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WORKPLACE OF A COSMONAUT-WELDER FOR WELDING OF OBJECTS ON THE SURFACE OF THE MOON

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ABSTRACT

When permans explore the Moon, not only the development of specialized electron beam welding equipment, but also auxiliary equipment, which is the workplace (WP) of a cosmonaut-welder, is very relevant. The paper describes the working project for the manufacture of the cosmonaut-welder WP, which is adapted for performing electron beam welding and related technologies with a hand tool in Earth orbit and on the surface of the Moon. The development of the WP took into account the peculiarities of the surface of the Moon and, first of all, the reduced gravity compared to the Earth, low temperature, and the presence and action of lunar dust (regolith). It is shown that the main technical characteristics of the cosmonaut-welder WP are: transport dimensions, mass characteristics, service area, selection of the chassis design of the mobile WP, as well as the specific choice of the electric drive and its power supply (autonomous, solar battery, battery or onboard network of the space station). The object of research and calculations was the typical design of the lunar module of DB "Pivdenne" Enterprise. The proposed workplace of the cosmonaut-welder is made in the form of a folded "cradle". In the transport position, it should take up a minimum of space and have a minimum weight. Several variants of the cosmonaut-welder workplace are proposed and considered according to the following parameters: dimensions in the transport position, the number of moving elements from the point of view of the influence of lunar dust — regoliths, the weight of the structure, convenience and ease of transfer from the transport position to the working position. Calculations of the necessary weight of the cosmonaut-welder workplace for performing work on the surface of the Moon have been carried out. The measures that ensure the reliability of the operation of the cosmonaut-welder workplace in open space and on the surface of the Moon are given.

KEYWORDS: workplace, cosmonaut-welder, electron beam welding, spacecraft engineering

INTRODUCTION

During exploration of the near-earth space and the surface of the Moon, it will be necessary to perform mounting, and in a number of cases also repair-restoration operations. Electron beam welding is a priority technology during fabrication of structures in spacecraft engineering, which allows producing reliable joints with guaranteed tightness without lowering of their strength and with preservation of weight and dimensional characteristics [1]. Over the recent years this welding process has regained its popularity among the researchers [2].

New generation electron beam tool developed at PWI for performance of welding and related processes, is capable of operating both in the manual (during work performance by cosmonaut-welder), and in the robotic version.

There are many situations, when we cannot do without the cosmonaut-researcher. These are non-standard situations, when it is necessary to assess the scope of violations, and determine the methods for performing the work or repair operations. There is a large number of operations, (primarily, repair-restoration operations or fixing the fragments of large-sized structures), for which it is difficult or impossible to prepare in advance. Moreover, occurrence of emergency situations is probable, which require performance of urgent technological operations, such as cutting, welding or brazing, during which the process and scope of operations will be determined by the cosmonaut directly in site.

During exploration of the Moon a lot of attention is given to establishing long-term lunar bases (LLB) and the infrastructure for these constructions. Taking into account the special physical conditions on the surface of the Moon, i.e., first of all, superhigh vacuum (up to 10^{-11} Pa), the required tightness of LLB structures can be ensured using welding. Therefore, development of specialized electron beam welding hardware and auxiliary equipment, which is the cosmonaut-welder workplace (WP) is relevant in exploration of the Moon.

Welding operator WP developed at PWI, is designed for performance of technological and repair operations in service of base modules on the surface of the Moon. It is required for operator movement to the place of performance of the operations of maintenance and repair of the space module skin, with the possibility of its lifting, tilting and rotation around the vertical axis [3].

During work performance in the Earth orbit, with the height close to 300 km, the movement of the flying object is accompanied by frequent changes of day and night: during every 90 minutes of flight the man is in the dark for 45 min. Human adaptation to the sun's rays, the brightness of which is doubled, also becomes relevant. Therefore, there is the need for artificial lighting for the cosmonaut-welder workplace during operation in complete darkness.

THE OBJECTIVE

of this work is creation of cosmonaut-welder workplace, meeting the modern requirements to space hardware, and using modern component base and advanced materials.

To achieve this objective, PWI "Space Technology" Department developed the working design for manufacturing cosmonaut-welder WP which is adapted for performing electron beam welding with the hand tool in the Earth orbit or on the surface of the Moon. During performance of this work, the peculiarities of the lunar surface were taken into account, first of all, reduced gravity, compared to Earth, low temperature and presence and impact of the lunar dust.

