System of Continuous Control of Output Parameters in Ultrasonic Technological Devices

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Abstract – This article is devoted to developing of new method of vibration amplitude control, which is able to provide continuous measurement during of the ultrasonic technological processes. Thus, it is possible to control mechanical vibration amplitude of the radiating surface measuring part of electric current flowing through piezoelectric vibrating system. The spent experimental researches have confirmed efficiency and accuracy of this method.

Index Terms – Ultrasound, amplitude, current.

I. INTRODUCTION

MAXIMUM EFFICIENCY of different technological processes realized under the influence of ultrasonic vibrations can be achieved only at providing of optimal parameters of ultrasonic influence.

One of the main parameters, which characterizes ultrasonic influence is amplitude of mechanical vibrations from radiating surface of ultrasonic vibrating system [1]. Value of vibration amplitude of radiating surface depends on electromechanical properties of vibrating system, conformity with electronic generator and acoustic features of processed media.

Due to extremal nature of cavitation influence in liquid media it is necessary not only to set defined value of vibration amplitude for initiation of processes but also maintain optimal value of the amplitude at different changes of medium parameters (density, concentration, viscosity) and influence of destabilizing factors (changes of medium temperature and materials of vibrating system, damping action of medium on the vibrating system, etc.).

As optimal ultrasonic influence provides maximum productivity of the process and obtaining of end product of the best quality, there is a need in continuous control of parameters of ultrasonic influence (vibration amplitude). At that control should act during the whole life cycle of the ultrasonic device beginning with its initial set-up, realization of technological processes, diagnostics and repair.

Methods of immediate amplitude measurement by visual observation of vibrations of radiating surface through the microscope are widely used for control. Among such methods improved one based on the application of sources of stroboscopic illumination [стистопион] is the most precise. However, its use is possible only in clear air, that is why it can be applied only for setup and preparatory diagnostics of the ultrasonic device ignoring influence of liquid media.

Because of specific of practical realizations of ultrasonic technologies (need to carry out measurements in liquids, including corrosive ones, cavitational destruction of introduced sensors) all methods of traditional vibrometry are not suitable for solving task of continuous control of vibration amplitude in the technological apparatus.

There is a necessity to create new method of vibration amplitude control, which is able to provide continuous measurement not only during the setup but during of the ultrasonic technological devices. This method should be based on indirect measurements of electric parameters of the ultrasonic device determined by the amplitude of mechanical vibrations of the radiating surface.

II. THEORY

As it is known [2], ultrasonic piezoelectric vibrating system is an electric load for the electronic generator. It changes its electric parameters under the influence of external actions from processed media (changes of acoustic load), external actions from the electronic generator (changes of feeding voltage and flowing current) and also the changes of internal state (changes of temperature, vibrational displacements and voltage).

Analysis of equivalent circuit of the piezoelectric system lets determine, that value of mechanical vibration amplitude of the ultrasonic vibrating system in the interval of linearity of system attributes is directly proportional to value of mechanical branch current (difference between total current of the vibrating system and its capacitive component determined by capacity of the piezoelectric elements of the system), i.e. it is defined as:

$$A = M \cdot I_m$$

where $A$ is a mechanical vibration amplitude of radiating surface of the ultrasonic vibrating system, $I_m$ is a mechanical branch current of the ultrasonic vibrating system, $M$ is a proportionality coefficient.

Thus, it is possible to control mechanical vibration amplitude of the radiating surface measuring part of electric current flowing through piezoelectric vibrating system.

Unfortunately this method is not widely used, as there is no information about value and dependence of magnitude of proportionality coefficient on parameters of used piezoelectric vibrating systems.

For practical application of this method, confirmation of possible control of absolute value of vibration amplitude of the radiating surface according to electric parameters of the ultrasonic vibrating system, creation of special devices for practical realization of this method, determination of accuracy of such measurements and delimitation of its usability in real working conditions of the ultrasonic vibrating system there is a need to investigate this method in details.

