System of control of pulse processing with hyperfine wire during electroplastic deformation

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Abstract
The control system diagrams of influence of direct, alternating and pulse current on motion bars, wire and tape within plastic deformation of metal have been suggested. As a basis of control system the mathematical model has been taken describing the temperature fields in the zone of input of direct, alternating or pulse current to the movable blank with variable velocity. The parameters of heat control are determined in the calculating device be means of the inverse problem for heat conduction equation and compared with measurements of current sensor (control parameter). The system control of process electroplastic deformation is developed. Numerical experiments carried out. Parameters control of temperature field during the transition process are defined. The sample model for rolling system that was tested at production of sample parties of tape has been produced.

1. Introduction
Plastic deformation of high-melting and hard metals can be observed at higher temperatures. The blank is heated by means of internal and external sources of heat which are normally currently-operating ones. The heating by internal sources of heat can be referred to as heat of electric current in the direct zone near the deformation unit. Such type of heating makes it possible to increase metal plasticity and leads to decrease in the strength of plastic deformation.

Today the various methods of processing of the blank with electric current in the stream with a plastic deformation have been scientifically proved and experimentally implemented [1 - 4]. It has been proved that it is appropriate to process fine and hyperfine wire with pulse electric current of high-density within safe voltage (less than 40V). It decreases energy costs for plastic deformation process and improves physical and mathematical properties of metal. In particular, the processing with pulse current simultaneously with plastic deformation that relates to electroplastic processing, increases electronic conduction up to 5-10 % which is significant for metals used in electrotechnic industry for light-load cables [1, 4].

The research conducted in different countries shows that electrocontact heating for thermal treatment of fine wire and tape is rational to use in continuous production processes simultaneously with electroplastic metal deformation [1, 4]. However, there are some other principal problems within control of plastic deformation process of movable wire temperature measurement and its degree of heating [5-7].

The scheme of supplying of pulse and direct current are described in the papers [2, 4]. Despite the variety they all can be combined into one schematic diagram, shown in Fig. 1.

The processed blank (wire) moves in relation to fixed contacts K1 and K2 which are supplied with pulse or direct current. A deformation node can be used here as a second contact [4]. An electro contact heating device was designed and produced at one of Kryvyi Rih’s enterprises; the rollers dipped in conducting liquid were one of the contacts in this device, while the other was a hard-alloyed die.

The supplying of pulse current to the wire during the drawing was implemented also with roller or liquid contacts with the die placed between the contacts [4].
2. The paper’s objective

The objective of the research is to develop the systems that control the process of fine wire drawing with closed and open adjustment systems and to determine the parameters of processes’ control.

3. The materials and results of the research

If in order to insure the optimal temperature and energy-power mode during EPD with ECH it is necessary to have a corresponding adjustment system. Such system can be built either closed with adjustment by temperature, draw force or both, or open, controlled by the given algorithm.

In the solution of practical task of creating high-performance ECH plants combined with electroplastic processing that provide high efficiency and reliability of the drawing process with minimal power inputs the systems of subjected parameters’ adjustment are used. The parameters of pulse generators were chosen considering the deformation parameters of the drawing process under the condition of having every part of the wire that goes through the deformation site processed with at least one pulse of the current. The frequency of pulses’ movement and their porosity was determined based on the proportions [4]. Based on these proportions a pulse generator was designed and built, which was used for the experiments. The efficiency of current’s effect on the wire drawing process was estimated by the decrease of the deformation force, which was registered by the electronic sensor.

In order to provide the optimal energy-power and temperature mode during the drawing a proper adjustment system is created. The closed systems by type of [5-7], with the adjustment of temperature or the drawing force and the open systems, that are controlled by the given control algorithm were implemented in our research.

We have designed and studied two closed systems of regulation. In the first of them the control of plastic deformation of fine wire occurred by means of force and temperature, in the other one – within drawing and heating.

