Efficiency Increase of Operation of the Ultrasonic Technological Devices (By the Example of Welding of Thin List Materials)

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Annotation **– The article is devoted to the voltage regulators used at the design of ultrasonic technological devices. The schemes of thyristor and chopper voltage regulators are discussed, their advantages and disadvantages of these circuits are named. The results of application of different circuits and rules of regulation are analyzed.**

Key words **– ultrasonic device, regulation, chopper regulator, thyristor regulator.**

I. INTRODUCTION

Maximum efficiency of different technological processes realized by the application of high-intensity ultrasonic vibrations is provided only in the case of optimum parameters of influence.

One of the main parameters of inflluence determining the efficiency of ultrasonic influence is the amplitude of mechanical vibrations of the radiating surface of the ultrasonic vibrating system [1].

Vibration amplitude of the radiating surface of the ultrasonic vibrating system depends on the properties of the vibrating system and parametres of supply voltage. The stability of vibration amplitude, the character of transient processes and effect of external destabilizing factors in set mode are determined by the properties of control system of supply voltage parameters used in the ultrasonic vibrating system. Amplitude stability finally causes the quality of realized processes.

There is a number of ultrasonic technologies, where the requirements to the stability of value of vibration amplitude are high. So, e.g. the stability of mechanical vibration amplitude during the ultrasonic welding causes the quality of the seam along its length.

Experimental investigations of the welding process of thin list films (with the thickness of 30 up to 70 micromicron) at the formation of lengthy seams showed, that existing ultrasonic equipment [Giminey ultra, etc.] is not suitable for solving this problem. The characteristics of weld seam vary greatly from the begining up to the end of the seam, jam of the leading edge occurs, etc.

To solve these problems studies of functionality of existing ultrasonic welding equipment were carried out in order to reveal the reasons of destabilization of the influence amplitude degrading the quality of the seam. As a result of the investigations technical solutions on stabilization of the vibration amplitude during the welding process were proposed and realized.

II. THE STRUCTURE OF THE STANDART ULTRASONIC GENERATOR

To find out the reasons of degrade of regulation quality of the vibration amplitude and the way of stability increase of vibration amplitude at the formation of lengthy seams the structure of the ultrasonic equipment was analyzed.

Fig. 1 shows the block diagram of the standard ultrasonic generator.

The elements 1, 2, 3, 4 compose electroacoustic path of the transformation of the electric power of the industrial networks into the energy of elastic vibrations of the ultrasonic frequency. Unit 1 is the regulated source of d.c. voltage, which comes to the transistor chopper 2. The conversion frequency is specified by the controlled generator of the ultrasonic frequency 5.

At the output of the chopper 2 the square voltage with amplitude, which equals to the voltage at the output of the source 1, is generated. This voltage comes to the matching circuit 3, where the first harmonic of the input signal is separated and amplified. From the output of the matching circuit the voltages comes to the piezoelements of the vibrating system. Elements 6, 8, 10 of the block diagram evolve feedback signals. The microcontroller is used as a unit 7, which realizes the algorithms of control and stabilization of mechanical vibration amplitude of the ultrasonic vibrating system and it also coordinates the operation of all other units of the ultrasonic generator.

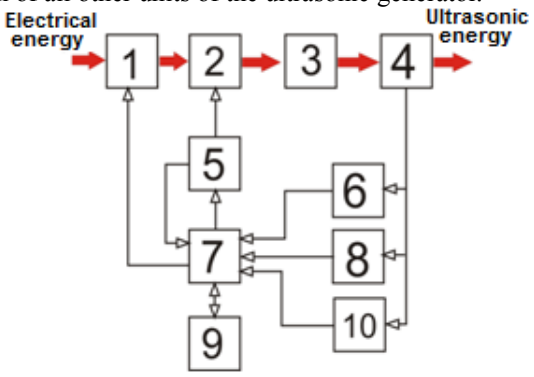


Fig.1. – The block diagram of the ultrasonic generator

As a rule, regulated source of dc voltage is the thyristor regulator providing control of vibration amplitude. Let's consider it in more detail.

III. THE THYRISTOR VOLTAGE REGULATOR

The circuit of the simple thyristor voltage regulator is shown in Fig. 2. Rectified two halfwave line voltage comes to the thyristor from the diode bridge. The duration of the half-wave charging the capacitor C2 depends on the moment of the thyristor opening. The thyristor automatically closes, when the voltage reduces to zero. Thus control signal of the thyristor should be synchronized with the begining of the half-wave of the line voltage.

