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HIGH-FREQUENCY EQUIPMENT FOR LIVE TISSUE WELDING (REVIEW)

**G.S. Marynskyi¹, V.A. Tkachenko¹, V.O. Bysko¹, S.E. Podpryatov^{1,2}, S.S. Podpriatov^{1,2},
S.D. Grabovskiy¹, S.V. Tkachenko¹**

¹E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine

²Kyiv City Clinical Hospital No. 1
121 Kharkyvske Hwy, 02091, Kyiv, Ukraine

ABSTRACT

Technology and equipment for high-frequency welding and treatment (coagulation, cutting) of live tissues in surgery is ever wider used in medical practice of many countries of the world. This work, which has been performed on the base of both the materials posted on the Internet and authors' own materials, is a general review of the most typical representatives of such basic equipment, which is proposed by the leading world manufacturers. The main features and advantages of the respective equipment are given as claimed by its developers. The work is designed both for users and for developers of new equipment.

KEYWORDS: electric welding surgery, high-frequency welding of live tissues, equipment, world manufacturers

INTRODUCTION

Technology and equipment for high-frequency (HF) welding and treatment (coagulation, cutting) of live tissues in surgery is ever wider applied in medical practice in many countries of the world. It should be noted that although the “welding” term initially applied for joining live tissues in medicine in Ukraine is more and more often used in foreign publications, in this or that form, there it mostly pertains to vessel closure. In Ukraine the term “welding” of live tissues has a broader meaning. Ukraine certainly is the world leader by the diversity of electrosurgical welding procedures [1–4].

At present a large number of high-quality electrosurgical equipment is manufactured in the world, including welding equipment, which is continuously evolving and is being improved. The actual need for such equipment is constantly growing, and the world market volume reaches billions of US dollars [5]. By our approximate estimation, the potential volume of the Ukrainian market of welding electrocoagulators is equal to approximately 1.5–2.0 thou pcs.

GENERAL CHARACTERISTICS AND REQUIREMENTS. DESIGN FEATURES AND COMPONENTS

In the general case, the equipment for live tissue welding is an HF generator, usually of output power of 15–300 W, with the necessary tools connected it, through which the HF current directly influences the biological tissues at monopolar (Figure 1, *a*) or bipolar (Figure 1, *b*) connection circuits [6].

A fundamental difference in the connection circuits in case of application of a monopolar variant, in

the fact that just one generator output (one electrode) is connected to the organ being operated on, while the second electrode is placed under the patient's body. In case of application of a bipolar variant, both the generator outputs (both the electrodes) are connected directly to the tool. Accordingly, the current runs between the tool electrodes in a very limited zone, where surgery is performed (Figure 2).

Both the circuits have their advantages and disadvantages and are widely used in practice, complementing each other. The working frequency of current at generator output is in the range from 300 KHz and higher, and it is usually equal to 400–500 kHz. The lower frequency threshold and other restrictions on the use of frequency ranges are due to limitations imposed by the respective norms and standards [6]. It should be noted, however, that there is positive practical experience of application of 66 kHz working frequency at bipolar circuit of tool connection that is due, among other things, to reduction of losses in the tool connection cables with lowering of current frequency. It is especially noticeable when working with high power. The working voltage and current, supplied into the zone of impact, are selected, proceeding from the nature of the live tissue being operated on, connection circuit, etc.

MAIN MANUFACTURERS

Nowadays the electrosurgical equipment which is used or can be used for live tissue welding is manufactured by many leading companies in different countries of the world. These are, first of all, Medtronic and Johnson-and-Johnson (USA), ERBE, Martin and BOWA (Germany), etc. [7]. Among them there

