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ELECTRIC DRIVES IN THE EQUIPMENT FOR MECHANIZED AND AUTOMATIC ARC WELDING

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Summary. *A wide range of equipment for welding and renewal production of general and special purpose is considered. The analysis of the use of electric drives in the equipment for arc mechanized welding and surfacing is carried out. The trends for the use of equipment of modern types are indicated, such as: automatic and semi-automatic machines. Based on the carried out analysis of the main representatives of these types of techniques, the directions for their improvement and the requirements for elaboration of the operation modes for the motors, which ensure the implementation of the production, installation of correction movements of the welding systems are formulated. It is determined, that in order to control and ensure the implementation of these movements, a wide range of electric drives of both direct and alternating current is used. In particular, for all linear displacements of the welding equipment, some relatively simple constructions of electric drives are used, which are based on electric motors of direct current. It is noted that the use of collector motors of low power (up to 100 W) in the electric drives due to the choice of feedback structures makes it possible to regulate the range at least 1:10 with rigidity of mechanical characteristics β≥5% in the whole range of regulation. The estimation of the properties of thyristor and transistor electric drives based on simple constructions for operation of welding equipment systems is given implementing traditional technologies for welding and surfacing. It is noted that the asynchronous frequency-regulated electric drive is widely used at present, mainly in the development of welding and surfacing systems of complex structures. The basic directions of step and brushless DC electric drives use are formulated. The investigations of the pulse mode of the vector-controlled synchronous electric drive carried out by mathematical modeling and simulation proved the possibility of its application in technological processes providing high-dynamic modes for mechanized and automatic arc welding.*
Key words: *welding equipment system, transfer control, electric drive, electric motor, vector control.*

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Introduction. Modern equipment for arc mechanized and automatic welding and surfacing is rather complex type of equipment with specific systems and units.

Automatic machines and semiautomatic devices, as the main representatives of this type of equipment, are constantly being improved and the basis of this are the following areas: the application of new welding and surfacing technologies; development of new environments and areas of use; new possibilities of technical means for conducting the arc process [1].

A wide range of automatic and semiautomatic machines structures for welding and renewal production from the mass produced for general purpose, to those that are developed to solve special problems under certain conditions should be noted.

The use of a certain number of mechanisms equipped with electric motors performing operation, installation or corrective movements of the apparatus systems is characteristic for all equipment of automatic and semi-automatic welding by fusible electrode. In order to control these movements a wide range of different electric drives, both direct and alternating current is used [2].

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The Objective and task. The objective of this work is to consider and analyze the structures of electric drives of equipment for arc mechanized welding and surfacing with the determination of trends in of their modern types and structures use, as well as the estimation of the possibility of synchronous electric drives use for highly dynamic technological processes of welding.

Analysis of electric drive designs of equipment for arc mechanized welding and surfacing. The main and partially auxiliary systems of mechanized and automatic welding equipment equipped with electric drives are shown in Fig. 1.

It should be noted that it is possible to use electric drives with synchronous and asynchronous motors, direct current motors both collector and stepper and gate power up to 400 W practically in all welding systems. Everything depends on the tasks of welding and surfacing industries and the reasonability, which includes the costs and opportunities for regulation. The range of these engines feeding voltages meets the industrial requirements. The exceptions are weld-surfacing semiautomatic devices, where according to safety conditions electric motors with feeding voltage more than = 110 В, ≈ 42 В can not be used.

Electric drives of the welding equipment can be reversible and non-reversible, but practically all their designs should implement the function of electric braking by known ways.

