DOI: http://dx.doi.org/10.15407/tpwj2018.05.07

MODERN HARDWARE-SOFTWARE COMPLEXES FOR TRAINING OF WELDERS

L.M. LOBANOV[1], **N.M. MAKHLIN**[1], **A.E. KOROTYNSKY**[1], **V.E. VODOLAZSKY**[1] and **V.Yu. BURYAK**[1]
[1]E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazimir Malevich Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua
[2]SE «Scientific and Engineering Center of Welding and Control in Nuclear Power Engineering of Ukraine of the E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazimir Malevich Str., 03150, Kyiv, Ukraine. E-mail: electro@paton.kiev.ua

The article presents the results of development of technical means of semi-virtual type for training welders and welding production specialists at the SE «Scientific and Engineering Center of Welding and Control in Nuclear Power Engineering» (SEC WCNPE) in cooperation with the E.O. Paton Electric Welding Institute of the NAS of Ukraine and the G.E. Pukhov IPME of the NAS of Ukraine. The level of development of technical means, attained at the present time, for training and certification of welders and welding production specialists was considered, which allows predicting the expansion in the fields of application of modern information technologies, including those reproducing the mixed reality at maximum adaptation of virtual space to the real welding equipment and providing the remote access of telecommunication systems. It was shown that simplification of training and its approximation to the conditions of real welding processes is possible by using a new generation of welding simulators, in which modern information technologies are widely applied. 15 Ref., 3 Figures.

Keywords: *virtual reality, information technologies, arc welding simulators, training, welding equipment, certification of welders*

The technical means of training (simulators) can be classified according to the welding method, conditions of its realization, degree of simulation of real process and tools.

By the degree of simulation of welding process, all technical means of training can be subdivided into [1, 2]:

- computer simulators in which simulation of the welding zone and welding arc is carried out in the virtual space by means of computer graphics and image synthesis;
- simulators, providing simulation of the process of welding with a low-amperage arc without melting of electrode and formation of a weld pool;
- simulators using the elements of real welding process and welding equipment.

At present the simulators of all three types are presented at the world market of training equipment and technical means for training of welders.

For the computer simulators (mainly, of the development and production of companies from the USA, EU countries, Canada, Australia, Japan), a prominent example of which is the products of the Company SOLDAMATIC (Spain) , the maximum degree of using the virtual effects during simulating the welding process is characteristic[3–8]. In the simulators of this type, the reproduction of a welding situation, i.e. zone of arc burning, edge preparation, weld and molten pool, is carried out by imaging them on the display of a personal computer (PC) or on the screen of a special welding helmet with built-in virtual reality glasses. However, computer simulators have a number of drawbacks, limiting their capabilities:

- absence of a clear relationship between the parameters of welding process, welded joints and welding tools, which can be represented only conditionally by means of computer graphics;
- inevitability of using a system of special sensors and special welding helmets or similar devices with built-in virtual reality glasses, as well as the presence of communications, providing their connection with a PC or similar processors, which creates certain inconveniences for trainees and limits their capabilities of moving in space;
- need in preparatory operations for setting the limits of deviations from standard values of welding process parameters;
- need in the subsequent adaptation to real welding tools and processes;
- difficulties in the process of developing the necessary professional psychomotor skills in trainees who do not have initial training;
- high cost (from € 7000).

In the opinion of many specialists, the simulators of the second and third types are characterized by the

widest functional and didactic capabilities, providing the approximation of training process to the conditions of real welding process, as well as low-amperage and arc simulators for welder [1, 9].

The main feature of low-amperage arc simulators is the maximum approximation of the simulating welding process to the real one due to the existence of a low-amperage arc, the current of which is 4–6 A, and the power does not exceed 250 V·A, as a result of which the heat-affected-zone is formed in the simulator of a welded workpiece without melting of base and electrode metals.

