AUTOMATIC CONTROL DRIVE OF ELECTRODE MOVEMENT TRAJECTORY FOR THE ARC SURFACING MACHINES

S.V. GULAKOV and **V.V. BURLAKA**
Priazovsky State Technical University, Mariupol, Ukraine

Suggested is the design of the electrode movement mechanism for deposition of complex-configuration beads on working surfaces of machine parts and tools by using the automatic electron control system. The device is a modification of the connecting rod gear, in which the connecting rod is made with a possibility of automatic adjustment of its length.

Keywords: *electric arc surfacing, drive of electrode oscillation, connecting rod gear, automatic control system*

Control of a bead trajectory is necessary for providing quality formation of a deposited working layer with complex trajectory on a repairable part. In particular, a quick change of a movement trajectory, for example, in the apexes of zigzags (Figure 1), accompanied by possible distortion of a weld pool shape during change of electrode movement direction is to be taken into account [1].

The aim of the present work is to develop and investigate a simple and reliable device for electrode oscillation, allowing formation of the necessary trajectory of its movement.

A connecting rod gear (CRG) was used as a principle device for electrode oscillation. It provides the trajectory of movement of driven element close to sine. Change of the forming trajectory in it can be performed by means of control of a drive motor or change of geometric parameters of the CRG elements.

Formation of movement trajectory through control of the drive motor requires its frequent reverses and significant accelerations that results in overheating and reduction of system reliability.

Figure 1. Surface of the roll with deposited zigzag-shape beads

The work proposes a drive based on the CRG in which the connecting rod is made with a possibility of program adjustment of its length in the process of mechanism operation [2] (Figure 2). At that, minimum and maximum length of the connecting rod determine the boundaries for resulting «corridor» of allowable positions of the driven element (Figure 3, curves L_{max}, L_{min}). The linear parameters of the connecting rod are changed with the help of additional drive, mounted on it. Thus, it is possible to form a deposited bead of any shape in the ranges of «corridor» of allowable positions, for example, rectangular (Figure 3, curve *1*) or trapezoid (Figure 3, curve *2*) ones.

It follows from Figure 2 that a coordinate $y(\varphi)$ of electrode holder for geometry reasons is determined as

$$y(\varphi_{CRG}) = R \sin \varphi_{CRG} + \sqrt{L(\varphi_{CRG})^2 - (R \cos \varphi_{CRG})^2}, \quad (1)$$

where R is the crank length, m; φ_{CRG} is the angle of rotation of the CRG, degree; $L(\varphi_{CRG})$ is the connecting rod length, m.

It can be seen from expression (1) that control of the connecting rod length L during the oscillation period (complete crank revolution) can significantly influence on a principle of electrode holder movement.

Automatic control system (ACS) provides a change of the connecting rod length $L = f(\varphi)$ (see Figure 2) in such a way that the trajectory of electrode movement $y(\varphi)$ meets the set one.

Thus, the function $y(\varphi)$ can have the following form for obtaining the electrode movement trajectory:

$$y(\varphi) = Y_0 + \frac{H}{2}\frac{2}{\pi} \arcsin (\sin (\varphi_{CRG})), \quad (2)$$

where Y_0 is the displacement, m; H is the oscillation range, m.

Coefficient $2/\pi$ before the arcsine function is a standard. It is convenient to select displacement Y_0 equal

$$Y_0 = \frac{\sqrt{L_{min}^2 - R^2} + \sqrt{L_{max}^2 - R^2}}{2}, \quad (3)$$

that provides centering in the «corridor» of allowable positions.

