The Method of Indirect Control of the Parameters of Cavitating Liquid Media

Vladimir N. Khmelev, *Senior Member*, IEEE, Roman V. Barsukov, Dmitry V. Genne, Denis S. Abramenko, Evgeniy V. Ilchenko, *Student Member*, IEEE
Center of Ultrasonic Technologies, Biysk, Russia
Biysk Technological Institute (branch) Altai State Technical University named after I.I. Polzunov, Biysk, Russia

***Abstract* – The article is devoted to the method of indirect control of the properties of liquid technological media during the influence of ultrasonic high-intensity vibrations on them. As a result of the studies it was stated and proved the possibility of control of acoustic properties of processed technological media at different intensities of ultrasonic influence on changes of electric parameters of the piezoelectric ultrasonic vibrating systems.**

***Index Terms* – Ultrasound, ultrasonic generators, liquid media, acoustic load, control.**

I. INRODUCTION

AT PRESENT in different fields of science and industry physical, chemical or biological perfomances of ultrasound are used [1]. The processes realized with the application of ultrasound in liquid media are widely used [2]. It caused by the possibility of realization of cavitation process in liquid media changing the structure and properties of substances and materials.

For the realization of ultrasonic influence on liquid media ultrasonic technological devices are applied. To provide maximum efficiency (the productivity of the process) of ultrasonic influence applied devices should guarantee maximum effective energy transformation of electrical networks into the energy of mechanical vibrations of ultrasonic frequency, and also their introduction into processed media.

At that the necessity of design of universal ultrasonic technological device providing maximum effective influence on various technological media requires to solve the task of optimum matching of the system “electronic generator – ultrasonic vibrating system – processed medium”. In practice this task can be solved by the choice of optimum parameters (shape, size, material) of the elements of the ultrasonic vibrating system (concentrator of ultrasonic vibrations, working tools, etc.) and proper adjustment of the electronic generator.

However it should be noted, that processed medium, which is a load for the ultrasonic vibrating system, changes its parameters during the process bringing certain mismatch in this system. To maintain optimum parameters of introducing of energy into processed medium it is necessary to solve the task concerning with the control of the parameters of the properties of technological media subjected to ultrasonic influence.

The present paper is a continuation of similar studies carried out before and described in the papers [3,4]. The necessity of carrying out investigations is caused by a number of disadvantages revealed after the analysis of these works and need of their removal.

II. THEORY

For the matching of the ultrasonic vibrating system with the electronic generator of ultrasonic frequency following circuit of switching of piezoelectric transducer is used (see Fig. 1) [3].

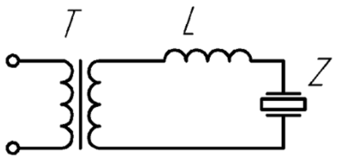


Fig. 1. The match circuit of the ultrasonic vibrating system with the output of the electronic generator

Presented circuit has an element Z, which is ultrasonic vibrating system (i.e. complex system uniting the piezoelectric transducer, the concentrating wave-guide, the working tool) influenced by processed technological medium.

The piezoelectric transducer transforms the energy of electric oscillations into the energy of mechanical vibrations. The system of electromechanical analogy allows to consider such energy transformation as a connection of additional complex load into the electric circuit. That is why the current flowing through the piezoelectric transducer will be determined by two components: current of mechanical branch and current of electric branch. In Fig. 2 the equivalent circuit of the piezoelectric transducer is shown.

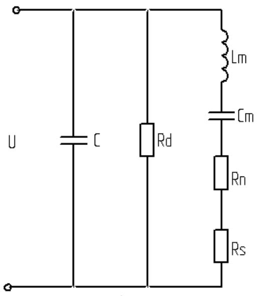


Fig. 2. The equivalent electric circuit of the ultrasonic vibrating system with the piezoelectric transducer

The electric branch includes static capacitance of the piezoelectric transducer C and dielectric loss resistance (see Fig. 2).

The mechanical branch has connected in series L element, C element and active elements determined by the properties of processed medium. According to existing opinions [2] inductance Lm is equivalent to varying mass of the transducer, capacitance Cm is equivalent to flexibility, ohmic resistance includes two items: Rn, which corresponds to mechanical loss resistance and Rs, which corresponds to radiation resistance.

To measure the parameters of liquid media subjected to ultrasonic influence the measuring bench was developed. Block diagram of the measuring bench is shown in Fig. 3.

The bench consists of module of output of mechanical branch current Im [5], F is a channel of frequency measurement, Utr is a channel of voltage measurement on the secondary transformer winding T (Fig. 1), Us is a channel of voltage measurement on the ultrasonic vibrating system.