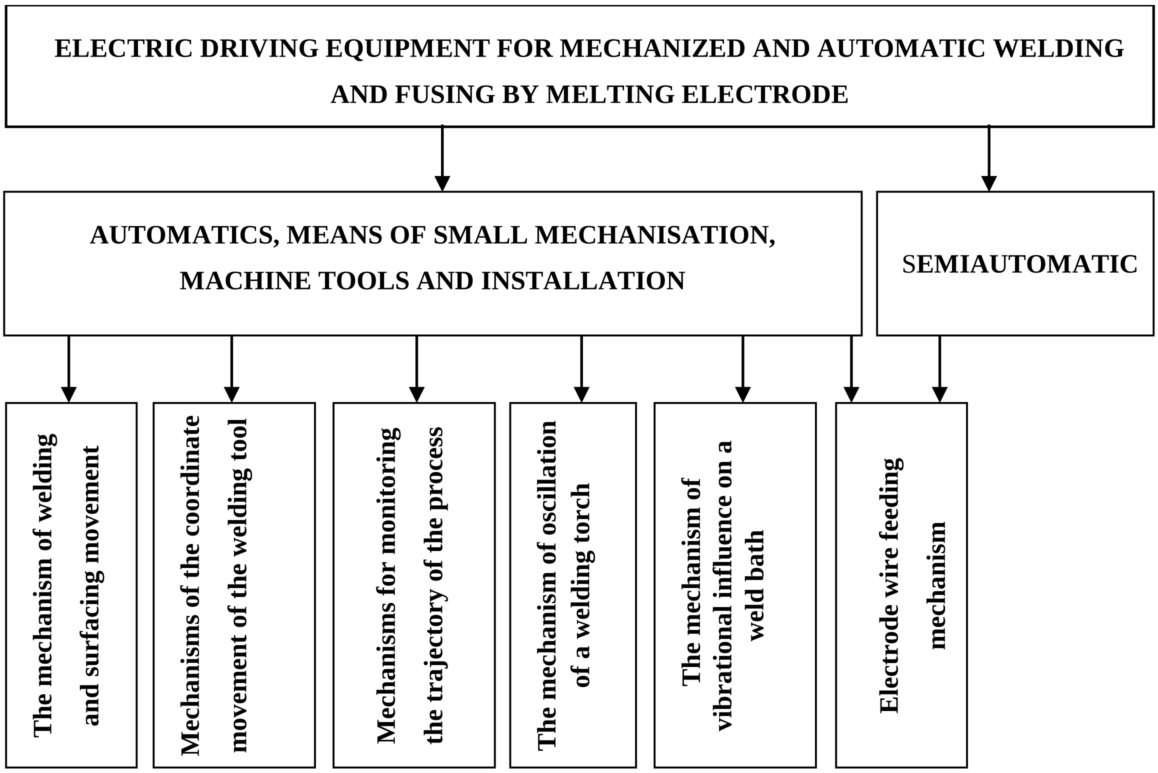

Figure 1. Main and partially auxiliary systems of mechanized and automatic welding equipment equipped with electric drives

Till present relatively simple designs of electric drives on the basis of direct current electric motors with thyristor or transistor regulators with phase or PWM control are used in a high-efficiency welding equipment for all linear displacements.

The part of such electric drives of mass production for industrial application was used in welding equipment systems, but most of their capabilities, particularly, in automatic machines and semiautomatic devices, were unused. Electric drives designs purposefully used in a number of welding equipment systems were developed and are still developing at Paton Electric Welding Institute.

Thyristor and transistor regulators for collector electric motors of low power (up to 100 W), which are easily reproduced and set up are quite popular in terms of their application in mechanized welding equipment and small mechanization means. The simple circuit technology for such electric drives proposed by the Paton EWI of the National Academy of Sciences of Ukraine makes it possible to obtain control range at least 1:10 with mechanical characteristics rigidity β≥5% in the entire range of regulation by means of choosing feedback structures. Such properties of thyristor and transistor electric drives of simple structures is quite sufficient for the operation of welding equipment systems implementing traditional welding and surfacing technologies.

Thyristor electric drive in reverse version integrated into the local control system BUSP1, BUSP2 was developed by Paton EWI IEE and acquired in mass production. This electric drive is used in welding and surfacing automatic and semi-automatic machines.

Semi-automatic machine ПШ107 (feed mechanism) developed with PWM transistor electric drive gives additionally the opportunity to feedback into it according to the welding process parameters providing additional stabilizing actions on the welding process due to the effect on the electrode wire feed rate [3].

Until now, transistor electric drives with free-running operation mode are used in some samples of mechanized welding equipment and that for small mechanization, particularly, while designing the sample models of different types of welding and surfacing machinery. Such electric drives with minimized, theoretically substantiated, circuit technology solutions [4] in a large number of versions are developed by Paton EWI. For example such electric drive version is shown in Fig. 2. The simplicity of the real scheme does not require extensive explanations. The task of the rotation frequency is carried out by the resistor R1. The voltage on this resistor is compared with the feedback voltage on the resistor R2 (E is EMF of the electric motor M1). Transistor VT2 opens, if the voltage of the problem Uзад > E . At the same time power transistor VT1 opens, feeding the voltage pulse to the electric motor. The frequency of these pulses depends on the electric motor parameters and the load changes on the operating mechanism shaft.

