The Development of Ultrasonic Vibrating System for Continuous Seam Welding

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Abstract – The article is devoted to the design of piezoelectric vibrating system providing transformation of longitudinal vibrations of the transducer into radial vibrations of welding instrument made in the form of diverging cone, on the external surface of which at the part of larger diameter cylindrical working surface is made. The presence of cylindrical working surface at the provision of rotation of vibrating system allows to carry out continuous welding of list and film thermoplastic materials. The design on the base of mathematical modeling and experimental studies of produced constructions let develop vibrating system providing ultrasonic influence with the amplitude of no less than 30 \( \mu m \), if the diameter of radiating surface is 92 mm and its width is 4 mm.

Index Terms – Ultrasound, transducer, welding, polymer.

I. INTRODUCTION

The application of ultrasonic welding for joining of different thermoplastic materials lets exclude the use of glues, increase joint efficiency, automate the process, join materials, which are polluted with liquid or dust-like substances. Ultrasonic welding allows to solve technological problems of different branches of industry, that is why, it is realized by the application of various equipment.

The use of new materials, production of articles with higher requirements to the quality of joining, necessity of leak-proofness of lengthy seams cause carrying out investigations on the design of new type of ultrasonic equipment.

As the main element of the equipment determining the possibility and quality of formation of continuous welding seam is vibrating system with welding instrument, its development is the principal part of the works on the construction of new types of ultrasonic welding equipment.

II. PROBLEM STATEMENT

The most perspective way of formation of continuous welding seam is ultrasonic welding with the use of ultrasonic vibrating system, which is able to provide the transformation of longitudinal vibrations of the piezoelectric transducer into radial vibrations of the welding instrument. The authors of several works [1] – [2] make attempts on the design of similar vibrating systems. However they are based on empiric calculations, and developed constructions in practice do not provide desired results due to insufficient vibration amplitude and irregularity of its distribution along the radiating surface.

The aim of the paper is to develop ultrasonic vibrating system with welding instrument transforming longitudinal ultrasonic vibrations into radial ones, which are able at maximum possible transformation coefficient to provide regular distribution of vibration amplitude along the radiating surface.

To achieve formulated aim it is necessary to solve following special tasks:

1. On the base of analysis of all well-known constructions, theoretical calculations and modeling to design the transducer with the concentrator (booster) for achieving specified resonance frequency with the fastening unit providing minimum damping of ultrasonic vibrating system;
2. Study different constructions of the working tools, which are able to perform transformation of longitudinal vibrations into radial ones, choose construction diagram, on the base of its modeling and theoretical calculations provide maximum transformation coefficient and regular distribution of vibration amplitude along the working surface of welding instrument.

III. THEORY

The main characteristics of the transducer of longitudinal vibrations into radial ones are resonance frequency and amplitude of ultrasonic vibrations on the radial working surface at specified value of amplitude of longitudinal vibrations at the input of the transducer. At reversed compression and tension of the material in longitudinal direction its cross-section increases and decreases, i.e. the diameter of working surface of the instrument changes. There is a unique correspondence between vibration amplitude on the external working surface \( \xi_R \) and amplitude of longitudinal ultrasonic vibrations \( \xi \) on resonance frequency. This relation is calculated through Poisson ratio, which for aluminum equals to \( K_{\mu_1} = 0.32-0.36 \).

To provide qualitative welding seam it is necessary to achieve regular distribution of vibration amplitude on the working surface of the welding tool with the values of no less than \( \xi_R = 30 \mu m \).

Fig. 1. The schematic drawing of the distribution of longitudinal vibrations in the rod.

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Existing design procedure of the ultrasonic vibrating systems allows to get only approximate parameters of single structural component [3] – [4]. Moreover the application of empirical formulae with the attraction of experimental results is rather time-consuming and it requires lengthy calculations and expenses. It should be noted, that to check calculated values is possible, when vibrating system is produced and its parameters are measured.

Thus the development and design of the ultrasonic vibrating system have following stages:
1) preliminary calculations of specified parameters (according to well-known procedures);
2) modeling and analysis of fatigue life;
3) correction of the geometry;
4) practical realization of calculated construction;
5) measurement of the parameters of developed ultrasonic vibrating system with the working tool;
6) final calculation with the correction of the parameters on the base of the data of experimental studies;
7) additional work of developed ultrasonic vibrating system and working tool for matching of their frequencies.

If it is not possible to work additionally components of the ultrasonic vibrating system and working tool, they are produced again with changed geometry.

The development of the vibrating systems was carried out with the use of CAD system, for example, T-Flex or KOMPAS 3D. The modelling was made by the program of finite-element analysis, for example ANSYS [5] – [6].

IV. RESULTS OF EXPERIMENTS

1. The Development of Piezoelectric Transducer

To solve the first of stated tasks there is a need to design piezoelectric transducer for the resonance frequency of 18±1.35 kHz with the amplitude of longitudinal vibrations of no less than 20 µm. Fastening unit (fastening belt) should be made at “zero” of longitudinal mechanical vibrations to provide minimum damping of the system and avoid transfer of vibrations to the technological equipment.

