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PATON EVGENY OSCAROVICH

On March 5, 2000, 150 years have passed since the birthday of Paton Evgeny Oscarovich (1870–1953), the outstanding scientist in the field of metal structures and welding, academician of the Academy of Sciences of UkrSSR (1929), Honoured Scientist of UkrSSR (1940), laureate of Stalin prize of USSR (1941), Hero of Socialist Labour (1943), founder and permanent director of the Institute of Electric Welding (1934–1953), vice-president of Academy of Sciences of UkrSSR (1945–1953). E.O. Paton went down in history of science as the author of classical manuals on bridge construction, the designer of unique projects of bridges, the head of a scientific school on the problems of welding which is recognized all over the world.

Evgeny Oscarovich is well characterized by his own words: «I have never been attracted by the work directed to the solution of subjects abstracted and isolated from practice. I tried to make my works and the works of my staff to the useful for the national economy. The best award for the man is to see the embodiment of ideas and results of works into the life». Different scientists including those involved in engineering estimate their achievement in different ways. Some of them are satisfied with receiving unique formula and consider their mission finalized. But such an achievement for E.O. Paton is only a step on the way to the main aim.

All life he was tireless at his work. He taught students, wrote manuals, improved methods of design of bridges, created unique projects and participated in their realization. He invited students to these works, fascinating them with his ideas, imparting the habits of a creative approach to the solution of technical problems.

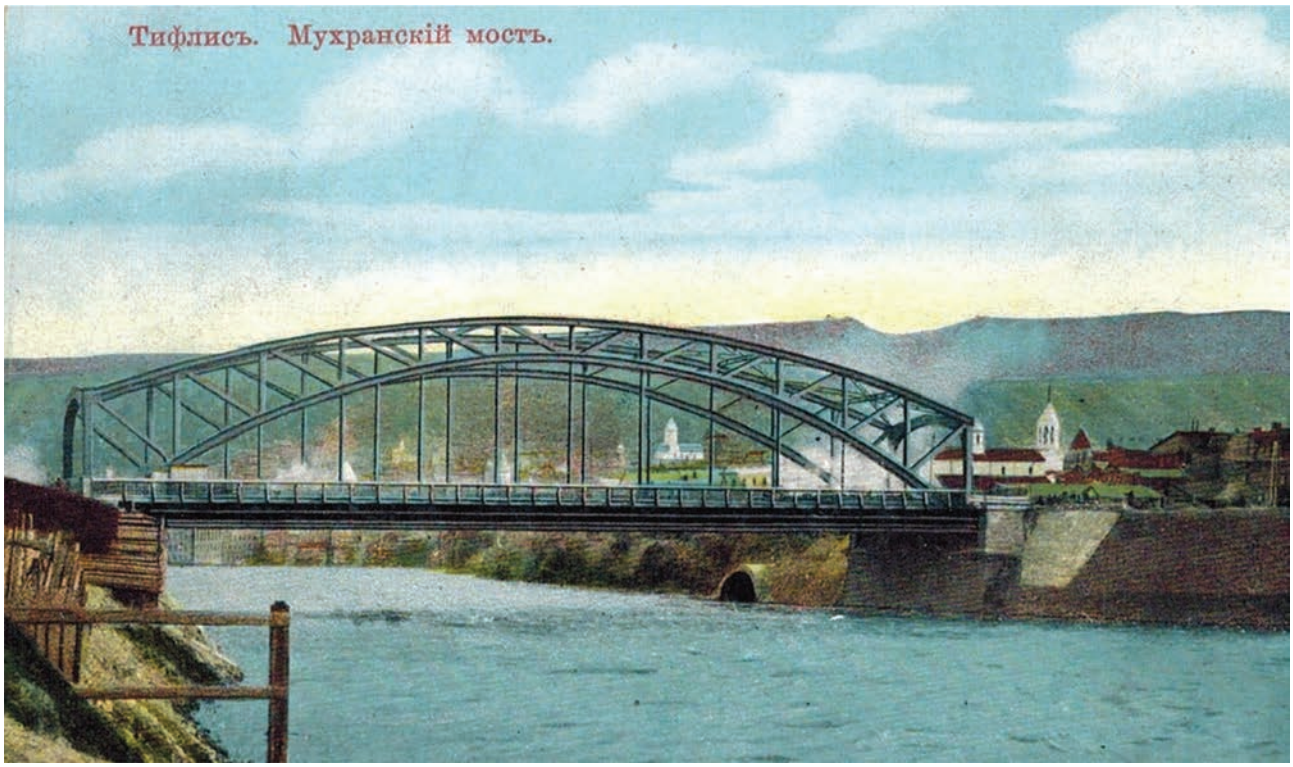
In the 20s E.O. Paton realized that the technology of fabrication of metal structures will be based on an electric welding and decided to study this technological process. He founded the Electric Welding Laboratory which in 1934 was transformed to the Institute of Electric Welding. Evgeny Oscarovich considered the development of a high-efficient method of welding suitable for manufacture of critical structures as one of the important aims of the Institute. By the end of the 30s the Institute managed to develop such method as the submerged-arc welding. The Second World War began. By the request of Evgeny Oscarovich the fall 1941 Institute was evacuated to the Urals where the mass production of tanks was organized. In the severest conditions it was necessary in the shortest terms to create the technology of welding of hard-to-weld armoured steels, to set the manufacture of welding automatic machines and flux. At that time Evgeny Oscarovich and his colleagues accomplished a really heroic deed in realizing all this. The famous tanks T-34, welded by the automatic machines, were continuously leaving the plant conveyor. The submerged-arc welding was also mastered at other defense plants owing to the efforts of E.O. Paton and his staff.

In postwar years the Institute was working in collaboration with hundreds of plants. New technologies of manufacture of ship hulls, large-diameter pipes, power, petrochemical and other equipment were created. At the same time Evgeny Oscarovich returned to his main idea, i.e. to the construction of all-welded bridges. The program of research works was scheduled and successfully fulfilled. This program envisaged the specifying of requirements to steel for welded structures, creation of rational welded joints and study of their strength, development of technology of welding both under shop and site conditions. At that time a method of welding vertical welds with a forced weld formation was also developed. The works of that period made a good start for a thorough study of materials science problems of welding, problems of strength of welded joints for different conditions of service, contributed to a wide application of mechanized methods of welding in site conditions. The first long all-welded bridge designed and constructed under the direct supervision of Evgeny Oscarovich and named after him was put into service in Kyiv in 1953.

E.O. Paton paid a great attention to the works made from the orders of the industrial enterprises. He considered an agreement with a customer as a certificate of recognition of usefulness of the research works. At a present transition to the market principles of organizing the economy, the progressiveness of the vital positions of the outstanding scientist becomes more evident.

E.O. Paton left us the property, the Paton traditions, which are followed now at the Electric Welding Institute headed by Paton Boris Evgenievich. In spite of hard times in the country economy, the Institute, which bears the name of its founder, PATON EVGENY OSCAROVICH, is still one of the most authoritative research centres in the field of welding and allied technologies. This is proved by its wide-spread relations both with Ukrainian enterprises, and with R & D centres and companies of many foreign countries.

Given the great contribution of the Electric Welding Institute to the world treasury of knowledge and technology in welding and allied technologies, International Welding Institute in 2000 founded the «Eugenij PATON Prize».



Mukhrani Bridge across the Kura river in Tiflis, built in 1908 by E.O. Paton's design

Grand opening for traffic of Evgenia Bosh Bridge, designed by E.O. Paton. Kyiv. May 10, 1925

Opening ceremony of the E.O. Paton bridge, November 5, 1953

Memorial sign with which the American Welding Society commemorated the E.O. Paton Bridge in 1995 as a prominent welded structure of the twentieth century

E.O. Paton bridge today

Designing the Kyiv pedestrian bridge at the end of Petrivska alley, well-known to all the Kyivites, gave me a lot of creative joy. e remains of a slope on the hilly bank of the Dnipro, which had not yet slid down, were an obstacle to continuation of the Petrivska alley. First, a project was put forward, which consisted in running a tunnel through this land mass. Such a solution seemed uninteresting and dull to me. is wonderful corner of Kyiv could be decorated by a light, beautiful bridge. It would look extremely aractive against the background of endless Dnipro expanses and magnicent Kyiv parks. I suggested making a deep recess in the slope and spanning it by a light pedestrian bridge with crescent laice trusses. They liked the idea, and it was approved.

E.O. Paton

Arched bridge over Petrovskaya Alley in Kyiv, built in 1912 by E.O. Paton's design

ІЦ ЕПЗ ІЕЗ
ім. Є.О. Патона

ENGINEERING CENTER OF ELECTRON BEAM WELDING OF E.O. PATON ELECTRIC WELDING INSTITUTE

The Department 57 of «Physical Processes, Machinery and Equipment for Electron Beam and Laser Welding» of the E.O. Paton Electric Welding Institute of the NAS of Ukraine and the Engineering Center of Electron Beam Welding for many decades have been specialized in the development of electron beam welding (EBW) technologies for many advanced structural alloys, as well as in the development of equipment for EBW and related processes for aerospace industry, power and chemical engineering, instrument manufacture and medicine.

