Efficiency analysis using complex ultrasonic vibrations in electroacoustic spraying of axial cutting tools

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Abstract. The article considers the electric spark intensification doping methods by using ultrasonic vibrations to obtain the method of electroacoustic deposition. The ultrasonic vibrations use in the deposition process is possible due to the use of an acoustic system at the end of which a naturally swirled waveguide is used. To analyze the waveguide oscillation amplitude dependence on the frequency, the article presents analytically obtained dependences of the longitudinal and torsional components of vibrations. The obtained results reliability of theoretical studies is confirmed by the good convergence of the theoretical and calculated frequency response resonant peaks. The electroacoustic deposition effectiveness method is confirmed by experimental studies of maintaining the hardened drills performance. The experimental data analysis showed a 2-4 fold increase in the total durability period of hardened drills.

1. Introduction
The wide and effective use of ultrasound in different processes largely depends on the type of oscillation. Application of ultrasonic vibrations in various processes found the use of longitudinal, torsional and integrated fluctuations. In connection with the ease of implementation, well-designed mathematical models and calculation bases, wide use in practice found longitudinal ultrasonic vibrations. Torsional ultrasonic vibrations have not found wide application due to the complex methods of implementation. Complex fluctuations include the coupling of longitudinal and torsional vibrations [11]. The implementation of such fluctuations does not differ from longitudinal, and their effectiveness and technological flexibility is much higher [14]. The expansion of effective use of energy in the technological practice of complex narrow can be associated with the development of the theory of transformation of this type of oscillations. The theory will allow to consider the dynamics of complex oscillations in a form convenient for engineering calculation, and, in addition to the basic formulas, to give a General method of calculation [12].

The formation of complex oscillations is possible through the use of a naturally twisted waveguide connected to the last stage of the concentrator of the longitudinal acoustic system. The consideration of the twisted waveguide as a naturally twisted rod [7, 8, 9], subject to the action of forces arising in the process or other type of processing leads to a certain dynamic three-dimensional problem.

2. The method of electro-acoustic spraying
The problem of rational use of material resources of modern Metalworking production can be solved by applying new methods of shaping and intensifying existing ones. One of the ways to solve this problem is to increase the wear cutting tool resistance by using various applying wear-resistant coatings methods to the cutting tool. Over the years and up to the present time, many different coating methods have been successfully applied, one of which is the method of electric spark doping [1, 2]. Each method has its
own advantages and disadvantages, but the main disadvantage of most methods is the special conditions for the environment in which the coating is applied. The method considered in the works differs in the complete absence of requirements for the coating environment [3, 4].

The essence of the method consists in transferring the electrode material melted by a pulsed current at the optimal gap between the tool and the electrode for an electric discharge. The gap is formed by performing ultrasonic longitudinal-torsional (complex) vibrations with the electrode. In addition, under the ultrasonic vibrations influence, plastic applied coating deformation is produced, which in turn increases the wear applied coating resistance. The ultrasonic vibrations use in the process of electric spark doping allowed us to obtain new properties of the known method. The effective ultrasonic vibrations use in various technological processes is largely due to the optimally selected acoustic system. Rod-type acoustic systems that form various types of ultrasonic vibrations are widely used in the practice of modern production [13]. Figure 1 shows an acoustic system that generates complex ultrasonic vibrations.

The figure shows: magnetostrictive converter-1, waveguide-2, amplitude graph in the acoustic system-3, plot of waveguide strain distribution-4. This type of oscillation can be obtained by using a waveguide in the form of a naturally twisted rod. The complex vibrations use in the coating process allows you to obtain a special type of impact on the surface to be hardened, which can be interpreted as a shear shock.

3. Amplitude-frequency characteristics of the waveguide

The results of theoretical studies were obtained depending on the amplitude and frequency for different types of naturally swirled waveguides [5].