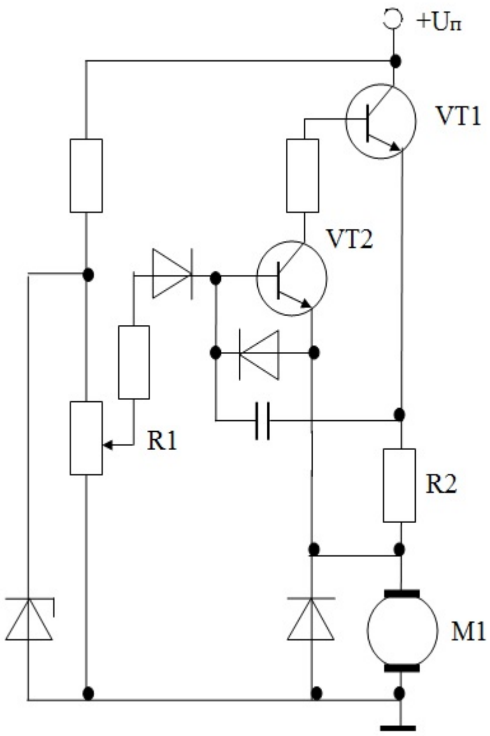

Figure 2. The circuit is an electric principle transistor electric drive

Lately asynchronous frequency-regulated electric drive is widely used, mainly in the development of welding and surfacing equipment of complex structures [5]. For an example, let us consider the structure of the equipment for electroslag welding of vertical, inclined and curvilinear joints, including electroslag apparatus in the form of fitting self-propelled device of heavy type equipped with all necessary mechanical and electromechanical correctors for the performance of high quality welding joints [6]. The general view of the installation with the device presented in Fig. 3, and in Fig. 4 is the photograph of the feeding electrode wires system with the control panel of the device system. The control system is based on the programmed controller of CJ1M type manufactured by Omron Company (Japan). Modern frequency inverters of Omron V1000 type are used to control the device asynchronous motors. At Patona EWI the experience in designing welding and surfacing devices of various purposes with the use of regulated asynchronous electric drive has already been accumulated.

Let us dwell on the application of non-collecting DC motors, which include step and thyratron motors in the welding and surfacing equipment structures.

Until the recent times considerable experience in engineering solutions concerning the application of step and thyratron electric drives has been gained at Paton EWI. In this case, these electric drives application is mainly directed to the equipment for different purposes such as underwater wet welding and for the implementation of new technical and technological solutions, such as: controlled impulse feed of electrode wire; modulated processes of the weld pool oscillation with controlled parameters; reduction of mass-dimensional characteristics of mechanisms and devices in general.

Figure 3. General view of the installation for electroslag welding

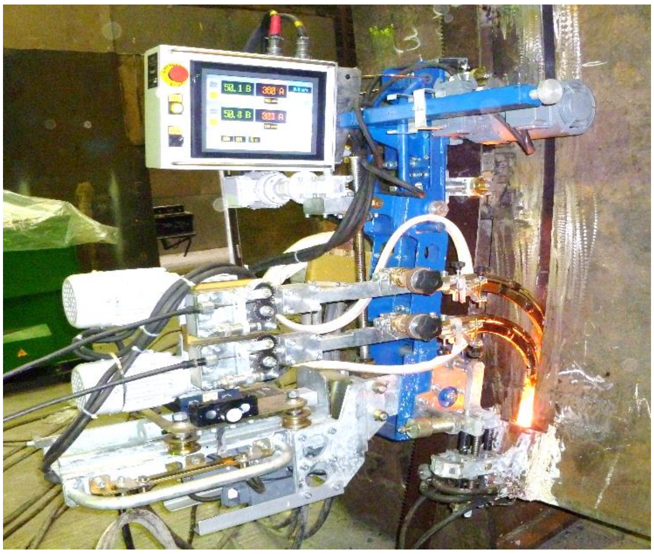

Figure 4. Device for electroslag welding (control panel and feeder mechanisms)

The installation and device for deep-water welding in the pipe with 170 mm diameterare shown in Fig. 5 and Fig. 6 [7].

