GENERAL PRINCIPLES FOR SELECTING THE COMPONENTS OF THE AUTOMATIC SYSTEMS USED IN ELECTRICAL EROSION PROCESSING EQUIPMENT

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Abstract: The continuity and stability of the erosive process in complex electrical erosion processing is heavily influenced by the automated advance system. The paper performs a complete analysis of the elements which make the automated advanced system, and of the connections between them, with the goal of selecting the optimum construction solution. The paper also contains the transfer functions and the components' selection modes.

Keywords: Complex electrical erosion, automated advance system, transfer functions, optimisation, converter, electronic controller, actuator, mechanical transmission.

1. INTRODUCTION

The automatic advance system ensures continuity and stability for the erosion process. The parameter being adjusted is the electrical state of the working area, statically characterized by the relative position of the processed and transfer objects and by the variation speed of the working area position. The adjustment loop is described in the fig.1. and has the following blocks [1]:

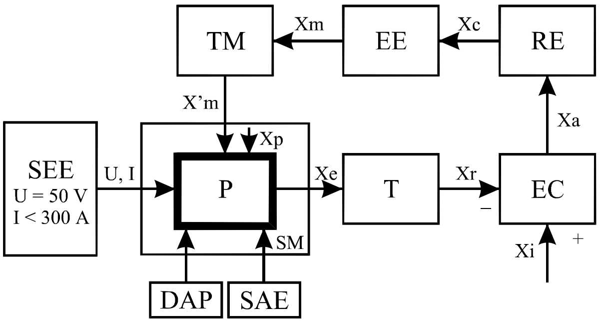

Fig.1. The system flow chart

2. POWER SUPPLY

It consists of an electrical rectifier which ensures the following electrical processing parameters: the voltage U = 50 V and the amperage I ≤ 300 A. Selecting them depends on the nature of the electrode material, on the size of the temporary contact area and on the quality of the surface to be obtained.

3. PROCESSING PROCESS

Processing takes place by means of the combined technological actions of electrical-chemical erosion and electrical erosion. The electrical-chemical action happens as a result of electrolysis and has a reduced effect in the whole processing.

Electrical erosion has the biggest effect which consists of achieving elementary momentary electrical contacts followed by their dynamical interruption as a result of the pressure between the transfer object and the processed object and of the relative shift of the two. Through experiments, the optimal peripheral speed has been set to 20 m/s.

The erosion process takes place under special dynamical conditions, resulting in resistive forces and moments which randomly stress both the power actuator and the elastic technological system. The resulting perturbations can produce:

- perturbation effects generated by parameters which are hard to control, such as inertia forces, the play from the cinematic couples and the rigidity of the elastic technological system;
- uncontrollable perturbation effects resulting from vibrations, varying masses, thermal stress, friction or amortisation originating in various sources.

The productivity of the processing depends both on the correct selection of the components of the automatic adjustment system and on the speed at which information is processed.

The mathematical model of the erosive process can only be obtained experimentally, based on the dependency between the erosion speed *v* and the working voltage *U*, analysed on the optimal processing interval U = 18..24 V, where it has a linear evolution (fig.2.). The slope of the graphic is calculated with the expression:

$$tg\alpha = \frac{dv}{dU} = \frac{v_2 - v_1}{U_2 - U_1} \qquad (1)$$

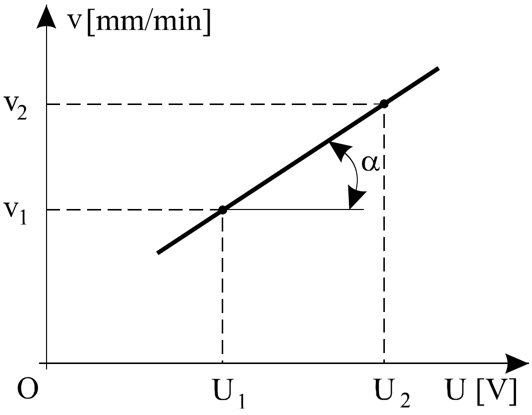

Fig.2. The process characteristic

which gives:

