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CONTROL OF THE ULTRASONIC EMITTERS PARAMETERS TO DETERMINE THE DEGREE OF TOOL MATERIALS AND PROTECTIVE COATINGS CAVITATION DESTRUCTION

Vladimir Khmelev
Roman Barsukov[1]
Aleksandr Barsukov

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A B S T R A C T

The article presents the results of studies aimed at identifying the possibility of using piezoelectric ultrasonic oscillatory systems (USOS), used to form cavitation effects in liquid media, as a sensor for controlling the degree of cavitation erosion of materials for working tools and protective coatings. The studies were carried out on the basis of the analysis of the piezoelectric ultrasonic oscillatory systems (emitters) physical equivalent circuits, formed from electromechanical analogues, taking into account the attached test samples. The results obtained made it possible to confirm the possibility and effectiveness of monitoring the ultrasonic oscillatory system parameters to determine the degree of cavitation destruction of tools and protective coatings, as well as to establish the sensitivity of the proposed control method.

1. INTRODUCTION

The relevance of the works on development of the method and means of control of cavitation destruction of materials and protective coatings (Hardes et al., 2019; Lamana, Pukasiewicz, Sampath, 2018; Lin et al., 2019; Romero, Tschiptschin, Scandian, 2019; Tudela, Verbickas, Burmistroviene, Zhang, 2018) is caused by the need to solve the problem of determining the applicability of created and used materials, especially for their exploitation in abnormal conditions of liquid media at elevated temperatures and pressures. One of the promising directions of solving this problem is the development of the method of indirect control of cavitation wear of materials and protective coatings by changing the electrical parameters of ultrasonic oscillatory systems (USOS). Studies (Khmelev et al., 2020; Khmelev et al., 2019) show the possibility of controlling the properties of media subjected to ultrasonic cavitation by controlling the parameters of piezoelectric ultrasonic oscillatory systems (emitters).

However, the earlier works have not established the dependence between the dimensions of the destructible working tools and protective coatings and the electrical characteristics of USOS with different design features. Determination of the magnitude of the relationship between the parameters of the prototype with the electrical parameters of ultrasonic radiators and the establishment of the sensitivity of controlling the degree

[1] Corresponding author: Roman Barsukov
Email: roman@bti.secna.ru

of cavitation destruction of materials and coatings makes the presented work relevant.

2. MAIN PART

Leave one clear line before and after a main or secondary heading and after each paragraph. Ultrasonic oscillatory systems designed to form ultrasonic oscillations and introduce them into the processed media contain a certain number of different components, the major of which are: piezoelectric transducer, waveguide structures (boosters), concentrating waveguides (amplifiers of amplitude), working tools (ends), attachment assemblies, etc.

Based on the theory of electromechanical analogies, such an USOS with a prototype can be presented in the form of a physical equivalent RLC substitution diagram (figure 1).

In the scheme shown in figure 1 the test sample is considered as a part of the waveguide system of an USOS and presents an attached half-wave test cylindrical waveguide with or without coating, which parameters will change in the process of its cavitation destruction (erosion). It is obvious that the electrical analogue of the test sample, being a part of the electrical model of the USOS, affects its parameters and characteristics as a whole.

Let us consider how some electrical parameters of ultrasonic radiators change in the process of cavitation erosion of the test sample for different variants of USOS (radiators) assembly. Table 1 shows different variants of USOS assemblies consisting of one transducer, different number of waveguide elements with different transformation coefficients and a half-wave cylindrical test working tool (test sample). Let us consider the influence of the cavitation wear value of the tool in the range of 0...100 μm.