The low-amperage arc simulators represent hardware-software complexes, in which by means of PC the direct measuring and evaluation of such continuously changing parameters of the welding process in time as current, voltage and arc length, welding speed, angles of inclination of the electrode simulator of welding tool with respect to the simulator of the workpiece welded is provided. The direct measurements in low-amperage arc simulators are performed with the help of a system of sensors of different physical nature included in their composition. The signals from the information outputs of these sensors, proportional to the parameters of welding process, are supplied to the inputs of multichannel matching module of the simulator, which performs frequency correction and adjustment of levels of input signals to the range of input voltages of the analog-to-digital converter (ADC). From the outputs of the matching module channels, the normalized analog signals are supplied to the inputs of a multichannel ADC, providing the conversion of the input analog signals into a digital code, supplied to the bus of PC data for the further processing and analysis. The result of the direct processing of the signals, received by the PC, is the information (displayed in numerical, graphical or tabular form) about the actual values of currents passing in the welding circuit and the circuits being a part of it, arc voltage, arc gap length, electrode inclination angles of the welding tool simulator. The mathematical processing of the data received by the PC also provides obtaining the information on the actual values of welding speed, effective heat power of the arc and energy input. The actual values of welding parameters obtained as a result of processing of data, received by the PC, are compared with their limit values, preset before the start of training session. In case of coming the actual value of the monitored parameter beyond the PC areas, regulated by the training task, the PC automatically generates the audio speech feedback signals with the trainee, reproduced by audio means, for example, headphones.

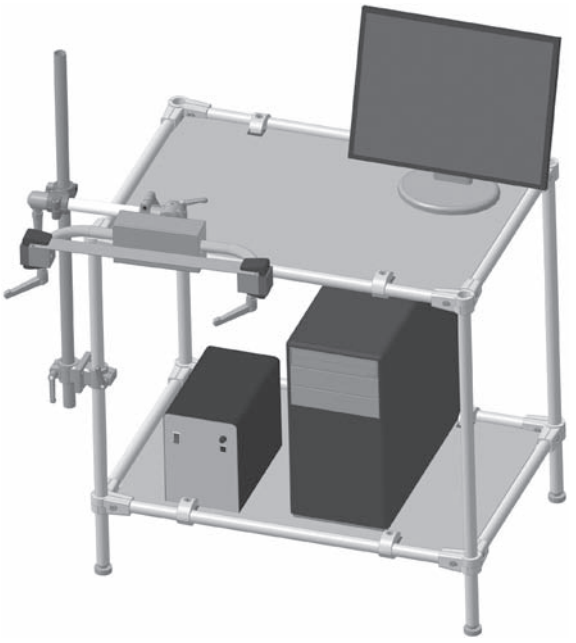

Figure 1. Simplified appearance of simulator MDTS-05M1 of modification OBTs 650 UKhL4.2

Among the known examples and models of the low-amperage arc welder simulators, at the present time the widest functional, technological and didactic capabilities are peculiar to the low-amperage arc welder simulator MDTS-05M1, designed and manufactured at the SEC WCNPE. It allows simulating the processes of manual arc welding with coated electrodes (MMA), welding with nonconsumable electrode (TIG) and welding with consumable electrodes (MIG/MAG). A somewhat simplified general view of the MDTS-05M1 simulator of the OBTs 650 UKhL4.2 modification is shown in Figure 1, and the basic parameters of the MDTS-05M1 simulator are shown below.

Basic parameters of the MDTS-05M1 simulator

Welding arc current, A . . . . . 4.5 ± 0.3
Open-circuit voltage, V, not more than 65
Number of information channels of the technological interface unit BTI-05M1 OBTs 650.05.00.000 6
Capacity of the analog-digital converter integrated into the technological interface unit BTI-05M1 OBTs650.05.00.000, bit, at least 11
Controllable and preset welding mode parameters:
- speed of welding (speed of electrode movement), mm/s 2–12
- length of the arc gap:
  - in the mode of simulating welding with a consumable electrode, mm 1–6
  - in the mode of simulating welding with a nonconsumable electrode, mm 0.5–4.0
- angles of inclination of the electrode across and along the weld, deg . . . . . ±85
- heat input, J/mm 11–50
- arc voltage, V 20–45
- average speed of electrode movement during manual arc welding (in the mode of simulation of electrode melting), mm/s . . . . . 4.0 ± 1.0

Speed of filler wire feed to the welding zone (welding arc), min^{-1} 10–20
Duration of training session, s 90, 180, 240, 360
Rated voltage of single-phase AC mains of 50 Hz frequency, V 220
Consumed electric power (without taking into account the power consumed by the computer and its peripheral devices), kV·A, not more than 0.35

The MDTS-05M1 simulator provides the feasibility of mastering the skills of arc exciting and supporting it in the technologically justified range of length, uniform movement of arc along the preset trajectory, as well as maintaining the inclination angle of the electrode to the surface welded, providing a regulated thermal mode of a weld pool. In TIG welding, a further mastering of the technique of filler material feeding into the weld pool is possible.