$$dv = \frac{v_2 - v_1}{U_2 - U_1} \cdot dU \qquad (2)$$

which, multiplied with *dt* becomes:

$$dv \cdot dt = \frac{v_2 - v_1}{U_2 - U_1} \cdot dU \cdot dt \qquad (3)$$

and in the operational domain:

$$v(s) \cdot s = K_P \cdot U(s) \cdot s \qquad (4)$$

whose transfer function is:

$$Y_p(s) = \frac{v(s)}{U(s)} = \frac{1}{K_P} \qquad (5)$$

4. SELECTION OF THE CONVERTER (T)

These equipments continuously monitor the electrical state of the processing area by means of the processing voltage $U_e = X_e$, which they change to the shape and amplitude used in the system.

The converters need to have the following performance:

- The measurement domain needs to correspond to the size of the monitored signal.
- The quieting sensitivity needs to be correlated with the working amperage minimum variation level.
- The degree of accuracy (the intrinsic tolerated error), for the stable functioning mode, needs to correspond to the proposed goal (obtaining results as close as possible to the real values of the measured parameter).
- The noise level of the translator needs to be as low as possible, so that it doesn't influence the quality of the measured parameter.
- Fast dynamics (the measured signal is not constant in time).
- Compatible with the structure of the automation equipment.

The parameters used for describing the processing process are:

- the voltage of the product;
- the working amperage;
- the current density.

The most used adjustment parameter is the voltage of the product, and the most frequently used converter is an integrating voltage divider, presented in fig.3.

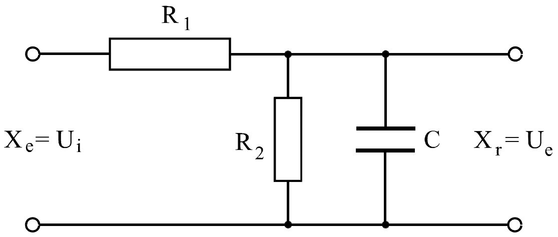

Fig.3. Integrating voltage divider

The resistance divider (R_1, R_2) creates the necessary division for reducing the amplitude, while the capacitator (C) filters out a part of the noise and pulsation coming from the control system.

The transfer function of the converter is:

$$Y_T(s) = \frac{U_e(s)}{U_i(s)} = \frac{K_T}{1 + T_T \cdot s} \qquad (6)$$

5. SELECTING THE ELECTRONIC CONTROLLER (RE)

The automatic controller is an active component, meant to supervise and run the process towards a permanent mode (stationary), which is sometimes compromised by certain perturbation factors, in which case the controller acts to reinstate the permanent mode.

A careful analysis of the installation and the product needs to be run for the selection of the controller, going through the following phases:

- analysis of the processing process to gather the dynamical properties of the adjusted object, the perturbation system and the cinematic and precision requirements;
- evaluation of the possibility to continuously monitor the adjusted parameter and the possible variation of the controller's action for the defined interval;
- selection of the controller in such a way that it ensures the required quality for the adjustment and that it can be integrated in the context of the adjustment loop (the higher the required quality of the adjustment, the more complex the controller).

To ensure the stationary mode, within acceptable limits, we need to know the allowable stationary tolerance and, if auto oscillations are accepted, it becomes necessary to specify their maximum amplitude and their period. If oscillations are not allowed, the tolerance gets accepted and no special requirements are issued for the duration of the transitory processes and of the adjustment tolerance. Thus, for a linear automatic system, described by a 1st or 2nd order equation it is recommended to use a proportional controller which ensures the proportionality between the change in the process and the size of the error.

