible due to irregularity of the properties of real materials, large number of conjugate elements, presence of the junctions, key flats, threaded connections, etc.

That is why the modeling by finite-element method is widely applied at the construction of the ultrasonic vibrating systems. The finite-element method is based on the idea of the approximation of continuous function by the discrete model, which is constructed on the set of piecewise continuous functions defined at finite number of the subregions called finite elements [4].

For the realization of finite-element method different software (CAE-systems) is used. Modern CAE-systems have human-engineered interface, iterative equation solve, they provide the creation of three-dimension objects, import of ready models from the other design environment, great choice of types of finite elements and also the possibility to choose the material of the model.



1 – radiating cover-plate, 2– piezoelectric element, 3 – bolt of the transducer, 4 – reflecting cover-plate, 5 – joined bolt, 6 – concentrator, 7 – working tool.
Fig. 1. Ultrasonic vibrating system.

For the design of solid models the complex of three-dimension design is often used, which lets exporting developed 3d models into the systems of finite-element modeling. The solid model should be saved in the required format to transfer it into the system of finite-element modeling. The most part of the systems of finite-element modeling use graphics engine Parasolid. For this purpose the file of solid model is saved with the extension .x_t, after that it is ready for the export into applied medium of finite-element modeling.

Modeling of the ultrasonic vibrating system and its constitutive parts often leads only to the determination of their resonance frequencies and distribution of vibrations along the acoustic axis or along the radiation surface.

In the article we analyze the possibility of finite-element method at the modeling of the units of the ultrasonic vibrating system for the determination of specific features influencing on the accuracy of obtained values.

II. Research of Modeling Features

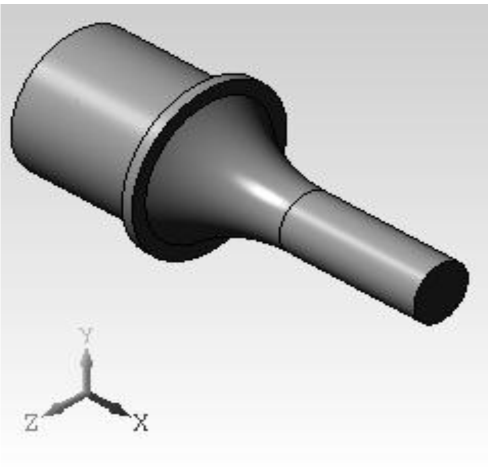
For solving of stated task we use modal type of the analysis. Firstly it is necessary to specify the characteristics of the materials (velocity of sound in the material, Poisson ratio) of studied object, as these properties determine the resonance parameters of the vibrating system. At the calculation of the resonance parameters the frequency range for the research is set and the number of vibration modes for the search is indicated.

The main stage of modeling is the assignment of the finite-element mesh. It is the size and the form of the finite element that determine the accuracy of calculations. At the generation of the mesh CAE-system creates it automatically adjusting under the construction of the object. Further the calculations are carried out.

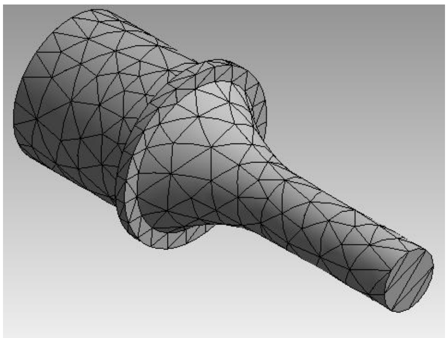
As an example the calculation of the ultrasonic concentrator automatically divided into finite elements is considered. The material of the concentrator is titanium alloy VT 1-0, the size of the finite element is 0.0046 m. Performed calculation gives resonance frequency for such model, which equals 19842 Hz. Calculated solid constructions and model divided into the finite elements are shown in Fig.2b.

The accuracy evaluation of the calculation of resonance frequency by the finite-element method is carried out by the comparison obtained design values with resonance frequency of developed units of the ultrasonic vibrating system, which have sizes and physical parameters corresponding to designed solid model. Moreover for the comparison the results of analytical calculations of different units according to specified and checked design procedure are used [5].

The measurements of proper resonance frequency of the units of the ultrasonic vibrating system are carried out by the piezoelectric receiving transducer with dry point contact at the connection of the concentrator to the piezoelectric transducer [6].



a)



b)

Fig. 2. a) solid model, b) model with the finite-element mesh made automatically.

Measured frequency of produced titanium concentrator is 20010 Hz. As it is evident from the results, the design of the mesh automatically leads to essential inaccuracy of the calculations.

In this connection for the analysis of the model suffering from bulk state of stress it was proposed to use tetrahedral type of the finite element. For further comparison we measure the ultrasonic concentrator with the following output parameters: the material of the concentrator is the titanium alloy VT1-0, the size of the finite element is 0.0046 m, type of the finite element is tetrahedral.

Performed calculation gives resonance frequency, which equals 19892 Hz, for such output parameters, that is a better result in comparison with automatic mesh.

Further researches are aimed at the determination of the influence of finite element size on the calculation accuracy for different types of the units of the ultrasonic vibrating systems. Firstly as a first model we calculate the concentrating unit being a part of the ultrasonic apparatuses for the cavitation processing of liquid and the ultrasonic welding tool in the form of two-dimensional waveguide.