CREATION OF THE WELDING OPERATOR WORKPLACE

The following concept was proposed: develop a workplace of cosmonaut — welding operator, providing the opportunity of comfortable work of a man in a spacesuit during performance of the above-mentioned operations when mounting LLB structures and for other operations.

The welding operator WP was developed, proceeding from the conditions that it will be necessary to weld LLB structure elements 3000 mm in diameter, 6000 mm long and 6 mm thick.

The main technical characteristics of cosmonaut-welder WP are as follows: transport dimensions, weight characteristics, service area, selection of the mobile WP chassis design, as well as specific choice of the electric drive and its power supply (automonous, solar battery, battery or on-board network of the space station). WP should be made in the form of a folded structure, which in the transport position takes a minimum volume at minimum weight, depending on the selected structure material.

In this work a typical design of lunar module of DB "Pivdenne" enterprise was taken as the object of study. The horizontal orientation module is an aluminium welded structure of a cylindrical shell, frame and torispherical bottoms. The module outer diameter is equal to 3000 mm, and WP supports are adjustable by 100 mm by height.

Figure 1 shows the general view of a typical lunar module design [4]. For increase of the amount of movement in height, the supports provide the possibility of additional manual adjustment (possibility of extending the movement by 100 mm). Sequential connection of such blocks into one structure with various purposes, such as residential and research modules, allows creating a base, sufficient for the man to stay on the Moon.

Taking these factors into account, several design variants of the cosmonaut-operator WP were proposed and considered, in compliance with the following requirements: minimal overall dimensions in the transport position, limited number of mobile elements, minimal structure weight due to the selected heat-hardenable aluminium alloy 2219 with heat-reflecting coating over the entire structure surface [4, 5]. Convenience and ease of its transfer from the transport into the working position are provided. Convenience of performance of technological work can be provided due to operator position with different manipulator positions: from minimal lower position to maximal upper one. Possibility of the operator taking the intermediate positions is also provided, for instance when performing repair of defects on the module surface. In this variant the operator is an inclined position. Considering the effect of reduced gravity, the comfort of performing the technological operations is impaired, which requires reliable fixation of the operator relative to the work object.

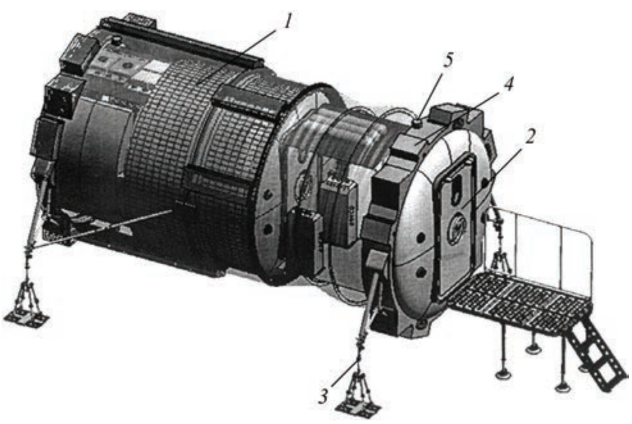

Figure 1. General view of a typical design of a lunar module of horizontal orientation with protection [4]: *1* — power shell with external coating; *2* — pressurized doors; *3* — mounting supports; *4* — docking device; *5* — pressure release device

During work performance on the surface of the Moon, the specialized cosmonaut-welder WP is one of the most complex tasks for realization of manual electron beam welding in the general complex of hardware for working in space [6]. Solving this problem will enable fixing the cosmonaut-welder for precise coordination of complex motions during welding.

Long-term operation and maintenance of such complex and volumetric equipment requires development of means for installation and scheduled preventive repair. It can be shell perforation as a result of accidental mechanical impact or from a meteorite strike. One of the main elements to solve this task is development of a welding tool and welder workplace to repair defects resulting from such phenomena.

Technical characteristics of welding operator workplace include the following; transport dimensions, weight characteristics, material for manufacture, service area, selection of the design of mobile workplace chassis, as well as specific choice of the electric drive and its power supply [7].

