The Development of Ultrasonic Welder For the Formation of Continuous Welding Seams

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Abstract – The paper is devoted to the design of formation of continuous seam by the ultrasonic welding. The base of the device is developed vibrating system consisting of the piezoelectric transducer of longitudinal ultrasonic vibrations with the working tool, which provides the transformation of longitudinal vibrations into radial ones. Designed welder helps to achieve tight joint of thermoplastic materials with different thickness due to the regulation of broaching speed and amount of clearance between the bearing and the working tool.

Index Terms – Ultrasound, transducer, welding, welder, longitudinal weld, continuous strip sealing.

I. INTRODUCTION

ULTRASONIC welding is widely used for the joining of separate units and elements during the production of the articles made of polymer materials.

To weld thermoplastic materials (polyethylene, polypropylene, pvc and others), which are characterized by low modulus of elasticity and high coefficient of ultrasonic vibration damping, ultrasonic seam welding is mostly applied.

For its practical realization the welders consisting of the ultrasonic vibrating system, the working tool with the radiating surface, the pressing unit of welding materials to the working tool, the mount of the device for the fastening of all the units of the welder, broaching unit of the materials to be welded and the generator of ultrasonic vibrations with the control system are used. Limited time of ultrasonic influence on the area of seam formation is not allowed to provide high quality of the seam joining at high speed of broaching. The attempts to compensate the short period of influence due to the increase of vibration amplitude exclude the possibility of monitoring and elimination of all possible changes of the parameters of welded materials and properties of the materials.

In this connection there is a need to develop the equipment for quality high-speed welding of list materials.

II. PROBLEM STATEMENT

The analysis of existing equipment used for technological purposes connected with the formation of continuous welding seams of different thermoplastic materials lets to determine the following facts.

Continuous ultrasonic welding can be realized by the different methods [1] – [3]:

1. Moving of the vibrating system with the welding tool of sliding type along the surface of the materials on the fixed bearing;
2. Broaching of welded materials between the vibrating system with the welding tool of sliding type and sliding bearing or bearing roller;
3. Broaching of welded materials between the surface of ring-type welding tool of the ultrasonic vibrating system rotating around its axis and pressure bearing roller.

The last method is the most effective and it is realized in different devices with the wide range of technical features and functional possibilities. The typical example of such device is the welder with the radiator having ring-type welding surface produced by Dukane Corporation. It has rotating ultrasonic vibrating system “Rotary Ultrasonic Sonotrode” (see Fig. 1), which provides following performance features of the device:

- Productivity: 0.3 – 2 m/min;
- Width of welding seam: 2 – 9 mm;
- Maximum distance between the edge of the material and formed welding: 400 mm;
- Consumed power: 400 VA.

Fig. 1. Rotating ultrasonic vibrating system “Rotary Ultrasonic Sonotrode”.

The main disadvantage of this device is small contact area of welded materials between radiating surface and bearing (bearing roller). This disadvantage is not allowed to achieve high efficiency and should be removed. Limited distance between the edge of the list and formed seam makes impossible the welding of lists with unlimited width or the formation of complex welding seams, which distance to the edge is changeable.

The aim of the paper is to design the ultrasonic welder on the base of the transducer of longitudinal ultrasonic vibrations into radial ones, which is able to provide the formation of continuous welding seams on the lists of unlimited width.
To achieve stated aim it is necessary to solve following special tasks:

1. To design the construction of the welder with rotating unit of piezoelectric vibrating system and the device of electric energy transfer to the electrodes of rotating piezoelectric transducer.

2. To create the unit, which regulates the clearance between the bearing and working tool, the orientation and control of the broaching speed of the materials and also the pressing of welded materials to welding tool with maximum area by static force, which is necessary for precise measuring of ultrasonic energy;

3. To provide optimum ultrasonic influence during the welding on the base of continuous parameter check-out of the piezoelectric vibrating system (through the collector).