Main directions of activity:

- development of technology and processing methods of EBW of materials and products with a thickness of welding edges from 0.5 to 250 mm;
- study of physical processes in welding pool during joining different metals and alloys of up to 250 mm thick;
- development of repair technologies for aircraft engine components and gas turbines;
- development of additive technologies for manufacture of products of a set shape by using the methods of layer-by-layer filler electron beam surfacing in vacuum with the use of powder materials (EBM — Electron Beam Melting) and wire (DM — Direct Manufacturing), manufactured in Ukraine;
- development and production of equipment for implementation of additive technologies in industry;
- improvement of welding guns and power sources for EBW;
- development of software for control of EBW installations;
- development, manufacture, putting into operation, warranty and post-warranty maintenance of electron beam equipment in accordance with the customer specifications and designated purpose of products on the territory of Ukraine, Europe, America and Asia;
- using of the own production facilities for manufacturing experimental batches of parts and assemblies for which the use of EBW is the optimal solution.

In recent years, a new generation of electron beam installations developed by the E.O. Paton Electric Welding Institute on the base of a model-oriented control has been mastered at twenty enterprises of aerospace and power industries, as well as at mechanical engineering enterprises in the USA, China, South Korea and India.

All the installations developed and delivered by the Department can be divided into several types according to the volume of a welding chamber: «small», «medium», «large» and «superlarge». At the same time, a characteristic feature of the installations, developed for EBW of large-sized parts is intrachamber mobile electron beam gun, which has from 3 to 5 axes and positioning accuracy of not worse than 0.08 mm.

General appearance of production area


Small-sized electron beam installation

This, of course, allows maximizing the capacity factor of internal volume of the vacuum chamber.

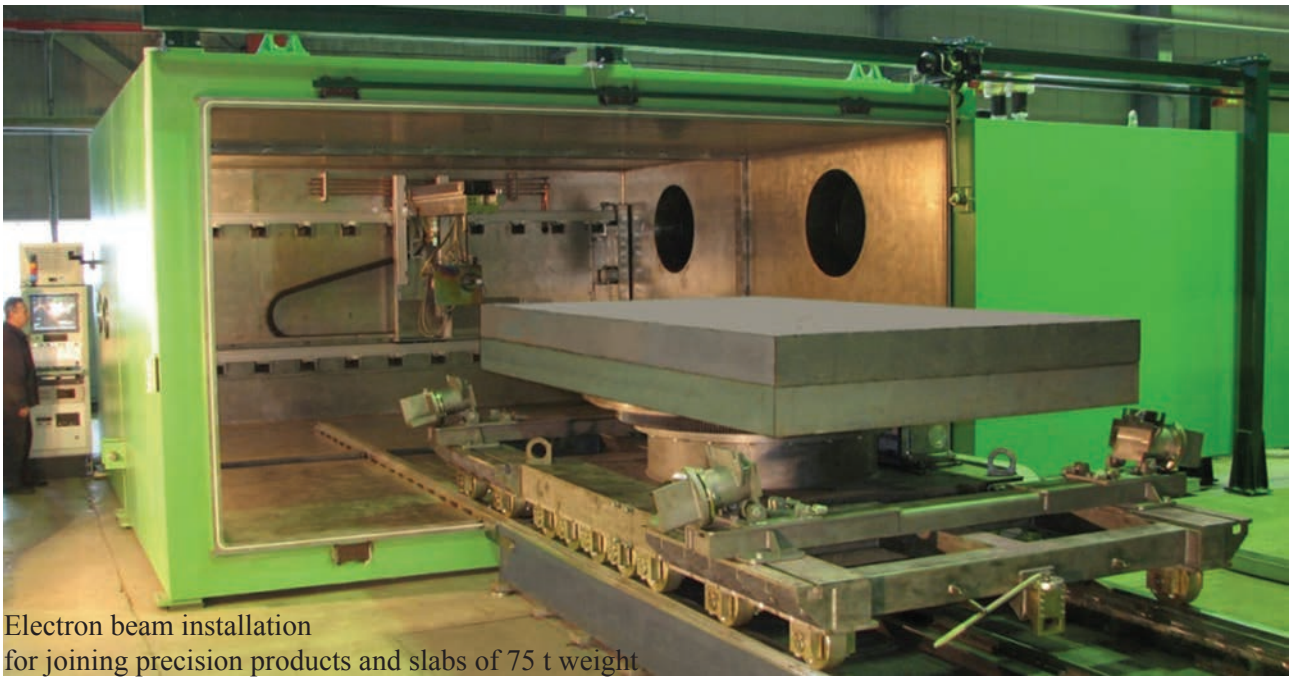
The presence of the 2000 m^2 production area, equipped with a gantry crane with a lifting capacity of 5/30 tons allows performing assembly and adjustment of installations for EBW with a volume of vacuum chambers of up to 100 m^3. If dimensions or mass of the vacuum chamber are beyond the admissible limit for transportation, then it is divided into sections with corresponding connecting flanges. The use of a box-like structure of walls and doors instead of a conventional T-shape strucutre provides a two times higher moment of inertia for the same thickness and, as a result, lower bending of the wall during pumping of the chamber. This, in turn, increases the accuracy of movement of the welding gun.

To control electron beam installations, distributed computer systems were developed and successfully used, for communication of whose elements industrial interface buses are used. For real-time monitoring and tracking of a joint, in the installations secondary emission RASTR electron systems are successfully used. The power complexes of electron beam installations have high-voltage power sources and welding guns of up to 120 kW at an accelerated voltage of 60−120 kV.

In addition to the typical nomenclature of installations for specific tasks of the Customer, namely, dimensions and shape of components to be welded, type and location of welded joints in the component, PWI designs and manufactures many variations of dimenisons of welding chambers, configurations of vacuum system, mechanism for moving electron beam gun and parts to be welded. Moreover, besides the equipment itself, the technology of welding structures is developed. It means that the Customer purchases the equipment together with the technology for EBW of specific parts.

By 2020, more than 150 sets of electron beam equipment have already been developed and delivered to different countries of the world. Our customers and partners are: Airbus Industry (France), Boeing (USA), British Aerospace (United Kingdom), Hitachi Works (Japan), MHI (Japan), GKN (USA), Halla Industrial Co. (South Korea), BIAM (China), The Harbin Institute of Technology (China), Doosan Heavy Industries & Constructions Co. (South Korea), Harbin Boiler Plant (China), SC SPKG «Zorya−Mashproekt», Lutsk Repair Plant «Motor», SE «Ukroboronprom», JSC «Motor Sich», PJSC «Poltava Machine-Building Plant», SE «Makarov Production Association Yuzhny Machine-Building Plant», SE Plant «Generator», etc.

Using the scientific potential of scientists of the National Academy of Sciences of Ukraine, the E.O. Paton Electric Welding Institute of the NAS of Ukraine is constantly improving the equipment and electron beam technologies in accordance with actual orders of industry.


Electron beam installation
for joining precision products and slabs of 75 t weight

RESEARCH AND PRODUCTION CENTER «TITAN» OF E.O. PATON ELECTRIC WELDING INSTITUTE

State Company «Research and Production Center «Titan» of E.O. Paton Electric Welding Institute of the NAS of Ukraine» was established in 1996, in keeping with the decision of academician Borys E. Paton, PWI Director, for research and production development of technologies and equipment in the field of electron beam melting of metals and alloys and their further introduction in the Ukrainian enterprises, as well as for intensification of research and experimental design work in the field of titanium metallurgy under self-financing conditions.

In the production facilities of SC «RPC «Titan» six electron beam installations are in operation, including: three electron beam installations, each of the annual capacity of 500 t; specialized electron beam installation of 1500 t annual capacity; electron beam installation for surface flashing of ingots of both round and rectangular cross-section; laboratory electron beam installation for development of new alloys, based on iron, nickel, titanium and other metals, as well as optimization of their production technologies.

The installations are fitted with axial electron beam guns Paton-300 of 300 kW nominal power, which have differential pumping that allows conducting the melting process in a stable uninterrupted mode.

In order to produce titanium alloy ingots, the following can be used as the initial charge: titanium sponge (briquetted, loose, unbroken blocks), titanium scrap, and alloying components in the form of master alloys.

SC «RPC «Titan» has introduced the technology of electron beam melting of high-quality ingots of titanium alloys, which contain inclusions of low and high density, of a guaranteed composition.

In order to reduce metal losses, SC «RPC «Titan», instead of machining, uses the technology of flashing the side surface of ingots of both the round and rectangular cross-sections. Application of the technology of electron beam melting of the ingot side surface allows removing the surface defects without machining the ingot surface that increases the metal yield up to 15 %, depending on ingot weight.

Each ingot is subjected to visual control and ultrasonic testing.

Electron beam installation UE5812

All-purpose electron beam installation UE5810

Electron beam installation UE121

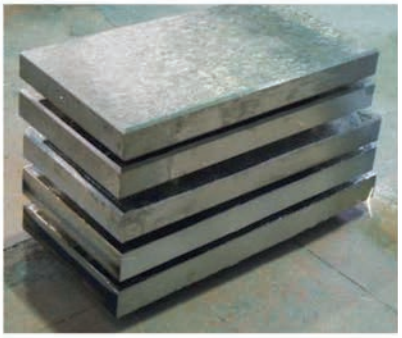
Electron beam guns Paton-300

Remelting sponge titanium briquettes into 400 mm diameter ingot of Grade 2

Producing 165×950×2500 mm slab-ingot of PT-3V titanium alloy

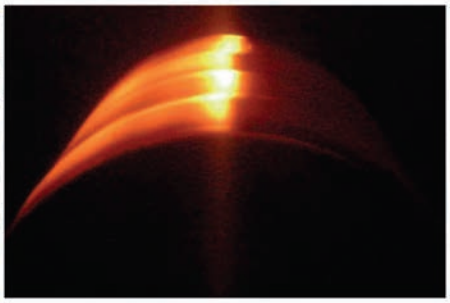
Titanium ingots of 100–600 mm diameter

Titanium ingot of 1100 mm diameter

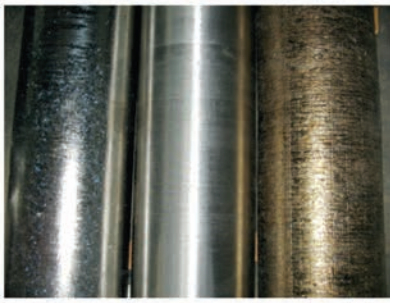


Titanium slab-ingots of 165×950×1500 mm dimensions

Electron beam installation UE185 for melting the ingot surface



Process of surface melting of titanium ingot of 1100 mm diameter



Titanium ingot surface: surface-melted; machined; cast

Product range of SC «RPC «Titan»

Range	Alloy grades
165×950×4000 mm; 150×530×4000 mm; diameter 80, 110, 150, 195, 300, 400, 500, 600, 830, 1100 mm, up to 4000 mm length	VT1-0, VT1-00, VT3-1, VT5, VT6, VT8, VT14, VT20, VT22, PT3V, PT7M, PT1M, 3M, ET3, Grade 1, Grade 2, Grade 5

Chemical composition of the ingots meets the requirements of national and foreign standards (DSTU, ASTM, AMS, etc.) Other alloy grades can be produced by agreement with the Customer.