Thus, for realizing of the rectangular trajectory of electrode movement the length of connecting rod of the CRG should be changed in such a way that an equation is fulfilled

$$R \sin \varphi_{CRG} + \sqrt{L(\varphi_{CRG})^2 - (R \cos \varphi_{CRG})^2} = Y_0 + \frac{H}{2}\frac{2}{\pi} \arcsin (\sin \varphi_{CRG}). \quad (4)$$

Solution of equitation (4) is the following:

$$L(\varphi_{CRG}) = \sqrt{\left[Y_0 + \frac{H}{2}\frac{2}{\pi} \arcsin (\sin \varphi_{CRG}) - R \sin \varphi_{CRG}\right]^2 + (R \cos \varphi_{CRG})^2}. \quad (5)$$

The trapezoid trajectory can be obtained through modification of the rectangular oscillation in the following way:

$$y(\varphi) = Y_0 + \frac{H}{\pi} \arcsin \times \left(\sin \begin{cases} \frac{\pi}{2} - \gamma, \text{ if } \varphi \in \left[\frac{\pi}{2} - \gamma; \frac{\pi}{2} + \gamma\right], \\ \frac{3\pi}{2} - \gamma, \text{ if } \varphi \in \left[\frac{3\pi}{2} - \gamma; \frac{3\pi}{2} + \gamma\right], \\ \varphi, \text{ if } \varphi \in \left(0; \frac{\pi}{2} - \gamma\right) \cup \\ \cup \left(\frac{\pi}{2} + \gamma; \frac{3\pi}{2} - \gamma\right) \cup \left(\frac{3\pi}{2} + \gamma; 2\pi\right), \end{cases} \right) \quad (6)$$

where γ is the half angular width of trapezium vertex.

At that, a range of trapezoid oscillation H' and parameter γ are in the ratio

$$H' = H\left(1 - \frac{2\gamma}{\pi}\right). \quad (7)$$

The ACS with proposed compound drive of the electrode movement should provide reliable operation, error-free continuation of operation after disconnection and further renewal of power supply, and good quality parameters, such as time of adjustment and re-adjustment.

The compound drive of electrode movement as a control object, including the CRG with variable length of connecting rod and direct current motor controlling this length, is sufficiently complex linear system with internal feedbacks.

Armature voltage is a parameter of control object using which the latter can be influenced from the ACS side. It should change in such a way that the coordinate of electrode holder X_{out} is changed on specified principle. At that it is necessary to provide a current of the armature at a secure level due to frequent reverses and accelerations of motor of the additional drive. The system should also be stable to self-excitation.

Implementation of the ACS in a form of classic single-loop adjuster with total negative feedback on electrode position results in unsatisfactory parameters of adjustment quality since the control object is an inertial element of the second row that complicates stabilizing of a closed system.

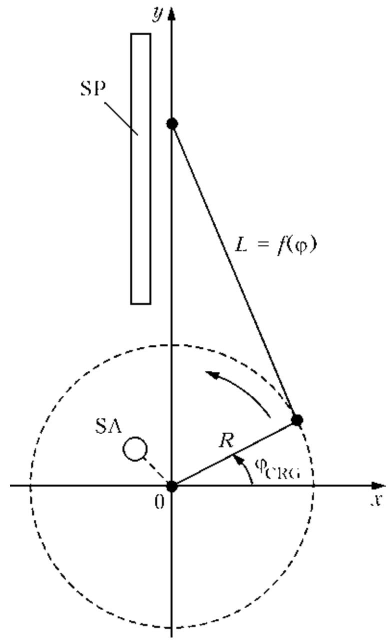

Figure 2. Kinematic scheme of the drive: SA — sensor of crank rotation angle; SP — sensor of electrode position

Improvement of adjustment parameters in the single-circuit scheme of automatic control is seemed to be impossible due to absence of information about operation of internal feedbacks in the control object.

The whole control system was divided into the embedded loops in order to have the possibility of their series adjustment and optimization for simplifying synthesis of the ACS and providing better adjustment characteristics. At that, separate adjustment loops provide «uncoupling» of internal feedbacks in the control object that gives the possibility of maximum reduction of adjustment time, preserving at the same time physical limitations on voltage and current of the motor armature.

