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Automatic Control of Electrostimulated Drawing

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Abstract—A system for regulating the parameters of electrostimulated drawing (the temperature in the deformation zone and the drawing force) is considered. This system produces a control signal for the unit generating powerful current pulses. The basic operating principle is periodic discharge of a precharged capacitor to a low-resistance load. For regulation of the pulse amplitude and increase in system power, the uncontrollable dc source in the charger is replaced by two irreversible thyristor converters, which are in series and operate in the same direction. That produces a controllable voltage at the power capacitors. To optimize capacitor charging, a two-loop subordinate control system is employed: the external loop regulates the voltage, while the internal loop regulates the current that charges the capacitors. The high speed of the transient processes in electrostimulated drawing—in particular, the rapid temperature rise in the deformation zone on account of the large current pulse (up to 10 kA) and the high pulse frequency (up to 400 Hz)—means that manual control is practically impossible. To boost the reliability and quality of electrostimulated drawing using a powerful current-pulse generator, an automatic control system for electrostimulated drawing is developed. It includes a single-loop system for regulating the drawing force and also delayed temperature feedback in the deformation zone. The dependence of the drawing force and temperature on the frequency of the current pulses is established by means of laboratory research and calculations using both new and familiar methods. A model of the proposed control system in MATLAB-Simulink software permits analysis of the operating conditions in electrostimulated drawing under automated control. The model is consistent with the actual parameters obtained in research on the electroplastic effect. The proposed model permits improvement in the characteristics and operating conditions of electrostimulated drawing. The formalized structure of the system, the proposed model of the system in MATLAB-Simulink software, and the oscillograms of the transient processes are considered. The single-loop automatic control system for the drawing force, with flexible temperature feedback in the deformation zone, permits optimization of the operating conditions and improvement in the reliability of electrostimulated drawing. The proposed system is recommended for use in studying electrostimulated deformation and also for the control of wire drawing in production conditions,

Keywords: automatic control system, pulse generator, charger, thyristor converter, powerful current pulse, temperature regulation, force regulation, simulation, transient processes

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The operation of powerful current-pulse generators is based on the discharge of precharged capacitors to a low-resistance load. The appearance of such generators permits study of the physical properties of metals under the action of currents. The results may be used, in particular, for the introduction of electrostimulated pressure treatment of metals in production conditions [1–3]. In Fig. 1, we show an economical high-speed pulse generator based on thyristor converters [4]. The generator creates a unipolar current pulse of sinusoidal form; the pulse length is about 120 μs, and the amplitude is 8–10 kA.

Generator operation is based on the periodic discharge of precharged capacitors to a low-resistance load. To reduce the power drawn by the generator from a 380-V grid and to regulate the charging voltage (the pulse amplitude), the uncontrollable diode-based rectifier in the charger is replaced by two controllable thyristor converters VS1 and VS2. When using a power source based on thyristors, the generator is able to produce pulses at a maximum frequency of 300–400 Hz. Thanks to the use of thyristor converters, there is no need to use current-limiting resistor R_{pr} for the charger. That increases its efficiency and decreases the power drawn from the ac grid [5].

To regulate the amplitude of the pulse, a two-loop subordinate control system is employed: the external loop regulates the voltage, while the internal loop reg-