The proportional controller is described by the equation:

$$U_i(t) = K_R \cdot U_e(t) \qquad (7)$$

and has the transfer function:

$$Y_{RE}(s) = \frac{U_e(s)}{U_i(s)} = K_R \qquad (8)$$

where K_R is the amplification factor (proportionality factor) of the controller having the diagram presented in fig.4. and its answer (fig. 5.) to a step unit input $U_i(t)=1$, presented in fig.6.

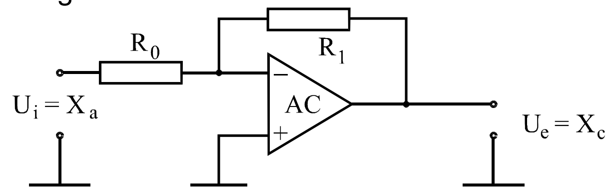

Fig. 4. Proportional controller

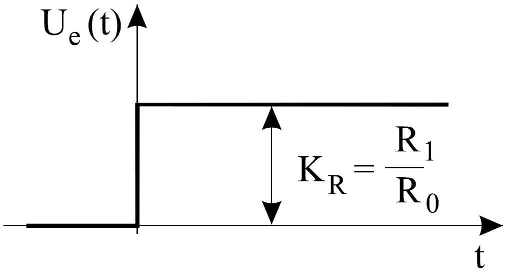

Fig. 5. The controller's answer

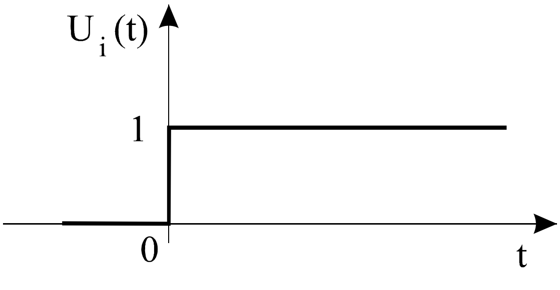

Fig.6. Step unit signal

6. SELECTING THE EXECUTING ELEMENT (EE)

The automatic advance control requires the usage of special execution elements which have to ensure [2, 3]:

- correlation of their own parameters with the ones needed in the

adjustment body to achieve the predefined mechanical and cinematic parameters;
- the linearity domain needs to be as extended as possible and the sensitivity needs to be high;
- good functional accuracy and safety;
- high reaction speed;
- the possibility to adjust the speed in wide limits;
- stable functioning in both moving directions;
- robust construction and high efficiency;
- stable functioning at very low speed;
- low time constants.

Actuator types:

6.1. ELECTRICAL ACTUATORS

They are electrical machines especially developed for servo systems. Their construction specific characteristics are: smaller sizes, low inertia moments and wide speed variation range in both directions.

In most electrical engines, the formula to calculate the dynamic load torque M_d which appears due to the inertia in transitory state ($d\omega/dt \neq 0$) is:

$$M_d = J_{rt} \cdot \frac{d\omega}{dt} = M_{mt} - M_{rr} \quad (9)$$

Where the total inertia momentum J_{rt} of the involved masses is the result of the division between the total gyration momentum $(GD^2)_r$ and the engine shaft:

$$J_{rt} = \frac{(GD^2)_r}{4 \cdot g} \quad (10)$$

The gyration momentum is the result of the following expression:

$$(GD^2)_r = G_m \cdot D_m^2 + \frac{G_1 \cdot D_1^2}{i_1^2} + \ldots + \frac{G_n \cdot D_n^2}{i_n^2} \quad (11)$$

