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Development of handheld laser welding equipment

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ABSTRACT: *This study is describing the development of an ergonomic handheld laser tool, capable of carrying out various laser welding operation. During the course of the study, various foreign and domestic analogues of the manual laser tool were examined and analyzed. The positive sides and disadvantages of each possible variant of the tool composition is described in this work from the standpoint of optimizing the criterion of ergonomics. The issue of safety techniques for working with a manual laser tool is studied, and the necessary safety measures for creating safe, harmless and favorable working conditions are given. The layout scheme of the hand-held laser tool was developed, taking into account the positions of increasing the level of its ergonomics. Conducted modeling of different layouts of a hand-held laser tool. Out of the few designed layouts, a design with a rotating mirror and a wheel, made for clamping the workpiece as well as keeping it in the focus of the lens, was chosen. Conducted tests using the developed manual laser tool has shown existing shortcomings of the design with the possibility of improvement of its ergonomics.*

NOMENCLATURE

Symbol	**Description**	**Unit**
M	Weight	*kg*
P	Laser power	*kW*
η	Efficiency coefficient	%
δ	Thickness	*mm*
λ	Laser radiation wavelength	*µm*
T	Temperature	*° C*
l	Length	*mm*

Greek letter

δ	Thickness	
λ	Laser radiation wavelength	

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I. INTRODUCTION

As a result of the study, the main requirements for the design of a portable handheld laser tool, coupled with a 2 kW diode laser, were determined. After that, the layouts of the handheld laser tool were modeled and a model, on the basis of which a working mockup was built, was chosen. Afterwards, from a series of tests, it was established that a characteristic defect of the welding process when using a handheld laser tool is the formation of wormholes and harmful additions. This is the case due to the fact that the operator needs to change his position evenly with respect to the workpiece during the process of welding, which is not always applicable. The tested prototype has turned out to be too heavy (about 3.5...4.0 kg) for proper maneuvering of the tool during welding. As a result, the manual laser tool was improved, and its ergonomics were improved. The specific results of the test usage of the handheld laser tool allow us to distinguish three areas of its further development:

1. Improvement of individual components of the created ergonomic manual laser tool and technological equipment.

2. Development of a handheld laser tool for stationary work (with a minimum of functional units and auxiliary measures).
3. Development of a handheld laser tool for carrying out work in semi-automatic mode, coupled with a position monitoring system, responsible for the control of the laser beam position relative to the surface of the product as well as monitoring the joint during the welding process.

II. EXPERIMENTAL SETUP

A number of recent publications show examples of the creation of portable laser complexes as well as manual laser tools [1-2]. Tasks that can be solved using such complexes relate to the restoration of parts of various machinery, welding of products from thin sheet metals, as well as woodworking works in the small and medium-sized enterprises. These complexes often utilize powerful diode lasers, due to their high efficiency of up to η=48...52%. It is, however, noted that in order to increase the flexibility of the delivery of laser emission, it is advisable to transmit it using an optical fiber. This technology is usually used for the Nd:YAG (radiation wavelength λ=1.06 μm) and for the diode (λ=0.808/0.940 μm) lasers. In this regard, the diode laser has the advantage that its radiation is used directly, and not through a converter medium.

For example, in the German Mobil Laser Tec company uses a manual laser tool, powered by the 1.5 kW Nd:YAG laser, for welding of shafts, utilizing a technology, where the filler wire is added by hand using a video monitoring system of the process (Fig. 1). They also use a universal handheld laser welding tool, coupled with a 3kW laser for welding thin sheet metals, including galvanized ones, on the industrial scale. Another handheld laser tool, coupled to a laser with a power of laser radiation of 0.5 kW and a weight of 1.5 kg, is used there for surface treatment of the parts.

Fig. 1 The process of manual laser surfacing of shafts with the addition of a laying wire by hand, using a video monitoring system for the process [1].