Figure 5. Installation for deep-water welding

Figure 6. Device for deep-water welding

The limited welding conditions determined the choice of motors for welding systems. These are step-by-step high-torque electric motors providing feed system direct-driving, as well as welding displacement. Step electric motors in direct-driving version of the electrode wire feeding mechanisms of semi-automatic machine submersible units for underwater wet welding are widely used. The structure of submersible unit with a step electric motor and a computerized control unit is presented in Fig. 7 In such semiautomatic machine, impulse and modulated electrode wire feed algorithms are implemented greatly simplifying the task of performing high-quality welds, particularly on the vertical plane. The selection of step motors, in addition to the above mentioned, is determined by high reliability while operating in fluid medium (e.g., insulating and lubricating fluid in compartment for feeding mechanism with electric motor), particularly due to the absence of commutator-brush unit [8].

Figure 7. Semi-automatic machine for underwater welding by wet method (submersible and control compartments)

In addition to the above mentioned, it should be noted that, step motors to stabilize the current in the windings of the engine uses pulse-width (key) regulation for current stabilization in motor winding are used in modern system drivers. It is possible to use cheap and simple unregulated power supply sources. The scheme with key current stabilization, regardless of voltage fluctuations, makes it possible to maintain the moment stability, providing high rate of current increase in the windings. Simultaneously with the regulation simplicity, it is possible to minimize losses, which is very important for automatic machines structures, where the electric motor in the submersible unit can be more than 200 m away from its power supply and control units

While developing the acceleration control (start-up) algorithm, the main criterion is to minimize start-up time in order to reach the given speed of the motor shaft rotation, which is the basis for the implementation of various types of electrode wire impulse feed.

As a rule, electric actuator with mass produced step motors is used in the considered structures of the welding equipment.

Another example of the mass produced step electric motors use is the installation for surfacing with surfacing product fluctuations with controlled frequency and amplitude. The installation makes it possible to increase the surfacing roller width, which means efficiency increase. In addition, the product fluctuations, and hence the weld pool make it possible to improve the overlay metal structure. The scheme of the installation with computerized electric drive system is shown in Fig. 8 [9].

At present computerized electric drives with thyratron motors is the basis for new technologies implementation, for example: the process of metered electrode wire feeding; products fluctuations with high frequency.

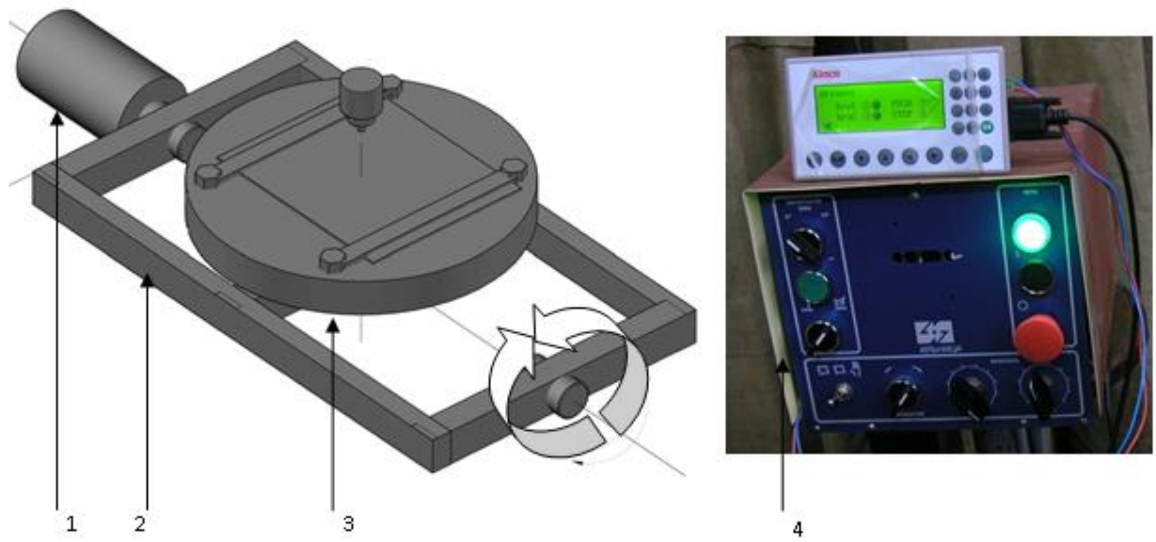

Figure 8. Structure of the installation for surfacing product oscillations with power supply and control units:
1 − step electric motor; 2 − the oscillating frame; 3 − place of surfacing part setting;
4 − power supply and control units