At this control method there is a ripples on the the output of the circuit. For ripple rejection it is necessary to increase the capacity of the output capacitor C2. Acceptable ripple amplitude can be achieved, if the capacity of the output is hundreds of microfarads (100-500 mf).

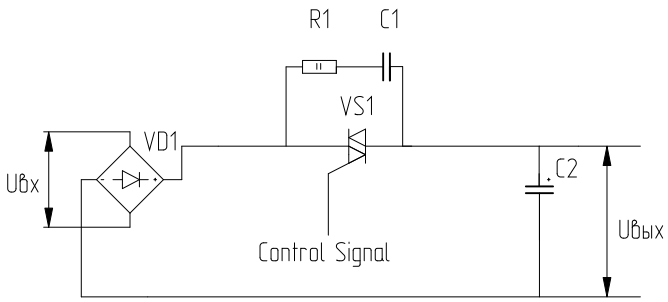


Fig. 2. – The circuit of the thyristor regulator

This circuit of the thyristor regulator has a number of disadvantages, the main of them is low rate of change of output voltage. Limiting factor is formation of large pulse current during speeded up charging of the capacitor C2 by the peak voltage.

The second disadvantage is impossibility to control the rate of voltage decrease at the output of the circuit. At that the control rate is determined by time constant of the capacitor discharge and the value of acoustic load. As the capacity of this capacitor is rather high (100-500 mf), the rate of output voltage decrease is small.

Thus it can be concluded, that this method of regulation is inertial.

On-off regulators are used in existing control systems of the thyristor circuits. They provide good quality of the regulation for inertial objects with little delay, such regulators do not need adjustment and are simple in operation. On-off regulators are the most common and widely used control metod [2].

The original function text of the output value of the on-off regulator is given:

```
void Regulator (unsigned int Current) {
if (Current > SetCurrent) {
        if (Y>PowerMin)         Y– –;
}else{
        if (Y<PowerMax)         Y++;
}
return Y;}
```

Function of the variables: Current is the current value of signal in feedback, SetCurrent is the setting, PowerMax is the maximum permissible value of power, PowerMin is the minimum permissible value of power.

Trial operation of ultrasonic equipment, which had the voltage regulator of this type, showed, that during the operation essential overcontrol took place, and vibrational behavior of transient and steady modes of operation was observed.

Fig. 3 shows transient characteristics of the thyristor regulator. The duration of the transient process is 0.5 sec.

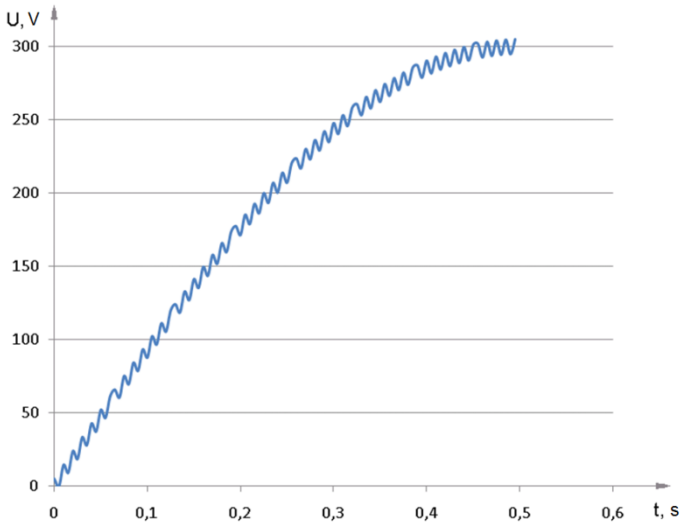


Fig. 3. – The transient characteristic of the thyristor regulator

Fig. 4 shows the feedback signal, which is in proportion to mechanical vibration amplitude of the ultrasonic vibrating system. It is evident from the diagram, that relative ripple amplitude in steady mode is 20%.