In the case of usage of a CO_2 laser, a number of special technological methods of laser welding of thin sheet metals (δ=0.1...3.0 mm) were developed by the Paton Electric Welding Institute of the National Academy of Sciences of Ukraine (PEWI) [3-4]. It these studies, it was established that the main disadvantage of using CO_2 laser radiation is the impossibility of using a flexible optical fiber to transmit radiation from the generator to the welding head. This drawback, characteristic to CO_2 lasers, is absent in systems utilizing a diode laser. The radiation of the latter is transmitted through a quartz fiber with a minimum bending radius of 250 mm, which opens possibilities of the usage of these technologies with the usage of industrial "robotic arm"-type manipulators, capable of operating with many degrees of freedom.

The most promising fields of industry for the implementation of handheld laser tooling are:

1. automotive industry [5];
2. aerospace industry;
3. railway stock construction industry [6];
4. shipbuilding [7].

The enterprises of these industries carry out different production tasks, including those related to welding, soldering of thin sheet metals (carbon steels, aluminum, titanium and magnesium alloys), which could be performed with the help of a hand-held ergonomic laser tool, - in the manufacture of single products or small batches of parts; as well as working in hard-to-reach places [3]. On the novel side of things, among the possible applications of the handheld laser tool, various laser surface cleaning, which is used in the cleaning of stamps and casting molds from organic compounds in various industries, has become widespread [8-9]. Other alternative uses of a portable laser complex, such as the restoration of the appearance of monuments, memorial boards, etc.; as well as cleaning welds and various surfaces before their painting, have widened the possibilities of possible uses of a handheld laser tool.

MODELLING OF DIFFERENT DESIGN LAYOUTS OF DIFFERENT DESIGN LAYOUTS OF A HANDHELD LASER TOOL.

Modeling of the layout for the handheld laser tool was carried out in the following stages:

1.The analysis of other existing handheld tools of analogous nature was carried out.

2.The anthropometric characteristics of the tool were compiled. The compliance of the tool with ergonomic requirements was clarified [10-16]. The possible working postures of the operator, the spheres of tool grip, rotation angles, movement zones and the optimal viewing angles were determined. Based on the observed deviations, recommendations were made and changes were made to the structure based on anthropometric data.

3.The purpose of the tool, its main and additional regulated parameters, the main tasks of the operator (which parameters he monitors, which he regulates, on which issues he makes a decision) and the sequence of performing operations were defined and taken into account; leading channels of information (visual, auditory); motor actions (manual control); contingent of persons for whom the instrument is designed; possible emergency situations and failures, work restrictions; conditions of accommodation and operation.

4.An assessment of control elements was carried out. When evaluating the control elements, the purpose and number of control bodies, the correspondence of the location of the control bodies to the work zones, the size, shape, color, sequence of handling and frequency of use of the control bodies were taken into account; the number of activations during operation, the direction, the amount of movement and the effort applied to it, the total amount of energy spent when performing operations related to control. When choosing tumblers and switches, the width of the widest part was taken into account; switching direction; number of switch positions; the surface area of the handle that can be grasped by the hand (length, width, depth).

5.Working conditions at the possible workplaces were assessed based on a comparison of regulatory requirements with the actual characteristics of the work environment. Possible adverse factors that may be present at this workplace were determined and analyzed.

The analysis of existing analogues and previous working experience allowed us to highlight the following requirements for hand laser tool assemblies. According to the results of the analysis, the handheld laser tool must have:

- a handling unit to hold it the tool the desired position;
- a control system for switching laser radiation and shielding gas on and off;
- an operator protection system - protection of the operator from laser radiation that can be reflected from the processing part;
- a protection system for working optics against possible splashes of liquid metal from the melt bath;
- welding bath protection system in the form of a supply of shielding gas to the welding zone;
- an auxiliary tool for holding a hand-held laser tool in the focus of an optical lens;
- a system, responsible for the visualization of the working zone;
- a system of limiting switches to ensure emergency shutdown of laser radiation.
- a system of feeding the planting wire.

III. RESULTS AND DISCUSSION

Based on the requirements described above, the following variants of the handheld laser tool were designed and analyzed.