### III. THEORY

#### 1 The Development of The Construction Providing The Rotation of The Ultrasonic Vibrating System

To decrease the friction between working tool and the bearing during the broaching it is necessary to provide the rotation of the working tool of the ultrasonic vibrating system and realize the transfer of electric energy to the piezoelectric transducer. For this purpose there is a need to design damping units and to investigate the process of vibration transfer on the body of the rotating vibrating system and the unit of electric energy transfer to the rotating ultrasonic vibrating system.

1.1 The Development of Damping Units And Investigation of The Process of Vibration Transfer On The Body

At the calculations of the dampers and during the welding process previously developed ultrasonic vibrating system converting longitudinal vibrations of the piezoelectric transducer into radial vibrations of the working tool is used (see Fig. 2).

The ultrasonic vibrating system operates at the resonance frequency of 20 kHz, it vibrates with the amplitude of radial vibrations of 35 µm and has two units of fastening (fastening belts), which are located in “null” of longitudinal vibrations.

To minimize the transfer of ultrasonic vibrations from the fastening units of the ultrasonic vibrating system to the body and the bearings providing the rotation, and exclude the damping of the ultrasonic vibrating system, fasten in rotating body several dampers were examined and the construction shown in Fig. 3 was chosen.

As it is evident from the results of modeling the damper partially transfers vibrations to the body.

However the vibration amplitude, which is transferred by the dampers to the body, does not essentially influence on the operation of the system, deterioration of ultrasonic influence does not occur. The transfer of ultrasonic vibrations to the body is minimal and operation life of bearings does not decrease. The dampers are easy to produce and install and their maximum external diameter is smaller than the diameter of radial radiating surface. Owing to this fact it is possible to design the body of the rotating ultrasonic vibrating system with external diameter, which is smaller than the diameter of the radial surface of working tool. It helps to use the device both for the formation of welding seam at the edge of the material and the welding of the lists of unlimited width.

#### 1.2 The Development of The Body of Rotating Vibrating System

The model of developed construction of the body providing the rotation of the ultrasonic vibrating system is shown in Fig. 5.
Developed body of the ultrasonic vibrating system consists of the front hub 1, the body 2, and the rings of the body 3, back hub 4, two bearings 5 and twelve screws 6.

The body helps to provide the rotation of the ultrasonic vibrating system and it has maximum diameter of all prominent parts smaller than the diameter of working tool (84 mm), provides radial run out of working tool of no more than 0.05 mm. Such construction helps to realize the welding of lists of unlimited width.

1.3 The Development of The Collector

For power supply of the piezoelectric elements in rotating vibrating system it is necessary to have the transfer unit of ultrasonic energy. The application of contact (brush) collector reduces the efficiency of energy transfer due to even short-term loss of electrical contact. It is determined by the fact, that high-frequency electric oscillations are transferred through the collector. Short-term loss of electrical contact in the collector (even for one period of vibrations) leads to mismatch in phase of supply voltage and vibrations of resonance system. At that vibration amplitude of working tool changes from maximum value to zero [6].

That is why at the design of the collector we use two broad contact rings of small diameter and four brushes for each ring in order to provide maximum fit area, minimum contact resistance between brushes and rings and minimum tangential velocity at the rotation of the body.

The model of developed construction of brush unit is shown in Fig. 6.

Brush unit consists of two brush-holders 1, eighth brushes 2, eighth springs 3, eight clicks of the springs 4, the bracket 5, two contact rings 6, the insulator 7, two screw nuts 8 and 2 bolts 9.