Where $i_i = n_m/n_i$ is the partial transmission rapport between the engine and the mechanical transmission axle i. As for most cases the situation of $i_1 < i_2 < \ldots < i_n$ exists, we can notice that, as the axle gets farther away from the engine, the partial gyration momentum drops. For this reason, for low precision calculus, determining $(GD^2)_r$ can be done fast, depending on the gyration momentum of the engine and a correction parameter, K = 1.1...1.25:

$$(GD^2)_r = K \cdot G_m \cdot D_m^2 \quad (12)$$

For the total gyration momentum, reduced at the engine axle for a system of elements engaged in a rotation and translation movement, the calculus is:

$$(GD^2)_r = G_m \cdot D_m^2 + (GD^2)_{rrot} + (GD^2)_{rtr} \quad (13)$$

Where the gyration momentum, reduced for the translation can be specified with the help of the weight (G_{tr}) and the speed (v_{tr}) of the translated object and with the help of the angular speed of the engine (ω_m):

$$(GD^2)_{rtr} = 375 \cdot G_{tr} \cdot \left(\frac{v_{tr}}{\omega_m^2} \right) \quad (14)$$

For calculating the total motor torque, dynamical state, the following expression is being used:

$$M_{mt} = M_{rr} + M_d \quad (15)$$

Where the load torque reduced to the engine axle is:

$$M_{rr} = M_m + \sum_{i=1}^{n} \frac{M_{ri}}{i_i^2 \cdot \eta_i} \quad (16)$$

Determined in relation to the actual motor torque M_m, the load torque which acts on axle i (M_{ri}), the transmission rapport between the engine and the axle i and the yield of the considered cinematic chain (η_i).

Because the total motor torque, reduced to the engine axle, cannot be exactly calculated, it can be approximated by the expression:

$$M_{mt} = K_m \cdot M_{rr} \quad (17)$$

Where K_m = 1.5...3.0 represents a safety coefficient.

Based on the results of the calculus, an electrical engine will be selected from the catalogue, having the total torque:

$$M_{mt.cat} \geq M_{mt.calc} = M_{rr} + M_d \quad (18)$$

Types of electrical actuators

a) Continuous current actuators

Continuous current actuators can have several constructive versions. They can be engines with a cylindrical rotor and a radial air-gap, engines with a disc rotor and an axial air-gap or cylindrical rotor and permanent magnets. The first option has a low inertia, acceptable acceleration time, but it requires to be connected to the process through a mechanical transmission.

The last two options do not require the intermediary mechanical transmission, having the possibility to be directly connected to the exit mechanism (the bolt-nut mechanism), allowing therefore the usage of a rotating movement decoder for directly measuring the movement. The very low time constants are obtained for the electrical engines with the disc rotor. The maximum response speed is obtained on the powering of induction engines with commanded rectifiers.

The transfer function of engines is of the type:

$$Y_M(s) = \frac{n_M(s)}{U_M(s)} = \frac{1/K}{1 + T_m \cdot s + T_e \cdot T_m \cdot s^2} \quad (19)$$

Where K = k·Φ is the constant of the machine with separate excitation or derivation; T_e is the electromagnetic time constant; T_m » T_e mechanical time constant.

b) Non-synchronous actuators

These can be either biphasic or triphasic, where adjustment of the speed is done by adjusting the powering tension with static converters.

c) Synchronous actuators (step by step engines)

They are engines with permanent magnets, with various constructions, depending on the required precision, the preset dynamics (amortisement, response time) and on their own characteristics (number of turns and the powering method for them).

Step by step engines can be either active (they are rarely used, having large steps – mainly for actuating at high rotation speed) or reactive (mostly used, having small steps). Both types can have multiple phases or multiple states.

The selection of these engines is done by comparing the load parameters (the reduced load torque M_{rr}, the reduced inertia momentum J_r and starting frequency f_p) to the limit dynamic characteristics from the catalogues. The selected engine will have the dynamical starting characteristic situated over the working point of the engine P(f_p, M_{rr}).

The transfer function of the engine is:

$$Y_{MPP}(s) = \frac{\theta(s)}{i(s)} = \frac{K}{K_E + f \cdot s + J_r \cdot s^2} \quad (19)$$

Where: J_r – the inertia momentum reduced to the engine axle; f – the global viscous rolling friction coefficient; K_E – the equivalent elasticity of torsion introduced by the engine torque and the mechanical component; K – the electromechanical constant of the engine.

