Hardware provision of electrostimulated wire drawing

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Abstract. The electrostimulated drawing process monitoring system (EDPMS) is considered, covering such indicators as temperature in deformation zone and drawing force, which forms control signal to generator of high-power current pulses, principally based on periodic discharge of a pre-charged capacitor to low-resistance load. In order to increase reliability and quality of electrostimulated drawing process control system (ESDPACS) is implemented, including single circle system of drawing force control, as well as delayed temperature feedback in deformation zone. Dependences of change in drawing force and temperature on frequency of pulse reproduction are obtained from the results of laboratory tests and calculations using known and original techniques. To analyze operating modes of electrostimulated drawing using automated control system, ESDPACS model was implemented in the Matlab-Simulink environment. Developed model allows to improve technical characteristics and operating modes of the system. Structural diagram of ESDPACS, its model in Matlab-Simulink environment, oscillograms of transition processes are presented in the paragraph. A single circle drawing force automated control system with flexible feedback on temperature in deformation zone allows to optimize operating modes and to increase reliability of electrostimulated deformation process.

1. Introduction

The attention of the researchers in the field of physical material science and metal working is focused on the application of the external energy effects for the increase in the service properties. The progress in the development of the modern metal working technologies is connected with the application of electric currents of the high density [1]. Especially, it is concerned with the metallurgical, aircraft, automobile and aerospace branches of industry. In shaping of the metal parts the current effects are the multiple-factor ones and they consist in the decrease of forces in metal working, the flow stresses, the increase in plasticity, the acceleration of ageing and recrystallization, the decrease in the grain size, the decreasing in the residual stresses, the decrease in the elastic recovery [2]. It is concerned with the processes of forging and rolling [3], drawing [4], metal working [5], joining of materials [6], sintering [7], sheet forging [8].

The application of current effects is represented in most details in the two last rewios [9, 10]. In spite of the intensification of deformation the reliable experimental and theoretical ideas of the processes of plastic deformation are very limited and the physical nature of metal plastification effect is studied not evidently. It retards the application of the promising phenomenon in metal shaping.
technology. The solution of problems in the investigation of the mechanisms of developed electrostimulated plastic deformation and its practical application in metal shaping is possible only with the use of the sources of powerful short current pulses.

For the electrostimulated metal working the different sources of direct, alternating and pulse current with different forms and parameters of frequency, duration and amplitude depending on the concrete type of production, the technological process, the material [1, 2] are used. For the wire drawing from the difficult to deform steels and alloys the application of the sources of powerful single-pole current pulses is the most effective [2].

The diagram of powerful current pulse generator and the control system of electrostimulated drawing are presented in the paper.

2. Automatic control system of electrostimulated drawing process

With the advent of generators of high-power current pulses, principle of which is in discharge of pre-charged capacitors to low resistance load, it has become possible to study change in physical properties of metals under current impact, and to use the results obtained in the industry, for electrostimulated metal processing in particular. Figure 1 shows the scheme of economically effective high-speed pulse generator, made using thyristor converters [11]. The generator produces unipolar current pulse of sinusoidal shape of 120 microseconds duration and amplitude of 8-10 kA.

![Figure 1. Diagram of the generator.](image)
300–400Hz. Use of thyristor converters made it possible to remove current-limiting resistor $R_3$ from the charger circuit, which increased efficiency and reduced power consumed from AC network [12].

To regulate magnitude of pulse amplitude, two-circuit system of subordinate voltage regulation (SARS) is implemented. Internal circuit of automatic control system is organized as a circuit for charge current control, and external circuit is for capacitors charge voltage regulation. Limitation of the maximum charge current is carried out by $S_2$ voltage regulator limiting unit, $S_1$ current controller limiting unit allows to set the minimum and maximum value of thyristor converter control angle [13]. Thus, in generator circuit, two-zone power regulation of current pulses is provided:

- due to pulse reproduction frequency change, when the charge voltage of capacitors is stabilized
- by changing charge voltage using thyristor converter.

Voltage reference can be supplied either manually (from Q1block) or from the signal of process programmable controller.

The first attempts to apply revealed electroplastic effect in metal processing with pressure led to unreliable work of drawing mill due to fundamental difference between electrostimulated drawing and the ordinary one:

- high degree of temperature rise in zone of deformation due to considerable value of current pulse (up to 10 kA) and frequency of its reproduction (up to 400Hz);
- reduction of force of current impulses applied to the workpiece being processed.

Thus, reproduction frequency of current pulses must correspond to the speed of workpiece movement. For example, if current pulses are applied at a moment when the workpiece starts to move, temperature of the workpiece can rise to 1000 degrees in a fraction of a second, causing failure of a workpiece and the drawing tool even before the acceleration process begins.

Due to high speed of transition processes during electrostimulated drawing, manual control is almost impossible, which leads to the need of drawing parameters high-speed automated control systems design [14].

Figure 2 provides a diagram of the system of electrostimulated drawing parameters control (ESDPCS) - temperature in deformation zone, and drawing force. ESDPCS contains a single-circuit system for drawing force regulation, which is based on $RU$ force regulator with constraint, which output signal is fed to SFI block generating control pulses.