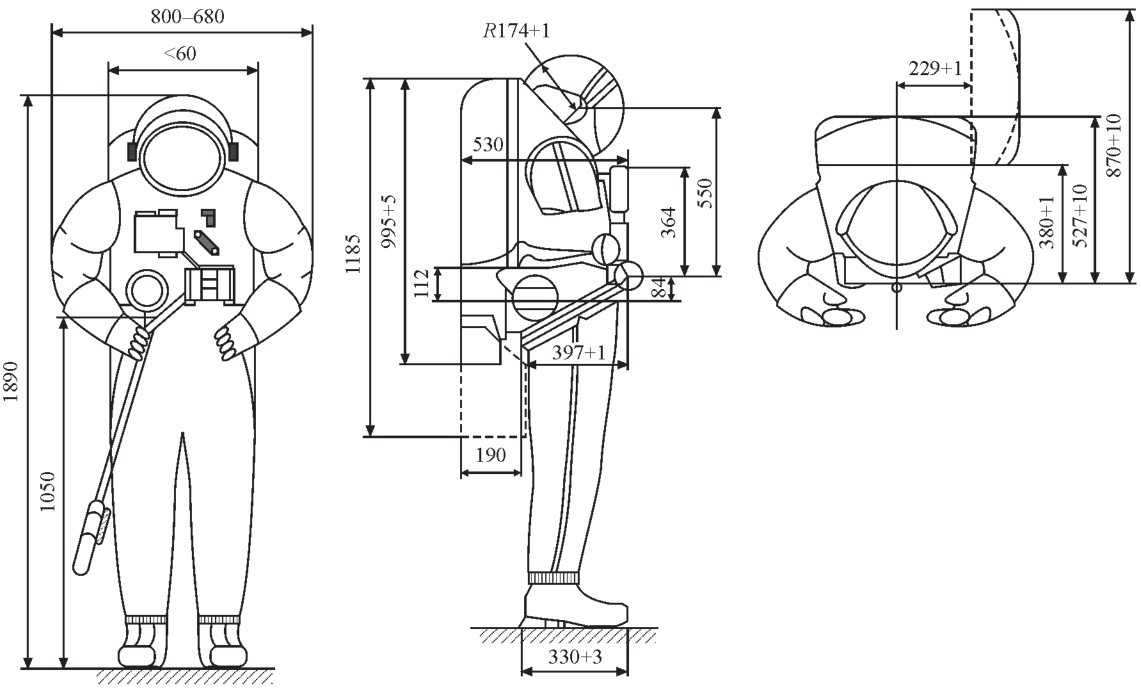

Figure 2. Tentative overall dimensions of a cosmonaut in a spacesuit

Figure 2 shows the tentative overall dimensions of a cosmonaut in a spacesuit. The welder's platform – "cradle" was developed for these data. A single variant of the "cradle" was developed, as this device is directly connected with the welding operator and cannot change.

The workplace proper is made in the form of a folded "Cradle" (Figure 3). It should take up minimum space and have minimum weight in the transport position. Special grips are holding the "cradle" frontal frame in the transport position and provide fixation of all the elements in such a shape. In the working position, the grips are holding the "cradle" side frames in the vertical position. Mounted on the workplace platform is a bracket to prevent slipping of the welder's feet during the workplace tilting, when working in the upper zone. Workplace tilting at an angle of approximately 30° is ensured by pitch drive, and workplace rotation by an angle of ±15° is performed by swing drive. Both these drives are located at the end of the other lever of workplace movement.

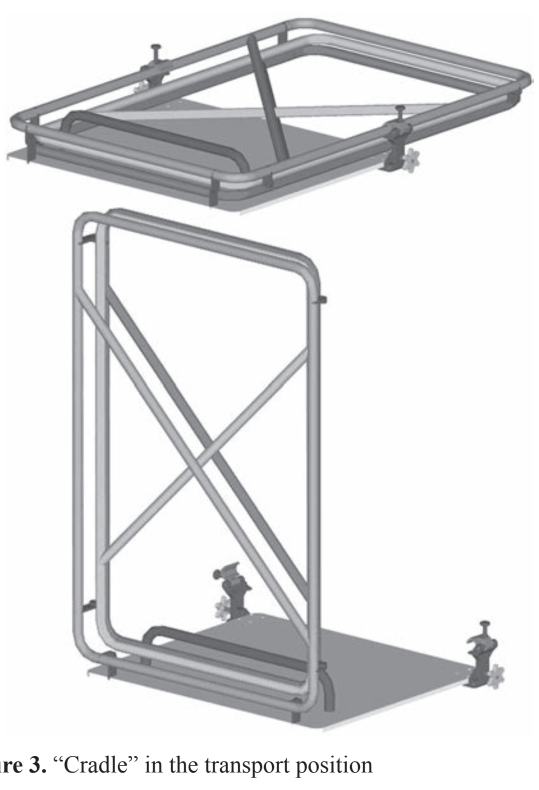

Figure 3. "Cradle" in the transport position

Figure 4 shows the intermediate transformations of the "cradle" from the transport into the working position. The process of deployment of all the structure elements is shown sequentially. The locking handrail is opened and closed by welding operator by turning the handle, when entering the "cradle".