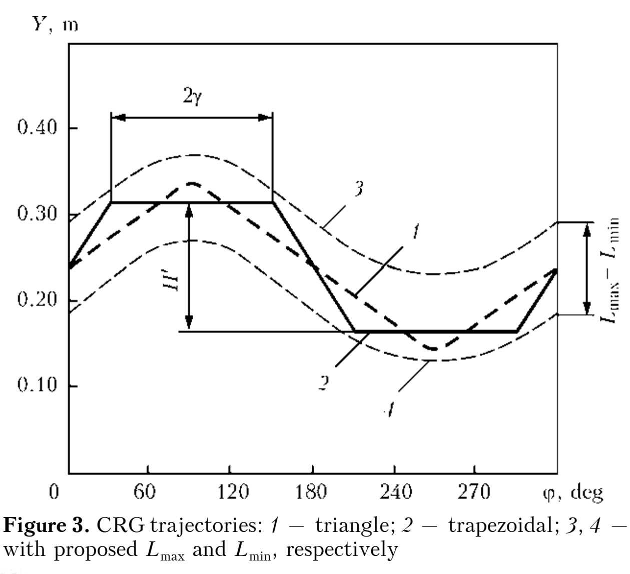

Figure 3. CRG trajectories: *1* — triangle; *2* — trapezoidal; *3*, *4* — with proposed L_{max} and L_{min}, respectively

The control system has three adjustment loops: adjuster of current of armature, rate and position. The task of each adjuster in structural scheme of control system for electrode oscillation mechanism is maximum quick and accurate processing of corresponding task. At that, formation of the negative feedbacks is possible.

Pulse hysteresis adjuster provides a formation of current of motor armature of the additional drive that predetermines a high reaction rate of the system and small loss of power in the adjuster.

The ACS was realized in practice on the ATMEL single-chip microcontroller ATMegal 168-20. Combining of the most of adjustment functions in one chip allows obtaining a system with a possibility of flexible setting of virtually all adjuster parameters. Besides, application of a mircomodulator allows easily providing diagnostics of the drive operation in real time and detecting its faulty operations at minimum time.

The main drive motor is a DC motor with independent excitation by 230 W power, nominal armature voltage 110 V, 2.9 A current and 2400 rpm nominal revolution rate.

Motor with excitation from constant magnets of DP-40-40 type was selected for the additional drive. It can be explained by simple control (adjustment of a rate of shaft revolution is carried out only through change of voltage on the armature), small response time (electromechanical time constant of around 300 ms), large limit moment (around 5 M_{nom}), good weight-dimension indices and high power-to-weight ratio (40 W at 1.1 kg weight).

A mode of motor operation in the linear drive can be classified as an intermittent duty (S3 on GOST 183–74) since time of oscillation cycle (around 30 s) does not exceed the time constant of machine heating. Hence, the control system allows short-time fivefold overloads of the motor during reverses; at that, the root-mean-square current of the armature, taken as a cycle time, does not exceed the nominal one that guarantees absence of the overheating.

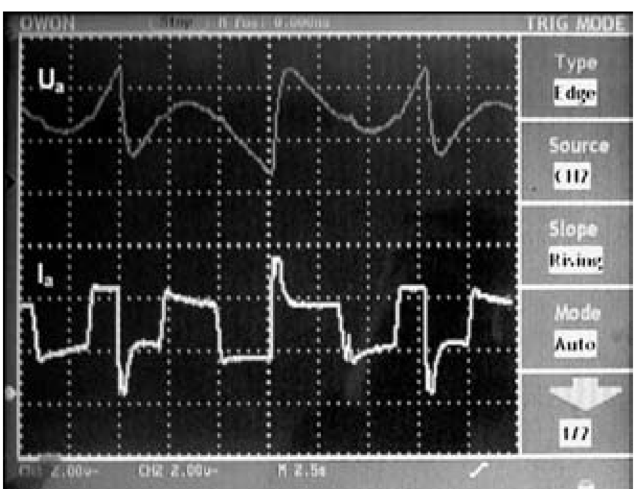

Figure 4. Oscillograms of armature voltage U_a and current I_a of motor of the additional drive at execution of triangular trajectory of the electrode movement

Selsyn motor with balanced three-phase voltage system supplied on winding of its stator was used for determination of rotation angle of the crank of movement mechanism. The electromotive force of the rotor winding and voltage of one of the phases is supplied on control circuit. The rotation angle is determined programmatically on phase shift between the signals mentioned above.