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INTERNATIONAL CENTER FOR ELECTRON BEAM TECHNOLOGIES OF E.O. PATON ELECTRIC WELDING INSTITUTE

Technology of electron beam evaporation (atomization) and further physical vapour deposition in vacuum (EB-PVD) for producing thick films and massive condensates with specified structure and properties began to be developed at PWI under the leadership of Borys O. Movchan at the start of 1960s. Created during 1975–1991 at PWI, EB-PVD technologies and equipment (15 industrial multichamber units) were introduced in many enterprises of the Ministries of Aviation, Shipbuilding and Gas Industries for deposition of heat- and corrosion-resistant and thermal barrier coatings with an outer ceramic layer on gas turbine blades for various applications.

State Self-supporting Company «International Center for Electron Beam Technologies of the E.O.Paton Electric Welding Institute of the NAS of Ukraine» (ICEBT) founded in 1994, continues systematic research for creation of new materials and protective coatings, which are produced by application of EB-PVD technologies. Scientific fundamentals of EB-PVD technologies of producing amorphous, nanocrystalline, dispersion-strengthened, microlaminate, porous and gradient materials and coatings; specific technologies and new examples of EB-PVD equipment, which gained international recognition, are protected by numerous patents (USA, Europe, China), in particular joint patents with customers.

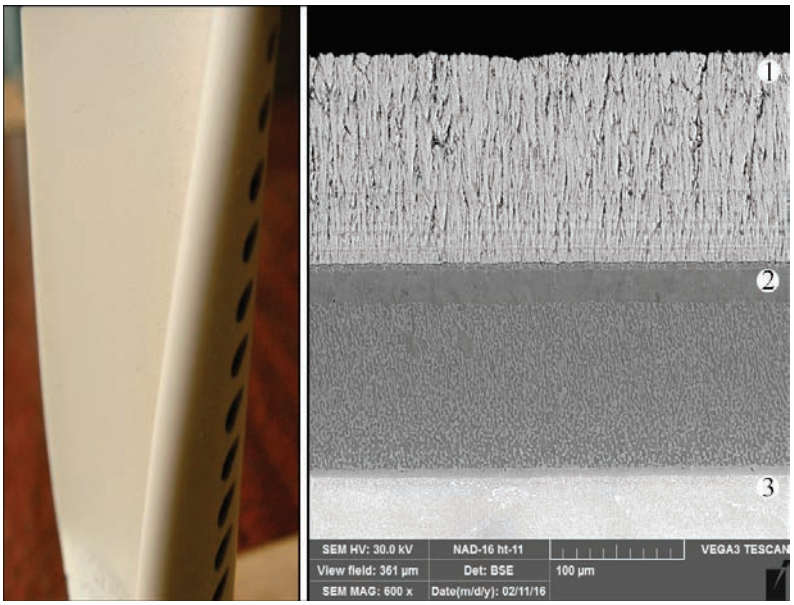
Developed at ICEBT technologies for deposition of gradient protective coatings provide a higher level of repeatability of the composition, structure and fatigue life, compared to coatings which are produced by the traditional multistage technology. For instance, the graded thermal barrier coatings of NiCoCrAlY(AlCr)/YSZ type for protection of gas turbine blades (see Figure), with ceramic layer thickness of approximately 160 μm have a low level of heat conductivity (approximately 1.2 W/(m.K), and their thermal cyclic fatigue life is 2–3 times higher than that of the traditional thermal barrier coatings.

Technology of deposition of multilayer damping/erosion-resistant nanostructured coating for protection of parts from titanium- and aluminium-based alloys was developed.

The main ICEBT customers for fulfillment of research contracts are foreign companies and research centers of the USA (General Electric, Pratt&Whitney, Honeywell, Pennsylvania State University), Canada, Japan and India.

Active cooperation was established with the enterprises and organizations of the People's Republic of China. Here, both the equipment and advanced technologies are proposed to all the customers. Over the recent years, 4 licenses for the right of industrial use of patents for deposition of thermal barrier coatings were sold to PRC, together with 6 electron beam units, and training and upgrading of the qualifications of Chinese engineers and technicians was performed.

It should be noted that the first EB-PVD unit, designed and manufactured at ICEBT at the end of 1990s, was supplied to Beijing (Beijing Institute of Aeronautics and Astronautics). All together, ICEBT designed, manufactured and supplied to Chinese customers 13 EB-PVD units, which are operating both at research organizations (Beijing Institute of Aeronautics and Astronautics,



Appearance and microstructure of gradient thermal barrier NiCoCrAlY(AlCr)/ZrO_2–8 % Y_2O_3 coating on a blade of gas turbine engine:

1 — outer ceramic layer of ZrO_2–8 % Y_2O_3;

2 — heat-resistant NiCoCrAlY layer with AlCr gradient zone;

3 — high-temperature alloy

EB-PVD units developed and manufactured at ICEBT, are operating in PRC, USA, Canada and India

Beijing Aeronautical Manufacturing Technology Research Institute, Beijing Institute of Aeronautical Materials), and at industrial enterprises in the cities of Xi'an, Guizhou, Shenyang, Chengdu.

In 2019 the license for the use of the technology of high-rate EB-PVD of corrosion-resistant alloys for deposition of protective coatings was purchased by SC SPKG «Zorya–Mashproekt» (Mykolaiv), and joint research is continued on improvement of composite coatings of metal/ceramic type, which are used in this enterprise.

ICEBT is developing variants of hybrid EB-PVD technologies, which combine the physical and chemical processes of deposition of inorganic materials in vacuum. EB-PVD hybrid nanotechnology and the respective equipment are a real basis for further progress of science and technology and economy, in order to produce protective coatings in different sectors of modern mechanical engineering.

Over the recent years, a new direction began to be developed at ICEBT, alongside the above-mentioned traditional areas of technology, namely EB-PVD technology of deposition of nanostructured coatings («islet» and continuous) on powders and granules of various materials.

All together, over the 25 years of ICEBT existence 17 EB-PVD units for various applications have been manufactured and supplied, and 6 licenses for the right of industrial use of patents for protective coating deposition have been sold to foreign customers (PRC, USA, Canada, and India). The new generation units proposed to customers, are fitted with modern Western vacuum components, improved electron beam projectors with cathode life extended up to 100 h, stabilized high-voltage power source that corresponds to the European standard CEI 61000-3-4, and modern industrial computers for the control system.

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PATON TURBINE TECHNOLOGIES

Paton Turbine Technologies LLC (PTT), being the assignee of «Pratt & Whitney-Paton» (PWP) marked its twenty-fifth anniversary in 2018.

At the start of 1990s, United Technologies Corporation (UTC), one of USA largest financial-industrial groups, addressed B.E.Paton with the initiative to create a scientific-research center for further advance of scientific developments in the field of EB-PVD technology, started earlier at PWI under the leadership of such well-known scientists as B.E. Paton, B.O. Movchan, I.S. Malashenko, V.O. Timashov, and oth.

The main specialization of the established Joint Venture consisted in improvement and adaptation of the production of thermal barrier coatings (TBC) for the world market (Figure 1). TBC application is one of the ways to improve the service life of components of the turbine hot section and more efficient operation of gas-turbine units (GTU). In combination with internal cooling, TBCs provide a lowering of temperature on the base alloy surface, and, hence, allow raising the turbine inlet gas temperature, thus increasing its efficiency, and also promote protection from external erosion impact and prevent metal degradation under the impact of the external gas environment, thermal and residual stresses. International experience of the last decades, particularly in the aviation industry, confirmed the rationality of application of electron beam physical vapour deposition (EB-PVD) in vacuum, in order to produce thermal barrier ceramic coatings with a columnar rather dense structure of formed crystallites. This is exactly the structural feature that ensures a fatigue life margin of the ceramic coatings at varying thermal cyclic loading in operation (Figure 2).

The process of formation of electron beam thermal barrier coatings on a heat-resistant bond coat was mastered at PWI. Further successful development of the technology led to formation of a regular thermally grown oxide layer (TGO) on the boundary with the metal interlayer during ceramics deposition. It was developed and certified due to the efforts of Ukrainian and USA specialists of Pratt & Whitney-Paton.

At the start of its activity, Ukrainian-USA Joint Venture Pratt & Whitney-Paton entered into production and intellectual cooperation with Pratt & Whitney Company, which together with British Rolls-Royce Company and USA General Electric belong to the «big three» of aircraft manufacturers.