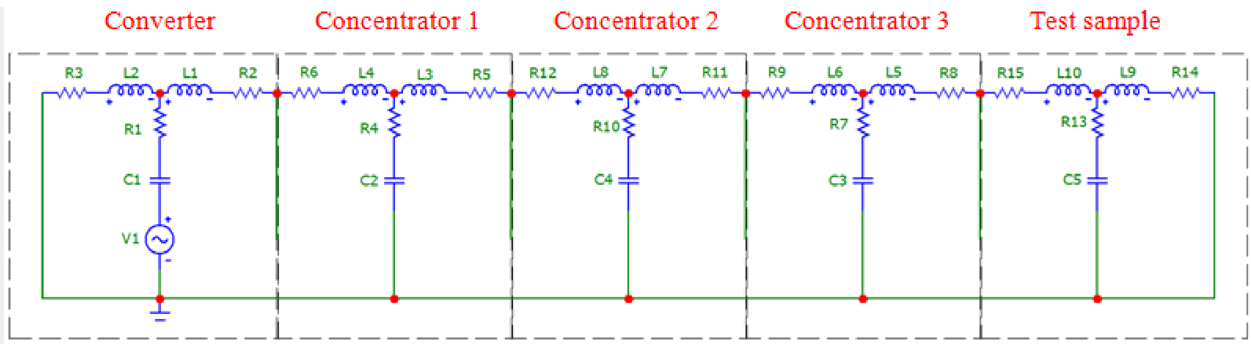


Figure 1. Electrical model of an USOS with different components

Table 1. Title (Times New Roman, 10pt, align Left, single spacing) (Kusi-Sarpong et al., 2018)

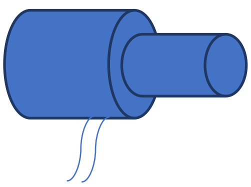
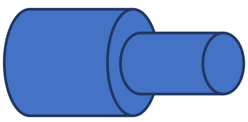
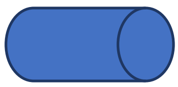
Converter (half-wave, KC = 1, 1.5, 2)	Concentrator 1 (half-wave, K_1 = 1, 1.5, 2)	Concentrator 2 (half-wave, K_2 = 1, 1.5, 2)	Concentrator 3 (half-wave, K_3 = 1, 1.5, 2)	Half-wave cylindrical working tool
		. . .	. . .	

Figure 2 shows the dependences of impedance Z of the USOS on the amount of wear ΔL of the cylindrical tip for different versions of the assembly (the number of waveguide elements of the same type connected in series) of the USOS and the amplification coefficients K of its elements.

From the curves shown in figure 2, a, it follows that consecutive build-up of the USOS construction by half-wave elements without gain (K = 1) has no effect on the dependence of impedance Z on the wear value of the test sample (the curves are almost identical). The range of impedance change ΔZ when changing ΔL with series connection of half-wave elements with K = 1 does not change.

Sensitivity of control of ΔZ from ΔL is $\frac{\Delta Z}{\Delta L} = 0.09$ Ohm/μm and does not depend on the parameters of the current assembly.

From the curves shown in figure 2, b, it follows that t consecutive build-up of the USOS construction by half-wave elements with gain coefficients K = 1.5 leads to an increase in the range of impedance change ΔZ when changing ΔL.