The longitudinal and torsional components are determined by the formula (1)

\[ U(x, t) = U_0(x) \cdot e^{i\cdot k \cdot t}, \quad \phi(x, t) = \phi_0(x) \cdot e^{i\cdot k \cdot t}, \]

where \( U_0(x) \) and \( \phi_0(x) \) - longitudinal and torsional component amplitude multipliers.

At the end of the waveguide, the these multipliers values for \( x=1 \) are equal.
\[ U_0(l) = \frac{\alpha_{21} \cdot A}{R_0} \cdot \frac{a_1 \cdot \cos \frac{k \cdot l}{c_2} - a_2 \cdot \cos \frac{k \cdot l}{c_1}}{\cos \frac{k \cdot l}{c_1} \cdot \cos \frac{k \cdot l}{c_2}}, \]

\[ \phi_0(l) = \frac{\alpha_{21} \cdot A}{R_0} \cdot \frac{\cos \frac{k \cdot l}{c_2} - \cos \frac{k \cdot l}{c_1}}{\cos \frac{k \cdot l}{c_1} \cdot \cos \frac{k \cdot l}{c_2}}. \]

The received dependences analysis showed that by waveguide changing the geometrical parameters, such as groove width, angle of twist, it is possible to change the acoustic system resonance frequency and the ratio of the longitudinal and torsional component of the oscillations, up to change the direction of the complex vector. The theoretical dependence analysis of the amplitude on frequency changes, obtained in previous works [5], [6] showed that outside the resonant frequency, the longitudinal and torsional components of ultrasonic vibrations ratio changes, which in turn leads to a change in the vibration vector of the complex component. This phenomenon can be used when calculating a waveguide with a given ratio of complex vibrations components. Changing the waveguide geometric parameters allows you to influence both the value of the speaker system resonant frequency, and the direction and amplitude of complex vibrations.

Figure 2 shows the calculated and experimental frequency response of waveguides made of VT5 and steel 45.

![Figure 2](image_url)

**Figure 2.** Frequency response of a twisted waveguide made of VT5 and steel 45

The characteristics analysis showed good convergence of the theoretical and experimental characteristics. The theoretical peak shift in both cases is probably due to the error in the experiment [10]. In addition, the experimental characteristic has a second rise in amplitude, which is not present in the calculated characteristic. This fact can be explained by the presence of reflected waves in the acoustic system, the influence of which was not taken into account in the theoretical calculations. The theoretical and experimental peaks deviation of the frequency response does not exceed the permissible values and is 4 percent.

**4. Conclusion**

The effectiveness of the applying wear-resistant coatings electroacoustic method is confirmed by studies on the example of drills, as one of the most common types of cutting tools. 2 batches of 27 P6M5 drills with a diameter of 12 mm were selected for the experiment. The first group was strengthened by applying a wear-resistant coating of hard alloy VT5. The second group was not strengthened. After drilling 50 holes in a plate made of 45 steel, the cutting capabilities of the drills were evaluated. In total, 500 holes were drilled. The experiment results in the form of a graph of the probability of preserving the cutting abilities of drills are shown in figure 3.
Figure 3. Probability graph of maintaining the cutting abilities of drills

As a result of hardening, 100% preservation of cutting abilities is observed after drilling 200 holes. This value was 70% for non-hardened patients. An even greater discrepancy in probability is observed when drilling 300 holes of 85% and 40%. In addition, it should be noted a significant increase in the probability of maintaining the cutting capacity of hardened tools throughout the entire working time. Thus, after 20 minutes of operation, the hardened drills had no failures, and after 30 minutes - 85% compared to 40% of non-hardened drills. After 40 minutes of operation, the non-hardened drills were almost completely exhausted, while 55% of the hardened drills were in working condition. The efficiency of hardening 100 drills after 20 minutes of work will be expressed by an increase in the total period of durability by 1.43 times, after 30 minutes of work - by 2.02 times, and after 40 minutes by 4.7 times.

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