Just one year after the Company was established, manufacture of high-tech electron beam equipment for the USA partners began in Kiev, which was stage-by-stage placed and upgraded in the USA and Singapore.

In 1998, EB-PVD ceramic coating was first deposited on blades of the first stage of PW 4000 aircraft engine, some series of which were designed for Airbus A300-600, Airbus A310-300, Boeing 747-400, at RC Pratt & Whitney-Paton in Kiev. Now the Company achievements include formation of coatings on the components of CF-6 aircraft engines, produced by GE Aviation for Airbus A300/310/330, Boeing747, Boeing 767; CFM-56 produced by CFM International (joint

Figure 1. General view of the Company production facilities: *a* — coating shop, *b* — shop for repair of gas turbine engine components

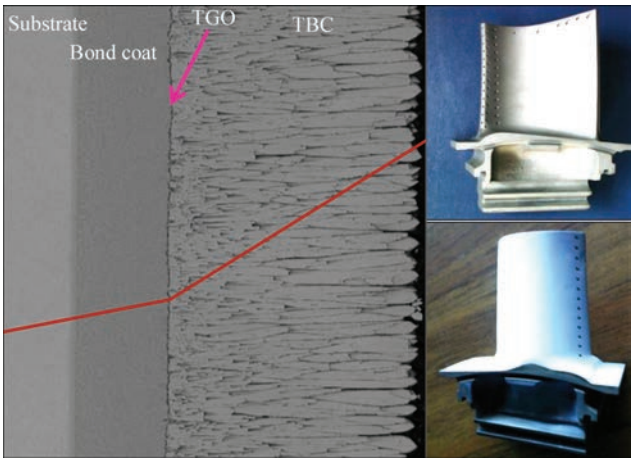


Figure 2. Thermal barrier coating and appearance of blades with metal and ceramic coatings

venture of Safran Company and USA General Electric) for Airbus A319/320/321 and Boeing 737. Over the last thirteen years the coatings were successfully deposited on more than 280 thou blades and 18 thou rings of additional power units APU 131-9 Honeywell.

Another important page in the history of PTT development is long-term cooperation with Siemens Industrial Turbomachinery AB Division (Swedish Branch) on deposition of thermal barrier coatings on blades of SGT 800 turbine (nominal power of 47/53 MW). By the level of pollutant emissions into the atmosphere at 50 to 100 % load it was noted by experts as the best among the medium-power generating turbines. The active cooperation phase started in the first quarter of 2006, and during this time EB-PVD metal and ceramic coatings were deposited on more than 60 thou blades of SGT 800 turbines of four different generations. Here, the production efficiency was higher than 99.8 %. And now Paton Turbine Technologies, as a leader in thermal barrier coating sector, is developing and testing original coatings for a new generation of single-crystal blades of 1-st stage of the modified SGT 800 turbine, which will be marketed this year.

At present thermal barrier coatings on various types of base alloys and metal layers are produced at PTT by EB-PVD method. Today TBC are deposited on a wide range of blades and vanes, made from high-temperature nickel alloys of equiaxial, directional crystallization and single-crystal alloys of different generations, for instance, MAR M-247, CMSX-4, PWA-1484, Rene-5, CM-186LC, IN-939, ZhS-32, ZhS-36, etc. Used as bond coats are metal layers of MeCrAlY (+Hf, Si) systems, formed by the methods of EB-PVD, high-velocity flame spraying in an oxygen-containing atmosphere (HVOF), plasma spraying in low vacuum (LPPS); aluminide NiAl and platinum-aluminide (Pt, Ni)Al coatings (Figure 3).

In addition, the majority of them are now produced in Kiev. Development strategy of Paton Turbine Technologies reflects targeted diversification for creation of a production complex, which helps producing various types of coatings or their systems. These coatings are used for the components of hot section of turbines in gas turbine engines. The composition and method to produce metal coatings are selected, depending on their functional features, and base alloy type of the component to be coated. It is important to note that testing coated samples for thermal cyclic fatigue showed that some systems of thermal barrier coatings provide the fatigue life of more than 3700 thermal cycles at maximum temperature of 1100 °C.

Our Company experienced periods of ups and downs, and 2014 was a quite serious challenge, when USA partners withdrew from RC «Pratt & Whitney-Paton» and its assignee — Paton Turbine Technologies Company was organized on its base. Owing to the support of PWI and Institute directorship personally, as well as maximum interest of the new PTT partner in the development of Paton Turbine Technologies, the Company received an impetus for further growth, and reaching new horizons, both in commercial production and in mastering advanced technologies.

At present, owing to the knowledge, creative approach and proper organization of production, the EB-PVD units manufactured at Paton Turbine Technologies/Pratt & Whitney-Paton, continue operating successfully to fulfill the aviation industry orders in the USA and Singapore. International cooperation with Siemens Industrial Turbomachinery AB, Honeywell, Meyer Tool, Inc., and Kawasaki Heavy Industries, Ltd. Companies continues to develop. For international positioning of the Company, it is important to note that PTT is included into the data base of Siemens Industrial Turbomachinery AB as a qualified and approved supplier (SIT Approval Supplier Data Base (ASD) SQ).

The high level of the Company was confirmed by ISO 9001, AS 9100, ISO 14001, FAA, and NADCAP certificates, which are revalidated on a regular basis.

The Company purposefully maintains a high level of production organization, which was established by USA partners. In 2009 Pratt & Whitney-Paton reached the Silver Level in ACE system (Achievement of Competitive Excellence) within the United Technologies Corporation, and Paton Turbine Technologies continues maintaining the operation of all the key elements of the system up to now.

Stable and confident development of Paton Turbine Technologies is also reflected in the Company personnel policy. Over the last three years, 67 workplaces

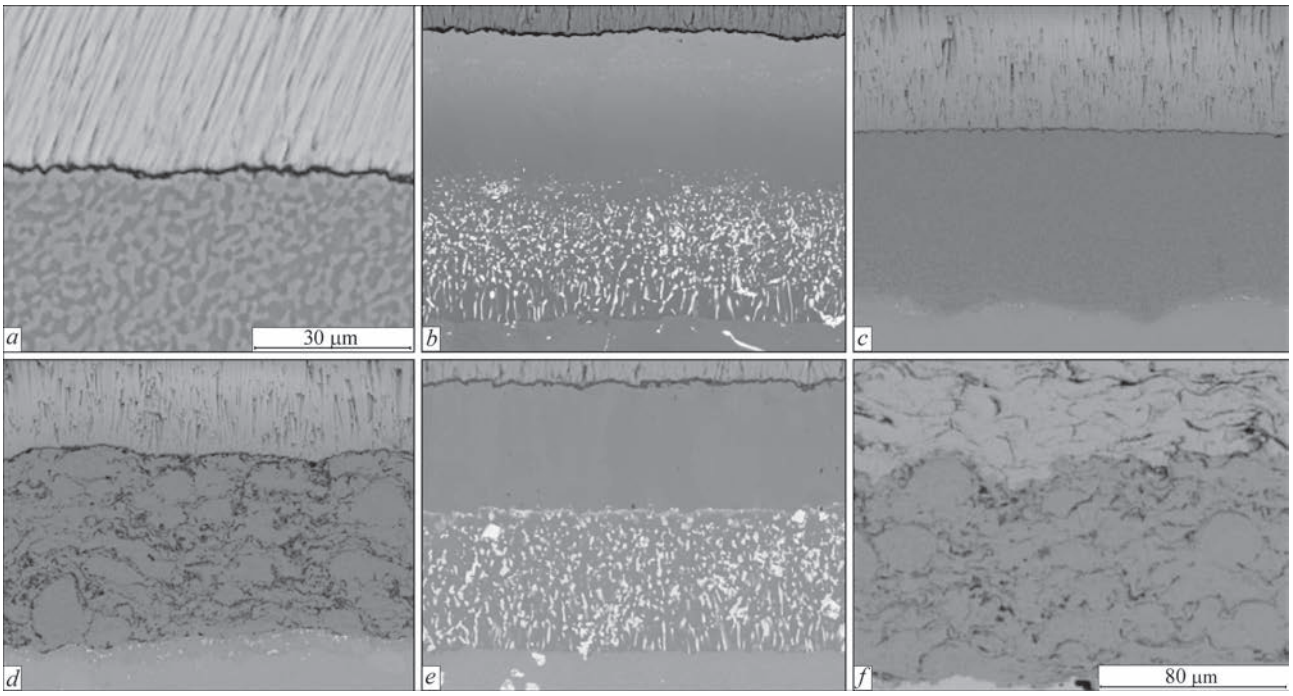


Figure 3. Different types of bond coats in thermal barrier systems of coatings produced by EB-PVD: (*a*–*e*) and APS: *a* — EB-PVD; *b* — PtAl; *c* — LPPS; *e*, *f* — HVOF; *e* — NiAl

were additionally created (more than 50 % Company growth, compared to 2014). Here, the number of employees with higher education is more than 2/3 of the Company total staff. A significant rejuvenation of the workforce took place.

During development of EB-PVD coating technologies more than 25 different patents were granted over the twenty-five year history. Here, the patented technologies have been and are currently used in actual production. Paton Turbine Technologies/Pratt & Whitney-Paton developed and registered Company Specification both for metal PWP-400 (18 coating types) and for ceramic coatings — PWP-100.

Together with development of «traditional» areas, the scientific and technical units of Paton Turbine Technologies continue investigations in the field of creating fundamentally new types of protective coatings. To the Company's credit are the new types of advanced MeCrAlY coatings, produced by EB-PVD of the coating alloy with addition of alloying elements. Development of ceramic coatings was continued in the application of new materials, based on a mixture of REM oxides. Such materials have the heat conductivity below that of standard ZrO_2-Y_2O_3 ceramics. Application of EB-PVD of such materials allows producing new generation ceramic coatings, which is exactly realized in PTT.

