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Development and analysis of coatings cavitation erosion model by controlling changes in the acoustic properties of liquid media in limited volumes with resonant dimensions

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Abstract. The article considers the influence of the extent of cavitation wear of materials and their coatings on the acoustic properties of the sounded liquid media in a limited volume. The model of an liquid media bounded by a volume with resonant dimensions is considered based on an electromechanical analogy system. The parameters and characteristics of the sounded liquid media most sensitive to changes in the dimensions of the volumes confining them as a result of their cavitation erosion are determined.

1. Introduction

The relevance of works on creation of method and means of control of cavitation wear of the materials and their coatings is due to the need to solve the problem of determining the suitability of created and used materials, especially for their operation in abnormal conditions of liquid media at elevated temperatures and pressures. One of the most promising directions of creating such a method is the development of indirect control of the cavitation wear of materials and their coatings by the change in the electrical properties of ultrasonic vibrating systems, which create high-intensity ultrasonic vibrations in liquid media in front of the materials or coatings [1-3]. The authors found the relationship between the electrical parameters of piezoelectric ultrasonic vibrations emitters and the properties of the liquid media subjected to cavitation impact, in the case when at some distance from the radiating surface is placed a sample, which is subjected to erosion due to ultrasonic high-intensity impact. As a result of the formation of the cavitation process, destruction (erosion) [4-8] occurs both on the surface of the transmitter and on the surface of the investigated sample, which causes a change in the size of the gap between them, in which the cavitating liquid medium is enclosed.

The data obtained earlier allow us to consider the question about the change of acoustic properties of liquid media bounded by a volume of finite dimensions during the course of the cavitation process in them.

To investigate the change of acoustic properties of liquid medium enclosed between the surface of the emitter and the surface of the investigated sample destroyed by cavitation erosion, let us consider schematically the area of cavitation effect on the investigated sample (figure 1). The following designations are used in figure 1: 1 - ultrasonic radiator, 2 - liquid medium, 3 - sample subjected to cavitation erosion. During cavitation erosion of the investigated sample, the gap L between the surface of the ultrasonic radiator and surface of the investigated sample changes on ΔL from L_1 to L_2



(cavitation erosion of radiating surface is a known constant for the given conditions and does not change in the process of control).

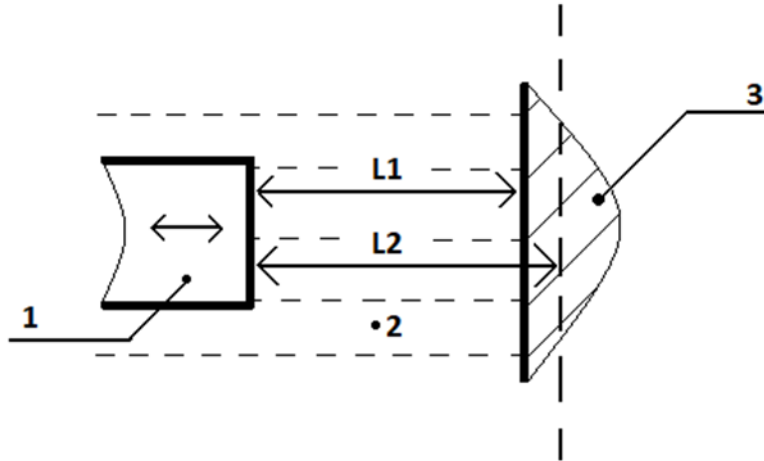


Figure 1. Area between the ultrasonic transmitter and the sample subjected to cavitation erosion.

Let's consider how the impedance of the water gap L changes when the size of the gap changes. Since we are talking about cavitation erosion of the surface of metals or their coatings, the loss of material is insignificant, which should be taken into account when modeling the process. Table 1 shows the initial data for model building.

Table 1. Input data for model building.