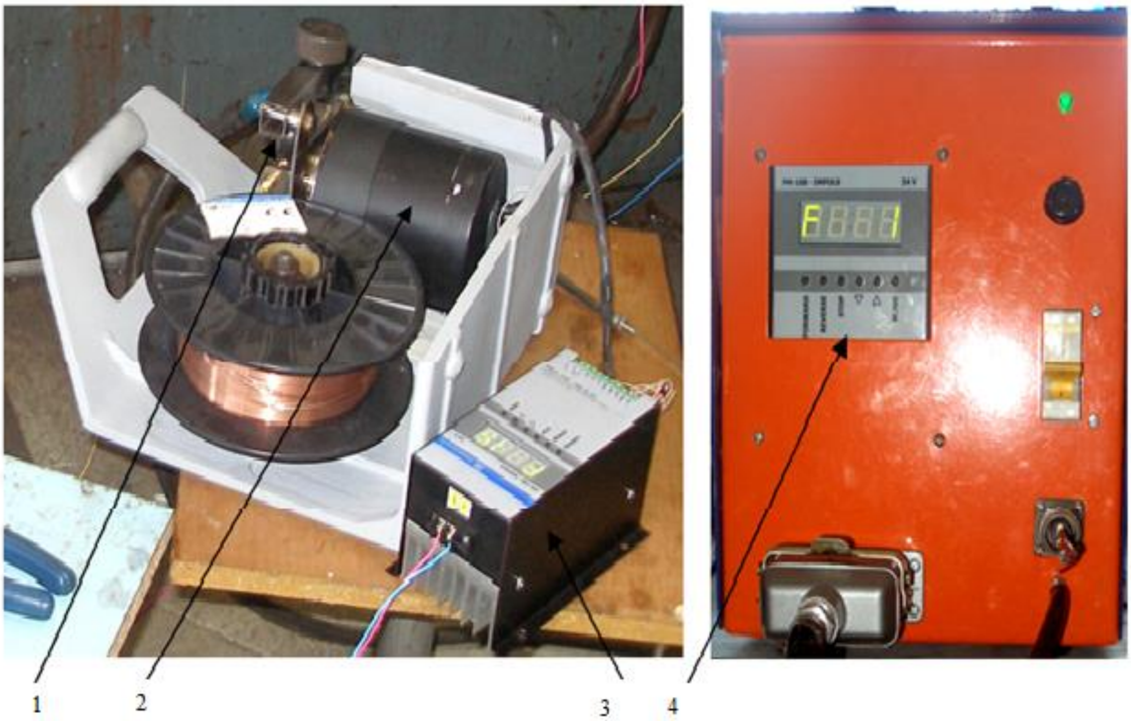

Figure 9. The mechanism of impulse feed on the basis of computer electric drive:
1 − feed roller with clamping mechanism; 2 − electric motor; 3 − electric controller;
4 − regulator built-in the control unit of semi-automatic machine

In fig. 9 presented Semi-automatic machine for welding and surfacing by continuous and powder wires with pulsed control feed algorithms. The wire feed system is equipped with computerized cycle control of semiautomatic machine operation and thyratron motor operation. This system of domestic development and manufacturing makes it possible to get the electrode wire pulse feed with the frequency of about 60 Hz including the possibility of the amplitude and porousness control, as well as obtaining reversible motion in the pulse motion cycle [10].

By means of such semi-automatic machine, a number of unique achievements were obtained, among them the overlap welding of aluminum plates with thickness up to 0,9 mm by electrode wire diameter 1,0 mm in diameter without backing. Automatic machine for underwater welding by wet method with the use of thyratron motors of the electrode wire feed system and coordinate motion systems is shown in Fig. 10.