The brush unit was tested for wear resistance of the brushes and the contact rings at the transfer of ultrasonic energy to developed ultrasonic vibrating system (rotation frequency is 10 revolutions per second, the current is 1 A, electric energy supply achieves 1000 V and frequency is 20 kHz). At the operation of the ultrasonic vibrating system with rate of rotation of 10 revolutions per second for 60 minutes the change of temperature of the brushes and contact rings does not exceed 10°C, it means that loss of electric energy and sliding friction are small. Carried out measurements of the amplitude of radial radiating surface of working tool show, that at the use of the brush unit for the transfer of ultrasonic energy to the ultrasonic vibrating system the amplitude of radial radiating surface reaches 35 µm at 100 % of power of the generator. Deviation of the amplitude from its nominal value does not exceed 5%.

2 The Development of The Pressing Unit

One of the main units of ultrasonic equipment influencing on quality, productivity and possibility of formation of continuous welding seam is the pressing unit (anvil) of the materials to be welded to the working tool.

2.1 The Development of Anvils For The Pressing of Welded Materials to The Ultrasonic Vibrating System

To achieve high productivity of the welding process it is necessary to develop the anvil providing the pressing of welded materials to the radiating surface of working tool of maximum area with maximum static force, which is enough for precise proportioning of ultrasonic energy.

During the development of the constructions for the pressing of welded materials to the tool two types of anvils (rotating and sliding types) were studied. The model of the first developed anvil (type A) is shown in Fig. 7.

The advantages of the anvil of A type are:
– simplicity of production and installation, possibility of calibration and clearance adjustment;
– the anvil of A type gives the possibility of putting of cuts on the surface of the roller in order to obtain necessary drawing on the welding seam;
– due to small zone of pressing of welded materials to the radial radiating surface of the working tool the anvil of A type provides the formation of curvilinear welding seams of the materials of unlimited width.
The disadvantage of the anvil of A type is small area of pressing, and as a result of it the productivity of the welder is not high.

To provide larger area of pressing and increase productivity the anvil of B type was developed (see Fig. 8).

![Fig. 8. The model of the anvil of B type.](image)

The advantages of the anvil of B type are:
- high productivity due to larger area of pressing (15×4=60 mm²);
- contact zone of the materials and the working tool does not depend on the thickness of the materials and amount of clearance.

The disadvantage of the anvil of B type is complexity of installation, high rate of friction, and as a result of it bite of the materials between the anvil and the working tool. It is also impossible to perform curvilinear welding seams.

To combine the advantages of the anvils of A type and B type the anvil of C type (see Fig. 9) for the welder was designed.

![Fig. 9. The model of the anvil of C type.](image)

The anvil of C type consists of side plates 1, a bearing 2, a broaching belt 3, a guide roller 4, a roller for pulling of broaching belt 5, a broaching roller 6, a tensioning clamp 7, a tensioning bolt 8, an electric motor with a pulley 9, a driven pulley 10, a driven belt 11, a roller for pulling of driven belt 12. The anvil of C type is used for rounding of welded materials of unlimited width on the bed of B type. To avoid friction between welded materials and the anvil the broaching belt made of steel is applied.

The advantages of the anvil of C type are:
- large area of pressing (70×4=280 mm²);
- simplicity of installation, calibration and clearance adjustment;
- at the application of such anvil friction force between the materials and the belt is so high, that materials are broached without the broaching unit;
- contact zone of the materials and working tool does not depend on the thickness of materials and amount of clearance.

The type of the anvil is chosen according to industrial requirements. The anvil of A type is intended for the formation of curvilinear welding seam at low speed. The anvil of C type provides high speed of formation of rectilinear seam.

### 2.2 Kinematic Diagram of The Pressing Unit

To find out optimum size of the welder bed, provide the calibration, precise adjustment of the amount of clearance between radiating surface of the working tool and the anvil of A type the kinematic diagram of the device was developed (see Fig. 10).

For calculation of dependence of the amount of clearance on geometric sizes of the roller, working tool and their positional relationships the dependence presented by formula (1) was obtained.

