BEGINNING OF THE ERA OF SPACE WELDING TECHNOLOGIES

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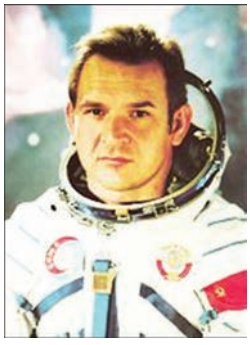
In October 16, 1969, for the first time in the world on the «Soyuz-6» space vehicle the USSR pilot-cosmonauts Georgy Shonin and Valery Kubasov conducted experiments on welding and cutting in open space using the universal automated unit «Vulkan».

Sergei Pavlovich Korolev, creator of practical cosmonautics, already in the early 1960s, specified the task before the E.O. Paton Electric Welding Institute to develop a program of experiments to perform welding and cutting in space. This research program, the ultimate aim of which was the creation of welding equipment and technologies for joining materials in space using welding, began to be realized in 1964, and in October, 1969, the experiments were conducted.

Georgy Stepanovich Shonin (1935–1997) — USSR pilot-cosmonaut, Hero of the Soviet Union

In 1957, he graduated from the Yeisk Naval Aviation School. He served in the Soviet Navy. In 1960, he was selected to the cosmonaut corps. In 1968, he graduated from the N.E. Zhukovsky Air Force Engineering Academy, Candidate of Technical Sciences. In October 11–16, 1969, he made a space flight as the commander of the «Soyuz-6» space vehicle. Since November, 1990, G.S. Shonin was reserved.



Valeri Nikolayevich Kubasov (1935–2014) — USSR pilot-cosmonaut, twice Hero of the Soviet Union

In 1958, he graduated from the Moscow Aviation Institute. In 1958–1966, he worked at the RSC «Energia». He was involved in designing of manned space vehicles. In 1966–1993, he was on the rolls in the cosmonaut corps. He made three flights into space (1969, 1975, 1980). In October, 11–16, 1969 he made the first space flight as a flight engineer of the «Soyuz-6» space vehicle (in the crew with Georgy Shonin). During the flight, for the first time in the world an experiment on welding in space was conducted. After leaving the cosmonaut corps, he continued his work in the RSC «Energia», and since 1997 he was a research adviser.

Automated welding unit «Vulkan»

The automated welding unit «Vulkan», in which experiments on welding and cutting in open space were conducted, was designed and manufactured at the E.O. Paton Electric Welding Institute.

In creation of the unit leading scientists, designers, technologists, assemblers of equipment and testers of the Institute took part. A great help in creating the unit was provided by the specialists of the S.P. Korolev RSC «Energia». It allowed performing fusion welding in three different methods: by a low-pressure arc with a consumable electrode, by a constricted low-pressure arc with a hollow cathode and an electron beam. The unit «Vulkan» consisted of two compartments. In a one (nonsealed) of them, devices to perform each of the mentioned welding methods and a rotating table with samples to be welded were located. During operation, in that compartment a low pressure — space vacuum was maintained. In another (sealed) compartment, an autonomous battery power source, a secondary power source (SPS was designed by the Institute of Electrodynamics of the NAS of Ukraine), control units and measuring instruments were installed. The unit was equipped with a remote con-

trol. The mass of the equipment is about 50 kg. The power of welding devices for different methods ranged from 0.6 to 1.0 kW.

The unit «Vulkan» was located in the airlock compartment of the «Soyuz-6» space vehicle. For the period of experiments, that compartment was depressurized. Inside the pressure was maintained close to the outboard pressure of $1 \cdot 10^{-4}$ mm Hg. During the experiment, the crew was in a sealed return compartment, separated from the airlock compartment by a closed hatch.

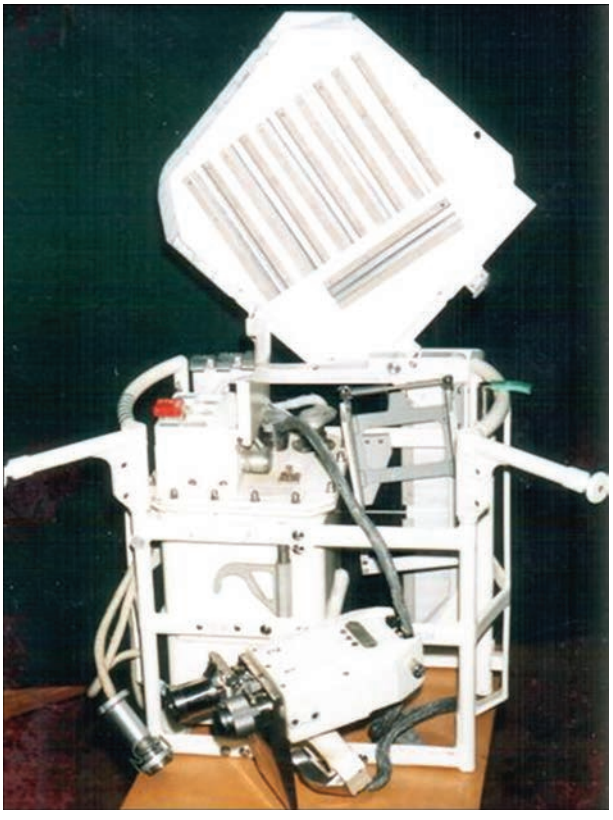
Kubasov V.N. and Shonin G.S. with the unit «Vulkan» before flight at the «Soyuz-6» space vehicle (1969)