An important part of the software of the MDTS-05M1 simulator is the educational and methodological documentation (EMD), which includes a training program, a test program, a library of theoretical material on the realized welding processes and a library of reference data containing the types and sizes of characteristic welded joints, as well as the types of basic defects in these joints.

The technical solutions, capabilities of the hardware part, information resources and structure, including methodical one, the software of the MDTS-05M1 simulator found its wide application both as technical means for training the personnel of welding production in the educational institutions of vocational education and training centers for training and improving the skills of welders in Ukraine, Russia, Kazakhstan, Macedonia, Belarus and other countries. Only in Russia there are more than 1200 simulators of this type in operation, while in a number of educational institutions, training and certification centers of the Russian Federation, on the basis of the MDTS-05M1 simulators the whole training classes and laboratories for training welders in MMA-, TIG- and MIG/MAG welding were created. The experience in using the MDTS-05M1 simulator confirms its high operational safety, economy and efficiency both for professional selection and initial professional training of welders, as well as for improving their skills, production training and testing, and in a number cases — for admission control also.

The traditional approach to training welders using real welding processes is associated with a significant consumption of metal, welding consumables and electric power. It is possible to intensify and qualitatively improve the process of training skills with simultaneous reduction in the operating costs only with the use of hardware and software means of a high scientific and technical level, providing the combination of the real and virtual reality. To the greatest extent, the arc welding simulator TSDS-06M1, designed and manufactured at the SEC WCNPE, corresponds to this approach.

The simulator TSDS-06M1 provides:

- scale reproduction of real processes of arc welding;
- measurement of instant and averaged values of process parameters with comparison of the possible deviations from the preset or standard values in dynamics;
- computer registration and processing of the obtained information, its documentation, storage and reproduction in digital, graphical or table form;
- performing feedback with the trainee (tested);
- automatic and unambiguous evaluation of actions and skills of the trainee or tested welder during the welding processes realization.

According to the structural design, the TSDS-06M1 simulator is in many respects similar to the MDTS-05M1 simulator, but differs from the latter in the number and parameters of sensors of the measuring system and the schematic-circuit solutions. The general view of the TSDS-06M1 simulator is shown in Figure 2, and its basic parameters are given below.

Basic parameters of the TCSD-06M1 arc welder simulator

Rated welding current of power module, A 300
Load duration of (LD) at a rated welding current and cycle duration T_c = 5 min, % 60
Open-circuit voltage, V, not more than 65
Voltage of supplying single-phase mains of 50/60 Hz frequency, V . . . . . 220 ± 33
Controllable and preset parameters:
  welding current (as-preset, at an accuracy of ± 5A):
    in MMA welding, A 80, 100, 120, 140, 160, 180
    in TIG welding, A 80, 100, 120, 140
    in MAG welding, A . . . . . 125 ± 10
  arc voltage:
    in MMA welding, V 21–28
    in TIG welding, V 9–16
    in MAG welding, V 20–22
  length of arc gap:
    in MMA welding, mm 2–5

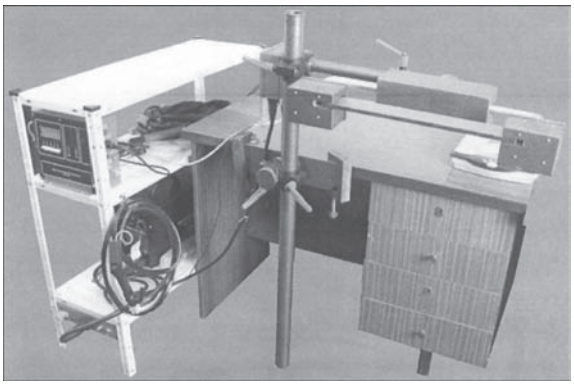

Figure 2. General appearance of simulator TSDS-06M1

in TIG welding, mm 0.5–4.0
electrode wire feed speed in MAG welding, mm/s (m/h) 2.92–3.33 (105–120)
inclination angles of welding tool electrode (in flat and overhead positions of welded specimen), deg . . . . . ±(45 ± 5)
welding speed:
in MMA welding, mm/s (m/h) 1–5 (3.6–18.0)
in TIG welding, mm/s (m/h) 0.5–2.5 (1.8–9.0)
in MAG welding, mm/s (m/h) 4.0–5.5 (15.0–20.0)
heat input:
in MMA welding, J/mm 70–410
in TIG welding, J/mm 60–300
in MAG welding, J/mm 80–120
inert gas (argon) consumption in TIG welding, l/min 5.5–12.0
duration of training (testing) session, s 90, 180, 240, 360
Electrical power consumed by the power module, kV·A, not more than 5.0
Number of information channels of the technological interface unit BTI-06M (OBTs 611M.05.00.000) 8
Capacity of each channel of the analog-digital converter built-in into the technological interface unit BTI-06M (OBTs 611M.05.00.000), bit, not less than 12
Consumed electric power (without taking into account the power consumed by the power module, computer and its peripheral devices), kV·A, not more than 0.50