Essential disadvantage of the measuring bench used at carrying out experiments and discribed in the paper [3] was an absence of amplitude stabilization of driving voltage on the primary transformer winding T at reading of amplitude-frequency characteristics. As a result as the frequency of the generator approaches to resonance frequency of the ultrasonic vibrating system, on the secondary winding of the transformer considerable voltage depression is occured. Since the calculations of equivalent electric parameters of the medium are made under the assumption, that driving force remains unchanged during the reading of amplitude-frequency characteristics, measured values of amplitude of mechanical branch current and voltage on the piezoelements do not represent the facts. In proposed measuring bench the voltage on the transformer is stabilized by the power regulator controlled by the microcontroller of the ultrasonic technological device.

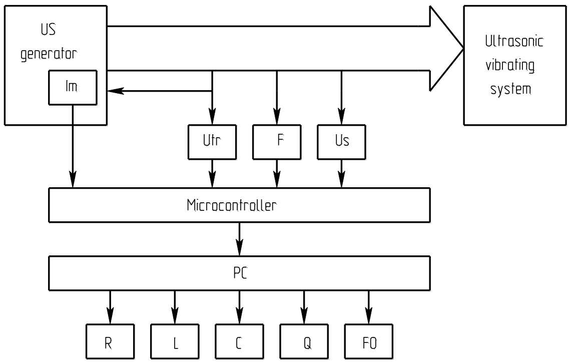


Fig. 3. The block diagram of the measuring bench

At the use of the circuit of the output of the mechanical branch current [5], obtained values are proportional to the current Im and they are suitable for the construction of amplitude-frequency characteristic of the mechanical branch current and also for further calculation of Q of mechanical circuit. However, to obtain the value of equivalent electric value in units of measurement of the metric system, it is necessary to define absolute value of the mechanical branch current and absolute value of the voltage on the piezoelements. For obtaining of absolute values of mentioned magnitudes the calibration of measuring channel of current of mechanical branch (Im), voltage across the system (Us) and voltage across the transformer (Utr) of the measuring bench was carried out.

For the calculation of the parameters of the equivalent circuit following expressions are used:

$$R_M = \frac{U_{s0}}{I_{M0}}, \tag{1}$$

$$L_M = \frac{QR_M}{\omega_0} = \frac{QU_{s0}}{\omega_0 I_{M0}}, \tag{2}$$

$$C_M = \frac{1}{QR_M\omega_0} = \frac{I_{M0}}{Q\omega_0 U_{s0}}, \tag{3}$$

where I_{M0} is a value of current of mechanical branch at the resonance; Us_0 is a voltage drop on the piezoceramic transducer; Q is a Q factor of the system; ω_0 is a resonance frequency.

To calculate the values of Q factor amplitude-frequency characteristic of the current of mechanical branch was applied, its typical form is shown in Fig. 4.

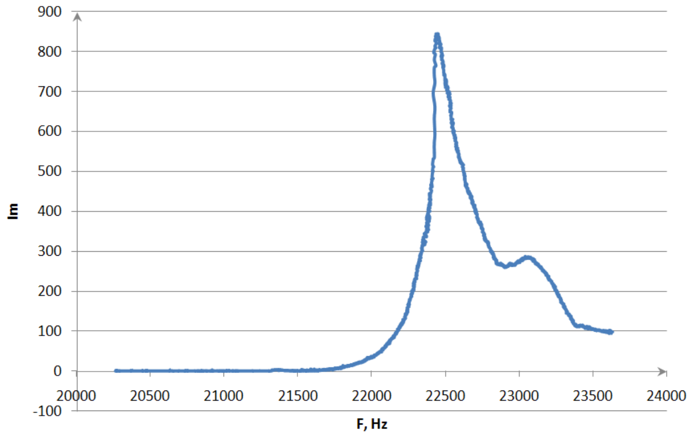


Fig. 4. Amplitude-frequency characteristic of the current of mechanical branch

Q factor is calculated on the base of the expression (4) connecting the current flowing through vibrational contour with the current at the resonance and frequency [6].

$$\frac{I}{I_0} = \frac{1}{\sqrt{1 + Q^2\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)^2}}, \tag{4}$$

where ω0 is a resonance frequency; ω is a present frequency; I0 is a current at the resonance frequency; I is a current at present frequency; Q is a Q factor, the expression for Q factor of resonant circuit was obtained.