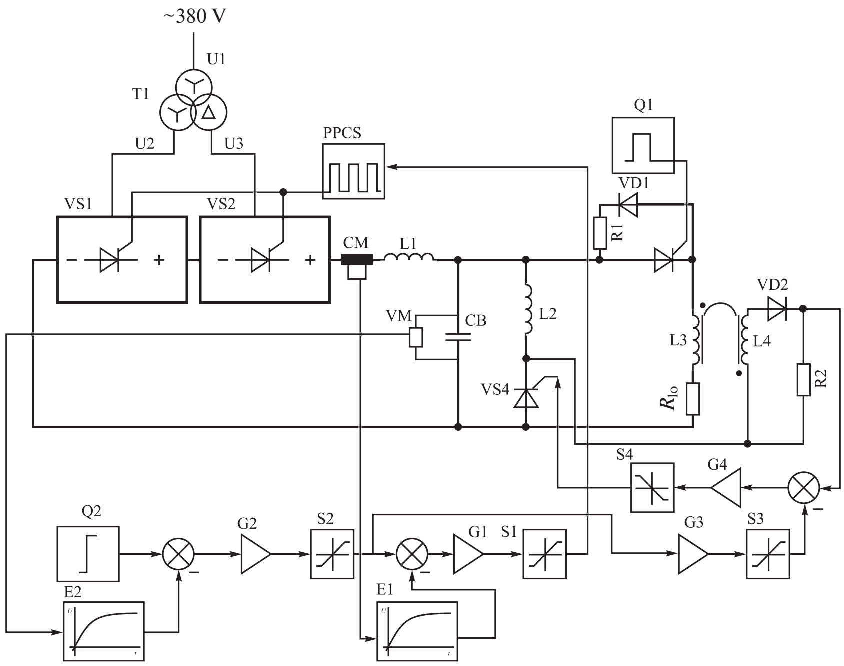

Fig. 1. Structure of generator.

ulates the current that charges the capacitors. The maximum charging current is set by a unit limiting the voltage regulator S2; the unit limiting the current regulator S1 establishes the minimum and maximum control angles of the thyristor converter [6]. Thus, the generator is characterized by two-zone power regulation of the current pulses:

(1) on account of change in the pulse frequency with stabilization of the voltage charging the capacitors;

(2) on account of change in the charging voltage by means of the thyristor converter.

The voltage specification may be set manually (from module Q1) or on the basis of the signal from the programmable controller.

The first attempts to use the electroplastic effect in pressure machining of metals proved unsuccessful, on account of the radical differences between electrostimulated and traditional drawing:

(1) the rapid rise in temperature in the deformation zone because of the considerable magnitude of the current pulse (up to 10 kA) and the pulse frequency (up to 400 Hz);

(2) the decrease in the forces when current pulses act on the billet.

Thus, the pulse frequency must correspond to the billet speed. For example, if a current pulse is supplied at the onset of billet motion, the billet temperature may be increased to 1000°C within fractions of a second. That leads to failure of the billet and the drawplate before the onset of acceleration.

The high speed of the transient processes in electrostimulated drawing means that manual control is practically impossible. Thus, we need an automatic high speed control system for the drawing parameters [7].

In Fig. 2, we show an automatic control system for electrostimulated drawing. Specifically, it controls the temperature in the deformation zone and the drawing force. The system includes a single-loop system for regulating the drawing force, which is based on a force regulator RU with a constraint. The output signal from this regulator is sent to module SFI, which forms the control pulses.

The control pulses formed in module SFI, whose frequency is directly proportional to the output signal of module RU, is sent to the input of the generator of powerful current pulses in Fig. 1. The limiting module at the RU output forms the maximum and minimum pulse frequency. The two dynamic components Isr and dF simulate the decrease in the drawing force under the action of the powerful current pulses on account of the electroplastic effect. The model is obtained on the basis of laboratory research and calculations using original methods to measure the current, force, and temperature in the deformation zone [8–12]. The feedback with respect to the drawing force is based on module DF.

The force-specification module S2 forms a signal proportional to the force obtained experimentally in electroplastic drawing of wire of specific type and cross section at specific speed.