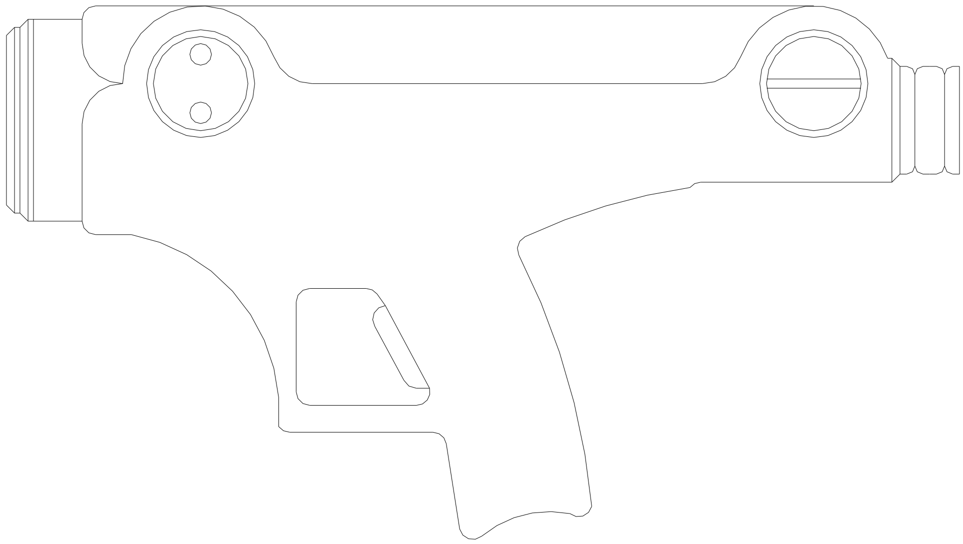

Fig. 3 Appearance of a "pistol" model layout of a handheld laser tool with a button for controlling laser radiation.

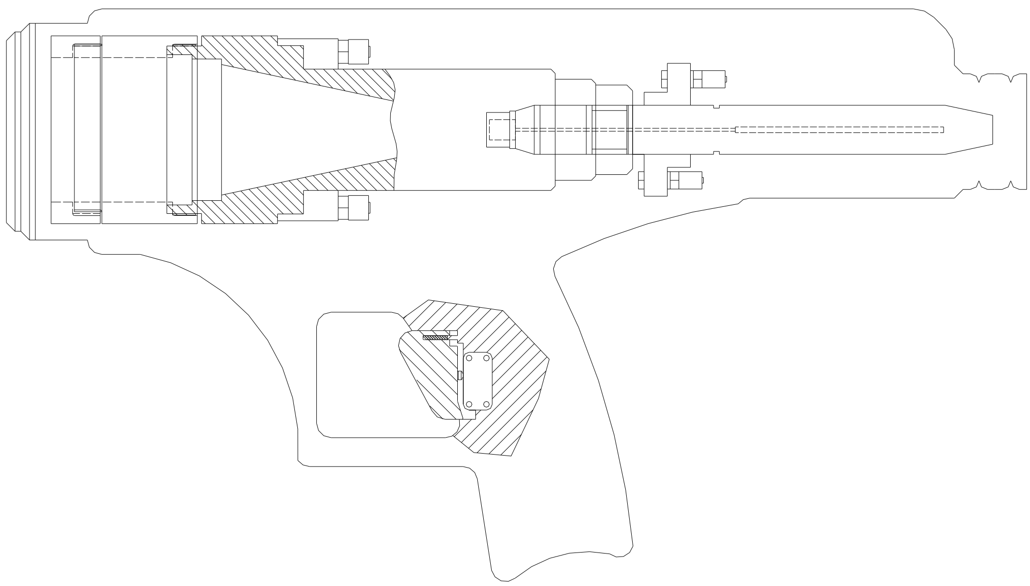

Fig. 4 Cross-section of a "pistol" model layout of a handheld laser tool. The location of the optical fiber, the focusing system and the button for controlling the laser radiation is shown.

The model, shown on fig. 3 and 4 represent a classic laser "pistol"-type tool. It is light in weight, compact in size, and has a minimal number of controls. Disadvantages of its design include:

1. Difficulty in manufacturing the body of the tool;
2. The absence of an auxiliary second handle, which entails the difficulty of holding the tool in the desired position;
3. Lack of systems, designed for protecting the welding bath and working optics as well as visualizing the processing area, feeding the welding wire and providing automatic off-switches upon reaching a critical point.