Outer space, where manned space vehicles and stations fly, differs from the conditions on Earth by a number of so-called outer space factors and, first of all, by microgravity and space vacuum. Experiments on welding in space were a completely new direction among the works performed by our Institute. Therefore, when the directions of works on welding in space were determined, different types of welding both in the solid phase as well as fusion one were considered. But the most flexible and widespread types of welding works in space for performing possible assembly and repair-restoration operations are the methods of fusion welding. To apply welding methods that require the use of gases in outer space is very difficult. Outer space is a completely open infinite volume. Therefore, gas molecules are rapidly removed into outer space. Great difficulties also arise when using the method of arc welding with a consumable electrode in space. As the pressure of surrounding atmosphere decreases, the nature of arc discharge is changed. At low pressure, the plasma-forming substance is no longer gas, but fumes of filler and welded materials. Although the pressure of fumes in the region of the arc column is higher than the surrounding one, it is not enough to obtain a localized arc discharge. A great influence on the process of arc welding with a consumable electrode is exerted by microgravity. It complicates the transition of molten electrode metal into the weld, and the metal droplets located on the electrode can reach very large sizes. The problems discussed above are practically absent in electron beam welding. Space vacuum only contributes to a high-quality performance of electron beam welding, and microgravity does not significantly affect this process.

Paton B.E. and Kubasov V.N. near the unit «Vulkan»

The carried out experiments made it possible to establish that the most suitable type of welding in outer space is electron beam welding. It was found that during prolonged zero gravity and space vacuum, the processes of welding and cutting with an electron beam proceed stably and the necessary conditions for normal formation of welded joints and cuts are provided. Thus, the experiments carried out in

Set of the «Universal» equipment for manual electron beam welding



Universal manual tool (URI)

the unit «Vulkan» provided a wealth of information that allowed creating new models of space welding equipment in future and develop technologies for welding in space.

The carried out experiment started the era of space welding technologies.

The works on creation of equipment and technologies for welding in outer space were continued.

During the work in outer space on board a space vehicle, the most unexpected situations may arise that require the use of welding and related technologies, and often the type and scope of operations will have to be determined by cosmonauts directly in situ. They will have to work in different areas of a space vehicle and deal with different structural materials. For these purposes, at the E.O. Paton Electric Welding Institute a universal working tool (URI) was created. The tests of URI in outer space were carried out aboard the «Salyut-7» station by cosmonauts S.E. Savitskaya and V.A. Dzhanibekov. The carried out experiments on welding, cutting, brazing and coating showed good results and confirmed a high efficiency of the URI equipment in outer space.

The next generation of equipment for welding in outer space was the creation of the «Universal» equipment. Its main difference from the URI was the more than double increase in output power. In addition, a number of basic components was modified, which provided an increase in reliability of the tool. The «Universal» complex passed comprehensive on-land tests and was recommended for the use as a standard tool at orbital manned stations. Unfortunately, for a number of objective reasons, the «Universal» complex was not tested in outer space, although it was supposed to be tested both on board the space shuttle «Columbia» as well as at the «Mir» station.

Hand electron beam tool of a new generation

Analysis of the results of on-land technological experiments, conducted using the «Universal» equipment showed that it can be used to weld aluminum and titanium alloys, as well as stainless steel of up to 1.5 mm thickness.

At present, at the E.O. Paton Electric Welding Institute the works on creation of the next generation of electron

beam tool for welding in outer space are carried out, which includes triode electron beam gun, separated from high-voltage power source. The separation of electron beam gun from power source and the use of flexible high-voltage cable with small-sized high-voltage connector for this purpose makes it possible to significantly reduce the dimensions and weight of the tool, increase its maneuverability when carrying out technological processes in outer space, increase the duration of continuous operation and operational reliability, as well as to facilitate the replacement of tools for different technological purposes directly outboard the space vehicle.

In electron beam tool of a new generation, the power was significantly increased — up to 2.5 kW, which allows welding aluminum and titanium alloys, as well as stainless steel with a thickness of 6 mm. The electron-optical gun system allows obtaining a sharply focused beam with a diameter of not more than 0.6 mm. The mass of the gun is 2.5 kg (twice lower than in the «Universal»). The life of cathode is significantly increased and is equal to 30–40 h. The replacement of a worked out cathode unit can be performed in orbit during 5–10 min. The tool is provided with the possibility to operate not only in manual but also in automatic mode using robotic devices or manipulators.

Recently, all over the world the works related to exploration of the Moon are carried out. At the E.O. Paton Electric Welding Institute, the equipment is developed to perform electron beam welding under the conditions of the Moon surface when creating long-term lunar bases and infrastructure for these constructions. Taking into account special physical conditions on the Moon surface, first of all, ultrahigh vacuum (up to 10^{-13} mm Hg), the necessary sealing of joints can be reliably secured only by welding. Therefore, the creation of welding equipment and technologies for assembly and repair-restoration works on the Moon surface is very relevant during its exploration by a human. In addition to ultra-deep vacuum, there are other physical features on the surface: a sharp change in temperatures from +140 °C at day-time to –170 °C at night, reduced gravity (1/6 of gravity on Earth), lunar dust (regolith), etc. All these features should be taken into account when developing both welding equipment as well as when creating auxiliary devices — workplace of the operator. In the developed design of a gun the conditions for electron beam formation in an ultra-deep vacuum were taken into account, which differ significantly from those in on-land vacuum installations and in near-Earth space, where space vehicles and manned space stations fly.

We are convinced that space welding equipment and technologies, the foundation of which was laid 50 years ago by the «Vulkan» experiment, will find application in different projects during construction of industrial complexes on Earth orbit, exploration of the Moon and flights to other planets, and also on the study of fundamental space phenomena.