Focusing on the realities of the market of protective coatings for aircraft engines and industrial gas turbines, alongside EB-PVD of MeCrAlY type coatings, the Company began actively developing and using other methods of protective coating deposition. Platinum-aluminide coatings are widely used as a metal bond coat for GTE first stage blades. These coatings are a separate group of platinum-modified aluminide coatings.

Our Company achievements already include thermal barrier coatings deposited on platinum-aluminide coatings of the Customer for the aircraft engine blades, the fatigue life of which exceeded 1000 thermal cycles. Starting from 2018, a platinum electroplating section was set up and has been operating in the Company. It is fitted with competitive Ukrainian equipment. This year we will finish setting up the laboratory and will commission the production section for gas-phase aluminizing, based on available equipment, upgraded in the Netherlands. This will widen PTT production line as to producing aluminide and platinum-aluminide coatings for foreign and Ukrainian partners. It is important that the result of long-term study of the properties and features of forming platinum-aluminides was the developed at Paton Turbine Technologies optimum composition of the coating, which, as the bond coat, ensures formation of reliable thermal barrier systems with sufficient service life, both on equiaxial crystallization alloys, and on single-crystal alloys of different generations (Figure 4).

As alternative and less expensive methods of coating deposition, Paton Turbine Technologies production complex developed and introduced coatings produced by the methods of HVOF and APS (air plasma spray). Processes of thermal spraying are widely

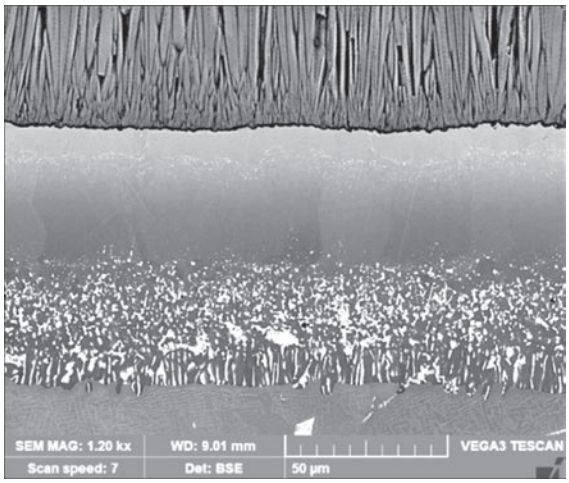


Figure 4. Structure of platinum-aluminide coatings formed as a bond coat in the system of thermal barrier coating deposited by EB-PVD

applied for deposition of thermal barrier coatings and bond coats for components of engines and land gas turbines. These deposition technologies are popular from the viewpoint of cost, as well as due to the simplicity and repeatability of the process. HVOF process allows forming rather dense coatings of NiCoCrAlY (+HF, Si) system (with less than 2 vol.% porosity), which due to the features of the lamellar structure and alloying complex demonstrate good resistance to high-temperature oxidation and thermal stability, that allows applying them both as independent protective coatings, and as bond coats for thermal barrier coatings, deposited by APS method (Figure 5). In terms of cost, APS-coatings, which are produced in air or shielding atmosphere, are more profitable in commercial use for components of industrial and power turbines, and provide a fatigue life of more than 1000 thermal cycles. TBCs deposited by this method have low heat conductivity.

APS unit was also used for development of a method of producing abradable ceramic coatings of ReSZ system: they are used in the turbine flow section to minimize the radial gap above the blades, in order to reduce the gas losses and increase the turbine effectiveness. These coatings have sufficient erosion and corrosion resistance, heat resistance, proper porosity (>20 %), etc. In the case of the blade interaction with the casing, the coating protects the blade and the casing from serious damage, improves the turbine efficiency and reduces fuel consumption.

It should be noted that Paton Turbine Technologies performs new developments, aimed at further progress of modern technologies, their adaptation in production not only for the aerospace industry, but also for other sectors, in particular, transport engineering, metallurgy, and chemical industry.

At present, producing wear-resistant coatings is in great demand with different customers in the market. Using the HVOF unit, PTT started really applying the method of high-velocity thermal spraying of wear-resistant, corrosion-resistant and antifriction coatings of the type of WC, Cr, C_2, Mo, PG-10N-01, etc., for rotation products and on flat abradable surfaces (Figure 6).

In 2006 Pratt & Whitney-Paton began developing a new direction, namely repair of gas turbine engine components. Now, a separate shop is functioning in the production complex, which performs comprehensive repair of both serial batches of aviation products, and of individual components. Advanced methods of blade repair include welding and brazing to extend the operating life of blades of turbines and gas-turbine units as a whole. At reconditioning products after service most attention is given to high-temperature brazing in vacuum. Diffusion brazing of high-temperature nickel alloys as to its technological capabilities is equivalent to argon-arc welding and provides the required physico-mechanical properties of the joints.

The entire repair cycle includes the operations on product cleaning, removal of used coatings, machining and heat treatment, operations of cladding,

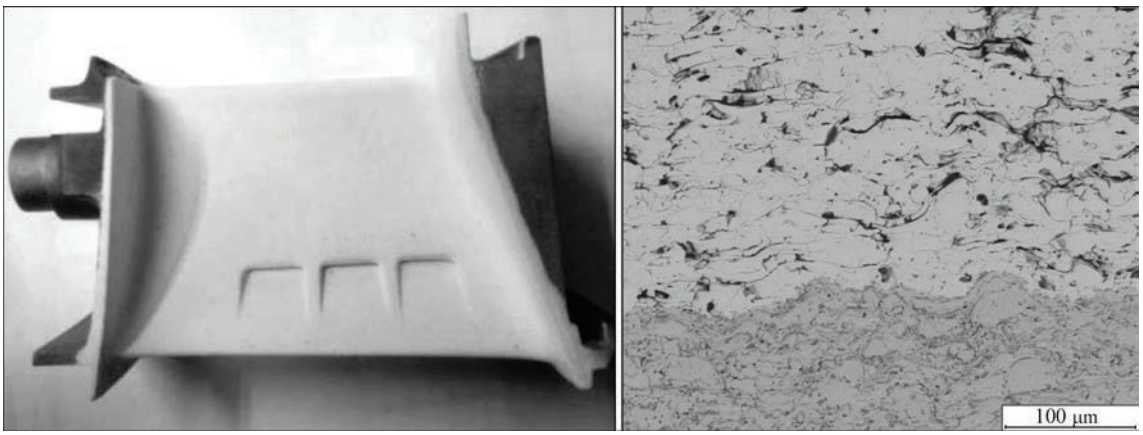


Figure 5. Blade with thermal barrier coating, produced by the methods of HVOF/APS and structure of the interphase between the metal (HVOF) and ceramic (APS) layers of TBC system

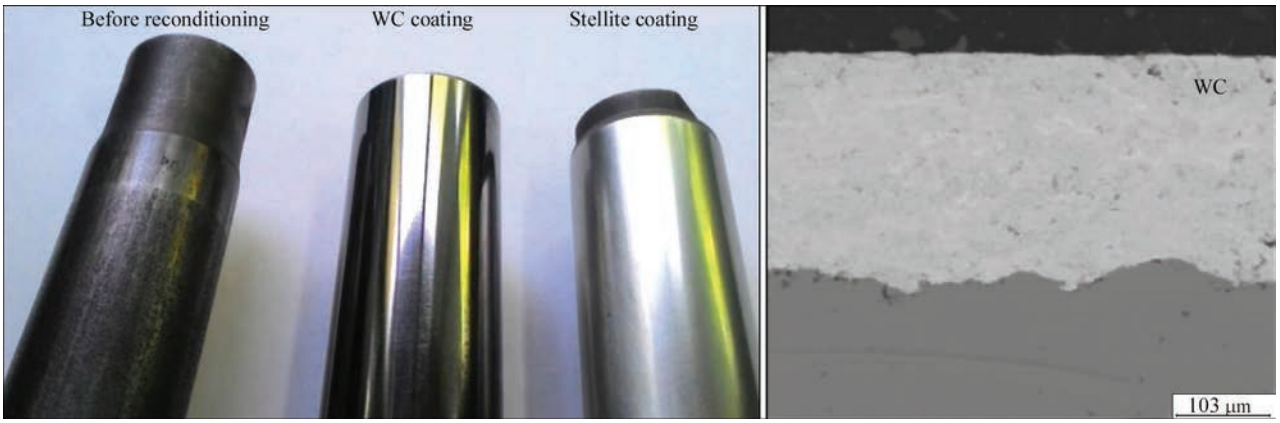


Figure 6. General view of the shaft after operation and reconditioning with deposition of wear-resistant coatings of WC and Stellite type, and microstructure of WC coating