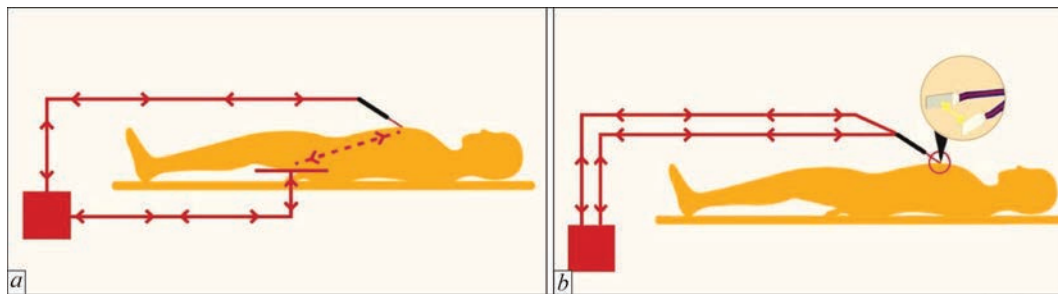


Figure 1. HF generator: *a* — monopolar circuit; *b* — bipolar circuit

are also Ukrainian manufacturers such as “Contact” Company and ISPC “Scientific-Research Institute of Applied Electronics Soc.” (Ukraine), “Patonmed” (Ukraine) and some others.

American Corporation Medtronic plc is one of the world’s largest manufacturers of medical equipment, having its operational and executive headquarters in Minneapolis, Minnesota (USA). In 2015 Medtronic announced a successful completion of acquisition of Covidien plc Company. In keeping with the terms of acquisition agreement, Medtronic Inc. and Covidien plc are merged into Medtronic plc Company. Today, according to published data, the Company has about 90 thou employees, including more than 11 thou of scientists and engineers. It is present in the market of more than 150 countries. Last year its income was equal to 31.69 bln USD [8].

Covidien Company, and now Medtronic plc proposes ValiLab™ units, which realize the LigaSure™ technology [9]. LigaSure technology is that of bipolar closure of vessels by HF current. The feedback program used for controlling the applied amount of energy depends on the scope of the tissue, vessel density and it realizes the limitation of heat evolving in the target tissue. As stated by the developers [10], LigaSure™ technology, which is based on ValeyLab™ energy platforms, still remains the most advanced technology of vessel welding and dissection in the world.

The developers guarantee that:

- in one second LigaSure™ measures the tissue impedance 434000 times, calculates and regulates the level of applied energy by a unique algorithm;
- in two seconds LigaSure™ reliably and stably closes vessels of up to 7 mm diameter, which can stand 3 times the normal systolic pressure;
- in three seconds the surgeon, using LigaSure™ technology, can close the vessel, dissect it and safely go over to the next part of the procedure, due to a short cooling time (to $< 60^\circ$ in less than one second), which is achieved, among other things, also by application of a unique nanocoating.

Note that comparative testing, conducted in March, 2018 with the authors’ participation in Medtronic Center in Shanghai, showed that the local vessel closure technology, realized in EKVZ-300 “Patonmed™” units is not inferior to LigaSure™ technology.

As an example of this company equipment, we can mention ValleyLab™ FT10 unit (Figure 3), which realizes LigaSure™ technologies [12].

As claimed by the developers [11], this device provides:

- improved efficiency of LigaSure™ electroligation system;
- TissueFect™ system scans the tissue resistance and adapts the characteristics of energy applied with the frequency of 434 kHz;

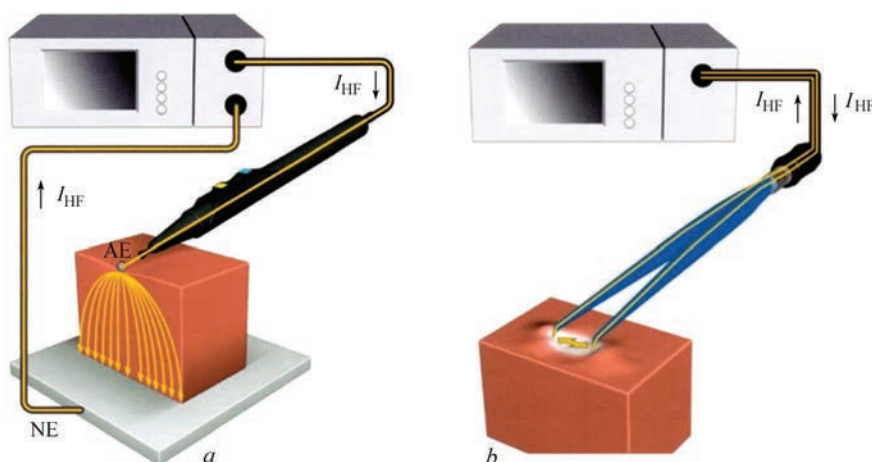


Figure 2. Current flowing in monopolar (*a*) and bipolar (*b*) circuits



Figure 3. Appearance of ValleyLab™ FT10 unit

- automatic identification of the tool and automatic adaptation of power minimizes the time of the unit adjustment before and during surgery;
- one sensory screen with simplified control;
- internet connection and exclusive ValleyLab™ Exchange system of updating the software;
- unique ValleyLab™ mode for improvement of dissection with hemostasis;
- REM™ adaptive system (system of following the patient's neutral electrode);
- Autobipolar mode, Soft coagulation mode;
- 10.1 kg weight;
- 368×462×178 mm dimensions.