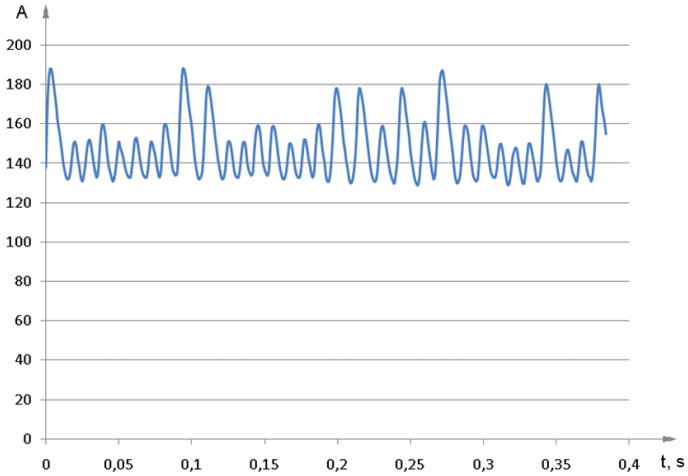
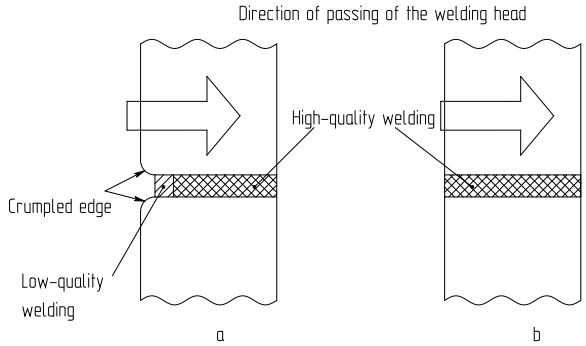


Fig. 4. – Changes of the time of feedback signal directly proportional to the amplitude of the ultrasonic vibrating system

The fluctuations of the amplitude in the technological processes are inadmissible. For instance, during the ultrasonic welding of thin list thermoplastic materials (at the formation of lengthy uninterrupted weld) it is necessary to provide minimum duration of the transient process and high stability of the amplitude in steady conditions. If these requirements are not fulfilled, the quality of welding seam will degrade.

As an example Fig. 5 shows the draft of the welding seam made by the device with the thyristor regulator (on-off regulator).

Low speed of signal increase leads to the following defects: incomplete penetration of starting part of the welding seam, crumpling of the edge of welded material; overcontrol leads to the burning of welded materials.



a– the seam made by the device with on-off regulation;
b – the seam made by the device with proportional regulation
Fig. 5. – The draft of the welding seam

For realization of the ultrasonicwelding where the requirements to the stability of mechanical vibration amplitude of the ultrasonic vibration system are high, it is necessary to use high-speed circuit of voltage regulation of power supply of high-frequency stage of the ultrasonic generator.

IV. CHOPPER VOLTAGE REGULATOR

The chopper regulator has more advantages than the thyristor one.

The example of the chopper regulator circuit is shown in Fig. 6.

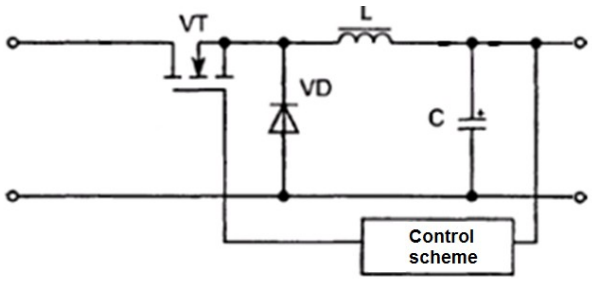


Fig. 6. – The circuit of the chopper regulator

The circuit of the chopper regulator shown in Fig. 6 consists of the following obligatory elements:

– Power key VT, which realizes high-frequency current commutation (as a rule powerful bipolar or field-effect transistor is used as a key);
– Discharge diode VD;
– Low-frequency ripple filter LC;
– Control circuit realizing the stabilization of voltage or current [3].

The circuit of the chopper regulator is simplier, as there is no need to synchronize control signal with the line voltage. The control of the key of the chopper regulator is made by high-frequency PDM-signal. The ripple amplitude at the output of the chopper circuit is smaller than at the output of the thyristor regulator. In the circuit of the chopper regulator the capacity of the output capacitor is 3 mf. The use of such capacity and high-frequency signal for the regulation let speed up the changes of voltage at the circuit output and therefore the duration of transient processes reduces. The transient characteristic of the chopper regulator is given above. The duration of the transient process does not exceed 40 msec.