Parameter	Value
Frequency of generated ultrasonic vibrations	20000 Hz
Medium subjected to ultrasonic exposure	Water
Ultrasonic exposure conditions	Normal conditions (atmospheric pressure, $t = 20\text{ }^{\circ}\text{C}$)
Mode of ultrasound exposure during control (by intensity)	Pre-cavitation
Cavitation wear range, ΔL	100 μm

2. Main section

Consider the water gap enclosed between the surface of the emitter and the surface of the investigated sample as a physical equivalent electrical circuit (model) shown in figure 2.

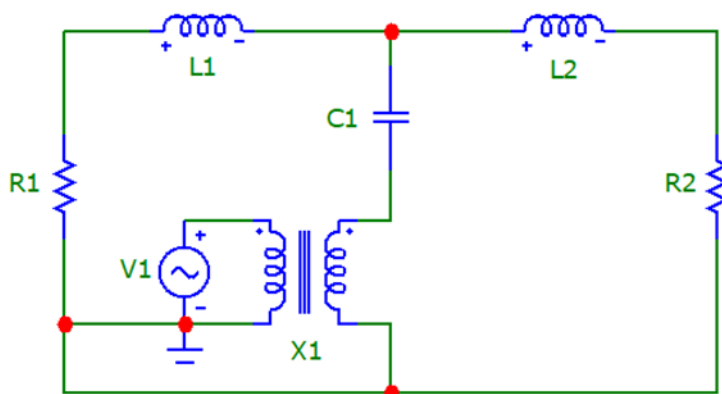


Figure 2. Equivalent electrical diagram of the water gap enclosed between the surface of the emitter and the surface of the studied sample.

When calculating the parameters of the equivalent circuit, the assumption was made that the initial gap L_1 corresponds to $\lambda/2$, at a frequency formed in the water gap of 20 kHz, i.e. the size of L_1 is resonant. This condition is due to the need to strengthen the relationship between the insignificantly changing gap L and the acoustic properties of the water gap.

In the process of control, the pre-cavitation mode of ultrasonic influence should be realized, i.e. there should be no further destruction of the surface. Such mode provides maximum stability of physical properties of investigated medium (density, ultrasonic vibrations propagation velocity).

Analysis of the built model allows obtaining dependencies of real and imaginary components of water gap impedance on the size of this gap L , as well as dependencies of phase shift between impulsive force and vibrational speed (current and voltage on the source V_1) on the size of gap L .

Figure 3 shows the obtained dependencies of the impedance Z of the water gap on its size, obtained for different values of active losses in the liquid medium.