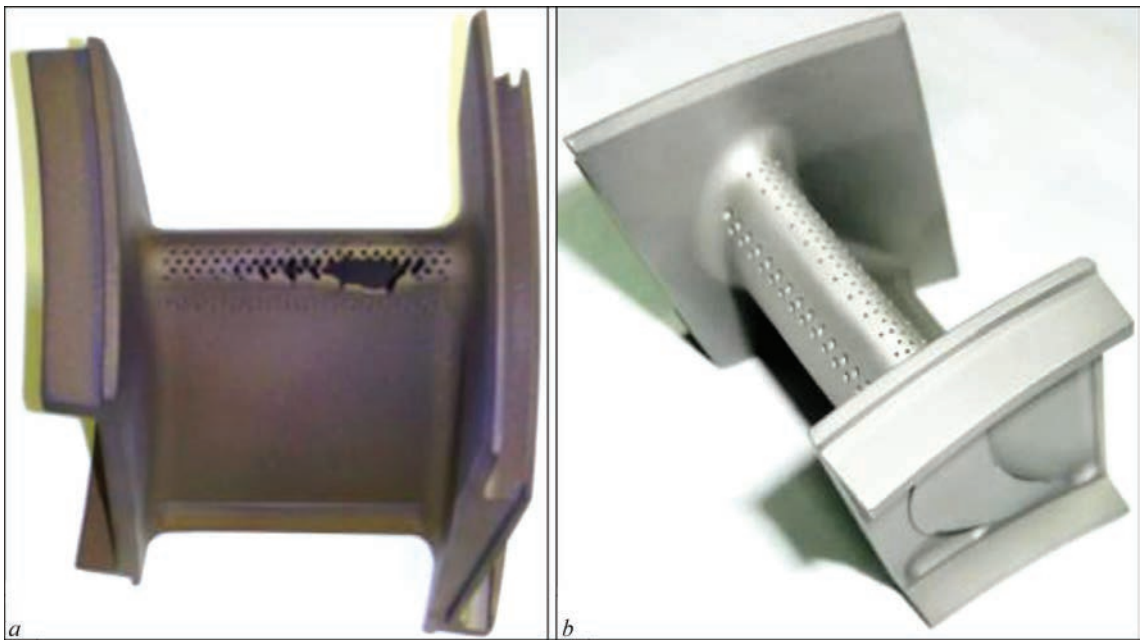


Figure 7. General view of the nozzle blade after operation with burn-out on the leading edge (*a*) and after reconditioning for further operation (*b*)

brazing, restoration of the dimensions and profile, coating deposition, hardening, etc. The main attention is given to combining higher strength and low-temperature ductility of the repaired areas, and ensuring heat resistance of base alloys of the reconditioned products. Paton Turbine Technologies

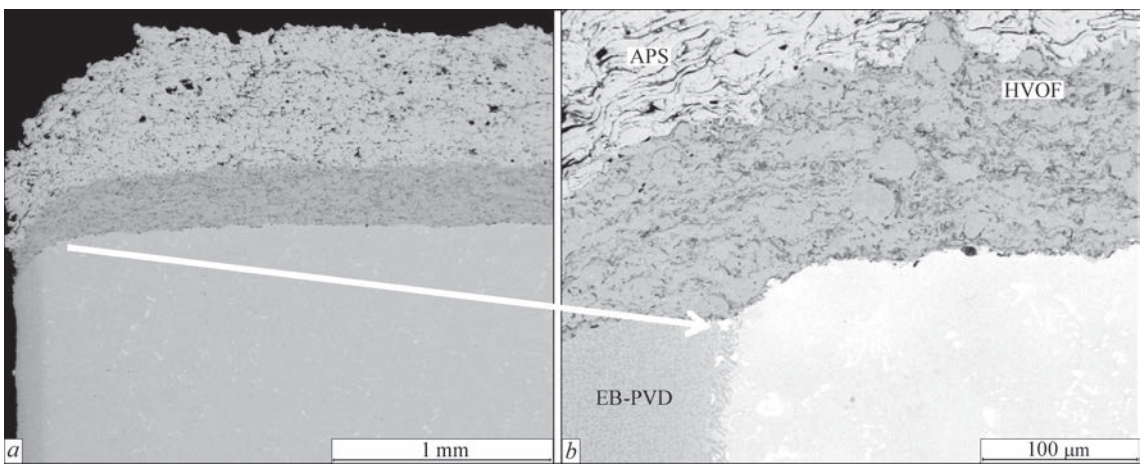


Figure 8. Combining various coating types on the tip of power turbine airfoil: *a* — fragment of airfoil; *b* — joint line of two types of protective and thermal barrier coatings

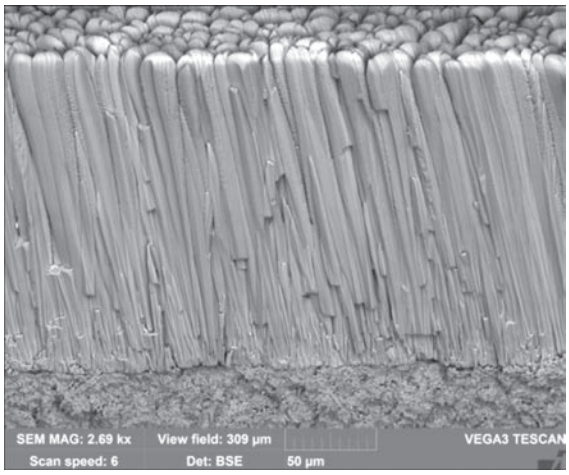


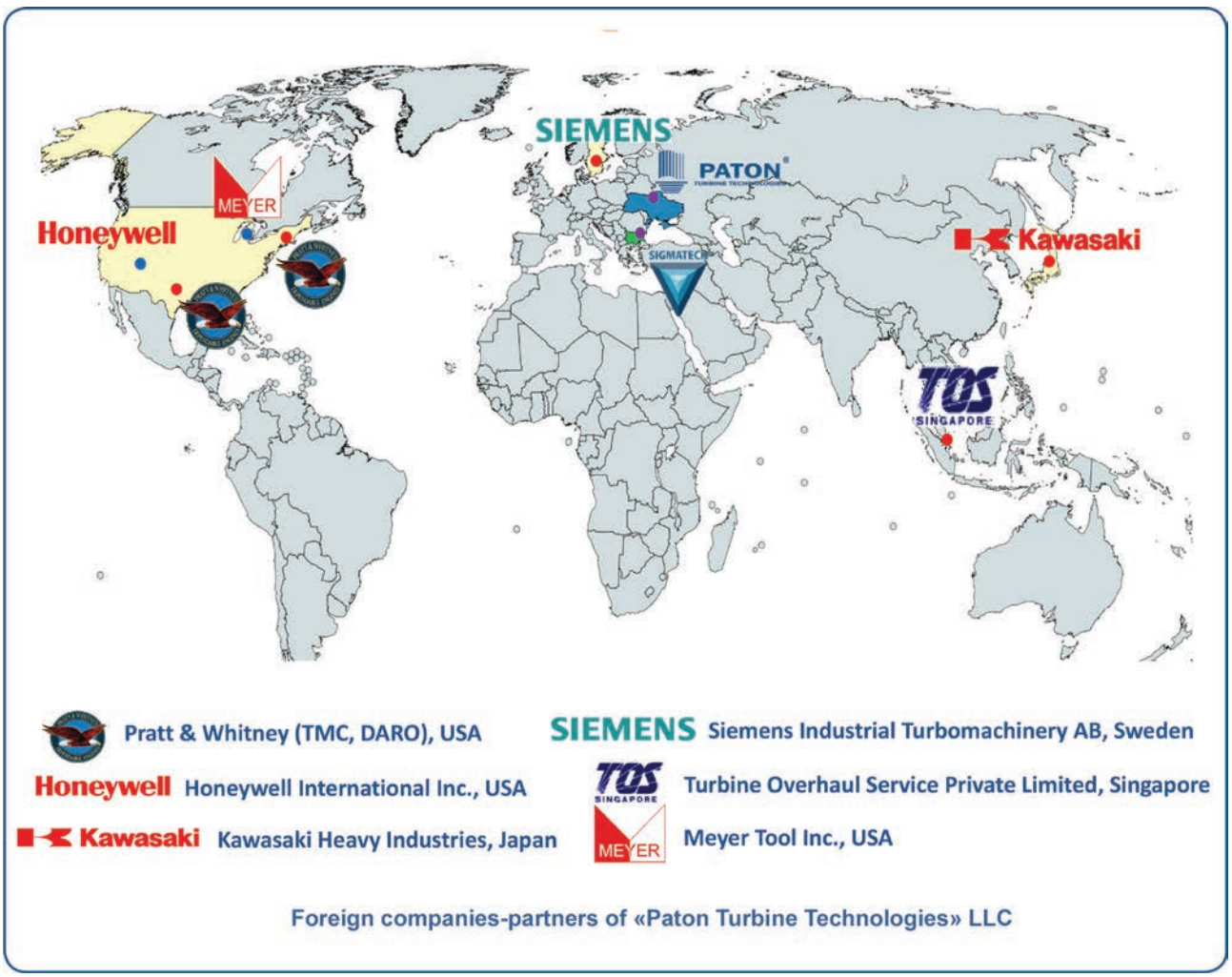
Figure 9. Classical columnar structure of thermal barrier coating produced by EB-PVD

performs reconditioning of components of RD-33, AL-31, D 30KP, D 36, TVZ-117, DSU GTDE-117 aircraft engines and industrial gas-turbine units, GTK 10-4, GTK 10I, MS 3002, DR-59, etc.

In order to repair burns-through, mechanical and corrosion-erosion damage, crack «healing» and restoration of the dimensions of blades, segments and other gas turbine components, multilayer preforms or composite filler metals are now used, which ensure optimization of the processes of formation of sound strong welds with sufficiently high physico-mechanical characteristics. The new mastered cladding and brazing technologies allow repairing the casting and service extended developed defects (cracks, burns-through, fusion, degradation, etc.) of the components of GTE hot section (Figure 7).

Having the knowledge, skills, experience and production capacity, PTT now conducts the entire complex of reconditioning of gas turbine engine components after service, and performs the full cycle of repair and deposition of various types of coatings, required for this product type (Figures 8, 9). This method includes expert assessment, fault detection, a set of thermomechanical operations, and testing. Thus, customer requirements are satisfied in «all inclusive» format, i.e. the entire reconditioning process is in one place.