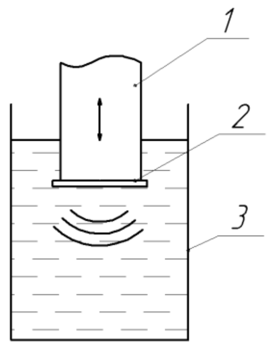
$$Q = \sqrt{\frac{\left(\frac{I_0}{I}\right)^2 - 1}{\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)^2}}. \tag{5}$$

In practice such expression of Q factor is more suitable, as it do not require the construction of full amplitude-frequency characteristic of the circuit.

III. Experimental Results

As a base of the measuring bench the generator of the ultrasonic device Volna 0.4/22 OM [7] with half-wave ultrasonic vibrating system and working ending with the radiating surface of 176 mm^2 was used. Distilled water, acetone, alcohol and machine oil were applied as studied media. The measurements were carried out at different power levels of ultrasonic influence in two different technological volumes.

The processing of technological media took place in culindrical vessels (as it is shown in Fig. 5). With the volume of 500 ml and 250 ml, the height of liquid column was 95 mm and 90 mm, respectively. The distance from the bottom of the vessel to the surface of working tool for the volumes of 500 ml and 250 ml was 73 mm and 68 mm, respectively.



1 – wave-guide-concentrator; 2 – working tool; 3 – technological volume
Fig. 5. The placement of ultrasonic radiator in volume

For each of liquids 5 measurements at 6 power levels were carried out.

On the base of obtained experimental data with the use of formulae (2), (3), (4) the values of R, L, C elements of the equivalent electric circuit of the ultrasonic vibrating system were calculated.

Fig. 6 shows the dependences of ohmic resistance of the mechanical branch on the current of the mechanical branch Im.

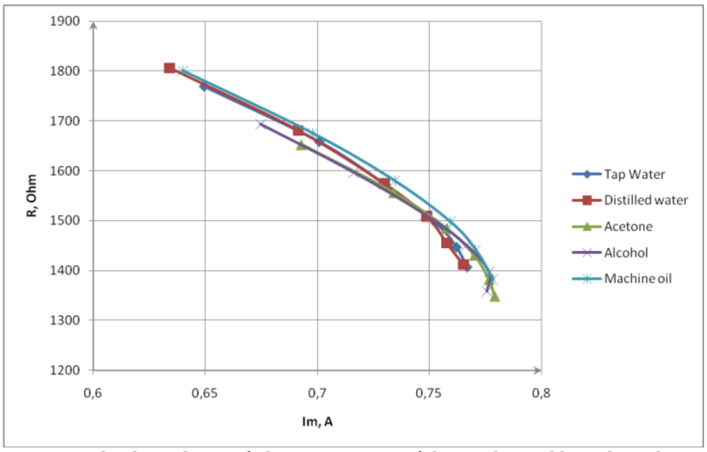


Fig. 6. The dependence of ohmic resistance of the mechanical branch on the current of the mechanical branch

Presented dependences have decreasing character. With the increase of vibration amplitude of the surface of working tool the cavitation develops in medium, at that degree of damping of acoustic vibrations in processed medium increases. However, in contrast to this effect the phenomenon of acoustical reflection from steam and gas bubbles generated near working tool occurs. In a whole the properties of the medium approach to the properties of air, which equivalent ohmic resistance is lower than the resistance of liquid.

Knowledge of the value of ohmic resistance of equvalent electric circuit of the ultrasonic vibrating system, range of its change lets perform optimum matching of the ultrasonic vibrating system with the electronic generator at the stage of adjustment.

Fig. 7 shows the dependences of inductive part of impedance of the mechanical branch on the current of the mechanical branch Im.

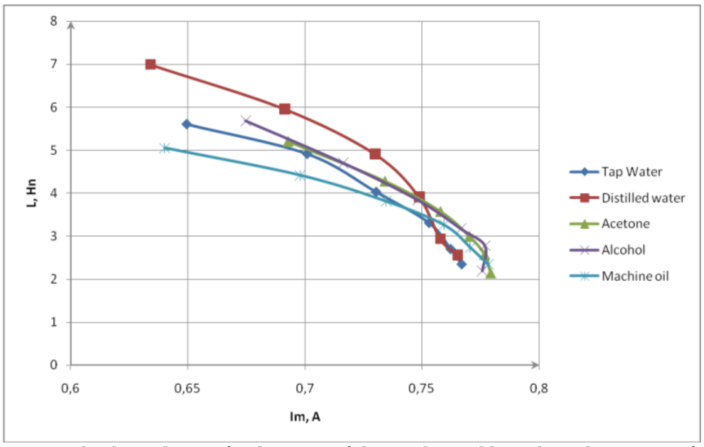


Fig. 7. The dependence of inductance of the mechanical branch on the current of the mechanical branch

The curves presented in the Fig. 7 have decreasing character, that can be explained by the reduction of density of insonified medium as a result of its loosening by steam and gas bubbles.

