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CONTROL OF LASER-FIELD TECHNOLOGICAL COMPLEXES FOR TOOL HARDENING

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ABSTRACT

Specific features formation of hardened layer of metals with unknown curvature under the joint action of laser radiation and an electrostatic field are described. It is shown, that the quality of the technological process of hardening depends on not only the energy characteristics of the hybrid technological complex, the temperature of the surface layer, but also on the accuracy of positioning the focus of laser radiation and its perpendicularity with respect to the surface of the part. The results of the studies show, that the deviation of the laser radiation focus from the surface of the part should not exceed 8-10 μm, and its vertical not more than 1 degree.

Keywords: laser hardening, laser-field technology, quality indicators, thermal influence zone, electrostatic field.

1. INTRODUCTION

Automation of the laser-field hardening process of parts in mechanical engineering makes it possible to increase the efficiency of the technological process [5]. The most expedient is the development of an automatic control system for hybrid technological complexes with stabilization and optimization of their energy, time and spatial characteristics to obtain the required output parameters of technological processes. Applying models allows the use of design procedures, which are based on the introduction of adequate models data banks with all possible technical elements of the complex. The information support of the automatic control system includes models of individual dynamic modules, and models of signals and noise affecting them, requiring adequate mathematical models of the technological process. However, due to the complexity of the physical processes occurring during laser-field processing of materials, they do not give a complete picture of the phenomena occurring in the joint action zone of laser radiation and the electrostatic field on the metal [6, 8].

2. EXPERIMENTAL RESEARCH

According to the results of experimental studies, the depth of the thermal impact zone for various parameters of the hybrid technological complex does not exceed 1 mm [1, 4]. The photographs (see Figure-1 and Figure-2) show pronounced zones of thermal influence for various steels at a certain diameter of the focal spot and electric field strength, which indicates an abrupt change in the conditions for the formation of the microstructure, that is, microstructural changes associated with the transient processes take place throughout the volume of the zones.

Based on experimental studies, obtaining dependencies of the process quality indices on the parameters of a hybrid technological complex is labor-intensive and long-lasting. Therefore, simulation based on known physical laws and experimental data is relevant.

To control the parameters of the optical system and electrostatic field system of a hybrid technological complex, it is necessary to model the surface of the product, for example, a worm cutter [2]. Construction of the surface of protrusions and depressions of the instrument executed according to a scheme that is universal for the gear cutter. Application of the developed mathematical model of tool cutting edges allows to optimize the conditions for shaping its working surfaces and to control the parameters of the technological complex at different stages of technological process in tool production [7].

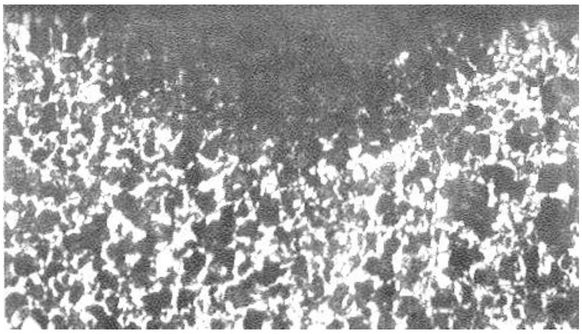

Figure-1. Microstructure of alloy steel Cr15 (bearing steel, GOST 801-78), processed in quenching without reflow (x 200, E=0 MV/m).

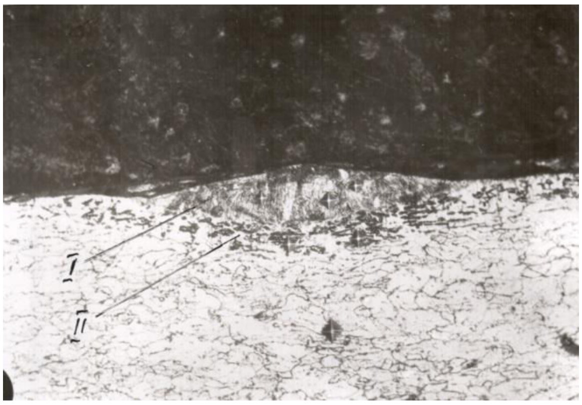

Figure-2. Microstructure of steel 10 (GOST 1050-88) treated by pulsed laser radiation (x200, E = 3.13 MV/m).

Figure-3 shows a fragment of the tooth of a worm cutter using laser-field hardening technology of steel W18Co5V2 (high-speed steel, GOST 19265-73). Figure-4 shows its microstructure.

Figure-3 shows the uniform distribution of roughness in the spot of the thermal influence zone, which determines its quality. The microstructure of the part (see Figure-4) is a hidden-needle martensite and carbides. The carbide heterogeneity in the structure of the milling cutter corresponds to 1A on a scale of 1, which satisfies GOST 19265-73.