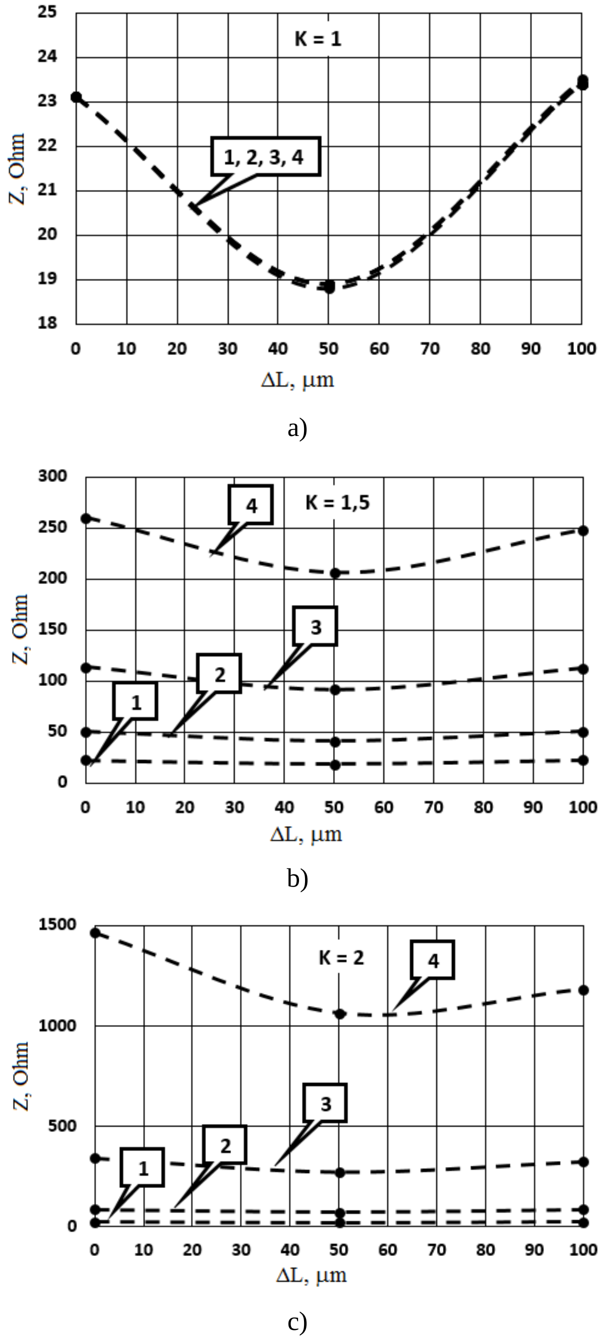


Figure 2. Dependence of impedance Z of the ultrasonic radiator on the wear value of the cylindrical tip ΔL for different variants of the USOS assembly and amplification coefficients of its elements. 1 - converter + test sample; 2 - converter + 1st concentrator + test sample; 3 - converter + 1st, 2nd concentrators + test sample; 4 - converter + 1st, 2nd, 3rd concentrators + test sample; 4 - converter + 1st, 2nd, 3rd concentrators + test sample

At consecutive increasing of the construction by half-wave elements "Concentrator 1", "Concentrator 2", "Concentrator 3" the range of change ΔZ at change ΔL increases by 120%, 400% and 1127%, respectively, with respect to the assembly "Converter + Test sample". Absolute values of the range of change ΔZ are 4.4 Ohm, 9.7 Ohm, 22 Ohm and 54 Ohm, respectively.

The sensitivity of the control of ΔZ when changing ΔL is

$$\frac{\Delta Z1}{\Delta L} = 0.088\frac{\text{Ohm}}{\mu\text{m}},\ \frac{\Delta Z2}{\Delta L} = 0.194\frac{\text{Ohm}}{\mu\text{m}},$$

$$\frac{\Delta Z3}{\Delta L} = 0.44\frac{\text{Ohm}}{\mu\text{m}},\ \frac{\Delta Z4}{\Delta L} = 1.08\frac{\text{Ohm}}{\mu\text{m}}\ .$$

From the curves shown in figure 2, c, it follows that consecutive build-up of the USOS construction by half-wave elements with gain coefficients K = 2 leads to a greater increase in the range of impedance change ΔZ when changing ΔL. At successive increasing of the construction by half-wave elements "Concentrator 1", "Concentrator 2", "Concentrator 3" the range of change ΔZ at change ΔL increases by 295%, 1700% and 10000% respectively, with respect to the assembly "Converter + Test sample". Absolute values of the range of change ΔZ are 4 Ohm, 15 Ohm, 72 Ohm and 405 Ohm, respectively.

The sensitivity of ΔZ control is $\frac{\Delta Z1}{\Delta L} = 0.08\frac{\text{Ohm}}{\mu\text{m}}$,

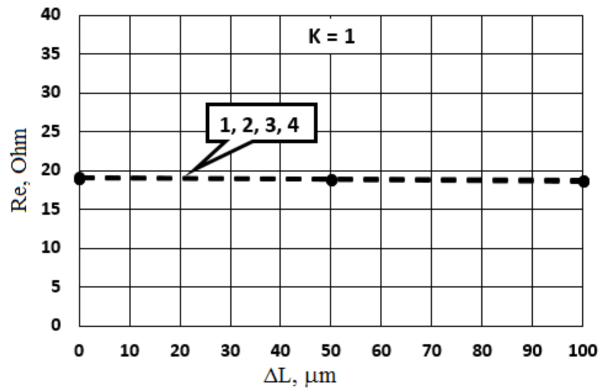
$$\frac{\Delta Z2}{\Delta L} = 0.316\frac{\text{Ohm}}{\mu\text{m}},\ \frac{\Delta Z3}{\Delta L} = 1.44\frac{\text{Ohm}}{\mu\text{m}},\ \frac{\Delta Z4}{\Delta L} = 8.1\frac{\text{Ohm}}{\mu\text{m}}$$