![Fig. 10. The kinematic diagram of the operation of pressing unit with the anvil of A type.](image)

\[ A = R1 + R2 + ZZ, \]

and also

\[ A = \sqrt{H^2 + (L_o + \Delta L)^2}. \]

Comparing these two expressions we get:

\[ R1 + R2 + ZZ = \sqrt{H^2 + (L_o + \Delta L)^2}; \]

Having expressed the amount of clearance ZZ, the dependence of clearance on geometric sizes of the anvil and the working tool was obtained:

\[ ZZ = \sqrt{H^2 + (L_o + \Delta L)^2} - R1 - R2; \]

where
- ZZ is a clearance;
- \( \Delta L \) is a longitudinal motion of the anvil;
L₀ is a distance between the centers of the roller and the working tool at ZZ=0. \( L₀ = \sqrt{(R₁+R₂)^2 - H^2} \);

R₁ and R₂ are radii of the roller and the working tool, respectively;
R₁=35; R₂=46; H=80.9.

The dependence of the amount of clearance on longitudinal motion of the anvil of A type is shown in Fig. 11.

For adjustment of the clearance within the limits of 0.01 to 0.2 mm reduction ratio of longitudinal motion to the amount of clearance equals 15. Such ratio is enough for exact positioning of the anvil for thin materials (up to 0.01 – 0.5 mm). To adjust the clearance with in the limits of 0.2 to 1.5 mm the reduction ratio changes to 9. Though at such thickness of the materials precise adjustment of the clearance is not required, the ratio, equals 9, is high, it points that, the choice of geometric sizes was correct.

To estimate effective area of the contact zone of welded materials between the working tool and the anvil of A type the formula of contact zone area on geometric sizes of the roller and the working tool, and also on the amount of clearance and the thickness of the film was deduced.

\[
S = \frac{2\pi \times R₂ \times \alpha}{360} \times B \tag{2}
\]

Where
\[
\alpha = 2\text{Arc}Sin \left( \frac{Y}{2 \times R²} \right);
\]

\[
Y = \frac{1}{A} \sqrt{(A + R₂ + R₁ + x)(A + R₂ - R₁ - x) \times (A - R₂ + R₁ + x)(A - R₂ - R₁ - x)};
\]

A is a distance between the centers of the circles:
A = R₁ + R₂ + ZZ;

S is an area in the contact zone of the material with the working tool;
ZZ is a clearance;
B is a width of the surface of the working tool;
x is a thickness of the materials.

The dependence of the area in the contact zone on the clearance at different thickness of the materials for the anvil of A type is shown in Fig. 12.

As it is evident from the graph for the anvil of A type the area in the contact zone grows with the increase of thickness of the material and decrease of the clearance. Increasing the area in the contact zone the productivity proportionally rises.

2.3 The Development of Bearing Positioning Unit

For automatic and manual adjustment of the clearance according to described above kinematic diagram of the device the unit of bearing positioning of A type was developed, it provides its motion at right angle to the axis of the roller. Developed unit of bearing positioning of A type is shown in Fig. 13.

Developed unit of bearing positioning consists of stationary platform 1, non-stationary platform 2, step motor 3, compensating spring 4, drive screw 5, two pressing bolts 6, two pressing springs 7, three balls 8 and six limiting screws 9. The stationary platform 1 is fastened to the bed of the device, and the non-stationary one 2 is spring-loaded to the stationary platform and it moves at the right angle to rotation axis of the roller by three balls 8. The motion takes place by the rotation of drive screw 5 by step motor 3.

Developed pressing unit with the anvil of A type with the possibility of clearance adjustment is shown in Fig. 14.
The unit of bearing positioning provides the simplicity of installation of the anvil of A type in the welder.

3 The Development of The Bed of The Welder

To provide welding of materials with unlimited width for its use in conveying production and also for manual welding for the formation of the seam near the edge of the materials it is necessary to design the bed, which has several design features:

- presence of the broaching unit for orientation and broaching of welded materials;
- possibility of disconnection of the pressing unit;
- supply of working plane at the side of prominent part of the working tool;
- supply of cooling of the ultrasonic vibrating surface;
- the unit of bearing tightening should have possibility to eliminate axial and radial clearance.