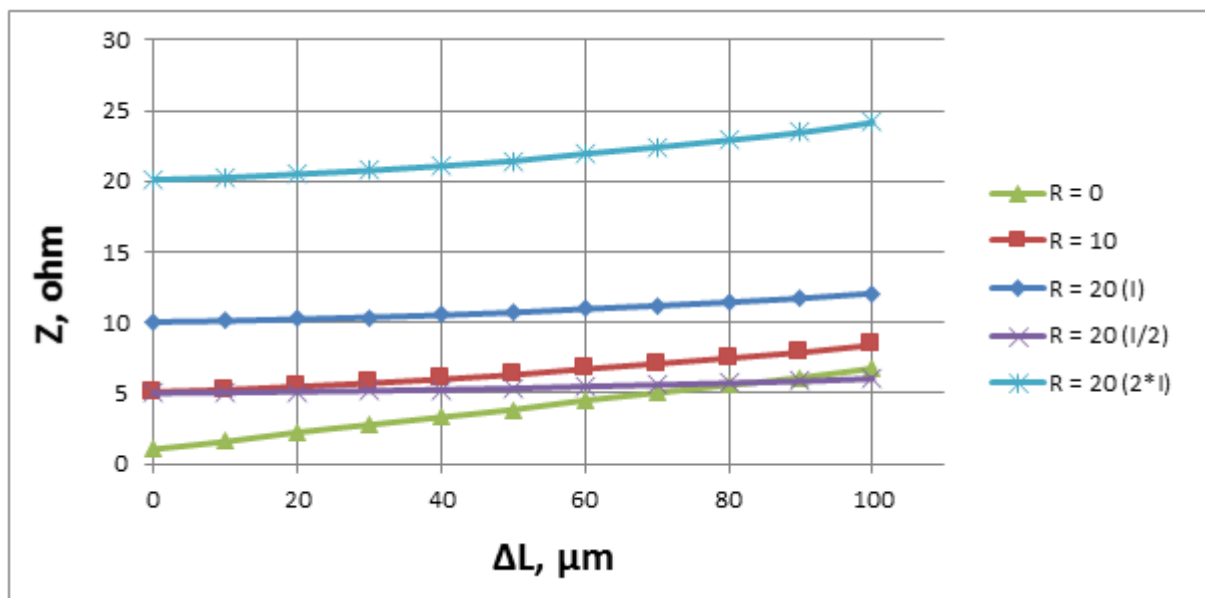


Figure 3. Dependence of impedance Z of the water gap on its value, obtained for different values of active losses R in the liquid medium.

The curves in figure 3 illustrate an increase in impedance Z with an increase in the gap ΔL . The value of loss R influences the slope of the obtained dependencies. As R increases, the sensitivity of Z to a change in ΔL decreases.

The dependencies shown in the figure are obtained for different values of ultrasonic amplitude. In particular, $R=20$ (I), $R=20$ (I/2), and $R=20$ (2*I) dependencies were obtained for the following conditions: I - the initial amplitude of ultrasonic exposure, I/2 - reduced by half the amplitude of ultrasonic exposure, 2*I - the doubled amplitude of ultrasonic exposure. It follows from the obtained dependencies that the steepness of the obtained curves increases with increasing the amplitude of the ultrasonic exposure.

Figure 4 shows the dependence of the imaginary component of the impedance Z of the water gap on its value, obtained for different values of active losses in the liquid medium.

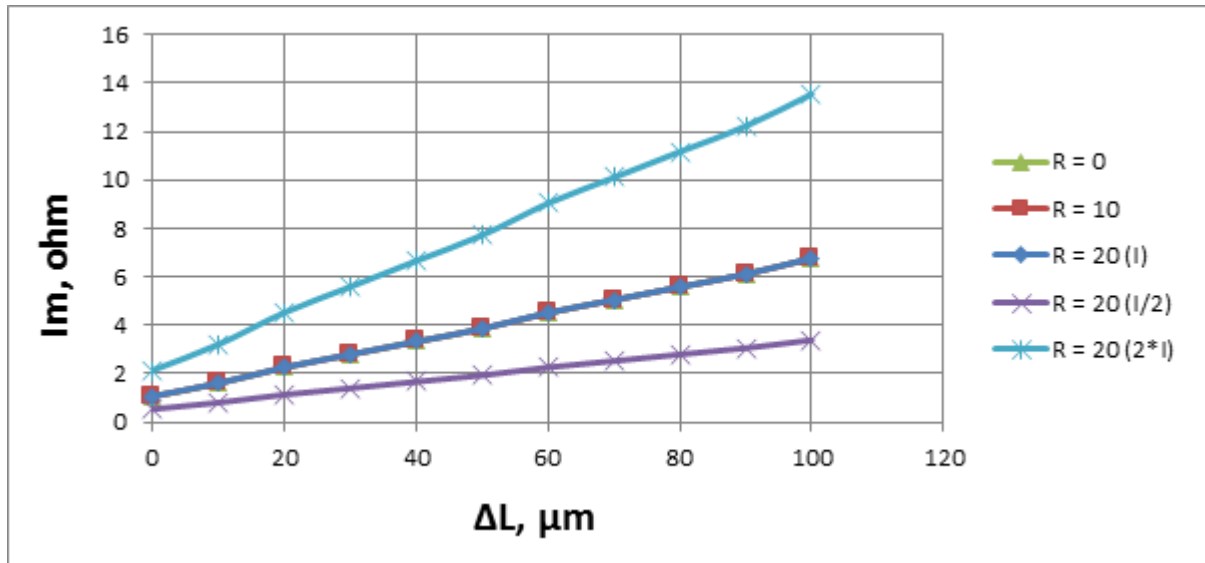


Figure 4. Dependence of imaginary component of impedance Z of water gap, obtained for different values of active losses R in aqueous medium.