An example of a more accessible and compact instrument of this Company is ValleyLab™ LS10 unit (Figure 4) [12], designed for vessel closure. With a weight of 5.5 kg, its overall dimensions are 300×377×105 mm, and it is easy to transport. It ensures fast (in 2–4 s) welding of up to 7 mm vessels. It uses optimal energy characteristics to achieve welding up of vessels and tissue masses with minimal heat propagation. The unit has a simplified control panel with one on/off button and one socket for tool connection by the “plug in and work” principle. The unit identifies, which tool is connected at this moment, and automatically adjusts the instrument operational parameters for fast and stable result of vessel closure.

A more complex multifunctional instrument of the Company is the ForceTriad™ device (energy platform) (Figure 5) [13, 14].

This is a fully functional electric surgery system, which ensures electro-surgical cutting, coagulation and bipolar sealing of vessels in one LigaSure™ generator.

The energy platform of this device is designed for open and laparoscopic surgical procedures and it includes:

- TissueFect™ sensing technology for all tissue types;
- ValleyLab™ mode for electric surgery;
- LigaSure™ closure technology for vessel sealing.



Figure 4. Appearance of ValleyLab™ LS10 unit

As claimed by the developers [14, 15], ForceTriad™ energy platform is the only fully functional energy platform in the field, with the capabilities of remote updating of the software. Using the software updating system ValleyLab™ Exchange, the device can be readily updated in site, opening up the most advanced technology capabilities for surgeons, medical nurses and patients.

TissueFect™ sensing technology is a Covidien control system, designed for accurate control of energy supply, creating a range of variants to achieve the desired effect on the tissue.

The improved LigaSure™ tissue welding technology can join up to 7 mm diameter vessels inclusive and tissue bundles.

Bipolar resection with programmed addition of physiological solution allows the surgeons performing various urological and gynecological procedures in a saline environment.

Automatic tool identification is realized in the unit. The device, designed by all-in-one principle, is compatible with the regular electro-surgical tools and all the currently available and new LigaSure™ tools.

Welding cycles are faster, than those in the original generator at LigaSure™ vessel sealing. ValleyLab™ mode ensures a unique combination of monopolar hemostasis and dissection.

Ethicon Company, which is part of such a giant as Johnson&Johnson Corporation [15], whose products are known all over the world, is represented on the market of welding electrocoagulators by MEGADYNE™ unit [16] (Figure 6). As claimed by its developers, owing to optimized convenient design and



Figure 5. Appearance of ForceTriad™ unit



Figure 6. METADYNE™ electro-surgical generator optimized energy supply, MEGADYNE™ electro-surgical generator is a simple, but smart choice among the monopolar and bipolar power sources for performance of diverse medical procedures.

This device, which envisages operation in the monopolar and bipolar modes, has large displays, which are easy to read, and an intuitive power setting mode. It provides visual indication of the working current. There is also the function of calling the last used mode. The display is large and bright. The generator weight is 7.7 kg with overall dimensions of 368×439×179 mm.

KLS Martin Group Corporation (Germany, USA), has its branches and representative offices all over the world, and offers numerous equipment and tools on the market, including electro-surgical units for hemostasis and closing of vessels [17–21]. Among such equipment we will focus on their most recent development — maXium® Smart C unit (Figure 7).

As claimed by the developers [21], maXium® Smart C unit combines a proven maXium® user interface with maXium® power adjustment effect, used at coagulation, thus ensuring maximum efficiency in all the power ranges.

SealSafe® IQ bipolar system of vessel sealing, used in this device, allows efficiently sealing vessels or tissue bundles without any required prior preparation or detailed exposure of the tissue to be sealed. Owing to SealSafe® IQ program of providing precise current, specially adapted to such a type of application and special tools, just the tissue located between the tool jaws is sealed. It results in lower side thermal damage to the adjacent tissues.