OPTIONS OF COSMONAUT-WELDER WP DESIGN

Several options of cosmonaut-welder workplace have been proposed and considered based on the following parameters: overall dimensions in the transport position, number of mobile elements, structure weight, convenience and simplicity of transferring from the transport into the working position. The quality of welding operations performance largely depends on the position of cosmonaut-welder. Welding operations are performed by a man in a spacesuit in the vertical position. Figure 5 shows the variants of operator's position during performance of work on repairing defects on the module surface. Here, we had to tilt the operator. This is quite possible, in view of the low gravity value. The cylinder (the outer diameter of which is equal to 3000 mm) is resting on adjustable supports. The technical proposals were developed, proceeding from these initial data. Workplace inclination at an angle of ~300° is provided by a step drive, and the workplace rotation by an angle of ±150° is performed by the rotation drive.

The above-mentioned variant has better parameters of transport stowage the mobile workplace. The workplace should be transported using a four-wheel trolley with controlled stops.

Results of selection of operator workplace variants were used to make a 2D model, based on the mentioned variant. In some intermediate positions, the operator platform did not allow moving along the module outer surface.

For the platform to pass, it was necessary to move the workplace trolley, but such actions are inadmissible, as the trolley should stand on jack supports during the operator working in the workplace. This necessitated some changes in the length and position of manipulator base mounts. Manipulator base fasteners were moved to the position under the rear wheel axle; length of the first lever was increased to 1500 mm and length of the second lever — to 1800 mm.

Figure 5, *f* shows the upper position of the workplace, which enables servicing the module upper surface. This model allowed observing how the interaction of the operator, workplace and the module housing occurs during movement from the lower to the upper point, which commands the operator should issue from the control panel to the manipulator. The Table 1 gives the new dimensions of the welding operator workplace.

Workplace control panel should have the following commands. For the trolley: forward, backward, left, right, lower, raise the jacks. For workplace manipulator: forward, backward, up, down, left, right, tilt, straight, initial position. Initial position is when the operator is in the lowest position (Figure 5, *a*).

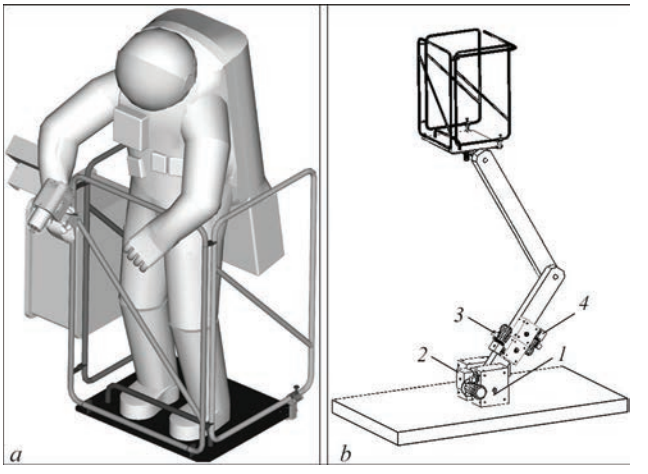

Figure 4. General layout of the welding operator platform and arrangement of the technological block with the seat for the tool and control panel in the "cradle": welding operator platform (*a*), manipulator with drives *1*, *2*, *3*, *4* (*b*)

The next stage of the work was selection of the principles of placing and choosing the drives, mounted on WP manipulator "arm" (Figure 4, *b*). Several variants of drive placing were considered. Drives *1* and *2* should be responsible for movement of the platform with welding operator and power supply and control modules. More over, these drives are responsible for movement of the structure of the workplace proper. The weight of welding operator in the spacesuit is ~220 kg. Weight of all the modules is ~25 kg. Weight of the workplace structure should be ~130 kg. Thus, the total weight of all the elements, moving in space, is ~ 375 kg. On the Moon the weight is 6 times lower, than on the Earth, i.e. it is equal to ~62.5 kg. The distance from the center of fastening of the first lever to the center of gravity is ~2 m. Then, the moment required for movement of the welding operator is equal to 125 kg/m. Drives *1* and *2* have up to 165 kg/m mo-