The TSDS-06M1 simulator complex includes an arc power supply module, a technological interface unit, a positioner, a PC with peripheral devices, a set of welding tools, a protective mask with a light filter, a set of welding specimens, headphones, a lightweight rack for mounting the arc power supply module in it, a unit of the technological interface and accessories of the simulator, as well as a specialized software. As a power supply module of the arc, the standard, specialized or universal welding power sources predominantly of inverter type with small modifications can be used. The positioner of the TSDS-06M1 simulator provides a fixing the welding specimen in the current conductor of the positioner; ability of installing a welding specimen in different spatial positions; realization of a special scheme of connecting the welding specimen to one of the poles of a welding power source; formation of signals proportional to the currents passing in welding specimen; ability of calibrating the circuit of measuring currents passing in welding specimen. The set of welding tools of the TSDS-06M1 simulator includes manual tools of a welder based on a widely used standard electrode holder for MMA welding, a torch for TIG welding and a torch for MIG/MAG welding. Welding tools are equipped with a three-axis sensor of angular positions of the electrode relative to the gravity vector. The set of welding specimens of the TSDS-06M1 simulator contains plate specimens for producing butt and fillet welds, as well as position welds of pipes and other rotating bodies. The shape and geometric dimensions of welding specimens provide their repeated use in training, testing, admission control or prequalification training. The same specimens can also be used for the qualification procedure of welders.

The software of the TSDS-06M1 simulator complex, as well as the software of the MDTS-05M1 simulator, is developed on the LabVIEW platform, which provides:

- input of initial welding data in the dialog mode;
- imaging of monitored parameters on the PC display;
- realization of feedback with a trainee (tested) by automatic supply of the speech signals («prompts»);
- control of welding process as a whole and according to certain parameters;
- statistical processing of results of the training session, testing, admission control or certification tests;
- obtaining the estimates of level of skills in welding techniques and the quality of works due to the availability of the expert system elements;
- documenting the results of the training session (testing, admission control or qualification tests);
- transfer of current information in the «online» mode through the channels of standard information systems and networks (for example, the Internet);
- remote establishment of requirements for testing, admission control or qualification tests.

The software of the TSDS-06M1 simulator includes training, testing and admission control programs for welders and the corresponding EMD, which is addressed not only to welders, who are directly involved in welding works, but also to other specialists of welding production. If necessary, the software of the TSDS-06M1 simulator can be supplemented also with the program of qualification of arc welding operators.

The curriculum (training program) is developed on the basis of the reproductive method, has a hierarchical structure and represents a two-level system of practical studies. The basic aim of the first, local level for the trainees is to achieve stable results in formation of certain skills in making the real processes of MMA-, TIG- and MIG/MAG welding. Moreover, these results should correspond to the preset values of the parameters of welding process and welding techniques. The aim of the second, integrated level of studies is to achieve and maintain the totality of skills and abilities formed at the local level, providing a stable repeatability of real welding processes in general with a preset level of quality.

It should be emphasized that automatic determination of coordinates of the welding arc spot and the actual welding speed when mastering maintaining of the

welding speed (speed of electrode movement) within the preset limits of welding speed is one of the most essential components in the professional training of welders. Providing a reliable control of these components is one of the most complex and still insufficiently solved tasks in the development of arc simulator welding systems (SWS). And although there are a number of ways to evaluate the speed of manual welding and devices for their realization [2, 10, 11], the multiple attempts to apply these methods did not lead to the desired result corresponding to the requirements to the modern SWS because of their technical or economic aspects. This caused the E.O. Paton Electric Welding Institute together with the SEC WCNPE to conduct investigations, theoretical and experimental works on the search for easy-to-realize, inexpensive and accurate methods for determining the coordinates of a moving arc and evaluating the welding speed, as well as the principles of designing devices for realizing such methods. As a result of the mentioned investigations and works, a comparatively easy-to-realize resistometric method for determining the coordinates of a moving arc and evaluating the welding speed, as well as a device for its realization [12, 13], was developed. This method is based on the method for determining the coordinate of a measuring probe in a conducting medium [14, 15], developed by V.V. Vasiliev and L.A. Simak at the G.E. Pukhov IPME, and further developed at the E.O. Paton Electric Welding Institute and SEC WCNPE for the arc SWS as-applied to a moving welding arc spot or its simulator. Taking into account the advantages of the resistometric method for determining the linear coordinate of a welding arc spot and measuring the welding speed, this method and digital devices for its realization were successfully used in all modern hardware-software simulator complexes (welding simulators) of the MDTS and TSDS series and widely represented in Ukraine and in a number of near and foreign countries.