From the dependencies shown in figure 2, it follows that two different values of ΔL correspond to one value of impedance. Therefore, the obtained dependencies can be used either in the range when ΔL = 0...50 or when ΔL = 50...100.

Figure 3 shows the dependences of the real part of impedance Re of the ultrasonic radiator on the amount of wear of the cylindrical tip ΔL for different versions of the assembly (the number of waveguide elements of the same type connected in series) of the USOS and the amplification coefficient K of its elements.

From the curves shown in figure 3, a, it follows that the consecutive build-up of the USOS construction by half-wave elements without gain (K = 1) has no effect on the dependence of the real part of impedance Re on the wear value of the test sample (the curves coincide). The range of impedance change ΔZ when changing ΔL is 0.

From the curves shown in figure 3, b, it follows that consecutive build-up of the USOS construction with half-wave elements with gain K = 1.5 leads to an increase in the range of change in the real component of impedance ΔRe when changing ΔL. If the construction is equipped consequently with half-wave elements "Concentrator 1", "Concentrator 2", "Concentrator 3" the range of ΔRe change at ΔL is 0.8 Ohm, 5 Ohm and 28 Ohm, respectively. Without the elements "Concentrator 1", "Concentrator 2", "Concentrator 3" the range of ΔRe change ΔL is close to zero.



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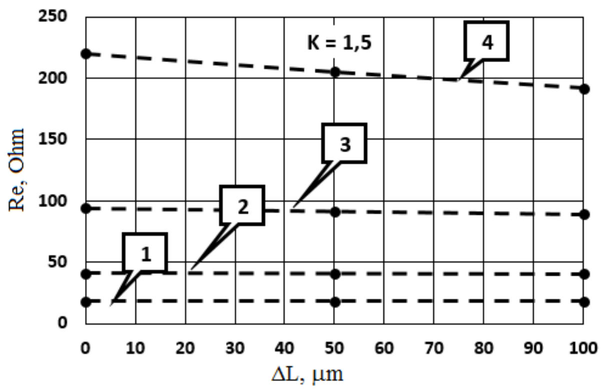

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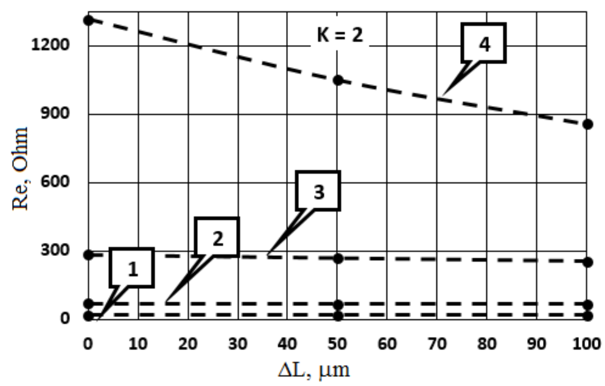


c)

Figure 3. Dependence of the real component of the impedance Re of the ultrasonic radiator on the wear value of the cylindrical tip for different variants of the USOS assembly and the amplification coefficients of its elements. 1 - converter + test sample; 2 - converter + 1st concentrator + test sample; 3 - converter + 1st, 2nd concentrators + test sample; 4 - converter + 1st, 2nd, 3rd concentrators + test sample; 4 - converter + 1st, 2nd, 3rd concentrators + test sample

Sensitivity of control of ΔRe parameter by change of ΔL is $\frac{\Delta \mathrm{Re}1}{\Delta L} = 0\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Re}2}{\Delta L} = 0.008\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Re}3}{\Delta L} = 0.05\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Re}4}{\Delta L} = 0.28\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$.