3.1 The Development of The Broaching Unit of Welded Materials

The model of developed construction of the broaching unit of welded materials is shown in Fig. 15.

The broaching unit consists of two pressing rollers 1, two stationary rollers 2, four guiding pins 3, four guiding bolts 4, eight springs 5, eight bearings of the cylinders 6, four sliding carriages of the bearings of pressing cylinders 7, two sliding carriages of the bearings of stationary cylinders 8, drive sprocket of the motor 9, driven sprocket of the cylinder 10, roller chain 11 of the motor 12, the platform 13, external bar 14 and internal bar 15.

The model of designed construction of the bed with the rotating body of the ultrasonic vibrating system, the broaching unit, pressing unit and brush unit is shown in Fig. 16.

The model has a bed 1, rotating body of the ultrasonic vibrating system 2, broaching unit 3, pressing unit 4 and brush unit 5.

The model of developed construction of the bed with rotating body of the ultrasonic vibrating system without upper cylinders and without pressing unit is shown in Fig. 17.

The construction of the bed of A type without upper part of pressing unit provides the use of the welder for conveying production with the possibility of welding of the materials with unlimited width.

Fig. 18 shows the model of the bed with rotating body of the ultrasonic vibrating system providing rounding of welded materials on the working tool.

Fig. 14. The model of the pressing unit with the anvil of A type.

Fig. 15. The model of the broaching unit.

Fig. 16. The model of the bed with detachable pressing unit.

Fig. 17. The model of the bed without pressing unit.
The construction of the bed of B type makes possible rounding of the materials on the working tool, thereby more area on the radial surface is used to increase the productivity.

At the application of the anvil of A type 2 (see Fig. 19), rotation gear 3 providing rotation around the axes 4, guides 5 and transfer mechanisms for moving of the device and the bearing it is possible to form curvilinear welding seams of the materials with unlimited width.

The rotation of turning gears 3 and motion of the ultrasonic vibrating system and the anvil should be synchronous for the realization of the welding process.

4 Practical Realization of Developed Ultrasonic Welder

The models of developed devices with the anvils of A and B type are shown in Fig. 20 and Fig. 21.

Developed ultrasonic welder for the formation of continuous seam welding has the broaching unit of welded materials and possibility of adjustment of the clearance between the anvil and the working tool. If it is necessary to join the materials of unlimited width there is a possibility of detachment of the upper part of the device together with the pressing unit.

The device with the anvil of B type can be applied in the conveying production for the welding of the materials with large width at high speed. The anvil should be fastened to the stationary bed with the possibility of its adjustment relative to rotating ultrasonic vibrating system. Vibrating system with working tool should be placed on moving beam of the line of welding of thermosetting materials with the possibility of precise positioning in vertical position (accuracy of vertical positioning should be no more than 30 µm). Vertical positioning of moving beam can be realized by hydraulic cylinder together with the electric pump or by the rotation of drive screws by stepping motor-reductor. The device with the anvil of B type does not have separate broaching unit, as the preorientation of welded materials should provide the rollers of conveying line and the broaching should provide the motor of the anvil of C type.
As a result of carried out researches two variants of the ultrasonic welder for the formation of continuous welding seams were developed. These ultrasonic welders have essential advantages in comparison with the equipment of foreign producers. So the first ultrasonic welder can form continuous welding seams at the speed of 1.2 m/min to 10 m/min (depending on the properties and thickness of the materials), and it provides the adjustment of clearance between the materials with the thickness of 0.01 mm to 2 mm. The device can be applied both for conveying production at the joining of the materials with unlimited width and for manual use with possibility of welding of the materials at the edge. The second welder is able to provide the productivity of welding up to 15 m/sec. It can be used in the conveying production for joining of the materials of unlimited width by curvilinear welding seam.

**REFERENCES**