Since the training complexes MDTS-05M1 and TSDS-06M1 are fully compatible with the modern digital channels and systems for transmission, storage, reception and reproduction of information (including the Internet), the opportunity appears to realize not only the remote training of welders on their basis (including with the use of real welding processes), but also the remote testing, qualification and certification of welding personnel. Such opportunities of a single information space will allow international and national centers of personnel certification not only to record the protocols of testing, admission control and qualification, but also to monitor their conductance, correspondence of knowledge and skills of the trainees (tested) to the national and international requirements. At the same time, due to replenishment of the EMD with the norms of the international educational standards and rules, during prequalification training the account for their specifics is simplified. Moreover, the procedures of testing, admission control and personnel qualification themselves can be performed in training or qualification centers, which are located at significant (almost any) distances from certification centers, issuing permission documents.

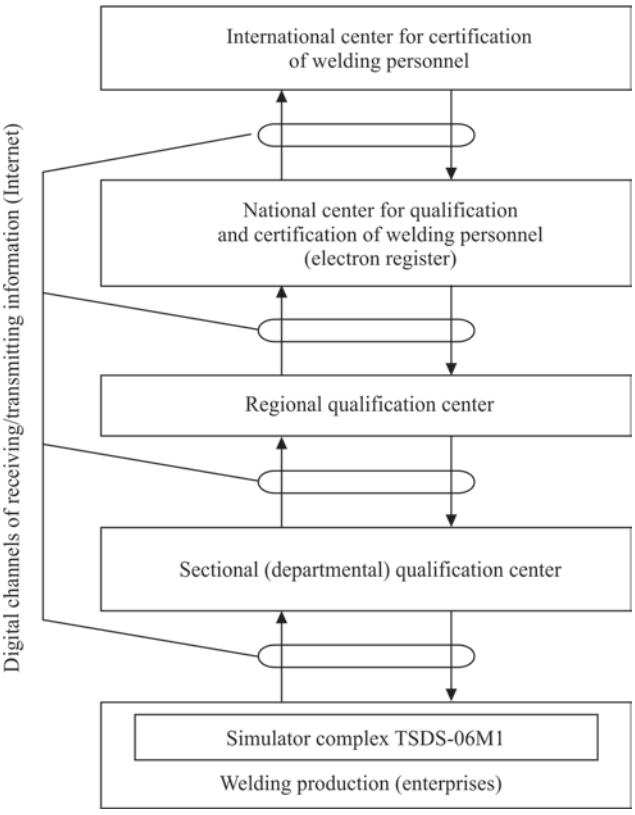

Figure 3. Structural scheme of system of remote qualification and certification of welding personnel (using the simulator TSDS-06M1)

The scheme of system of remote qualification and certification of welding personnel is shown in Figure 3.

It should noted especially that modernization of the existing simulation systems and the further development of additional means for training welders and specialists of welding production are possible only on the basis of analysis and generalization of practical experience in application of such technical means of training and qualification in the establishments and institutions of vocational education of all levels, training and qualification centers, as well as directly in production.

The accumulated experience in practical application of information technologies and the technical means developed in the last decades in training, improvement and qualification of welders and specialists in welding production creates favorable prerequisites

for solving the urgent problems of training welding personnel in the CIS countries and in other countries, which corresponds to the modern requirements.

Conclusions

1. The arc hardware-software complexes (welding simulators) using information technologies, developed at the E.O. Paton Electric Welding Institute together with SEC WCNPE, provide expansion of technological and didactic capabilities of modern technical means for training welders and specialists in welding production, intensification and simplification of the training process and its approximation to the conditions of real welding processes.