The curves in figure 4 illustrate an increase in the value of impedance Z with an increase in the gap ΔL . In this case, the value of loss R does not affect the steepness of the obtained dependencies.

Three curves ($R=20 (I)$, $R=20 (I/2)$, $R=20 (2*I)$) are also obtained for different values of ultrasonic amplitude: I - initial amplitude of ultrasonic treatment, $I/2$ - amplitude of ultrasonic treatment twice reduced, I - amplitude of ultrasonic treatment twice. They show that the steepness of the resulting curves increases with the increasing amplitude of ultrasonic exposure.

Figure 5 shows the dependence of the actual component of the impedance Z of the water gap on its value, obtained for different values of active losses in the liquid medium.

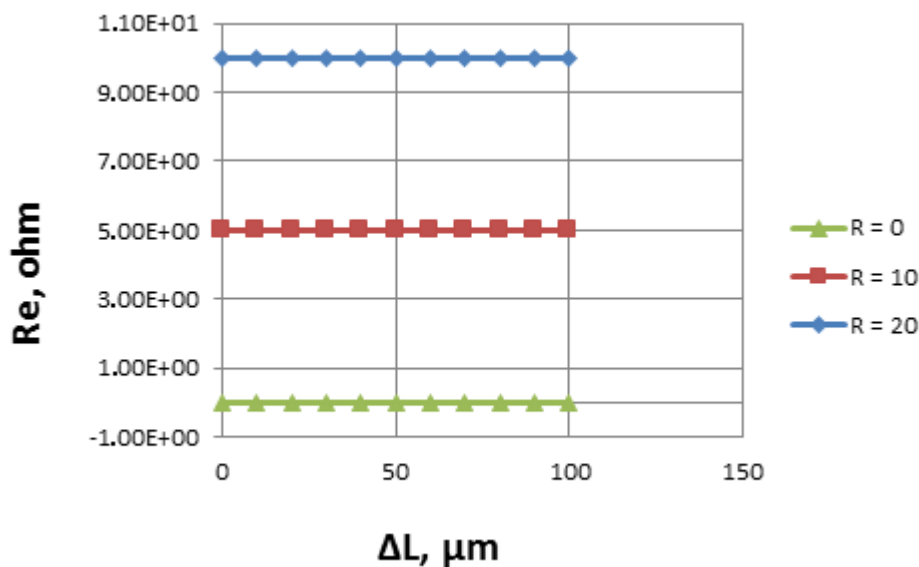


Figure 5. Dependence of the actual component of impedance Z of the water gap on its value, obtained for different values of active losses R in the aqueous medium.

The curves in figure 5 illustrate the lack of dependence of the actual component of impedance Z on the gap value ΔL , which is of no practical value in the development of the indirect control method of cavitation wear of materials and their coatings.

Figure 6 shows the dependencies of the phase shift between the driving force and oscillatory velocity (current and voltage on the source V1) on its gap value ΔL , obtained for different values of active losses in the liquid medium.