Figure 7. Appearance of maXium® Smart unit [21]

maXium® Smart C unit is available in three versions and it offers: informative screen, memory of previous settings (up to 500 words of memory), continuous displaying of the main parameters of the instrument.

In addition to the high-frequency part, maXium® Smart C units can be combined with argon feed system to solve the problems associated with extended superficial bleeding in parenchymatous tissues, which is difficult to cope with using classical coagulation. Thus, in the opinion of the authors, argon-plasma coagulation is an ideal complement to usual HF methods.

In combination with maXium® Smart Line series, it additionally incorporates the following elements: a system to provide efficient hemostasis, and it can be used in several ways; maXium® Beamer system, which reduces tissue carbonization during surgery, thus accelerating the wound healing process. The risk of perforation is also greatly reduced, owing to a small depth of HF current penetration.

BOWA MEDICAL Company [22] is a leading supplier of the entire spectrum of innovative energy-based surgical systems, produced in Germany. As claimed by the developers [22], the products and systems are ideally adapted to the requirements of daily medical care in hospitals, and they impress with their high flexibility and safety. Unlike the global market leaders, the BOWA Company product line is not large, but it is focused on electro-surgery. And their target markets are the European Union (mostly Germany), East European, Asian and CIS countries and Ukraine.

Among the instruments produced by BOWA Company, we will consider the ARC series units (Figure 8). This series consists of several modifications, which differ by their maximal output power (from 100 to 400 W) and functionality.

So, ARC100 unit has maximal power of 100 W, and it is fitted with medical tools designed for this power (pincers and monopolar scalpels).

Higher power units, for instance ARC400, have greater functionality and they are fitted with tools, designed for 400 W power (up to 280 mm clamps, ERG310, Night NIFF, LIGATOR special tools, bipolar scissors, etc.). Output powers and software allows these units to be applied in surgery, gynecology and urology [22].

The following convenient functions are realized in ARC series units: dialogue control and adaptive dis-



Figure 8. Unit of ARC series



Figure 9. Front panel of ARC unit with different number of connectors

play; reading information from the unit and software updating using programs, saved on USB-carriers. It greatly simplifies the daily work of the hospital staff. ARC new generation is easy to operate. Five configuration options are available, depending on the requirements to surgical intervention. The number of connectors (monopolar or bipolar) varies from one to two of each (Figure 9).

The unit has COMFORT function for automatic identification of tools and controlling the application cycles. “Setting up Master” program helps creating and optimizing the ARC unit configuration in the dialogue mode.

Power is maximal in MONOPOLAR mode at 400 W (for 200 Ohms), and in BIPOLAR mode it is 200 W (for 75 Ohms). Unit weight is 12.5 kg, its overall dimensions are 430×140×470 mm.

UKRAINIAN COMPANIES

“Contact” Company, based in Kiev, has been on the market of high tech endoscopic equipment for minimally invasive surgery since 2001 [23]. The Company is developing and manufacturing endoscopic units and systems for laparoscopy, arthroscopy, rhinoscopy, thoracoscopy, gynecology and urology. The company now has the following units in its arsenal: electro-surgical units EKONT-0201.1, EKONT-0201.2 (Figure 10) and EKONT-0201.3 (Figure 11), which is positioned by the developers as expert-class modern electro-surgical system [23].

These multifunctional units have maximal output power of up to 300 W.

Here are some of the features and advantages of EKONT-0201.3 system, claimed by the developers.

Special features of EKONT-0201.3 system are as follows: two monopolar channels; one bipolar channel; colour TFT display; neutral electrode circuit control system (ANECS); wide range of modern electro-surgical modes; interactive visual system of help during operation (InViNS help); continuous self-con-



Figure 10. Appearance of EKONT-0201.2 unit

trol of critical systems (ART-SCS); 100 sets of modes (programs), which are saved.

Advantages of EKONT-0201.3 system are as follows: special modes of argon-plasma coagulation (APC) for general surgery, laparoscopy and flexible endoscopy with maintenance of argon-plasma discharge starting from 5 W and up to 15 mm distances to the treated tissue; special mono- and bipolar modes for arthroscopy; special mono- and bipolar modes for urology and gynecology; fully automated system of vessel welding; special modes of polypectomy/papillotomy.