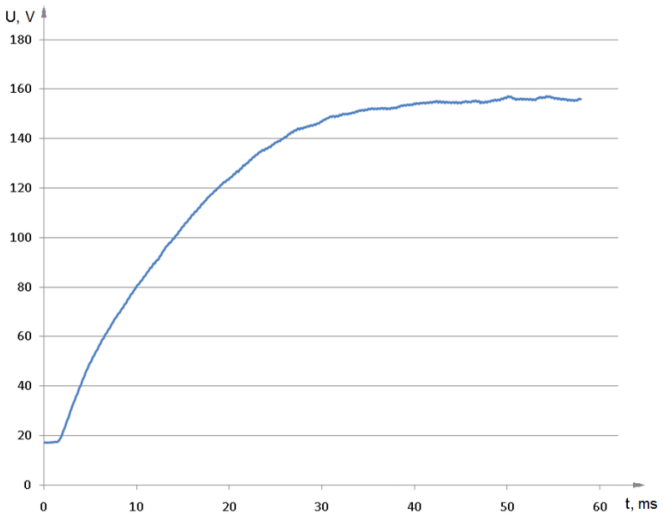


Fig. 7. – The transient characteristic of the chopper regulator

Higher speed of the chopper regulator operation lets realize qualitative control of the mechanical vibration amplitude of the ultrasonic vibrating system, e.g. with the use of the law of PID control, which in digital form can be expressed as follows:

As a microprocessor control unit the eight-bit microcontrollers are widely used in the ultrasonic devices. Most of them have only hardware-controlled multiplier, and division is made by corresponding mathematical algorithms. For this reason it is necessary to exclude all operations of division from the calculation formula replacing them by multiplication. Thus finally the calculation formula will be following:

where , —.

The original text of calculation function of the output value of the PID regulator is following:

```
void PID_Regulator (unsigned int Current) {
e = Current – SetCurrent;
sum += e;
delta = e – e_last;
e_last = e;
Y = Kp*e + Ki*sum + Kd*delta;
        if (Y>PowerMax) {
                return PowerMax;
        }else if (Y<PowerMin) {
                return PowerMin;
};
return Y;
}
```

To calculate the function itis necessary to transmit the current value of the signal in feedback and also to set a value of the variables Kp, Ki, Kd, which are the coefficients of the sections of the PID regulator.

Fig. 8 shows the feedback signal in proportion to the mechanical vibration amplitude generated during the formation of lengthy seam at the welding of thin list materials.

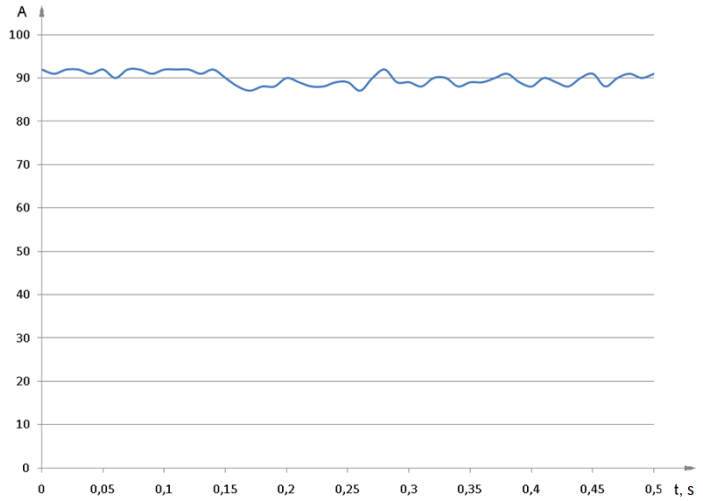


Fig. 8. – Change of siganl amplitude concerned with mechanical vibration amplitude during the formation of lengthy seam

From the diagram it is evident, that relative ripple amplitude does not exceed 5 % in steady mode.

The new ultrasonic device for welding of thermoplastic materials was developed with the application of the chopper regulator operating according to the law of PID regulation. The appearance of the device is shown in Fig. 9.


Fig. 9. – The appearance of the ultrasonic welding device with the chopper voltage regulator

Comparative investigations of welding quality of polyethylene and lavsan list materials were carried out. Fig. 10 shows the appearance of welding seams of polyethylene lists of high pressure (the thickness is 36 micromicron) formed by the ultrasonic device with the thyristor voltage regulator. As the material is thin, sluggishness of the regulator leads to considerable overcontrol and as a consequence to the destruction of the material and the degradation of strength properties of the seam.