Paton Turbine Technologies LLC is an example of successful adaptation and introduction of the achievements of fundamental science into production, development of modern technologies, and moving forward, while taking into account the urgent needs of the society.



Continuous way to improvement lasting more than 60 years

PILOT PLANT OF WELDING EQUIPMENT OF E.O. PATON ELECTRIC WELDING INSTITUTE

On January 1, 1959, the Pilot Plant of Welding Equipment of E.O. Paton Electric Welding Institute was founded, whose main task was mastering the technology of production and manufacture of experimental models of the advanced welding equipment, which was developed at the EDTB and other structural units of PWI. From that moment, the continuous movement of the Plant towards recognized leadership in the field of production of modern welding equipment and materials began.

For more than 60 years of its history, the team of the Pilot Plant has made hundreds of thousands of units of welding equipment, in which the advanced developments of domestic scientists in the field of welding, surfacing and metal cutting technologies were embodied. The equipment produced by the Plant has been often used in as wide as possible range of conditions in different parts of the world: from deepwater welding for the facilities of oil and gas exploration to the first ever open space welding operations; from repair of ships in hot equatorial or humid tropical climates to welding pipelines in the Extreme North. All this helped to gain valuable experience, which provided a solid foundation for the Plant to take the leading positions at this market — today PPWE is the only plant in Ukraine capable of producing welding equipment with welding currents from 150 A for domestic consumers to 10000 A for giants of Ukrainian and world industry.

Today the products range of the Plant has more than 60 items, of which more than 30 models are inverter welding equipment, more than 15 models are conventional equipment and more than 10 grades of welding electrodes.

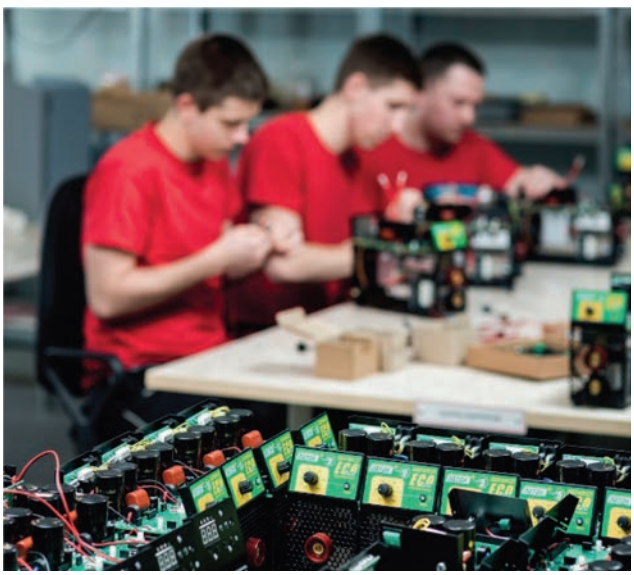
The inverter welding machines PATON™ occupy the largest part in the total volume of production of the PPWE equipment. They are commercially produced in the following categories:

- inverter rectifiers (welding currents from 150 to 500 A, operating from the power supply networks of 220 V/380 V);
- units for semi-automatic welding (welding currents from 160 to 500 A, operating from the power supply networks of 220 V/380 V);
- units for argon-arc welding (welding currents from 5 to 315 A, operating from the power supply networks of 220 V/380 V);
- multifunctional digital inverters (welding currents from 250 to 350 A, operating from the power supply networks of 220 V/380 V);
- units for air-plasma cutting.

For the most complete compliance with the market requirements, most units from the range of inverter equipment are produced in several series: units of general-purpose and professional series, which allow welding under particularly rigid working conditions.

Also, at the demand of ever-increasing customer requests, the Plant is actively working on expanding its range and modifying its existing models. Over the last year, the designing of the inverter rectifiers and semiautomatic units with a rated welding current of up to 500 A and the argon-arc inverter for welding with both direct and alternating current up to 315 A was completed and all were put into production. Already in 2020, it was already decided to replace the models of units with the currents of 315 and 250 A powered by a three-phase network with more powerful models of 350 and 270 A, respectively. The development of a new perspective model of unit for plasma-cutting with a rated current of up to 100 A is at the final stage.

In the production of units the most updated and high-quality components from the world's leading



manufacturers like INFINEON, VISHAY, KENDEIL and NXP are used and the units of professional series are equipped with accessories from a well-known German manufacturer Abicor Binzel. All this allows the Plant to produce «extra-class» products, the highest quality of which is reflected in the extended warranty period of up to 5 years.

The welding electrodes PATON™ also occupy a large part in the overall structure of the products manufactured by the Plant. Today, 12 grades of welding electrodes with both classic and improved composition are manufactured. And taking into account the variety of diameters and packaging variants, the number of assortment items in this category of products exceeds 50. The production uses modern technologies and rigid input quality control of raw materials, and a professional team of specialists constantly monitors the development of production of welding materials in order to timely introduce innovations.

The welding electrodes PATON™ meet all necessary requirements to products of this type and are regularly certified by relevant Ukrainian and international certification centers. In 2018, these products were certified to meet the EU standards requirements and regular deliveries of electrodes to the markets of European countries began and in 2019 a certificate was received that the manufacturing process was in compliance with the high standards of ISO 9001:2015.

This area of work of the PPWE is actively developing — today the process of organizing a new area for the production of welding electrodes PATON™ in Kyiv is at the final stage. After completion of commissioning works, several production lines of a new area will be able to provide the production of up to 600 t of welding electrodes per month. In addition to the production departments, the new complex of manufacturing welding electrodes in Kyiv includes an analytical laboratory, a mechanical testing laboratory and a department for welding and technological testing. The set of laboratory equipment allows carrying out the complex input control of all raw materials, controlling the technological process of electrode production and performing acceptance tests of each batch of finished products. In the near future, it is planned to launch a line of experimental molds for the development of new grades of electrodes with improved welding and technological properties.

It is important to note that a considerable part of PATON™ products is already exported and namely this vector has been identified as one of the main ones in the Plant's development strategy. Over the last year, a number of countries at which markets the deliveries of the products were organized, has increased to 30. In particular, in 2019, deliveries of welding units and electrodes were organized to India, Sri Lanka, Egypt, Turkey and Burkina Faso. Negotiations about the start of deliveries in 14 more countries, including such European countries as Spain, Croatia, Macedonia and Bulgaria; Middle Eastern countries — Saudi Arabia, Pakistan, Israel, as well as Asian countries — Philippines and Singapore are underway at different stages. In view of such high interest to the products of the Plant, it can be stated that a high reliability, wide functionality and many unique technical characteristics allow the PATON™ welding equipment to compete successfully with the products of the leading world manufacturers at the markets around the world.

Namely the choice of the PATON™ products by both domestic and foreign welders makes the staff of PWI to be proud of its work and inspires them for new achievements!

ENGINEERING CENTER OF PRESSURE WELDING OF E.O. PATON ELECTRIC WELDING INSTITUTE

The Department of Butt Welding of E.O. Paton Electric Welding Institute of the NAS of Ukraine and the State Enterprise «Engineering Center of Pressure Welding NTC «E.O. Paton Electric Welding Institute of the NAS of Ukraine» for many decades have specialized in the development of technologies and equipment for flash butt welding (FBW) of rails of various grades as well as pipes of different diameters and assortments.

The State Enterprise «Engineering Center of Pressure Welding» was found in 1987 for industrial implementation and extensive mastering of the Institute developments.

The main activity of the Center is the production of basic models of machines, repair and modernization of the equipment for FBW of rails in the field conditions, as well as training personnel to work in the mentioned areas.

The technologies and equipment developed at the PWI and manufactured at the Engineering Center, have quickly found a widespread applicaiton on the railways of Ukraine and in the world. In the conditions of high global competition, this technology and equipment became interesting to the leading world railway companies from Austria, France, Japan, USA, China and other countries.

In the last decade, in many countries an intense reconstruction of railways and rail track is observed. In these works high-strength rails with the hardness of up to *HB* 400 are used. According to the technological conditions, it is required to obtain the strength of welded joints practically equal to base metal of the rail steel and high ductile properties. Such indices could not be obtained using traditional technologies. The PWI conducts systematic studies of weldability of new high-strength rails of different world manufacturers (Austria, China, USA, Ukraine, Japan) in order to develop welding technologies which provide the required mechanical properties. This raises the need for a significant change in the control systems of welding machines and designs of their individual units. In particular, it was found that for high-quality welding of high-strength rails it is necessary to significantly change the technology of contact heating and the design of a mechanical part of the machines, that provide an increase in the clamping forces by 1.5–2.0 times.

It is known that during the operation of a continuous welded rail, the fixed rails are subjected to stresses related to changes in temperature, i.e. under the influence of the environment. Their impact leads to defor-

Geography of deliveries of machines for welding rails

Machine K900

Machine K960

Machine K1045

mation of the track, violations of the set dimensions of the track and in critical situations to accidents.

As a result of the carried out developments, in leading foreign countries a new generation of welding machines and the technology, known as «pulsating flashing», were created and patented. The first machines of a type K900 and K920 were designed at the PWI and tested on the US railways together with «Norfolk Southern Corporation» and other US customers.

Over the past five years, a new generation of machines of a type K1045 and K960 for FBW have been developed at the PWI with the tension of rails of up to 1000 m length.

For today, the Center has a successful experience in welding rail sections with the use of the developed equipment and technology for metro in the USA, China, Singapore and other countries of the world. Moreover, joining is performed directly in the tunnels.