Control pulses generated in SFI block, whose reproduction frequency is directly proportional to output signal of RU unit, are fed to input of high power current pulse generator, diagram and operation principle of which are presented above (figure 1). RU output limit block generates the maximum and minimum pulse reproduction frequency. Two dynamic links $I_{sr}$ and $dF$ simulate effect of wire drawing force reduction when subjected to high power current pulses due to electroplastic effect - EPD. The model was obtained from the results of laboratory studies and calculations using original techniques for current, force and temperature parameters measuring in deformation zone [15-19].

Drawing force feedback is made based of $DF$ block.

The $S_2$ force setting unit generates signal proportional to the force obtained experimentally by electroplastic drawing of wire of a certain grade and section at certain speed.

One of the factors inherent to electroplastic effect should be low temperature in deformation zone, usually not more than 250-300 degrees. Increase in temperature most often leads to processed material properties change, as in case of plastic deformation with heating. In this case, change in plasticity of metal is subjected to other physical laws. Thus, during electrostimulated drawing, it is necessary to monitor temperature in deformation zone, not allowing its rise. Due to this, a delayed feedback on temperature is introduced into the ESDPCS circuit. Temperature $\tau$ is determined in accordance with the expression:

$$Pe*\tau=C*m*\tau - Pr - Pk - Ph,$$

where $Pe=I^2ms*Re$ is the power applied to the workpiece under process, $I^2ms$ is meansquare current passing through the workpiece when pulses of variable frequency with constant amplitude (8-10 kA) are applied to processed material, $Re$ is equivalent resistance of wire being processed, taking into account the skin-effect; $\tau$ is temperature in deformation zone, $C$ is the constant, $m$ is mass.
of wire being processed (between the contacts), $t$ is current time, $Pr$ is the radiation loss, $Pk$ is convection loss, and $Ph$ is heat loss [20].

![Figure 2. ESDPCS diagram.](image)

In $Kv$ block, signal proportional to $Pe$ power is formed, and in DL block temperature in deformation zone $\tau^\circ$ is formed. The DL unit implements inertial part of temperature change during process of motor speed changing under setting and disturbing inputs. Temperature setting determines start of cutoff action and is implemented in $C4$ block. Delayed feedback (cut-off) in regard to temperature $\tau^\circ$ allows to maintain temperature of the set value in deformation zone due to change in reproduction frequency of current pulses in generator.

It is known that when wire moves, efficiency of electroplastic effect, as well as temperature in deformation zone, decrease due to decrease in time of current action on deformed part of wire. In order to take this phenomenon into account, $PR$ transformation and $D1, D2$ division blocks are introduced into the circuit.

In order to simplify the ESDPCS, dependence of force and temperature on frequency of current pulses in course of motion of the wire is linearized.

For analysis of operating conditions of electrostimulated wire drawing using automatic control system and its improvement, model of automated control system for electroplastic drawing in Matlab Simulink medium is completed (figure 3).

The diagram contains the following models:
- DC electric drive with system of subordinate regulation of the main parameters of electric drive: speed, rate of speed change and limitation of maximum torque ($Synch6$-$PG$, $Th-Ph$ $Trans$, VM5 VM7, Uni-Br, $K$, $Int$, $RS$, $RT$, $PY$, $DS$, $DT$ blocks); - generator of high-power current pulses with system of control pulses generation, figure 1 ($SFI GI$ blocks); - ESDPCS system ($RU$, $Isr$, $Isr1$, $Isr2$, $D1$, $D2$, $dF$, $DF$, $PR$ blocks).

The electrostimulated deformation transition processes were fixed on the $Scope1$ oscilloscope.

Figure 4 shows the process of automatic control system parameters change during acceleration of electric drive. Impulses increase in function of changing speed of electric drive, while there is no unacceptable increase in drawing force and unacceptable temperature in zone of workpiece deformation.

Figure 5 shows ESDPCS reaction on electric drive disturbing effect (for example, at decrease in supply network voltage), which led to a decrease in the speed of the electric motor.
Uncontrolled reduction of the motor speed leads to increase in temperature before cutoff begins. At the same time, temperature stabilizes at given (maximum) level, with a slight reduction of the drawing force. When required speed is restored, optimal electrostimulated drawing process is restored.

**Figure 3.** Model of automated control system for electrostimulated drawing process.

**Figure 4.** Transmission processes in ESDPCD during acceleration of electric drive. 1 – speed of electric motor; 2 – effect of drawing force reduction $\Delta F$ (electroplastic effect) with respect to regular drawing; 3 – amplitude of current pulses, A; 4 – temperature in zone of deformation.
3. Conclusion

1. Creation of economically efficient high-speed thyristor generators of high-power current pulses with a wide range of amplitude and pulse reproduction frequency made it possible to use such generators in study of electroplasticity effect in laboratory conditions, and to introduce installations in industry, in particular, for electrostimulated wire drawing (ESD).

2. To improve reliability and fail-proof operation of ESD process, and to optimize its modes, single-circuit drawing force automatic control system was developed, with flexible temperature feedback in deformation zone (ESDPCS), system synthesis was performed.

3. The model of the system designed was completed, analysis of stability, static and dynamic modes of operation was made.

4. ESDPCS is recommended for use in study of electrostimulated drawing processes, and for introduction into industry (i.e., for wire drawing).

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