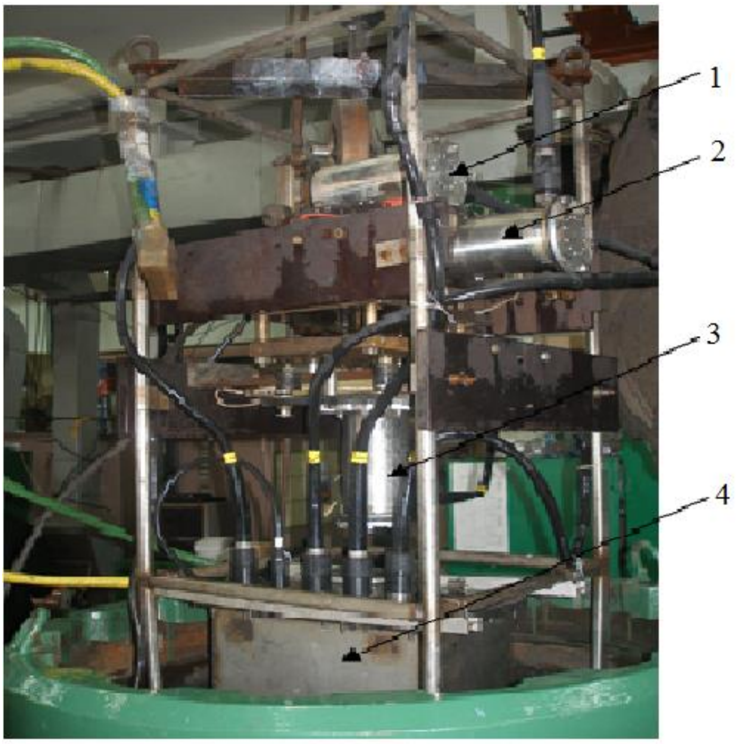

Figure 10. Automatic for welding and surfacing under water with electric motors of mechanisms: 1 - longitudinal displacement; 2 - transverse displacement; 3 - serving; 4 - bloc of control

The machine is equipped with general operation cycle control system during welding, as well as all motions. The control system is located in the submersible compartment. It should be noted that all electric motors of thyratron type are equipped with incremental rotational velocity sensors for feedback organization. The automatic machine makes it possible to conduct free-running welding along preprogrammed trajectory in water environment at about 500 m depth [11, 12]. Such automatic machine enables to solve a wide range of tasks dealing with welding and cutting under water by wet method. Electric drives with thyratron motors are constantly improved in order to obtain maximum velocity.

Investigation of dynamic properties of a vector-controlled synchronous electric drive. The use of electric drive to ensure the desired mechanism motion trajectory following has its own peculiarities. This is primarily due to the electromechanical properties of the chosen motor type. Synchronous motors with permanent magnets (PMSM) are now becoming more popular because of high dynamic quality indicators [13]. Therefore, the problem of synchronous electric motors (SM) application in welding machines is important. The widespread distribution of SD is due to good starting and operation properties. Advantages of SD in comparison with asynchronous motor are: higher efficiency factor; less dependence on feed voltage drop, etc. The operation of the electric drive in a wide range of velocity control can be provided by vector control systems. It is know, the synchronous electric drive with vector control is used in high-dynamic control of the coordinates of synchronous electric motor. The vector control system with the orientation along the vector of rotor flux linkage is widely used due to the high static and dynamic characteristics of such electric drive. Taking into account the requirements to the technological process of electrode wire feeding, including impulse one, in order to estimate the possibility of achieving the desired dynamic performance of the automatic control system (ACS), by the wire speed during ACS mathematical model development, vector-controlled synchronous electric drive (VCSED) was chosen as the drive for its feed.

While determining PI parameters of the speed controller (damping factor ζ=1), its standard setting was used [14]. ACS model parameters were calculated for the MSK030B motor with torque rating M_n=0.4 Hm and rated current I_n=1.5 A. During ACS mathematical model construction, the known structure diagram Fig. 11 of SD vector control system with the excitation from the steady magnets was used.