By the information of the developers [23], among its advantages are special APC modes for general surgery, laparoscopy and endoscopy with maintenance of argon-plasma discharge. It has special mono- and bipolar modes for arthroscopy, urology and gynecology.

Given below are some main modes for bipolar cutting, coagulation and welding.

Bipolar cutting/(hemostasis of 0–7 mm), 100 W. Bipolar coagulation: micro — 60 W, 100 Ohms; standard — 100 W, 100 Ohms; auto — 300 W, 20 Ohms. Vessel welding: 5 mm laparoscopic tool — 100 W, 20 Ohms; 10 mm laparoscopic tool — 300 W, 20 Ohms; general surgery — 300 W, 20 Ohms.

General characteristics are as follows: working frequency of 440 kHz, supply voltage of 220 V, consumed power of 690 W, weight of 8.0 kg, and overall dimensions of 350×140×350 mm.

ISPC “Scientific-Research Institute of Applied Electronics” Soc., Kyiv, is represented in the local market by electro-surgical units called “Nadiya-4” [24]. At present it is a whole line of units, differing both by their power and technological capabilities given in the Table 1. As one can see from the pre-



Figure 11. Appearance of EKONT-0201.3 unit together with the argon station



Figure 12. Appearance of “Nadiya-4” EKhVCh unit

sented materials, although the developers do not position these units as welding equipment, they largely meet the requirements made, which was the base for inclusion of this equipment into this review. Note, that units operating at the frequency of 1.76 MHz and even 3.5 MHz, are presented, alongside units with working frequency of 440 kHz, which can be regarded as a standard one for this type of equipment. Figure 12 gives the appearance of “Nadya-4” unit.

PWI, Kyiv, offers in the local market electrosurgical tools under “Patonmed™” trade name. Today PWI is represented by EKVZ-300 unit (high-frequency welding electrocoagulator). This device, the design of which was developed in 2010–2011, has been used with success in practical medicine in Ukraine, starting from 2012 in many specialities: from abdominal surgery to ophthalmology.

Its design features are multifunctionality, which is ensured by the capability of programming to accommodate the peculiarities of application in medical or veterinary science, as well as the needs of an individual user (surgeon).

EKVZ-300 functional diagram ensures operation in the following modes: bipolar cutting, manual welding — pulsed coagulation, controlled by the surgeon, and automatic welding.

A capability of simultaneous connection of two tools is envisaged with their switching and their one-time operation in the mode of one control pedal.

Working frequency of EKVZ-300 “Patonmed” unit is 440 kHz, its maximum output power is 300 W.



Figure 13. Appearance of EKVZ-300 unit

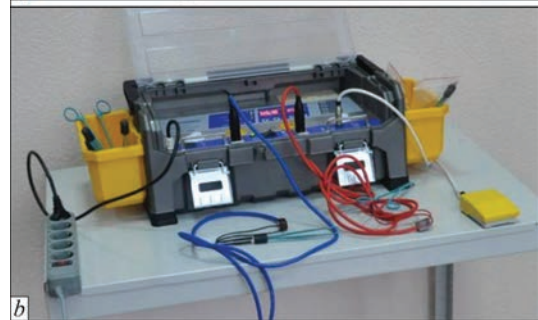


Figure 14. Appearance of mobile variant of EKVZ-300 unit in transportation (a) and working (b) position

Its weight is 7.5 kg, and overall dimensions are 410×400×130 mm.

From the time of its development, the unit has been continuously improved (Figure 13) [25]. At present, it has a great diversity of operating algorithms and parameters, depending on the type of surgical to be performed. This unit allows adaptation, correction and loading of additional programs by user preference. The capability of saving and using “favourite” programs and algorithms is envisaged. Other manufacturers’ tools can be applied.

The operating algorithm of modern EKVZ-300 units, which is described in sufficient detail in the patent [25, 26], and the respective proprietary software guarantee a reliable performance of the necessary tasks in live tissue welding.