6.2. HYDRAULIC ACTUATORS

The hydraulic actuators are electro-hydraulic systems, made from a linear or rotating hydro-engine (MH) and an electro-hydraulic servo-valve, with the purpose of making a hydraulic parameter (either the flow or pressure) proportional with a representative electrical parameter of the product. The basic diagram of the actuator is the one from fig.7. Here, i gets transformed, with the help of an electrical torque engine MC, into a linear movement x of the distributor drawer x, therefore ensuring the exit flow Q, proportional with the current i.

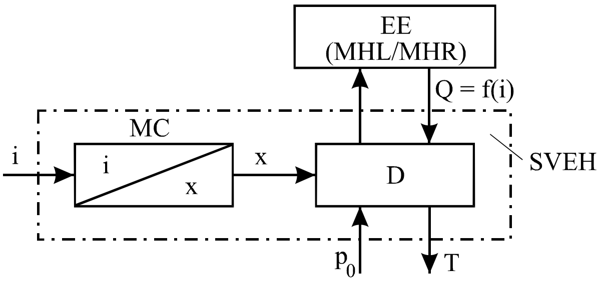

Fig. 7. The actuator basic diagram

The selection of the actuator is done by comparing the preset parameters with the ones presented in catalogues. These have to ensure, for the variation interval of the initial parameter i, [i_{min}, i_{max}], the required flow limits [Q_{min}, Q_{max}], under the condition of respecting the required dynamic performance.

The transfer function of the actuator is:

$$Y_{SV}(s) = \frac{Q(s)}{i(s)} = \frac{K_{SV}}{1 + T_{SV} \cdot s} \qquad (20)$$

And the one of the hydraulic engine:

$$Y_{MH}(s) = \frac{v(s)}{Q(s)} = \frac{K_{MH}}{1 + T_{MH} \cdot s} \qquad (21)$$

Where: T_{SV} and T_{MH} are the time constants of the two elements; K_{SV} and K_{MH} are constants of the components.

The general movement equation of the load is:

- For linear hydraulic engines:

$$m_t \cdot \frac{d^2x}{dt^2} + B_m(x) \cdot \frac{dx}{dt} + K_m(x) \cdot x = F_m - F_{rr} \qquad (22)$$

- For rotating hydraulic engines:

$$J_m \cdot \frac{d^2\theta}{dt^2} + B_{rot}(\theta) \cdot \frac{d\theta}{dt} + K_{rot}(\theta) \cdot \theta = M_m - M_{rr} \qquad (23)$$

Where F_m is the active force developed by the engine; F_{rr} is the resistive force reduced to the engine axle; m_t is the total weight reduced to the engine axle, which is calculated with the expression:

$$m_t = m_{piston} + m_{rod} + m_{load} \qquad (24)$$

J_m is the total inertia reduced to the engine axle, which is determined through the expression:

$$J_m = J_{rotor} + \frac{1}{i^2} \cdot J_{load} \qquad (25)$$

M_m is the active momentum developed by the engine; M_{rr} is the resistive momentum produced by the load, reduced to the engine axle; i is the transmission ratio of the cinematic chain; B_m, B_{rot} are the viscous friction factors; x, θ are the linear and angular movements; K_m, K_{rot} are the general elasticity factors (coils, membranes etc.).

7. MECHANICAL TRANSMISSION (TM)

The connection between the execution element and the process is made through a mechanical transmission, established based on the following elements:

a) The load movement type (translation, rotation or no movement). The connection between the execution element (F_m, M_m) and the mechanical assembly, related to the output of the action element:

- For the translation movement:

$$m \cdot \frac{d^2x}{dt^2} + D \cdot \frac{dx}{dt} + F_r = F_m \qquad (26)$$

- For the rotation movement:

$$J \cdot \frac{d^2\theta}{dt^2} + B \cdot \frac{d\theta}{dt} + M_r = M_m \qquad (27)$$

Where: m, J are the equivalent weight and inertia momentum; D, B are the viscous friction coefficients; F_r, M_r are the static resistive force and momentum; x, θ are the linear and angular movements.