One aspect of the electroplastic effect is the low temperature in the deformation zone—usually no

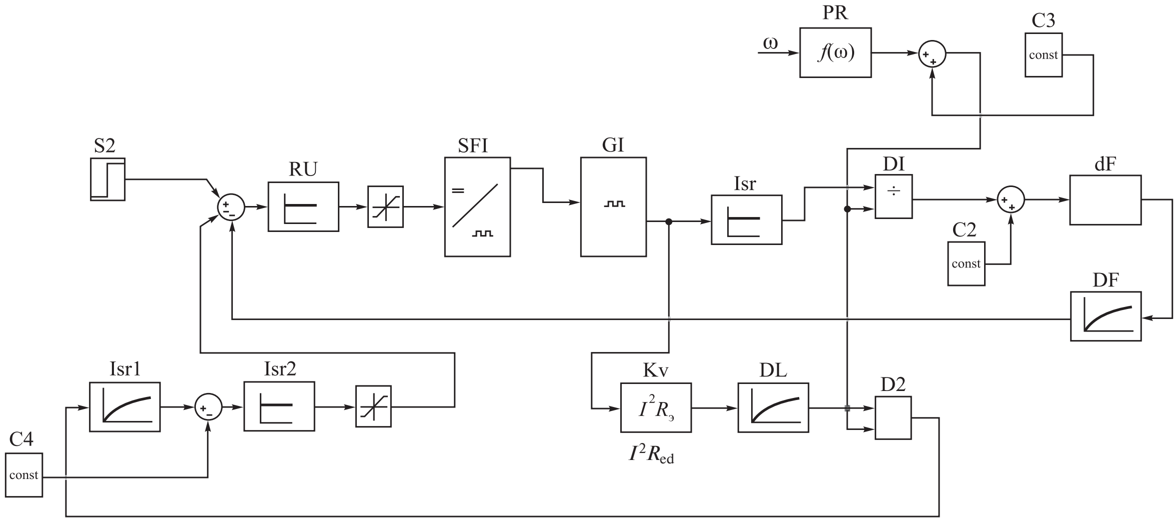

Fig. 2. Structure of the automatic control system for electrostimulated drawing.

more than 250–300°C. Increase in temperature most often changes the properties of the machined material, as in plastic deformation with heating. The change in plasticity of the metal is governed by another physical law. Thus, in electrostimulated drawing, the temperature in the deformation zone must be monitored, so as to prevent its increase. To that end, the system includes delayed temperature feedback in the deformation zone. The temperature τ° in the deformation zone is determined from the equation

$$P_{el}t = Cm\tau^\circ - P_{ra} - P_c - P_{co},$$

where $P_{el} = I_{ms}^2 R_{eq}$ is the power applied to the machined billet; I_{ms}^2 is the mean square current passing through the billet under the action of pulses of variable frequency with constant amplitude 8–10 kA; R_{eq} is the equivalent active impedance of the wire being drawn, taking account of the skin effect; °C is a constant; m is the mass of the wire (between the contacts); t is the time; P_{ra}, P_c, and P_{co} are the radiant, convective, and conductive power losses, respectively [13].

Module Kv forms a signal proportional to the power P_{el}, while module DL forms the temperature τ° in the deformation zone. The module DL corresponds to the inertial component in the temperature variation with change in motor speed when the specified actions and perturbations are applied. The temperature setting determines the cutoff and is specified in module C4. The delayed feedback regarding temperature τ° permits maintenance of the specified temperature in the deformation zone by changing the frequency of the current pulses from the generator.

We know that, in wire motion, the effectiveness of the electroplastic effect and the temperature in the deformation zone will be decreased on account of decrease in the time for which the deformed section of wire is exposed to the current. To take account of this, the conversion module PR and division modules D1 and D2 are introduced in the system. To simplify the automatic control system, the dependence of the force and temperature on the frequency of the current pulses in wire motion is linearized.

A model of the automatic control system for electrostimulated drawing is formulated in MATLAB-Simulink software so as to permit analysis of the operating conditions in electrostimulated drawing and improvement in the control system (Fig. 3).

Models of the following components are employed:

—a dc drive with a subordinate-control system for the basis drive parameters (speed, acceleration, and maximum torque), consisting of modules Synch6-PG, Th-Ph Trans, VM5–VM7, Uni-Br, K, Int, RS, RT, PY, DS, and DT;

—a generator of powerful current pulses, with a system forming control pulses, consisting of modules SF1 and G1 (Fig. 1);

—the automatic control system for electrostimulated drawing, consisting of modules RU, Isr, Isr1, Isr2, D1, D2, dF, DF, and PR.