From the curves shown in figure 3, c, it follows that consecutive increasing of the USOS construction by half-wave elements with gain coefficients K = 2 leads to a greater increase in the range of change of the real component of impedance ΔRe when changing ΔL. At consecutive increasing of the construction by half-wave elements "Concentrator 1", "Concentrator 2", "Concentrator 3" the range of change ΔRe at change ΔL increases by 1600%, 28900% and 450000% respectively, in comparison with the assembly "Converter + Test sample". The ranges of change ΔRe in absolute values for the considered assembly variants are 0.1 Ohm, 1.7 Ohm, 29 Ohm, 459 Ohm, respectively.

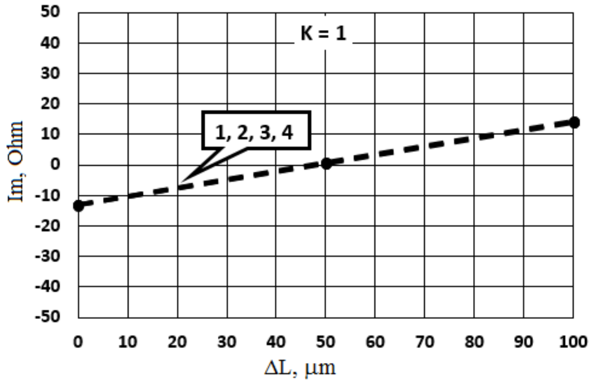
Sensitivity of control of ΔRe by change of ΔL is $\frac{\Delta \mathrm{Re}1}{\Delta L} = 0.001\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Re}2}{\Delta L} = 0.017\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Re}3}{\Delta L} = 0.29\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Re}4}{\Delta L} = 4.59\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$.

With increasing the number of series-connected elements of the ultrasonic oscillating system construction with amplification coefficients different from 1, the relationship between the actual impedance component Re and the parameter ΔL becomes stronger.

In figure 4 the dependences of imaginary part of impedance Im of ultrasonic radiator on the value of cylindrical tip wear ΔL for different variants of USOS assembly (number of one-type waveguide elements connected in series) and amplification coefficients K of its elements are shown.

From the curves in figure 4, a it follows, that consecutive build-up of the USOS construction by half-wave elements without gain (K = 1) has no influence on the dependence of the imaginary part of impedance Im on the wear of the test sample (the curves coincide). Range of variation of imaginary part of impedance ΔIm for all options under consideration is 27 Ohm. The sensitivity of the control of the parameter ΔIm by the change ΔL is $\frac{\Delta \mathrm{Im}}{\Delta L} = 0.27\frac{\mathrm{Ohm}}{\mu\mathrm{m}}$ and is a constant.

From the curves shown in figure 4, b, it follows that consecutive build-up of the USOS construction by half-wave elements with gain coefficients K = 1.5 leads to an increase in the range of change of imaginary component of impedance ΔIm when changing ΔL. At consecutive build-up of the USOS construction by half-wave elements "Concentrator 1", "Concentrator 2", "Concentrator 3" the range of change ΔIm at change ΔL is increased by 124%, 400% and 1000% respectively, in comparison with the assembly "Converter + Test sample". The ranges of ΔIm change in absolute values for the considered assembly variants are 26 Ohm, 58 Ohm, 132 Ohm, 296 Ohm, respectively.



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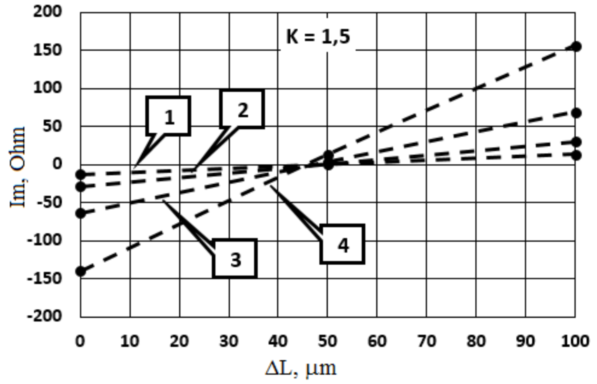