Fig. 8 shows the graphs of dependences of capacitive part of the impedance of the mechanical branch on the current of mechanical branch.

Increase of capacitive component is also connected with the development of cavitation in the medium and a s a consequence rise of compressibility of liquid.

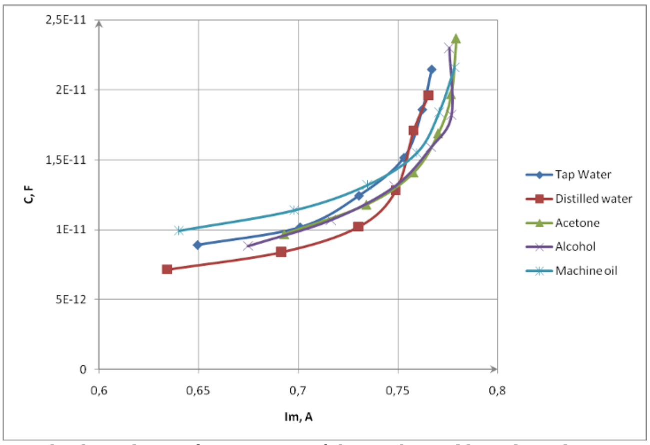


Fig. 8. The dependence of capacitance of the mechanical branch on the current of mechanical branch

Knowledge of the value of reactive elements of the equivalent electric circuit of the ultrasonic vibrating system, range of their changes lets firstly accomplish primary adjustment of the ultrasonic technological device at the stage of checkout. Secondly there is a possibility to correct the elements of matching circuits in the case of changes of reactive properties of processed media during the operation of the ultrasonic device [8].

Besides the properties of processed media such as damping coefficient of ultrasonic wave, density, compressibility the parameters of the technological volume influence on the degree of matching of the system "ultrasonic generator – ultrasonic vibrating system – processed medium". For the estimation of the character and degree of influence of the technological volume on the parameters of the equivalent circuits parameters R, L, C were measured during the processing of different volumes.

The results of measurements are presented in Fig. 9, 10, 11.

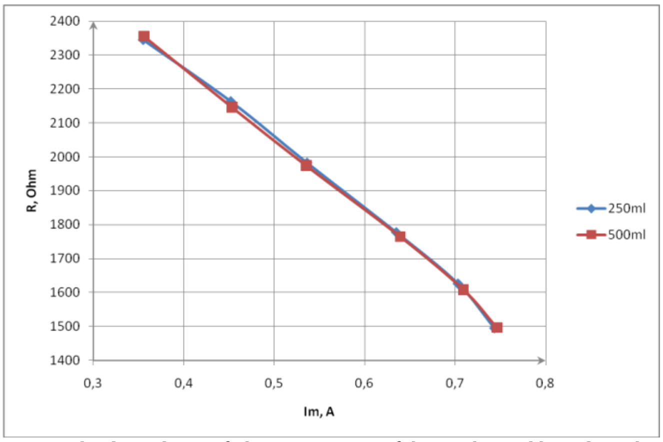


Fig. 9. The dependence of ohmic resistance of the mechanical branch on the current of the mechanical branch

From the dependence shown in Fig. 9 it is evident, that the change of the working volume does not essentialy influence on active component of the impedance of the mechanical branch, i.e. ohmic resistance of the mechanical branch depends on the parameters of the medium, but it does not depend on the geometry of the technological volume.

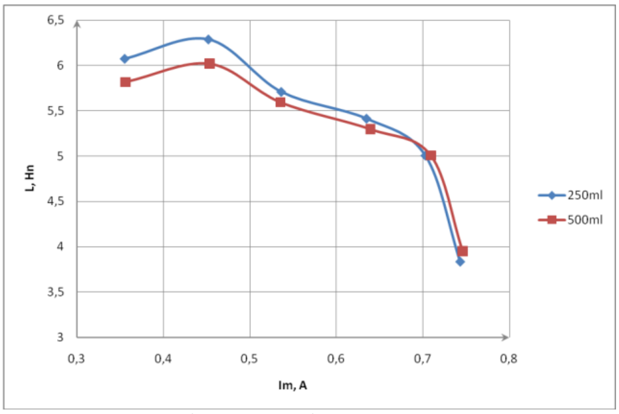


Fig. 10. The dependence of inductance of the mechanical branch on the current of the mechanical branch