The transient processes in electrostimulated drawing are recorded on the oscillograph Scope 1.

In Fig. 4, we show the parameter variation in the automatic control system during drive acceleration. The pulses grow as a function of the drive speed, with no impermissible increase in the drawing force or impermissible temperature in the deformation zone.

In Fig. 5, we show the response of the automatic control system for electrostimulated drawing with perturbation of the drive (for example, decrease in the grid voltage), leading to decrease in the motor speed.

With uncontrolled decrease in the motor speed, the temperature will increase before the cutoff acts. The

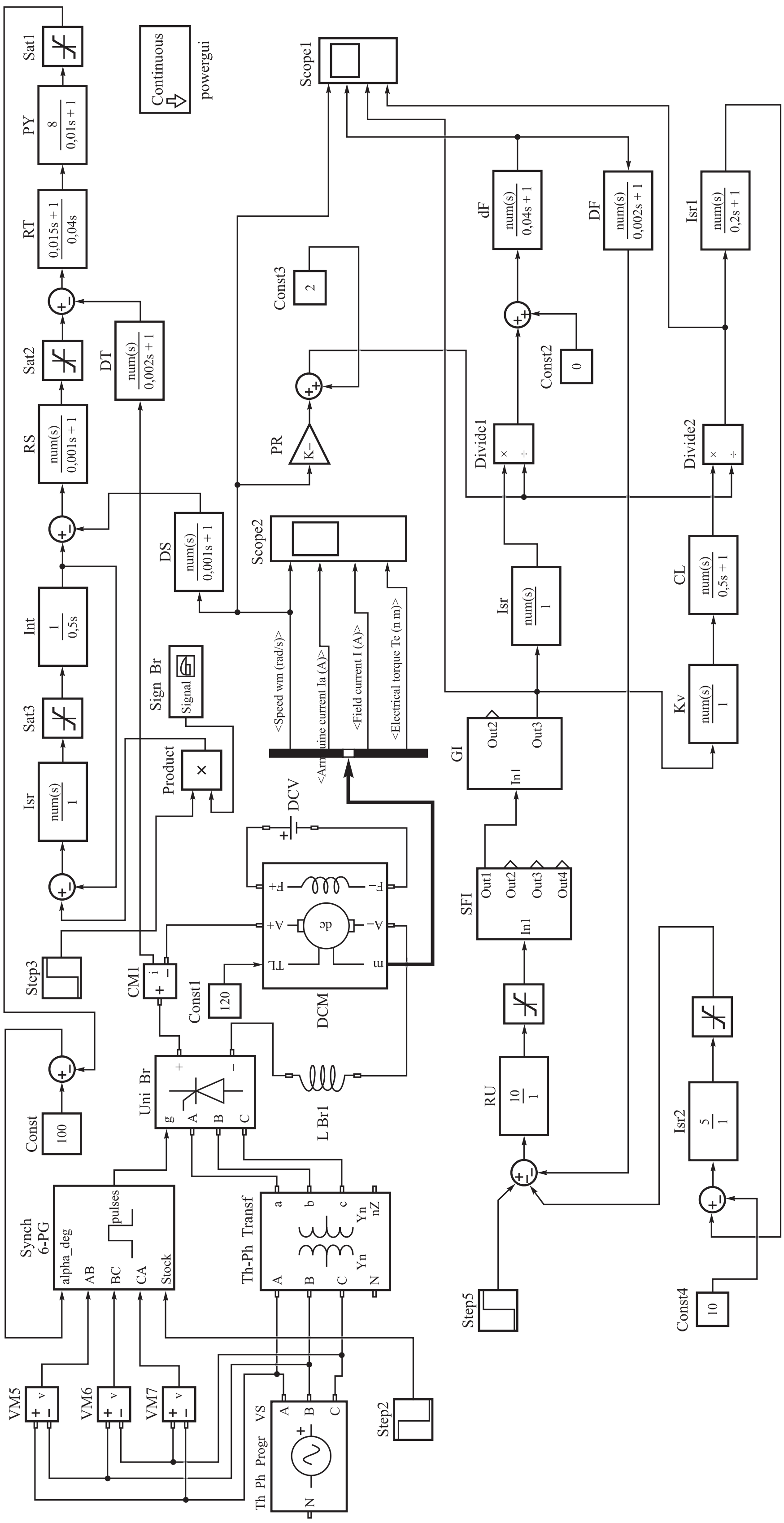

Fig. 3. Model of the automatic control system for electrostimulated drawing.

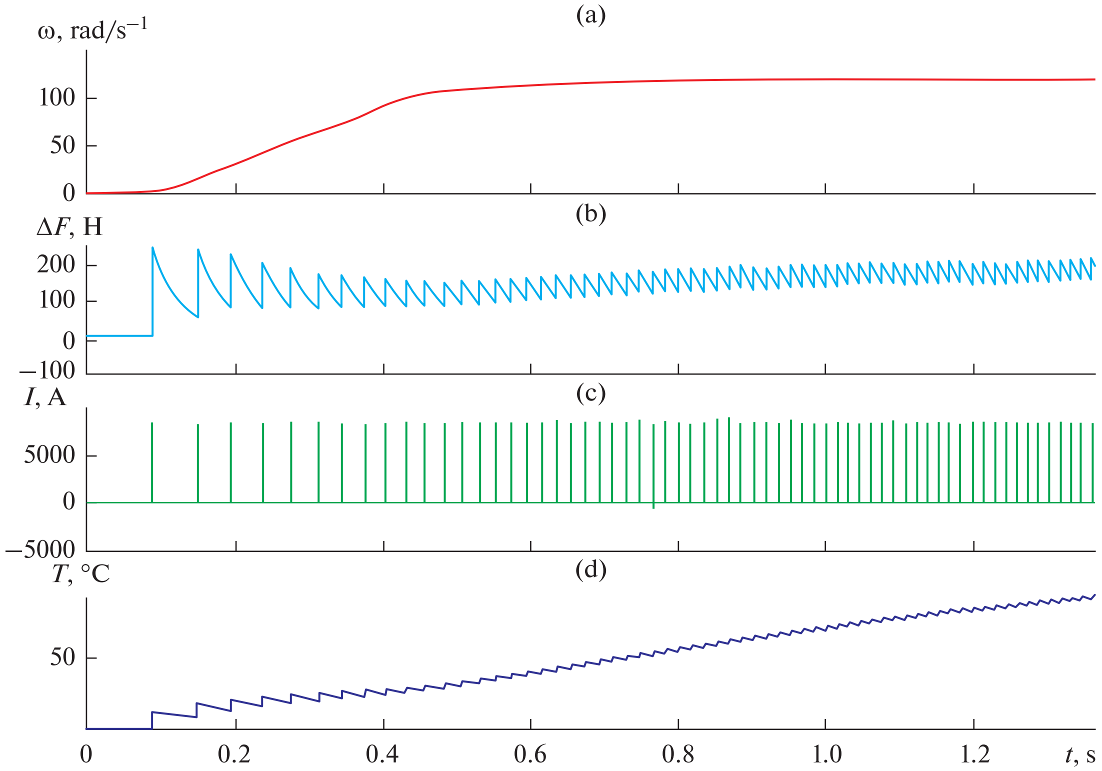

Fig. 4. Transient processes in an automatic control system for electrostimulated drawing during motor acceleration: (a) speed of electric motor, rad/s; (b) decrease in the drawing force ΔF (electroplastic effect) relative to normal drawing, N; (c) amplitude of current pulse, A; (d) temperature in the deformation zone, °C.