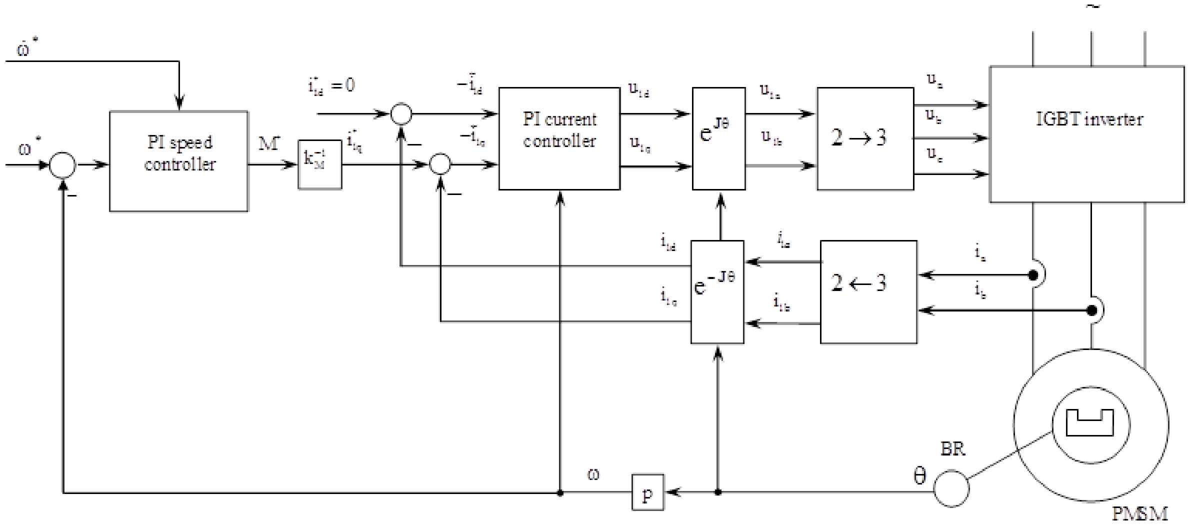

Figure 11. Structural diagram of PMSM vector control

In fig. 11 used the Standard notation are used in Fig. 11: u_a, u_b, u_c are SM stator voltages SD; u_{1a}, u_{1b} are calculating voltage vector components of the stator coordinate system (a-b) after Park-Goryev components u_{1d}, u_{1q} transformation in the coordinate system (d-q); i_a, i_b is stator current; i_{1d}, i_{1q}, i_{1a}, i_{1b} is stator current in stationary and rotary coordinate systems (a-b), (d-q) respectively; $\dot{\omega}^*$ is the derivative of velocity demand ω^*; $k_M = 0,29$ is torque coefficient; $\tilde{i}_{1d} = i^*_{1d} - i_{1d}$, $\tilde{i}_{1q} = i^*_{1q} - i_{1q}$ are the errors of currents i^*_{1d}, i^*_{1q} testing; $p = \frac{d}{dt}$ is differentiation operator; ω – rotor angular speed; θ is rotor rotation angle relatively to the stator.

The results of ACS mathematical modelling are presented in Fig. 12.