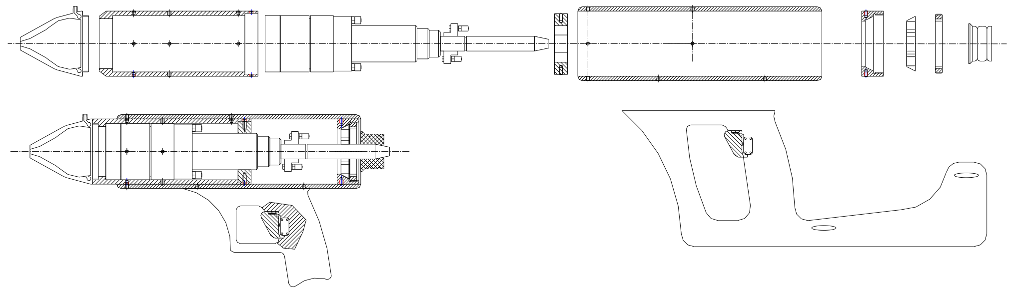

Fig. 5 Assembly diagram of a layout of a handheld laser tool with a modernized handle to facilitate welding due to better holding of the welding tool.

The model, shown in Fig. 5., compared to the previous model, has the following advantages:

1. ease of manufacturing of the head of the body,
2. the presence of welding bath protection systems,
3. and protection of working optics.

The disadvantages of this design include:

1. the difficulty of manufacturing of the handstop;
2. the absence of an auxiliary second handle, which entails the difficulty of holding the tool in the desired position;
3. lack of systems for visualization of the processing area;
4. feeding of the planting wire and limit switches.

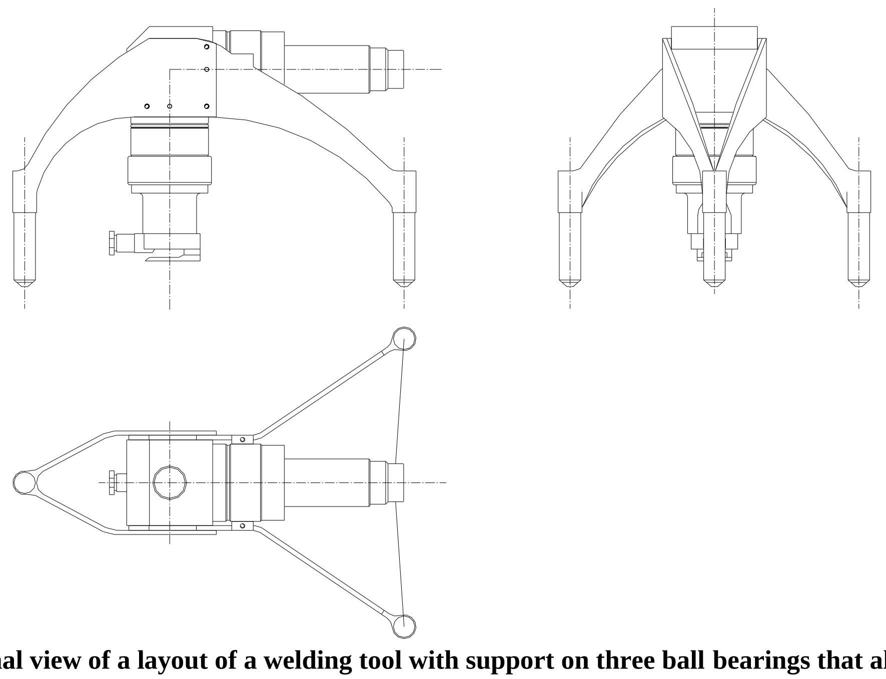

Fig. 6 External view of a layout of a welding tool with support on three ball bearings that allows for its installation in a position, perpendicular to that of the workpiece.

The advantages of the model, shown on fig. 6, include:

1. high stability of the tool placement,
2. the presence of a welding bath protection system,
3. a working optics protection system,
4. a handle to keep it in the right position;
5. an auxiliary means for holding a hand-held laser tool in the focus of an optical lens;
6. processing zone visualization system.

The main disadvantage of this model are:

1. the ability to weld only flat surfaces,
2. there is also no handle for holding and directing the tool;
3. a created system of limit switches.