CHINA-UKRAINE E.O. PATON INSTITUTE OF WELDING

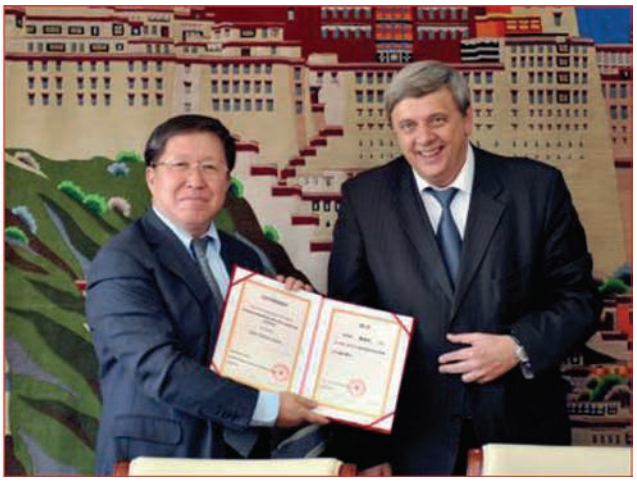
The China-Ukraine E.O. Paton Institute of Welding (CUPIW), found in 2011, is a platform for international scientific and technical cooperation in the PRC for implementation of the achievements and experience of the E.O. Paton Electric Welding Institute, other institutes of the NAS of Ukraine and enterprises in China and Ukraine, as well as for cooperation with Chinese partners on joint developments and organization of high-tech industries in the fields of shipbuilding, marine engineering, aviation, railway transport, production and transportation of oil and gas, power engineering, energy saving. This form of cooperation has no analogues in terms of the scale of already realised projects.

Currently, the China-Ukraine E.O. Paton Institute of Welding is a legal entity, acting under the Chinese law, which is a part of the Guangdong Academy of Sciences. All international cooperation activities within the framework of the CUPIW are funded by the Chinese side. The sources of funding from the Chinese side are applied projects of the central government of the PRC, the government of Guangdong province, the city of Guangzhou or state-owned industrial corporations, as well as joint-stock and private companies in the PRC. The financial support of the projects is carried out on a competitive basis, that is, in order to receive funding in China for each project, in the competition state institutions and enterprises of the PRC, as well as leading foreign companies in the field of welding and related processes, participate.

Within the framework of CUPIW, in the fulfillment of international projects a number of institutes of the NAS of Ukraine, leading technical universities of Ukraine, as well as large industrial enterprises and research and production innovation companies are involved. In particular, except of the E.O. Paton Electric Welding Institute of the NAS of Ukraine, the following academic institutes are involved in such cooperation: Frantsevich Institute for Problems of Materials Science, PTIMA. In the international projects within the framework of CUPIW, the following universities take the most active part: NTUU «Igor Sikorsky Kyiv Polytechnic Institute», Admiral Makarov National University of Shipbuilding. Also, for realization of production tasks, in particular for the production of critical units of high-tech equipment, CUPIW involves a number of industrial and scientific-production enterprises from different regions of Ukraine, in particular, from Kyiv, Dnipro, Kharkiv, Zhytomyr, Mykolaiv, Sumy and other cities.

Throughout the period of its activity, CUPIW in cooperation with the E.O. Paton Electric Welding Institute of the NAS of Ukraine (PWI) has realized several dozen major projects on modifying and implementation of the advanced developments of the PWI into industry. Among them the following could be mentioned:

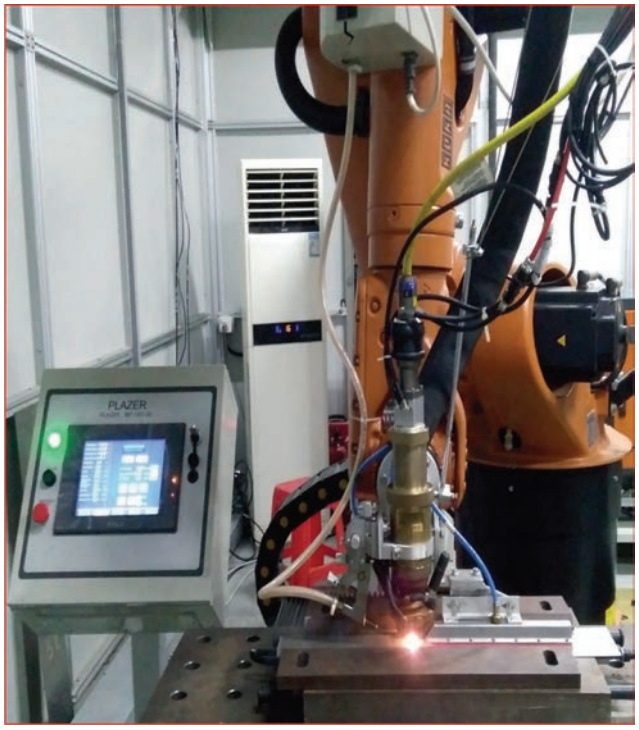
- development of universal equipment and technology for flash butt welding of structural steels, aluminum and titanium alloys and their industrial application;
- creation of new generation of equipment for flash butt welding of pipes (114–320 mm);
- development of technology and equipment for orbital welding of power equipment pipelines over the active flux layer (A-TIG);



Signing of official documents on establishment and organisation of activity of the China-Ukraine E.O. Paton Institute of Welding (2012–2013). From left — to right: Mr. Zhu Xiaodan, governor of Guangdong province; Academician B.E. Paton, President of the National Academy of Sciences of Ukraine, honoured Chairman of the CUPIW Board; Mr. Cao Jianlin, Vice-Minister of Science and Technology of PRC, honoured Chairman of the CUPIW Board; Academician I.V.Krivtsun, Deputy Director of the PWI, Chairman of the CUPIW Board

Equipment for narrow gap welding of long-length structures of titanium alloys of 20–120 mm thickness and up to 4 m length and welded product of titanium Ti4–Al–2V alloy of 120 mm thickness under the controlling magnetic field

● creation of technology and universal equipment for high-speed plasma as well as hybrid and combined (tandem) plasma-arc (Plasma-MIG) welding, its integration into a robotic complex;

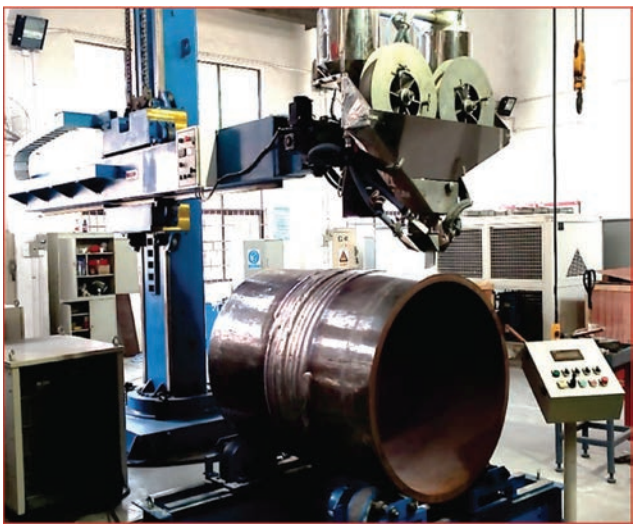


Robotic technological complex for high-speed hybrid laser-plasma welding

● creation of technology and new generation of equipment for microplasma and hybrid laser-microplasma pulsed current welding in different polar modes;

● creation of technology and equipment for automated arc welding of long-length structures (up to 4 m) of high-strength titanium alloys of large thickness (up to 120 mm) into a narrow gap in a controlled magnetic field;

● development of equipment and technology of electrodynamic treatment of welds of aluminum alloys for shipbuilding in order to effectively reduce and regulate welding deformations;



Electroslag surfacing of large-sized structures of the power equipment with the use of two strips

● development of technology and equipment for producing spherical shape powders from high-strength complexly alloyed titanium alloys using plasma processes;

● application of advanced electron beam technologies in turbine construction during producing billets of gas turbine blades by the method of hot isostatic pressing of powders (filling, degassing, compaction, sealing (welding) of containers with metal powder for further hot isostatic pressing);

● development of technology of diffusion welding of heat-resistant alloys based on Ni_3Al with controlled stress-strain state;

● improvement of equipment for high-frequency welding of living tissues, its adaptation to working conditions in the Chinese medical institutions;

● development of new titanium-steel plasma welding technologies and their testing in the production of bimetallic pipes for oil and gas transportation;

● creation of specialized equipment and technology of high-performance (up to 45 kg/h) electroslag surfacing with two strips of large-sized products of power equipment;

● creation of technology and equipment for high-performance plasma cutting of metals of increased thicknesses (up to 120−150 mm) on reverse polarity, its integration with systems of numerical program control in relation to the production of large-sized structures;

● development of new generation equipment for supersonic plasma spraying of heat-resistant, thermal-barrier, wear-resistant, corrosion-resistant and special coatings.

The China-Ukraine Welding Institute has a high authority in the PRC. The Government of the PRC highly appreciates the results of CUPIW's activities and the contribution of PWI to these activities. In particular, Ukrainian colleagues of PWI, who participated in the implementation of joint projects, were awarded more than ten governmental awards by the PRC, including the highest awards by the central government of the PRC.

Installation for electron beam welding for application in granular metallurgy

Awarding I.V. Krivtsun, Deputy Director of the PWI, 2019 (left) and V.M. Korzhyk, Chief of the PWI Department, Director of the CUPIW on the Ukrainian side (2014) the highest awards of the PRC Government — medals «For outstanding achievements in the international scientific and technical and economic cooperation»

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