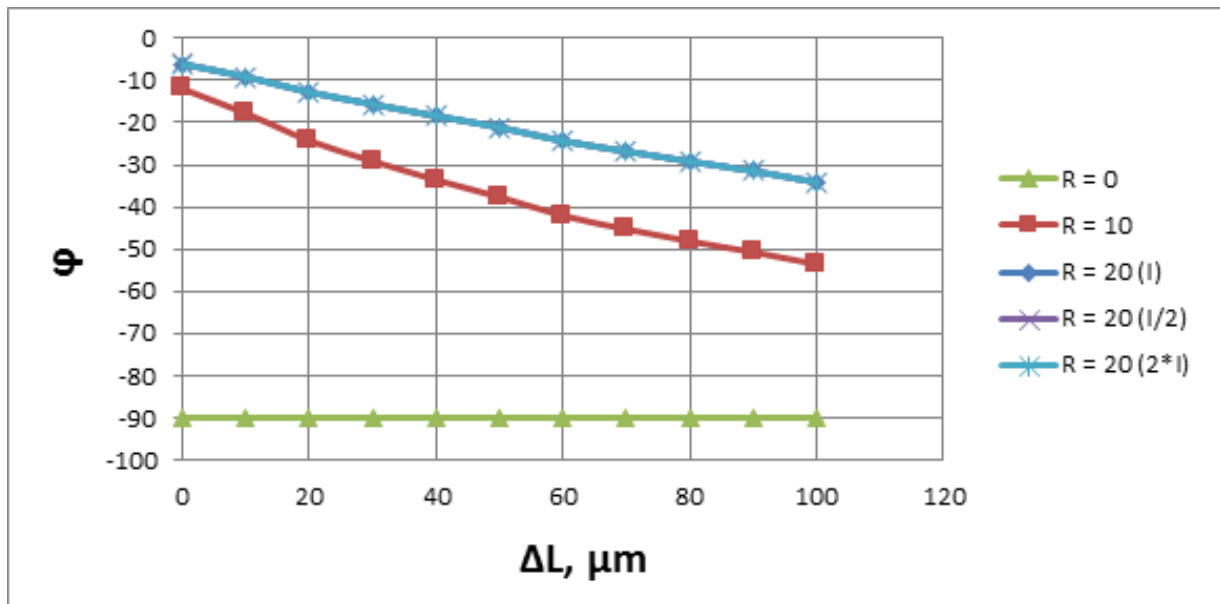


Figure 6. Dependence of phase angle between current and voltage at source V1 on its gap value ΔL , obtained for different values of active losses R in aqueous medium.

The curves in figure 6 illustrate the relationship between the phase angle ϕ and the gap value ΔL . The value of loss R influences the character of obtained dependencies.

Dependencies obtained for different values of ultrasonic exposure amplitude (I - original amplitude of ultrasonic exposure, I/2 - twice reduced amplitude of ultrasonic exposure, I - double amplitude of ultrasonic exposure) indicate that the amplitude of ultrasonic exposure does not affect the nature of the obtained dependencies (three curves under these conditions coincide with each other).

3. Conclusion

The proposed and developed model based on the use of electromechanical analogies can be used to control the cavitation erosion of coatings by changing the acoustic properties of liquid media in limited volumes with resonant dimensions.

As a result of the analysis of the developed model, it was found that the value of cavitation wear of materials and their coatings to a greater extent influences the imaginary part of the impedance of the liquid medium that carries out cavitation resolution and the phase shift between the driving force and the oscillatory speed of the piezoelectric radiator.

The presence of active losses of ultrasonic vibrations propagation in the medium under abnormal operating conditions (in terms of temperature and pressure) influences the dependence of the phase shift between the driving force and the oscillatory velocity from the gap size ΔL but does not affect the dependence of the imaginary component of the impedance of the medium from the gap size ΔL .

The amplitude of ultrasonic influence influences the dependence of the imaginary component of medium impedance on the gap value ΔL and does not affect the dependence of the phase angle ϕ on the gap value ΔL .

The obtained results of modeling indicate that under certain conditions it is possible to use the identified dependencies between the reactive properties of the processed ultrasonic vibrations of high intensity of the gap and the value of cavitation wear of metals and their coatings for practical implementation of the method of indirect control of the cavitation wear of materials and their coatings by controlling the electrical parameters of ultrasonic emitters.

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