Closed adjustment system that was tested performs the control of the drawing force with adjusting the current in the heating zone before the deformation site. The drawing force sensor is included in the device, which contains the control object and the adjustable power source that is connected to it, to adjust the heating degree of the wire. The device that adjusts the heating degree of a moving wire before the drawing, created by type of [8], (it additionally contains an optimal heating voltage search unit, that allows to increase the operating efficiency of the device) has a similar structure of the system. The block diagram of the system is shown on Fig. 2. The device that adjusts the heating degree of the moving wire before the drawing contains a control object 1 (a heated part of the moving wire), an adjustable power source 2, a control unit 3, a voltage sensor 4, a velocity sensor 5, a drawing force sensor 6, an optimal wire heating mode control system 7. After analyzing the data from the velocity sensor and the draw force sensor, the optimal wire heating mode control system before drawing searches for an optimal heating voltage. The control unit 3 produces the adjusting voltage at the output of the adjustable power source 2, providing the equality of the setting voltage $U_{pr}$ and the feedback voltage $U_{fv}$ at the voltage sensor’s output.

![Fig. 2. The block diagram of the device for adjusting the heating degree of the moving wire before drawing](image)

The use of this devise allowed to provide an optimal thermal condition of wire’s heating; with this condition the minimal value of drawing force is reached. Additionally the drawing process consumed a minimal amount of energy-power resources, the number of wire breaks was reduced, the quality of the processed material improved, the wear of the drawing instrument reduced.

The system of subjected parameters’ adjustment of EPD process slightly differs from the closed systems. The main (outer) loop in these systems can be a drawing velocity (plant performance) loop, the outer – a drawing force adjustment loop, with drive electric motor affecting the power supply voltage.
The adjustment system also contains the regulator of pulse current intensity of the part of the wire at the die’s input. The block diagram of such adjustment system is shown on Fig 3.

From the engineering standpoint the mathematical model in which the density of pulse current before the deformation site is selected is way that minimizes the force during EPD of the wire during both transitional and stationary drawing process is of most interest. In the mathematical model of finding the control parameters the inverse problem for the heat conduction equation and the optimization problem are solved.

The physical model of temperature distribution during the processing with pulse and direct current or with their simultaneous processing corresponds to one of the original and principal tasks for linear differential equation in partial derivative [5 10, 11]
3. If we consider in the quotation (1) \( v(t) \neq const \), \( \xi(t) \neq const \), we shall obtain non-stationary temperature distribution in the zone which length can vary. In particular, when \( 0 \leq \xi(t) \leq l = const \), mathematical model describes temperature distribution of blanks which length is declined and tends to zero within the processing.

4. If we consider in the quotation (1) \( v(t) \neq const \), \( \xi(t) = const, w_2 = 0 \), we shall obtain non-stationary temperature distribution in the zone of heating with direct current or with power current which length is constant. In this case, electric current effects only by means of heating on the blank under processing.

Having changed parameters in the quotations (1), (5), and in the conditions (2)-(4) as well, we shall get models describing peculiarities of certain technological processing of blanks. The basic parameter of control that mostly effects on temperature distribution is current strength \( I(t) \) possessing constant and variable values. The other parameters of control are processing speed \( v(t) \), function describing form and frequency of pulse current action \( f(t) \), and heat exchange coefficient \( \alpha \).

Assuming in equation (5) \( \frac{\partial u}{\partial t} = 0, \frac{\partial^2 u}{\partial z^2} = 0 \) The control parameter – function \( I(t) \) define in the form [5,11]

\[
I(t) = \frac{\ln(1 + \beta I_1) - \ln(1 + \beta I_0)}{\beta k \left[ l \int_0^h v(x) dx + v(t-t_0) \right]}, \quad 0 \leq t \leq t_0, \quad (6)
\]

The parameter of control for pulse source of power with current strength regulation that is necessary for optimal energy-power mode support in the zone of pulse current input can be obtained by studying more complete mathematical model. [10]. The parameter of pulse generator control is determined from the minimum of the functional (7) in the calculating unit BY Fig. 5 where the iteration method of optimization problem solving is implemented [11].

\[
J_E(v) = \int_0^1 \left( u(z,t,v) - u^*(z,t) \right)^2 dt + \frac{1}{e^2} \| I \|_2^2 \quad (7)
\]

The block diagram, shown in Fig. 5, implements the algorithm based on the solutions (1) - (4), (6)-(7), which allows by given program to control the pulse heat source during the electroplastic processing of ultrafine wire with the diameter less than 50 mcm.