Theoretical definition of proportionality coefficient $M$ is complicated, as it characterizes simultaneously transformation of electric energy in matching vibrational contour of the electronic generator, transformation of electric energy into elastic mechanical vibrations of the piezoelectric elements and amplification of these vibrations while spreading along the vibrating system.
In many cases influence of all mentioned parameters of transformation and amplification is defined at the design of the ultrasonic vibrating system and setup of the electronic generator and they remain unchanged during operation life of the ultrasonic device. During running of the ultrasonic device at the use of one vibrating system and its kitting of different changeable working tools (half-wave and multi-half wave length) it is possible the change of amplification coefficient, which characterizes amplification of mechanical vibrations during its spreading along the system. In this case value of proportionality coefficient $M$ will depend on amplification coefficient of changeable working tool and it can be presented in a following way:

$$M = M'K_U$$

where $M'$ is a proportionality coefficient between value of mechanical branch current and mechanical vibration amplitude, which ignores amplification coefficient of the ultrasonic vibrating system, $K_U$ is an amplification coefficient of working tool of the ultrasonic vibrating system.

Thus to control the value of mechanical vibration amplitude during the operation of the ultrasonic device it is necessary to perform calibration (calculation value of coefficient $M$ according to measured values $A$ and $I_m$), i.e. to carry out synchronous measuring of mechanical vibration amplitude and amplitude of mechanical branch current of the ultrasonic vibrating system during step-by-step increase of supply voltage of the ultrasonic vibrating system. The value of tangent of slope angle of the graph of the dependence of mechanical vibration amplitude on the value of mechanical branch current to X-axis will corresponds to the value of coefficient $M$.

III. EXPERIMENTAL RESULTS

To define the dependences experimental investigation on practical detection of proportionality coefficient were realized. The most simple, precise and universal method of direct measuring of absolute value of amplitudes, stroboscopic one, was used as a check one [мой патент, статья про особенности применения]. Measurement were carried out with the help of ultrasonic therapeutic device «TONZILLOR-MM» [3].

The choice of the device for experimental investigations was determined the fact that this device was equipped with the set of changeable working tools varying in length (half-wave, two half-wave), form of the working tool and required level of mechanical vibration amplitude on the working surface. The appearance of used in the investigations working tools is presented in Fig. 1.

During the experiments one vibrating system and different tools shown in Fig. 1 were used. Synchronous measurements of mechanical vibration amplitude by stroboscopic method [4, 5] and amplitude of mechanical branch current at the fastening of different changeable working tools on the ultrasonic vibrating system were carried out. Standard circuit of control system of the electronic generator was supplied with measuring circuit realizing differential method of current measurement flowing in the mechanical branch of the ultrasonic vibrating system. Measuring was realized without influence of acoustic load on the working tool (the measurement were carried out in air).

Obtained diagrams of dependences of mechanical vibration amplitude on the value of mechanical branch current are demonstrated in Fig. 2. From the obtained results it is evident, that dependence of value of mechanical vibration amplitude of the radiating surface on the mechanical branch current of the piezoelectric vibrating system is linear for the working range of the amplitudes.

If we approximate dependences to crossing with Y-axis, crossing point is located above center of coordinates. It allows concluding, that at the zero value of mechanical branch current there is a level of mechanical vibration amplitude. Practically it is impossible, it can be explained more complicated form of amplitude dependence on the value of current at small values. As this zone of the amplitudes is rarely applied in practice and also because of complexity of providing stable operation in this zone it will not be taken into consideration further.

![Fig. 2. Diagram of dependence of mechanical vibration amplitude on mechanical branch current for working tools different in length.](image)

For calculation of tangent of slope angle linear approximation of obtained dependences was carried out. As a result for each graphic dependence following equation was obtained:

$$A = M \cdot I_m + C$$

where $C$ is value of mechanical vibration amplitude in the crossing point with Y-axis.