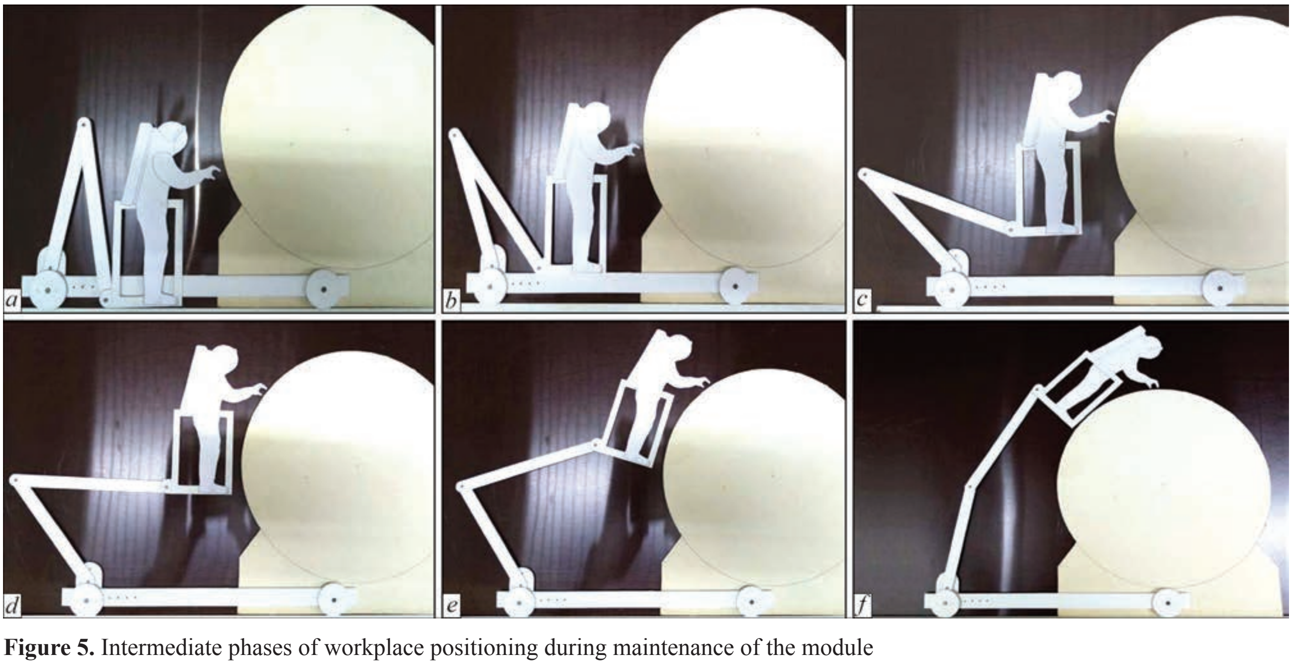

Figure 5. Intermediate phases of workplace positioning during maintenance of the module

Table 1. Dimensions of operator workplace

Parameter	Value, mm
Base between WP wheels	3000
Length of WP manipulator first lever	1500
Length of WP manipulator second lever	1800
Module diameter	3000
Depth of WP platform	820
Height of WP platform	1060
Width of WP trolley	220
Distance between trolley surface and first lever mounting axis	100

ment and drives *3* and *4* — 40 kg/m. At the stage of technical proposals the following drives were selected: gear motors NMRV 150/075 and NMRV 090/040.

Several variants of placement of the drives for controlling the manipulator arm position, WP inclination and rotation in the trolley base were considered. The most optimal is the WP manipulator variant with placing of the drives for controlling the manipulator arm position, WP inclination and rotation at the trolley base, which reduces the load on the manipulator even more, and greatly improves its characteristics. In this case, the weight to be moved in the smallest and the service area is greater than with all the other variants.

WP reliability is ensured by the following measures:

● application of verified component base with the required parameters and characteristics, ensuring their operation under the conditions, which are in place at different stages of ground-based training and during experiment performance;

● ensuring the quality of manufacturing, in accordance with the quality system acting at the enterprise;

● using the required safety factors during design and engineering optimization;

● conducting the required scope of ground-based experiments with application of advanced procedures, using limit testing modes with simulation of the conditions in place in standard and emergency situations.

CONCLUSIONS

1. Welding operator WP which is designed for performance of technological and repair operations in service of the station modules on the surface of the Moon, is an integral part of welding equipment.

2. Welding operator WP is necessary for operator movement from the place of performance of the operations on maintenance and repair of the space module skin with the capability of its lifting, tilting and rotation around the vertical axis.

3. Development of a specialized WP of cosmonaut-welder is one of the most complicated tasks in the overall complex of hardware for work performance in space. It enables fixing the cosmonaut-welder which is required for precise coordination of complex movements, ensuring quality and stable manual electron beam welding in orbit or on the surface of the Moon.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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