Carried out calculations of presented models with the following input parameters: the material is the titanium alloy VT1-0, the type of the finite element is tetrahedral; allow determining dependence (shown in Fig.3) of rated resonance frequency on the size of finite element for different types of the units of the ultrasonic vibrating system.

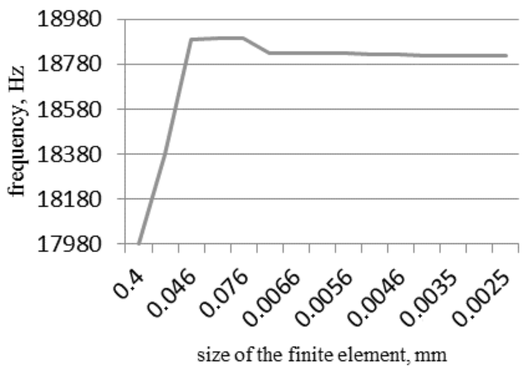


Fig.3. Dependence of calculated resonance frequency on the size of the finite element.

The comparison was carried out with produced welding tool, which resonance frequency equals 18810 Hz.

Based on obtained results it can be concluded, that finer mesh provides the increase of accuracy of the results. However, the partition in fine mesh at large sizes of studied part can lead to essential increase of calculation time.

As the units of the ultrasonic vibrating system have complicated appearance, the load along the model is distributed irregularly, that is why it is worthwhile to use fine mesh, in the places where larger deformation and stress gradients are expected [7] (for example, the zone of radial junction and cylindrical zone of smaller diameter on the ultrasonic concentrators). At the same time crude mesh can be applied in the zones with relative deformations and stress and also in the zones, which are not of interest for the designer (as it does not essentially influences on the parameters of the ultrasonic vibrating system). In this connection before the design of the finite-element mesh it is necessary to find supposed zones of stress concentration. Fig. 4 shows, that the calculation of different zones of the object can be realized with the application of meshes with different sizes of finite elements.

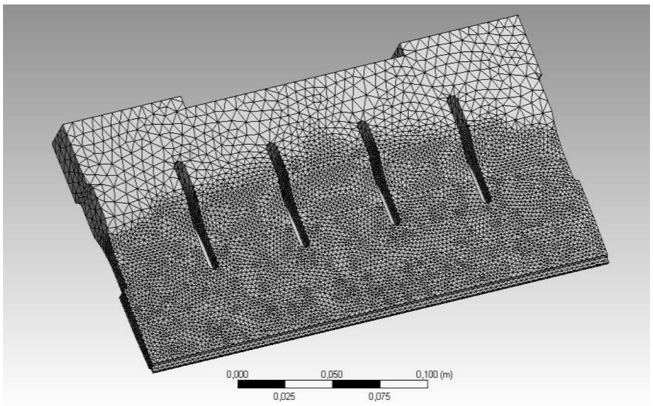


Fig. 4. Unit of the ultrasonic vibrating system with heterogeneous finite-element mesh.

Respectively, there is a need to prove the correctness of this statement carrying out the modeling of the units of the ultrasonic vibrating system with heterogeneous mesh.

Carried out calculations of presented model with the following input parameters: the material is the titanium alloy VT1-0, the type of the finite element is tetrahedral, the sizes of the finite element of crude and fine meshes are 0.007 m and 0.002 m, respectively, let obtaining rated value of resonance frequency, which equals 18860 Hz.

III. CONCLUSION

In the result of performed study we analyze the possibility and specialty of the application for the increase of the calculation accuracy of the units of the ultrasonic vibrating systems and it is proved appropriateness of the realization of the following procedures:

- to use tetrahedral type of the finite element;
- to apply the size of the finite element of no more than 0.007 m;
- at larger sizes of modeled part it is appropriate to use heterogeneous mesh of the finite elements.

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Vladimir N. Khmelev (SM'04) is deputy director for scientific and research activity at Biysk technological institute, professor and lecturer, Full Doctor of Science (ultrasound), honored inventor of Russia, laureate of Russian Government premium for achievements in science and engineering, IEEE member since 2000, IEEE Senior Member since 2004. His scientific interests are in field of application of ultrasound for an intensification of various technological processes.

Sergey S. Khmelev has got engineer's degree at 2007 and Philosophy degree (Candidate of Engineering Sciences) at 2011. He is leading specialist in development of ultrasonic vibration transducers, docent and lecturer in Biysk Technological Institute. His research interests are in field of designing and modeling of ultrasonic vibration transducers and in ultrasonic treating of high viscous liquid media. Author is laureate of Altai region premium for achievements in science and engineering

Ksenija A. Karzakova was born in 1992, she is student of Information Systems Engineerig specialty of Biysk Technological Institute (branch) Altai State Technical University named after I.I. Polzunov. Area of research interests is development and modeling of extended surface ultrasonic radiators for liquids treatment.

Galina A. Bobrova was born in 1992, she is student of Information Systems Engineerig specialty of Biysk Technological Institute (branch) Altai State Technical University named after I.I. Polzunov. Area of research interests is development and modeling of extended surface ultrasonic radiators for liquids treatment.