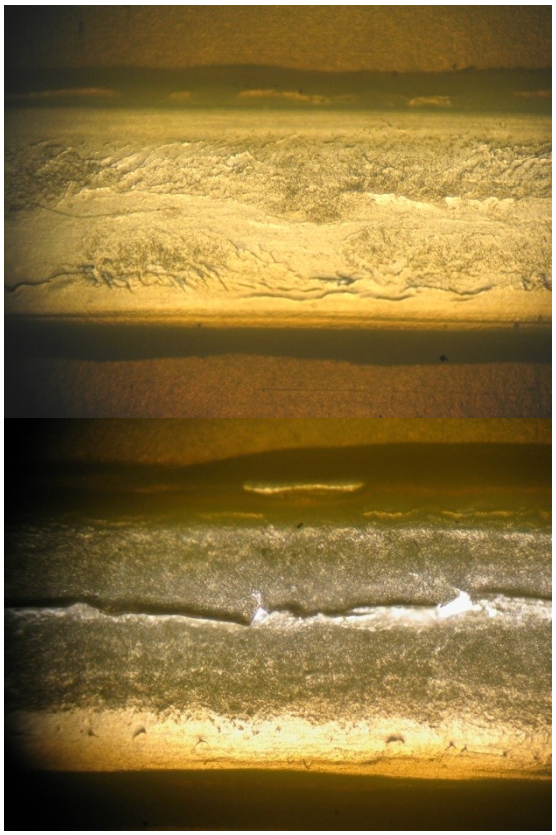


Fig. 10. – The appearance of the welding seam of polyethylene list made by the ultrasonic welding device with the thyristor regulator

Fig. 11 shows the appearance of the welding seam of the same material but it was made by the ultrasonic device with the chopper regulator. In Fig. 12 the appearance of the welding seam of multilayer list lavsan is presented. This device provides quicker regulation and as a consequence stable quality of the welding seam along the full length without warpage and destruction of the material.

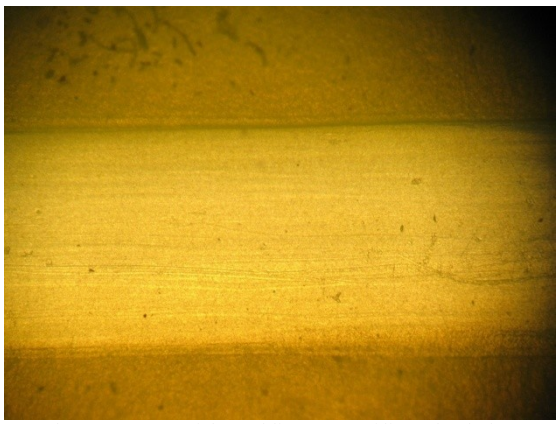


Fig. 11. – The appearance of the welding seam of list polyethylene made by the ultrasonic device with the chopper regulator

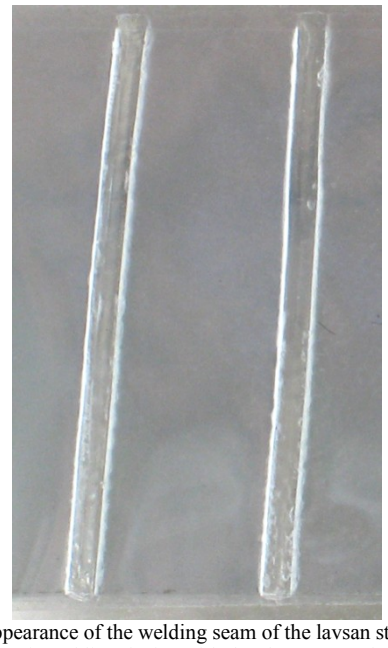


Fig. 12. – The appearance of the welding seam of the lavsan stripe made by the ultrasonic welding device with the chopper regulator

V. CONCLUSION

High speed of passing of transient processes in the chopper regulators makes possible the application of the laws of PID regulation, that finally essentially improves the control of the electronic generator causing noticeable growth of such characteristic of quality as rate of supply voltage change of the ultrasonic vibrating system (in 50-100 times), it considerably lowers ripples in the steady mode (in 4-6 times), decreases the duration of transient processes (in 3-5 times).

At the example of the welding of thin list materials it was shown, that the quality of the welding seam along the full length was higher, there were no areas with crumpled material and destruction markings. Thus it can be concluded, that the application of such regulation systems of vibration amplitude in the ultrasonic device is worthwhile and perspective.

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