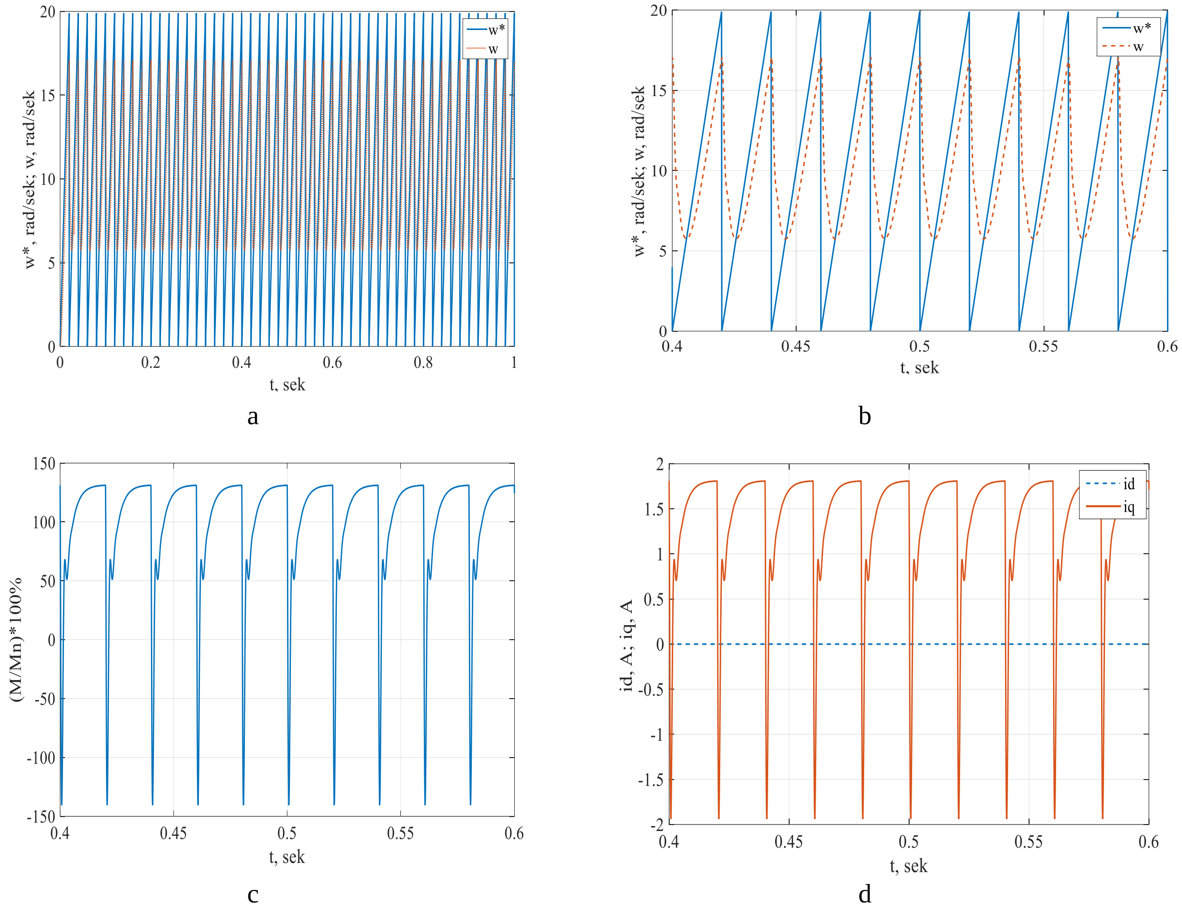

Figure 12. The results of automatic control system (ACS) mathematical modelling

The system modelling was carried out for velocity signal $\omega^* = 20\ \text{rad}/\text{sek}$ with the series sawtooth pulse frequency 50 Hz. The pulse duration in series was 0.02 sec. Active loading moment M_C=0.4 Nm started to act at 0.03 sec. The maximum rotation velocity of the motor shaft at series sawtooth pulse position did not exceed $\omega = 17.08\ \text{rad}/\text{sek}$. The motor full-stop while ACS pulse positioning the specification did not occur. Motor load moment did not exceed 150%.

Conclusions. Based on the analysis of electric drive structures of the equipment for arc mechanized welding and surfacing the trends of their application are identified. The prospect of non-collector electric motors (step, thyratron, synchronous) use for welding equipment while solving problems of significant increase of welding and surfacing efficiency with the implementation of impulse and oscillation control algorithms, the functioning of automatic and semi-automatic machine systems for performing arc processes with application fusible electrode is substantiated. The obtained results of mathematical modelling determine the importance of further investigations of operation modes of vector-controlled, direct synchronous electric drive for its use in technological processes of mechanized and automated arc welding.

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ЕЛЕКТРОПРИВОДИ ОБЛАДНАННЯ ДЛЯ МЕХАНІЗОВАНОГО ТА АВТОМАТИЧНОГО ДУГОВОГО ЗВАРЮВАННЯ

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Резюме. *Розглянуто базові конструкції обладнання для зварювального та відновлювального виробництв загального й спеціального призначення. Здійснено аналіз використання електроприводів обладнання для дугового механізованого зварювання й наплавлення. Вказано тенденції застосування обладнання сучасних типів, а саме: автоматів і напівавтоматів. На основі проведеного аналізу використання основних представників цих видів техніки сформульовано напрямки їх удосконалення та вимоги щодо відпрацювання режимів роботи двигунів, які забезпечують здійснення робочих, установчих або коригувальних рухів систем апаратів. Визначено, що для управління й забезпечення здійснення цих рухів використовується досить широкий спектр різних електроприводів як постійного, так і змінного струму. Зокрема, для всіх лінійних переміщень зварювального обладнання використовуються досить прості конструкції електроприводів на основі електродвигунів постійного струму. Зазначено, що застосування колекторних двигунів малої потужності (до 100 Вт) у складі електроприводів за рахунок вибору структур зворотних зв'язків дозволяє отримати діапазон регулювання не менше 1:10 при жорсткості механічних характеристик β≥5% у всьому діапазоні регулювання. Надано оцінку властивостей тиристорних і транзисторних електроприводів простих конструкцій для функціонування систем зварювального обладнання, що реалізує традиційні технології зварювання й наплавлення. Зазначено, що асинхронний частотно-регульований електропривод останнім часом знаходить досить широке застосування, переважно при розробленні зварювальних і наплавних установок складних конструкцій. Сформульовано основні напрямки застосувань крокових та вентильних електроприводів. Дослідження імпульсного режиму роботи векторно-керованого синхронного електропривода, проведені шляхом математичного моделювання, підтвердили можливість його застосування у технологічних процесах для забезпечення високодинамічних режимів роботи обладнання механізованого та автоматичного дугового зварювання.*

Ключові слова: *системи зварювального устаткування, управління переміщенням, електропривод, електродвигун, векторне керування.*

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