In addition to the stationary variant, its mobile variant (Figure 14) and other modifications were developed. The mobile variant, having the same technical characteristics as the stationary one, is convenient in case of the need to frequently transport the unit and



Figure 15. Appearance of EKVZ-300-2 unit

Table 1. Comparative characteristics of “Nadiya-4” electrosurgical units

Maximal power in modes	EKhVCh-3000RK	EKhVCh-300 Model-200	EKhVCh-200			EKhVCh-120	
			Model-200RKh	Model-120	Model-120RKh/1.76	Model-120RKh/3.5	
Monopolar cutting-1	300 W	300 W	200 W	200 W	120 W	120 W	120 W
Monopolar cutting-2 (mixed)	200 W	200 W	200 W	200 W	120 W	120 W	120 W
Bipolar cutting-1	300 W	–	–	–	–	–	–
Bipolar cutting-2 (closure)	300 W	–	–	–	–	–	–
Monopolar coagulation-M	–	200 W	120 W	120 W	120 W	120 W	120 W
Monopolar coagulation-M1	250 W	–	–	–	–	–	–
Monopolar coagulation-M (forced)	120 W	–	–	–	–	–	–
Bipolar coagulation B	–	120 W	120 W	120 W	120 W	120 W	120 W
Bipolar coagulation B1	120 W	–	–	–	–	–	–
Bipolar coagulation B2 (with higher tissue resistance)	120 W	–	–	–	–	–	–
Consumed power	600 W	600 W	450 W	450 W	450 W	300 W	300 W
Working frequency	440 kHz	440 kHz	440 kHz	1.76 MHz	440 kHz	1.76 MHz	3.5 MHz
Overall dimensions							
Electronic module	–			(290×215×125) mm		–	
Control pedal	–			(230×195×45) mm		–	
Complex weight	<6 kg		<4.5 kg				

at operation outside a stationary operating room, for instance, in veterinary medicine.

A further development of this series is EKVZ-300-2 “Patonmed™” unit, which realizes novel welding algorithms, based on multilevel feedbacks. It provides a stage-by-stage assessment of the quality of the tissue being welded and power feed regulation (Figure 15). It ensures improved functional performance of the tissue joint. This instrument has a large LC display. In this unit a function of the connected tool identification is realized, as well as automatic change of operating parameters and algorithms, in keeping with the peculiarities of the connected tool. It has a built-in system of self-control and activation of prompts for the surgeon, and controls the condition of the connected tool. It enables visualization of the changes in tissue parameters during joining, which allows conducting research and having the joint quality feedback.

Note that within one article it is impossible to describe the entire range of equipment for such a promising field as live tissue welding in medical and veterinary science. The authors presented the most characteristic samples.

CONCLUSIONS

1. The large number of models is indicative of intense competition in the market of electrosurgical equipment, which has already become habitual.

2. All the considered units without exception have similar claimed technical characteristics, which are due to the requirements to technical parameters of medical radiofrequency equipment, and they differ mainly by ergonomics, design and their inherent functions.

3. Most of the units combine the possibility of operating both by bipolar and monopolar circuit. Application of a monopolar tool is due to popularity and familiarity for the surgeon of a fine fast cutting impact of such a tool.

4. In some units, the high-frequency module is combined with other technological modules, for instance, argon-plasma or module for convection-infrared treatment of the tissue, targeting special branches of surgery, which require a powerful impact over an area to a small depth (for instance, liver surgery).

5. All the manufacturers are trying to achieve maximal automation of the process, minimizing the performer impact on evaluation of the tissue internal characteristics. The application principle consists in involving the surgeon into correct selection of the mode and tool, in accordance with the conditions of using the units in surgery, specified by the manufacturer. At the same time, evaluation of the tissue condition during its treatment and dosing of the impact on it are assigned to the unit algorithms.

6. The EKVZ-300 series units developed at PWI meet the highest world standards by their technical characteristics.

7. The functional of PWI electric welding units of EKVZ-300 series incorporates programs based of the results of developments by Ukrainian researchers and doctors in the fields of abdominal surgery, thoracic surgery, proctology, ophthalmology, neurosurgery, oncology and gynecology.

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ORCID

G.S. Marynskyy: 0000-0003-0753-0154,
V.A. Tkachenko: 0000-0003-2983-778X,
V.O. Bysko: 0000-0003-1574-5630,
S.E. Podpriyatov: 0000-0003-1350-7532,
S.S. Podpriatov: 0000-0001-5942-6311,
S.D. Grabovskiy: 0000-0002-9082-4059,
S.V. Tkachenko: 0000-0002-5524-6273

CONFLICT OF INTEREST

The Authors declare no conflict of interest

CORRESPONDING AUTHOR

G.S. Marynskyy
E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine.
E-mail: g.marynsky@gmail.com

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