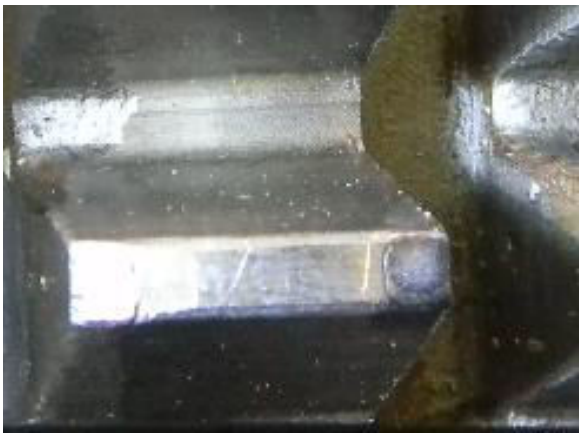

Figure-3. Tooth of a milling cutter from steel W18Co5V2, treated in quenching without reflow.

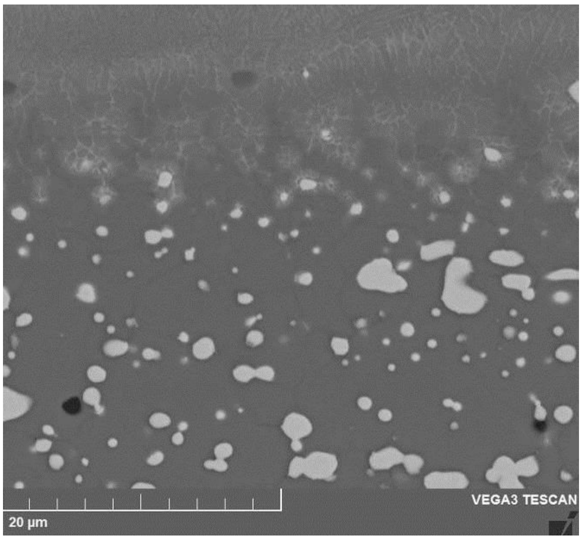

Figure-4. Microstructure of tooth of a milling cutter from steel W18Co5V2, treated in quenching without reflow (x200, E=2.88 MV/m).

In the microstructural investigation, a surface hardened layer with a non-etching structure and carbides was found on the working edge surface of the milling cutter teeth. The high hardness of the hardened layer (up to $HV_{0.1}$ 970) has a positive effect on the wear resistance of the milling cutter. The content of carbides, the amount of residual austenite, has a great influence on the wear resistance of tool steel. At a high temperature, only steel that is resistant to tempering is wear-resistant. The decrease in hardness due to the decay of martensite greatly reduces the wear resistance [2, 3].

When obtaining experimental dependencies, the statistical processing of the received data of the process quality indices was used. When measuring the microhardness at a fixed depth with the given technological parameters, their different values were obtained. These parameters change in repeated experiments in an unpredictable ways. However, it is possible to determine the probability p_m of the measured value of microhardness falling into the specified range of admissible values:

$$p_m = \lim_{N \to \infty} \frac{N_m}{N}$$

where:

N_m - the number of random variable observations in a given admissible values range;

N - total number of observations.

It is assumed that the distribution law of the studied data set is normal. Determine the average value microhardness and standard deviation at each depth. After the combined effect of laser radiation and electrostatic field on the tool metal, the hardness of the treated zone (see figure-3) in all cases increases: from 900 $HV_{0.1}$ at a matrix hardness of 805 $HV_{0.1}$ (sample steel W18Co5V2 at laser pulse energy W = 15 J, pulse duration 10 ms, E = 2.88 MV/m).

Due to the instability of the laser radiation parameters and the optical-physical properties of the surface, the quenching quality parameters are reduced, which depend on the stability and optimal values of the parameters of the technological complex. To stabilize them, a system for automatic control of the technological complex with negative feedback on the parameters of the quenching process, measured in real time, was developed. As feedback signals for the metal quenching process are the laser radiation energy density, temperature, and accuracy of positioning the focus relative to the surface of the part. The structure of the automatic control system of a technological complex is a system that is characterized by a large number of feedbacks and is nonlinear (figure-5) [7].

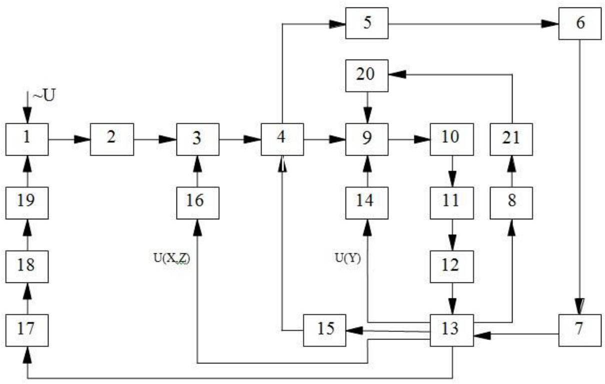

Figure-5. Automatic control system functional scheme of the hybrid laser-field technological complex.