Position of an oscillating platform with installed on it mechanism of electrode feeding is determined with the help of contact-free probe Micropulse, output signal of which has (−15 – +15) V change ranges and is renewed at 2 kHz frequency.

Liquid-crystal indicator of TIC154 type in standard connection scheme and four-button keyboard were used for the interactive adjustment of system parameters. The adjustment is carried out with the help of a hierarchical menu.

Supply voltage of both motors is formed by half-bridge inverters, controlled from a controller and manufactured using IRG4PC30UD transistors and IRS2113 drivers in the standard connection scheme. The possibilities of data exchange with personal computer through RS-232 interface and on-board re-programming of the controller are also considered in the scheme.

Application of the compound drive also allows changing of the oscillation amplitude during operation that provides the possibility of carrying out surfacing of a layer with predetermined distribution of properties, for example, surface of rolls with indentations [3].

A dependence of the optimum length of crank on the amplitude of required osculation trajectory at which additional drive requires minimum power [4] was derived by authors. This improves the dynamic characteristics of the system (reduction of moment of inertia) through a preliminary adjustment of the crank length before surfacing cycle.

Figure 4 shows the oscillograms of armature voltage and current of motor of the additional drive in changing connecting rod length during execution of triangle trajectory of the electrode movement with optimum selected length of the crank. Proposed system for control of the drive of electrode movement has characteristics which allow formation of the movement trajectory optimum for surfacing.

Developed electromechanical device for control of the electrode movement trajectory, including the CRG, set in motion by powerful electric drive, and device for measurement of the connecting rod length, consisting of the direct current drive, installed directly on it, and the ACS adjusting geometric parameters of the connecting rod according to specified principle should be noted in conclusion. The system is realized using microprocessor technology and provides minimizing of power of the device for measurement of the connecting rod length by means of preliminary selection of the optimum crank length. The inspection of the device under laboratory experimental-industrial conditions showed the high dynamic characteristics (override of around 10 %, time of adjustment 1.8 s at execution of step excitation) and sufficient (around 7 %) accuracy of operation of the oscillation mechanism.

The tests on stability of given system to influence of the external disturbances were carried out taking into account real mechanical characteristics of the device and limitations of the parameters (armature current and maximum speed). Optimization of the parameters of ACS control loops was carried out according to the results.

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DEVELOPMENT OF THE TECHNOLOGY FOR REPAIR OF THREADED HOLES IN AXLES OF RAILROAD CAR WHEELSETS

(Innovation Project of the NAS of Ukraine accomplished by the E.O. Paton Electric Welding Institute)

The technology developed is intended to repair damaged threaded holes M20 in necks of axles of railroad cars RU1-Sh by the explosion cladding method. The technology is characterized by low costs (compared to fusion welding), full strength of welded joints, absence of cracks characteristic of the overlaying repair technology in them, and absence of pores, lacks of penetration, undercuts and slag inclusions, shrinkage, reduction and decrease in diameter of seats of the axle necks for roller bearings.

At the first stage of the work the investigation objects were damaged threaded holes M20-6N of 180 mm long fragments of the necks of axles RU1-Sh, and at the second stage — damaged threads on the full-scale 1450 mm long axles. Coatings were applied by the explosion cladding method to a preliminarily made 20.4 mm diameter bore in a cylindrical tube of steel 20. The ingenious procedure was developed in collaboration with State Enterprise «Ukrainian Research Institute of Railroad Car Construction» for mechanical tests of welded joints on the repaired threaded holes. Fatigue resistance tests of the welded joints conducted under minimal and maximal loads (49 and 98 t, and frequency of 50 Hz) showed the average values of fatigue life equal to 122,000 cycles, which are only 4 % lower than the basic values of fatigue life of new axles equal to 127,000 cycles.

The new technology was used to repair damaged holes in two full-scale axles RU1-Sh transferred to State Enterprise «Ukrspetsvagon» and included into structure of a car truck, which is being subjected to field tests at the Panyutino–Lozovaya Station during 2011. Upon completion of the tests, the technology proposed is to be applied at railroad car repair plants of State Enterprise «Ukrzaliznytsya».