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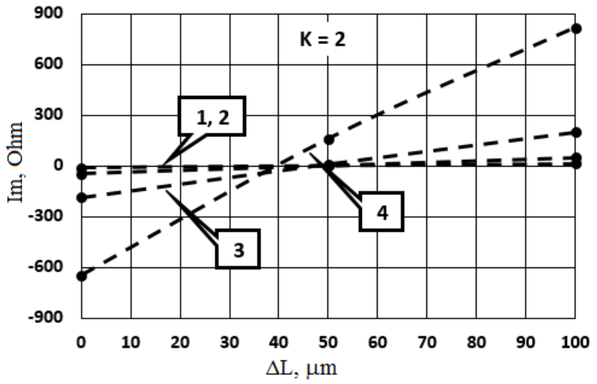

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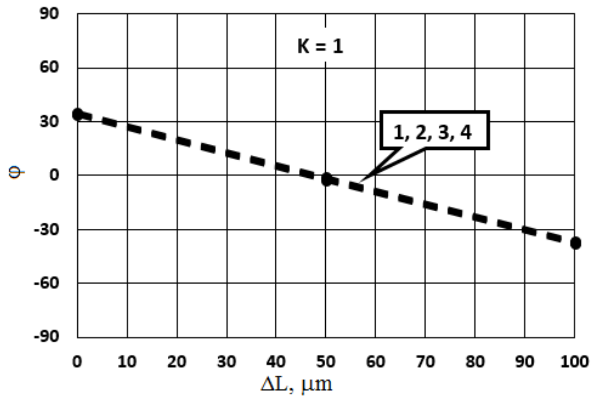
Figure 4. Dependence of the reactive component of impedance Im of the ultrasonic radiator on the wear value of the cylindrical tip for different versions of the USOS assembly and amplification coefficients of its elements.

Sensitivity of ΔIm parameter to the change of ΔL is $\frac{\Delta \mathrm{Im}1}{\Delta L} = 0.262 \frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Im}2}{\Delta L} = 0.588 \frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Im}3}{\Delta L} = 1.3 \frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Im}4}{\Delta L} = 2.96 \frac{\mathrm{Ohm}}{\mu\mathrm{m}}$.

From the curves shown in figure 4, c, it follows that consecutive build-up of the USOS construction by half-wave elements with gain coefficients K = 2 leads to a greater increase of the range of change of the imaginary component of impedance ΔIm when changing ΔL.



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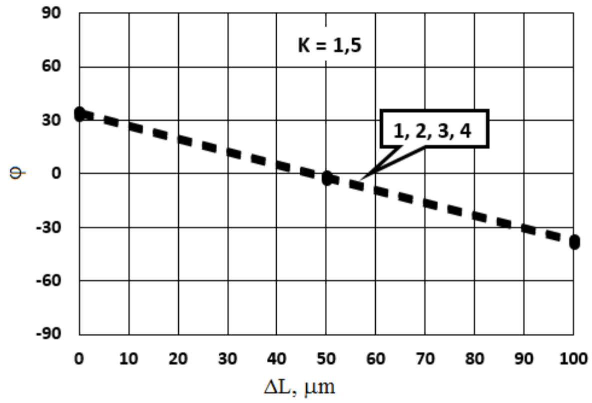

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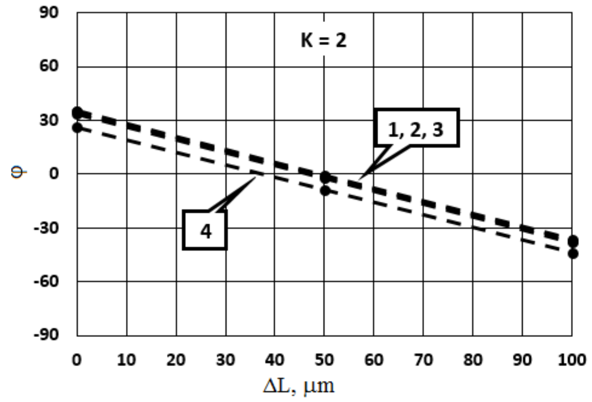

c)