The most used mechanical transmission consists of a belt transmission and a bolt and nut mechanism.

b) Comparing the static mechanical characteristics of the engine and the load, the basis for the optimisation of the transmission power. If an engine has a linear characteristic (C_{lm}), then the maximum useful power is expressed by the coordinates of the operating point

$$P\left(\omega_1 = \frac{\omega_0}{2}, P_{max} = M_1 \cdot \omega_1\right) \qquad (28)$$

If the load uses the maximum power at a different speed ω_2, a mechanical transmission becomes necessary to obtain the transmission ratio of $i = \omega_1 / \omega_2$.

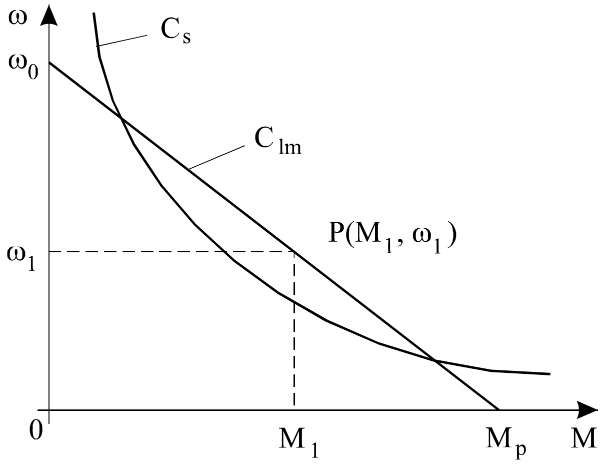

Fig.8. Mechanical characteristics

The selection of the transmission ratio is done by using the $ω_2$ speed from the hashed area which results from overlapping the two characteristics. Outside of this area, the transmission ratio is not efficient regarding the optimum power.

If the two characteristics do not overlap, a higher power actuator is needed, and if the hashed area is too big, the selected actuator is used at a lower power, ensuring a bigger power reserve in this way.

c) Using an optimal dynamic regime for the selection of the transmission ratio. The considered factors here are the influence of the transmission ratio i on the heat created by the engine and minimizing the heat loss during its start. Based on the minimum dissipated power, we set the condition $i = i_{dynamic}$. Practically, the two ratios are different, bringing them close to each other's value is done by adjusting the parameters of the transmission output. If $Δ = i - i_{dynamic}$ is not too big, the value i resulted from the previous paragraphs (a,b) can be used, as the power losses do not have a significant increase.

The essential factor in selecting a mechanism for transforming the rotation movement into a translation one is the result of multiplying the moved weight m and the working cruise l, in relation to which the following usage intervals are defined:

- The piston-cylinder mechanism - m·l = 0,05...0.5 [tm]
- The pinion-rack mechanism - m·l = 3...16 [tm]
- The bolt and nut mechanism - m·l = 0,2...14 [tm]

Improving the mechanical transmission precision can be done by:

- Eliminating the mechanical play between the relative move elements, by pre-tensioning them;
- Stiffening the mechanical structures to prevent vibrations;
- Reducing friction by using bearings, guides and mechanisms which have a reduced friction between their elements and adequated lubrication possibilities;
- Protecting the actuators from external perturbation (thermo-insulation, amortised foundations etc.)

8. CONCLUSIONS

The paper analyses the systems with automatic leading of the advance, as well as the elements which are part of their structure. The functioning principle, the possible component types, their advantages and disadvantages are presented, by pointing out, in most cases, the most used components in this field.

The main ideas revolve around the functioning principles, specific parameters, calculation specifics, movement equations, transfer functions and component selection methods.

The paper also contains a complete analysis of the components and of the specific links between them, in order to know them well for the selection of an optimum system version.

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