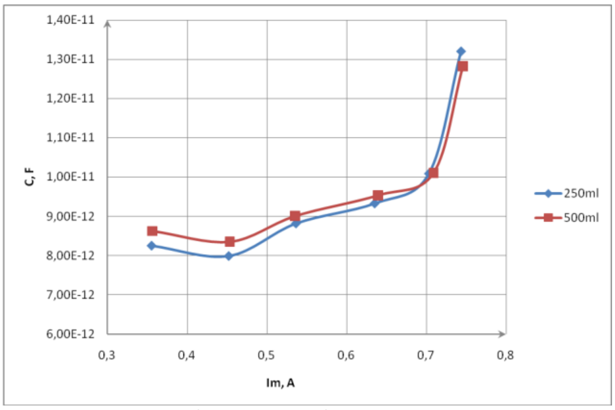


Fig. 11. The dependence of capacitance of the mechanical branch on the current of the mechanical branch

At the same time based on the dependences presented in Fig. 10 and 11 it follows, that the changes of overall dimensions of the working volume influence on the reactive component of impedance of the mechanical branch. Change of volume sizes leads to the changes of vibration distribution, it is possible the appearance of standing waves (resonance gaps) and as a result it has an effect on the reactive component of acoustic impedance of the medium.

IV. CONCLUSION

Carried out measurements let make more exact and prove the dependences between the parameters of processed technological media and measured electric values characterized the operation of the ultrasonic vibrating system. The character of these dependences is complex and it is defined by the parameters of ultrasonic vibrating system, processed media and working volumes. The possibilty of control of the parameters of the ultrasonic vibrating system connected with the properties of insonified media lets design the systems of on-line test of the processes taking place in the ultrasonic field and optimize the operation of the ultrasonic technological devices as a whole.

REFERENCES

[1] Ultrasonic transducers / Ed. By Kikuchi E. – M.: "MIR" Publishing, 1972. – 424p. (in Russian)

[2] Donskoy A.V. Ultrasonic electrotechnological settings – Leningrad: Energoizdat, 1982. – 208p. il. (in Russian)

[3] Khmelev, V.N. Method of Control Acoustic Load [Text] / V.N. Khmelev, R.V. Barsukov, D.V. Genne, D.S. Abramenko, E.V. Ilchenko // International Conference and Seminar of Young Specialists on Micro / Nanotechnologies and Electron Devices EDM'2011: Conference Proceedings. – Novosibirsk, NSTU, 2011. – P.236–240.

[4] Khmelev, V.N. Practical Investigations of the Method of Indirect Parameter Checkout of the Acoustic Load Parameters [Text] / V.N. Khmelev, R.V. Barsukov, D.V. Genne, D.S. Abramenko, A.V. Shalunov, E.V. Ilchenko // International Conference and Seminar of Young Specialists on Micro / Nanotechnologies and Electron Devices EDM'2011: Conference Proceedings. – Novosibirsk, NSTU, 2011. – P.241–244.

[5] Patent 2240073 Russian Federation. Method of the ultrasonic liposuction process control / Khmelev V.N., Barsukov R.V., Tsiganok S.N., Slivin A.N., Shalunov A.V; patent holder Altay State Technological University after I.I. Polzunov. – №2003107030

[6] Zernov N.V., Karpov V.G. Theory of radio engineering circuits – Leningrad.: Energy, 1965 – 892p. (in Russian)

[7] http://u-sonic.ru/devices/volna

[8] Khmelev V.N Approval of electronic generators with piezoelectric oscillatory systems to improve the efficiency of ultrasonic machines / V.N. Khmelev, D.V. Genne, R.V, Barsukov, S.N. Tsiganok, A.V. Shalunov, D.S. Abramenko // Proceedings of the Tomsk Polytechnic University. – 2010. vol. 317. № 4. – P. 139–143. (in Russian)

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. His biography published in 7th issue of book "Who is who in scientific and engineering".

Roman V Barsukov has got engineer's degree at 1998 and Philosophy degree (Candidate of Engineering Sciences) at 2005. He is leading specialist in designing of modern electronic ultrasonic generation devices, laureate of Russian Government premium for achievements in science and engineering, docent and lecturer in Biysk Technological Institute. His research interests are in field of ultrasonic equipment and technologies and in applying of high intensive ultrasonic vibrations for intensifying of technological processes and for changing of materials and substances properties.

Dmitry V. Genne has got engineer's degree on information science and measuring engineering at 2006. He is engineer and lecturer in Biysk Technological Institute. He is leading specialist in controlling of treating parameters of variously applied ultrasonic equipment. His research interests are in development of high -power electronic generators for ultrasonic technological devices.

Evgeniy V. Ilchenko (SM'11) is a student of Biysk Technological Institute. His research interests are in field of ultrasonic technological devices software development and ultrasonic technological devices creating.