The functional diagram of the automatic control system consists of the following components: 1 - power supply unit; 2 - resonator; 3 - optical system; 4 - device for moving the beam; 5 - photodetector of the focus position; 6 - amplifier; 7 - communication line; 8 - amplifier; 9 - part; 10 - pyrometer; 11 - communication line; 12 - the amplifier; 13 - microprocessor system; 14 - part movement drive; 15 - the focus position adjuster; 16 - actuator for moving the optical system; 17 - amplifier; 18 - communication line; 19 - phase voltage regulator; 20 - electrostatic control system; 21- communication line.

When justifying the choice of the mathematical model of the links, certain assumptions were made that allow linearizing their transfer functions. Calculations and studies of the automatic control system properties were carried out for a linearized system.

In accordance with the accepted assumptions, the transfer functions of subsystems are determined. Dynamic processes in the elements included in it are described by differential equations based on which the transfer functions are calculated and, using a package of applied programs, transient and frequency characteristics determining the quality of the automatic control system of the technological complex are obtained.

The analysis of research in the field of automatic control systems development shows the effectiveness of multi-loop systems with feedbacks based on informative parameters, measured in real time for the control of hybrid technological complexes.

The transfer function of the open system has the form:

$$Wr = \frac{K}{(T_1 p + 1)(T_2^2 p^2 + 2T_2 \zeta p + 1)(T_3 p + 1)(T_4 p + 1)}$$

where $K = \prod K_i = 0.0005$

The corresponding logarithmic amplitude and phase frequency characteristics are shown in Figure-6.

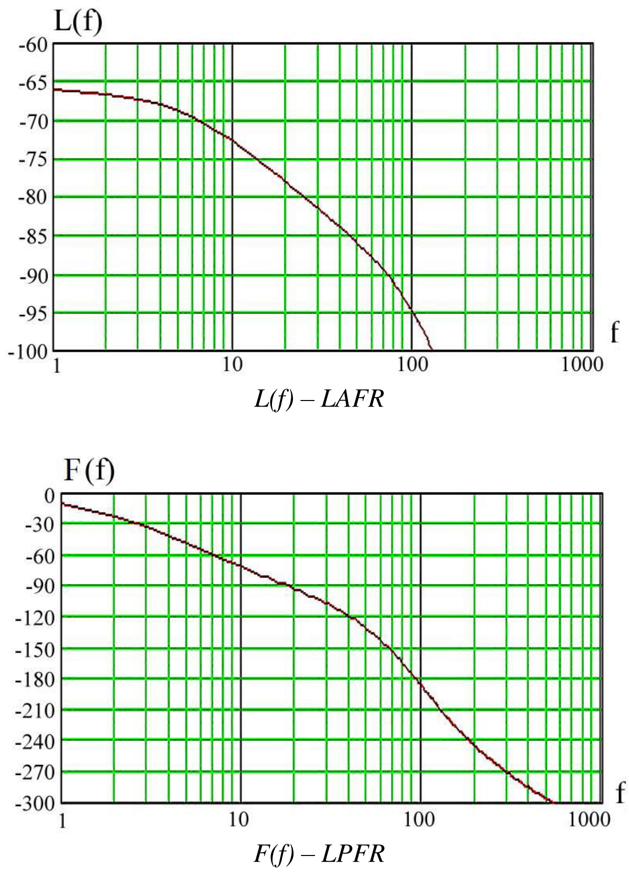

Figure-6. Logarithmic amplitude and phase frequency characteristics.

It can be seen from the graphs that the closed system will also be stable; the stability margin in amplitude is ~ 80 dB. Analysis of the remaining circuits shows that all the contours of the automatic control system are minimal-phase, stable, have a large stability margin in amplitude (not less than 20 dB).

3. CONCLUSIONS

Experimental studies on the effect of laser-field technology on metals show the possibility of optimizing the hybrid technological complexes energy parameters for quenching with obtaining the required quality indicators, which leads to a reduction in energy costs. The developed system of automatic control of a technological complex satisfies the requirements and provides stable parameters of quenching quality. In the process of heating a material with a flux of laser radiation that is constant in time, exceeding a certain critical value, the surface temperature fluctuates. By the appropriate selection of the laser radiation time structure parameters and the intensity of the electrostatic field, it is possible to achieve an almost complete elimination of the plasma flame effect on reducing the melting ability and increasing the depth of the heat-affected zone. The localization of hardening provides a rational design of hardened parts and minimal residual deformations.

ACKNOWLEDGEMENTS

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