Numerical values of total amplification coefficient for the ultrasonic vibrating system with different working tools were obtained at the stage of designing and were used calculation of numerical value of coefficient $M'$. All obtained data are shown in Table 1.
TABLE I
RESULTS OF LINEAR APPROXIMATION OF RESULTS OF MEASUREMENTS

<table>
<thead>
<tr>
<th>working tool #</th>
<th>C</th>
<th>M</th>
<th>k_C</th>
<th>M'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.81</td>
<td>32.27</td>
<td>28.11</td>
<td>1.148</td>
</tr>
<tr>
<td>2</td>
<td>19.82</td>
<td>32.51</td>
<td>28.45</td>
<td>1.143</td>
</tr>
<tr>
<td>3</td>
<td>16.99</td>
<td>31.17</td>
<td>28.5</td>
<td>1.094</td>
</tr>
<tr>
<td>4</td>
<td>19.46</td>
<td>15.65</td>
<td>14.73</td>
<td>1.062</td>
</tr>
<tr>
<td>5</td>
<td>16.57</td>
<td>18.63</td>
<td>16.55</td>
<td>1.126</td>
</tr>
<tr>
<td>6</td>
<td>18.49</td>
<td>16.05</td>
<td>15.35</td>
<td>1.046</td>
</tr>
<tr>
<td>7</td>
<td>20.07</td>
<td>14.31</td>
<td>13.16</td>
<td>1.087</td>
</tr>
</tbody>
</table>

From the table it follows, that value of the coefficient M' for the vibrating system with all tools is constant, deviation from mean value does not exceed 5%. Consequently if the ultrasonic device has a set of changeable working tools connected to one ultrasonic transducer, calculations of value of the coefficient M can be essentially sped up by calculation of value of coefficient M' only for one any working tool, and further it can be multiplied by amplification coefficient for chosen working tool.

As technological processes, which are interesting for us, are connected with ultrasonic influence on liquids, additional studies were carried out, which were devoted to measure mechanical vibration amplitude at stabilization of value of mechanical branch current and gradual increment of acoustic load. Results indicate, that the value of acoustic load (changes of density, viscosity, etc.) does not influence on the accuracy of obtained dependence.

These investigations were carried out in a following way. The vibrating system was fixed. Stroboscopic measuring instrument was set on the measuring in point of working end, which was congruent to geometric center of the working end. Initial state was the value of feeding voltage at that the value of mechanical vibration amplitude was 40 micron. Further to the area of working end, which was close to the point of amplitude measurement, rubber element was pressed. Final force of pressing was pressing, at that the value of feeding voltage increased in 50% to the initial state (operation without acoustic load). Inside this interval five measurements took place. The results of measurements showed that inside of stated acoustic loads stabilization of the value of mechanical branch current provided stabilization of mechanical vibration amplitude with the accuracy of no less than 7%. Obtained results were proved by carrying out investigations with the application of other ultrasonic devices.

IV. CONCLUSIONS

Thus as a result of carried out researches possibility to control mechanical vibration amplitude of the piezoelectric vibrating system in the value of electric current flowing through mechanical branch of the system was theoretically stated and experimentally proved. Data of the measurements showed adequacy of such measuring and possibility of application of proposed method for measuring of mechanical vibration amplitude directly during any technological process.

Moreover, after carried out investigation it was theoretically stated and experimentally proved, that:

1. Dependence of mechanical vibration amplitude of radiating surface of the piezoelectric vibrating system on the value of its mechanical branch current is linear in all operating range of amplitudes (up to 150 micron) of the ultrasonic device.

2. At equipping of the ultrasonic devices with one vibrating system with unchangeable working tool after calculation of numerical value of proportionality coefficient M it is possible to compare mechanical vibration amplitude and mechanical branch current during realization of any process based on the application of ultrasonic vibrations.

3. At equipping of the ultrasonic devices with one vibrating system with a set of changeable working tools for comparison of mechanical vibration amplitude and mechanical branch current it is necessary to calculate the value of proportionality coefficient M for each working tool. Calibration process can be simplified, if proportionality coefficient M' and known values of amplification coefficients of the ultrasonic vibrating system with each working tool are used.

REFERENCES


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