In order to determine the parameters of controlling the temperature field and the EPD process a program was developed. The program's structure is based on the modular approach. It allowed to combine the problem solution for the one-dimensional and two-dimensional heat conduction equations and, considering the technological features of processes, to carry out calculations while changing boundary conditions. An alternating direction method was used to solve the two-dimensional nonlinear equation, which allowed to have one solution module of the band systems of second order difference equations.

Fig. 5 shows the structure of program solution for nonlinear problem of one-dimensional and two-dimensional heat conduction equation. The numerous experiments have been carried out, the particular problems, direct and reverse ones, have been solved, the parameters of control of pulse effect of current on the heating zone have been determined.

![Fig.4. The system of EPD wire control](image)

**Fig.4. The system of EPD wire control**

RC, RV, RF – regulators of current, velocity and drawing force; SC, SV, SD – current, velocity and drawing force sensors; APS – adjustable power source; CC – controlled converter; EM – electric motor of drawing plant; AO – adjustment object (active area of the blank); \( U_{sv}, U_{sv}, U_v \) – voltages of setting the current, velocity and drawing force; \( U_{sv}, U_{sv}, U_v \) – voltages at the output of the current, velocity and drawing force sensors; I – integrator; CD – calculating device.
Fig. 6 shows diagrams of temperature distributions within parameter value, $I = I_1; 10A$, obtained by means of correspondent problems solutions. The diagrams prove that temperature in the result of pulse effect of current varies to a little degree. With the increase of parameter $I$ temperature rises a little.

![Module of interface for selection of equation type and data input](image)

![Module of numeric computation of two-dimension equation with formation of matrix diagram and graphs of temperature distribution](image)

![Module of numeric computation of one-dimension and two-dimension equation with internal sources of heating](image)

![Module of numeric computation of two-dimension equation and solution of optimization problem](image)

![Module of solution of tape systems of different equations of the second order](image)

Fig. 5. Structure of algorithm for determination of control parameters for temperature field

Figure 6. Temperature distribution for tungsten wire obtained with the following parameters value:

$T_c = 300K$, $\alpha = 1\frac{W}{m^2K}$, $\rho_n = 19.1 \cdot 10^3 \frac{kg}{m^3}$, $c = 137 \frac{J}{kg \cdot K}$, $\varepsilon = 0.5$, $\eta_0 = 10^{-3} m$, $\lambda = 124 \frac{W}{m \cdot K}$, $\rho_0 = 5.6 \cdot 10^{-8} \frac{\Omega}{m}$.

Fig. 7 shows diagrams of temperature distributions obtained in the result of non-stationary problems solution (1)-(4) with the current strength value $I = 1A$ and $I = 10A$. The graphs of temperature distributions have been designed according to the average temperature after each pulse of current.

$T_c = 300K$, $\alpha = 1\frac{W}{m^2K}$, $\rho_n = 19.1 \cdot 10^3 \frac{kg}{m^3}$, $c = 137 \frac{J}{kg \cdot K}$, $\varepsilon = 0.5$, $\eta_0 = 10^{-3} m$, $\lambda = 124 \frac{W}{m \cdot K}$, $\rho_0 = 5.6 \cdot 10^{-8} \frac{\Omega}{m}$

Fig. 8 shows the graph of dependence of current intensity that is necessary for maintaining the constant temperature before the die during the transitional process; the graph was obtained from the optimization problem solution (9) when the wire’s velocity changes in the limits of $0 \leq v(t) \leq v = const$.

![Fig. 6. Temperature distribution for tungsten wire obtained with the following parameters value](image)

![Fig. 7. Temperature distribution for tungsten wire obtained within the following parameters value](image)
4. Conclusions

The results of system of control analysis, realized and tested, have shown that for the technological processes of fine and hyperfine wire it is necessary to use the reliable system of regulation where the control of parameters of processing and their control should be implemented by means of sensors and calculation method on specified algorithm. It is appropriate to apply the systems of control which block diagram shown in Fig. 2-4 at drawing and thermal processing of low-plastic and high-melting wire, fine tape, blanks of finite length. They indicate that their application is reasonable in the processes of drawing and thermal processing of low-plastic and refractory wire, fine strip. The use of such control systems allows to obtain wire and strip with uniform physical-mechanical properties. The designed devices of automated EPD processes’ adjustment can find an effective use during pulse current processing, as well as during ECH before drawing of the nonferrous, refractory metals and hardly-deformed alloys.

Bibliography


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