2. The level of development of technical means of professional selection, training, improving skills, testing, admission control and improvement of qualification of welders and specialists in welding production, achieved up to nowadays, allows predicting the expansion of the areas of application of modern information technologies, including those reproducing the mixed reality with the maximum adaptation of virtual space to real welding equipment, as well as the use of telecommunication systems, providing the remote access through the global network.

3. While creating welding simulators of a new generation, the technologies of virtual reality combined with real welding equipment, real welding tools and simulators of welded products will get the advanced development, allowing creating almost any training situation with the support of a real-time mode and an effective system for evaluation of actions of trainees. Moreover, it is assumed that in welding simulators of a new generation the microprocessor devices and systems as well as digital systems of technical vision will find a wide application.

In conclusion the authors consider it necessary to note that in the development and introduction of hardware-software complexes (welding simulators) MDTS-05M1 and TSDS-06M1 V.L. Kobryansky, A.G. Skirta, I.V. Vertetskaya, M.I. Skopyuk, A.F. Muzhichenko, A.G. Siparenko, V.A. Bogdanovsky, V.M. Gavva, A.D. Cherednik, V.E. Popov, D.S. Oliyanenko, A.A. Mukha, S.F. Tarkhov, V.A. Fedotov took part and in mastering of industrial production of these simulators A.A. Sviridenko, N.M. Pasichny, V.N. Andrejchenko, V.E. Ivanov, A.U. Mnukhin, V.P. Tishchenko, G.I. Pisarev, A.V. Naumenko participated.

1. Paton, B.E., Korotynsky, A.E., Bogdanosvky, V.A. et al. (2010) Information technologies in education of welders and specialists of welding production: Methodology and technical means. *Svarka i Diagnostika*, **3**, 37–44 [in Russian].
2. Vasiliev, V.V., Simak, L.A., Bogdanovsky, V.A. et al. (2003) *Simulation modeling and training-education systems in electric welding*. Kiev, NASU [in Russian].
3. Koboyashi, K., Kato, H., Shimamoto, S. (2004) Modified training system for manual arc welding by using mixed reality and investigation of its effectiveness. *J. Japan Society for Precision Engineering*, 70(**7**), 941–945.
4. Heston, T. (2008) Virtually welding: A tour of welding simulators that could help the manufacturing word rethink welding training. *Fabricator*, 38(3), 56–59.
5. Porter, N., Cote, J., Gifford, T., Lam, W. (2006) Virtual reality welded training. *J. of Ship Production*, 22(**3**), 126–138.
6. Hasimoto, N., Kato, H., Ikehara, R. (2006) Training system for manual arc welding by using mixed reality–reduction of position–perception error of electrode tip. *J. Japan Society for Precision Engineering*, 72(**2**), 249–253.
7. *Product description Fronius virtual weldin*g. www.fronius.com/cps/rde/xchg/SID-BFA25696-036863A3/fronius_international/hs.xsl/79_15490_ENG_HTML.htm
8. (2018) Fronius Company as a pioneer of implementation of digital and communication technologies. *Avtomatich. Svarka*, **2**, 59–61.
9. Keitel, S., Ahrens, C., Moll, H. (2014) Computer-based technologies and their influence on welding education. *Ibid*., **10**, 51–55.
10. Danilyak, S.N. (1990) Problems of design of measuring transducers for control of heat content of welding pool and speed of welding simulators. *Modeling in simulating systems*. Kiev, Naukova Dumka [in Russian].
11. Bigdash, V.D. (1990) Devices of welding rate control in welding simulating systems. In: *Modeling in simulator systems*. Kiev, Naukova Dumka, 143–150 [in Russian].
12. Paton, B.E., Korotynsky, O.E., Bogdanovsky, V.O. et al. (2009) *Method of evaluation of welding arc movements parameters in arc simulating systems*. Pat. 86609, Ukraine [in Ukrainian].
13. Lobanov, L.M., Makhlin, N.M., Korotynsky, A.E. et al. (2018) Resistometric method of welding speed measurement for simulating welding systems. *The Paton Welding J*., **1**, 8–13.
14. Vasiliev, V.V., Grezdov, G.I., Simak, L.A. et al. (2002) Modeling of dynamic systems: *Aspects of monitoring and signal processing*. Ed. by V.V. Vasiliev. Kyiv, NASU [in Russian].
15. Simak, L.A. (1984) Method of automatic determination of probe coordinates in conducting medium on the base of differential transformations. *Elektronnoe Modelirovanie*, **6**, 90–91 [in Russian].

Received 20.03.2018