Developed construction of the piezoelectric transducer is shown in Fig. 2.

The piezoelectric transducer consists of a quarter-wave frequency lowering radiating cover plate 1, a contracting bolt 2, a reflecting frequency lowering cover plate 3, piezoelectric ceramic elements 4, ring copper spacers with outrigger electrode 5, insulating bushing 6, a ring copper spacer 7. At the development of the transducer the piezoelectric ceramic elements of standard size 50x20x6 mm are used. Obtained model of the transducer with the distribution of vibrations along the acoustic axis is shown in Fig. 3.

From Fig. 3 it is obvious, that fastening belt should be located in the minimum of mechanical vibrations (0.2 µm), that excludes the transfer of ultrasonic vibrations to the elements of the body and the construction.

Fig. 2. Developed piezoelectric transducer.

Fig. 3. The results of transducer modeling.

Fig. 4. Developed piezoelectric transducer.

2. The Development of The Transformer of Vibrational Speed

Transfer and simultaneous concentration (amplification) of acoustic energy from the end radiating surface of the piezoelectric transducer to working radiating tool are carried out by the transformer of vibrational speed – the concentrator.

The necessity of the use of the concentrator is caused by impossibility of obtaining of vibration amplitude more than 10 µm by the help of the radiator made according to Langevin scheme.

In this connection the transformer of vibrational speed (further concentrator) matched with the piezoelectric transducer at resonance frequency of 18±1.35 kHz and providing amplitude of longitudinal vibrations of the concentrator no less than 40 µm was developed. Fastening unit (fastening belt) should also be performed at “zero” of longitudinal vibrations.

The calculation of concentrator size for solving stated tasks is carried out by the procedures described in detail in [3] – [4] and it is defined more precisely according to results of modeling.

Fig. 5 shows the structural view of developed concentrator.
 Obtained model of the concentrator with distribution of vibrations along the acoustic axis is presented in Fig. 6.

Fig. 6. The results of concentrator modeling.

Fig. 7 shows the appearance of developed concentrator made of titanium alloy.

Fig. 7. The appearance of developed concentrator.

Two fastening units provide high stability of fixed vibrating system.

3 The Development of Working Tool

During the work on reveal of optimum construction scheme of working tool [7] the construction of working tool, shown in Fig. 8, was made.

Fig. 8. The structural view of working tool.

The model of distribution of vibrations along the acoustic axis of working tool is presented in Fig. 9.

Carried out calculations and the results of modeling show, that deviations of amplitude of radial vibrations of radiating surface from mean values do not exceed 3%.

Fig. 9. The results of modeling of modernized working tool.

Fig. 10 shows the appearance of developed working tool.

Fig. 10. Working tool.

4 Coordination at Frequency of The Elements of Developed Ultrasonic Vibrating System With Working Tool

After production of the piezoelectric transducer, the concentrator and working tool the measurements of their own resonance frequencies and amplitudes were made.

From the results of the measurements presented in Tab. 1 it follows, that deviations of resonance frequency of each element obtained by the finite element method do not exceed 5%.

However the joint of produced concentrator, working tool and transducer leads to disagreement and lowering of vibration amplitude amplification.

It is an evidence of inaccuracy of carried out calculations and it requires correction, as vibration amplitude is not enough for welding of thermoplastic materials.

<table>
<thead>
<tr>
<th>Element</th>
<th>Frequency value, $f_r$ (kHz)</th>
<th>Amplitude value $A$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory</td>
<td>Exp.</td>
<td>Theory</td>
</tr>
<tr>
<td>Piezoelectric transducer</td>
<td>19.5</td>
<td>19.5</td>
</tr>
<tr>
<td>Piezoelectric transducer + concentrator</td>
<td>19.8</td>
<td>20.1</td>
</tr>
<tr>
<td>Piezoelectric transducer + concentrator + working tool</td>
<td>19.3</td>
<td>20.3</td>
</tr>
</tbody>
</table>
To improve the conditions of frequency coordination the concentrator of underfrequency (its length was increased) was designed and produced. Working tool was completed. Fig. 11 shows the concentrator made of aluminum alloy.

![Fig. 11. Developed new modernized concentrator.](image)

In Fig. 12 completed working tool is shown.

![Fig. 12. Completed working tool.](image)

Improvement of the conditions of coordination worsens the distribution of vibrations along the radiating surface. The difference between maximum and minimum values of vibration amplitude of the surface achieves 2 µm. However such deviations cannot essentially influence on the quality of welding.

Carried out calculations of the parameters of vibrating system let obtain results presented in Tab. II.

![Fig. 13. Rotating ultrasonic vibrating system.](image)

The ultrasonic vibrating system ready-assembled with the transducer of longitudinal vibrations into radial ones is shown in Fig. 13.

V. CONCLUSION

As a result of the work ultrasonic vibrating system for the formation of continuous welding seams providing radial vibrations of welding instrument with amplitude of up to 35 µm at the deviations, which did not exceed 6 %, was designed.

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