Figure 5. Dependence of the phase φ of the ultrasonic emitter on the wear value of the cylindrical tip for different variants of the USOS assembly and the amplification coefficients of its elements. 1 - converter + test sample; 2 - converter + 1st concentrator + test sample; 3 - converter + 1st, 2nd concentrators + test sample; 4 - converter + 1st, 2nd, 3rd concentrators + test sample; 4 - converter + 1st, 2nd, 3rd concentrators + test sample

At consecutive build-up of the USOS construction by half-wave elements "Concentrator 1", "Concentrator 2", "Concentrator 3" the range of change ΔIm when changing ΔL increases by 300%, 1400% and 6000% respectively, in comparison with the assembly "Converter + Test sample". The ranges of change ΔIm in absolute values for the considered assembly variants are 24 Ohm, 97 Ohm, 386 Ohm, 1463 Ohm, respectively. Sensitivity of control of ΔIm parameter by change of ΔL is $\frac{\Delta \mathrm{Im}1}{\Delta L} = 0.242 \frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Im}2}{\Delta L} = 0.97 \frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Im}3}{\Delta L} = 3.38 \frac{\mathrm{Ohm}}{\mu\mathrm{m}}$, $\frac{\Delta \mathrm{Im}4}{\Delta L} = 14.6 \frac{\mathrm{Ohm}}{\mu\mathrm{m}}$.

Thus, when the number of series-connected elements of USOS construction with amplification coefficients different from 1 increases, the correlation between the real component of impedance Im and the parameter ΔL enhance.

Figure 5 shows the dependences of the piezoelectric system phase φ on the wear value of the cylindrical tip for different variants of USOS assembly and the amplification coefficients of its elements.

From the curves shown in figure 5 it follows that consecutive build-up of the USOS construction by half-wave elements with different amplification coefficients (K = 1, 1.5, 2) does not influence on phase dependence φ of ultrasonic radiator from parameter ΔL (the curves for different number of links of the USOS with different coefficients K coincide). Nevertheless, the variation range of parameter Δφ is 60 degrees, the dependence on ΔL is close to linear.

Sensitivity of parameter control Δφ when changing ΔL is $\frac{\Delta\varphi}{\Delta \mathrm{L}} = 0.6 \frac{\mathrm{degree}}{\mu\mathrm{m}}$ and is a constant.

3. CONCLUSION

As a result of the conducted research, the possibility of using piezoelectric ultrasonic oscillatory systems (USOS), used for formation of cavitation impact in liquid media, as a sensor to control the degree of cavitation erosion of working tools materials and their protective coatings was confirmed.

The results obtained on the basis of the analysis of the developed models allowed to identify the dependences of the electrical parameters of ultrasonic oscillatory systems on the degree of cavitation wear of the coupled half-wave cylindrical working tool.

The influence of the constructional composition of USOS and its individual components on the control parameters has been established. This allowed to identify the most sensitive to the value of cavitation erosion characteristics of USOS and to establish the sensitivity of the control of cavitation erosion of the tools depending on the different parameters of USOS. The most sensitive (to the degree of cavitation erosion of the connected half-wave cylindrical working tool) parameter of USOS is imaginary part of impedance of USOS, sensitivity of which strongly depends on the number of connected half-wave elements and their amplification factor. The phase-frequency characteristic of USOS is also of interest, which also has a strong correlation with the degree of cavitation wear and does not depend on the design features of USOS.

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Vladimir N Khmelev
Biysk Technological Institute (branch) of the Altay State Technical University,
Biysk,
Russia
vnh@bti.secna.ru
ORCID 0000-0001-7089-3578

Roman Barsukov
Biysk Technological Institute (branch) of the Altay State Technical University,
Biysk,
Russia
roman@bti.secna.ru
ORCID 0000-0002-6673-9807

Aleksandr Barsukov
Biysk Technological Institute (branch) of the Altay State Technical University,
Biysk,
Russia
alex_bars@u-sonic.ru
ORCID 0000-0003-3804-3340