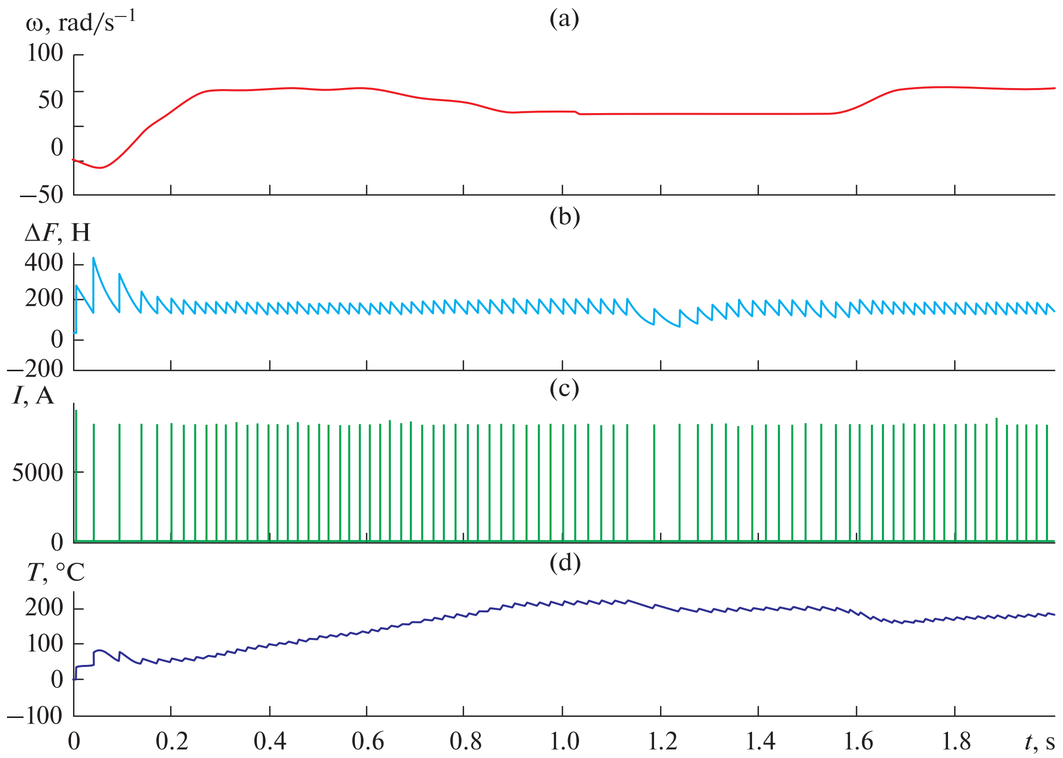

Fig. 5. Response of the automatic control system for electrostimulated drawing to perturbation: (a) speed of electric motor, rad/s; (b) decrease in the drawing force ΔF, N; (c) amplitude of current pulse, A; (d) temperature in the deformation zone, °C.

temperature stabilizes at the specified (maximum) level, with slight decrease in the drawing force. When the required speed has been reestablished, optimal electrostimulated drawing is restored.

CONCLUSIONS

Now that economical high-speed thyristor generators of powerful current pulses (with broad variation in the amplitude and frequency of the pulses) are available, they may be used in laboratory research on the electroplastic effect and also in production—in particular, in the electrostimulated drawing of wire.

To boost the reliability of electrostimulated drawing using a powerful current-pulse generator and optimize the process, an automatic control system for electrostimulated drawing is developed, with a single-loop system for regulating the drawing force and flexible feedback regarding the temperature in the deformation zone.

A model of the proposed control system in MATLAB-Simulink software permits analysis of the stability and the static and dynamic operating conditions in electrostimulated drawing under automated control.

The proposed single-loop automatic control system for electrostimulated drawing is recommended for use in studying electrostimulated deformation and also for use in production conditions,

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