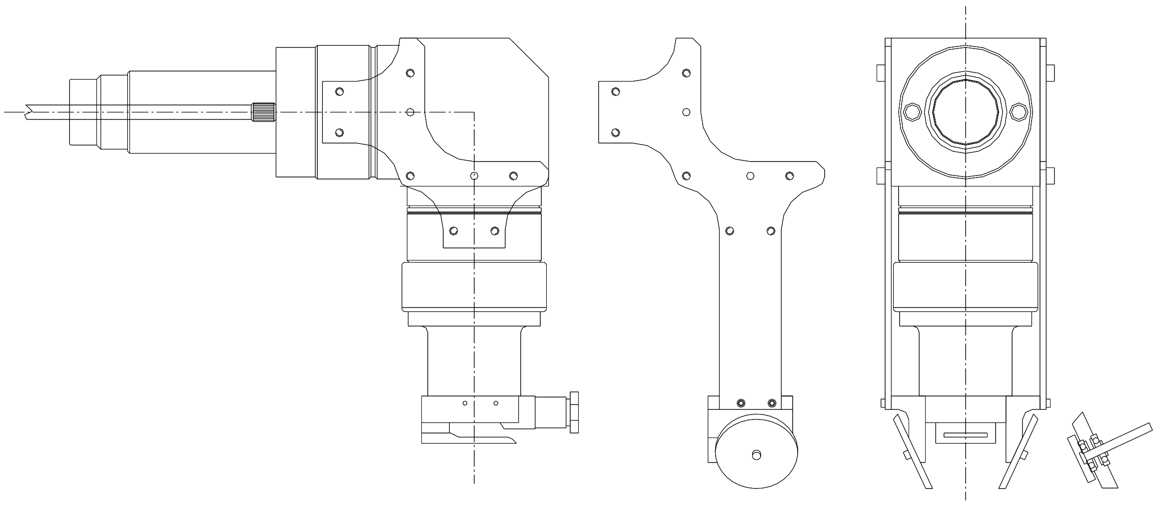

Fig. 7 A schematic of a layout of a handheld laser tool utilizing two wheels for clamping the workpiece during butt welding.

The layout of the model, shown in Fig. 7. has the same advantages and disadvantages as the previous one, but differs fundamentally in the presence of two rolling wheels, which are used in butt welding of materials to clamp welding parts.

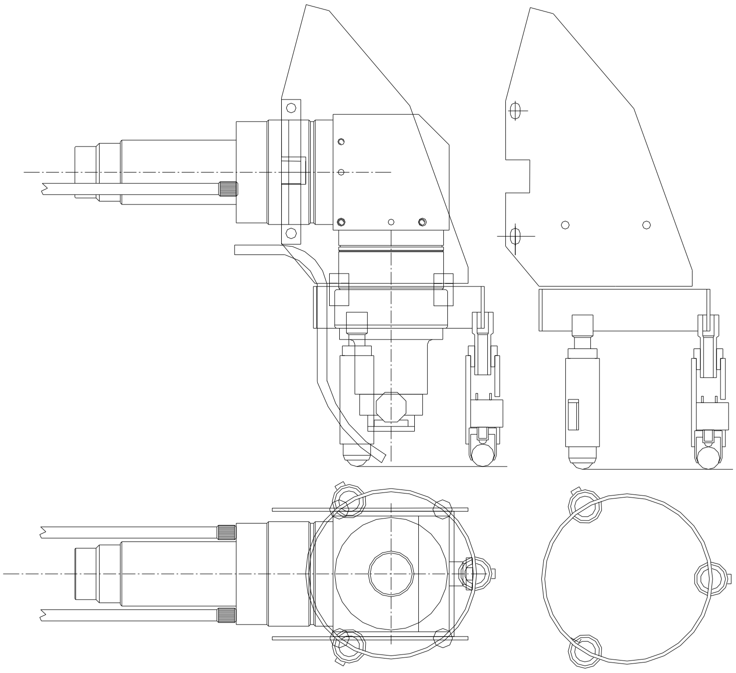

Fig. 8. The layout of the handheld laser tool with support on three spring-loaded ball bearings, securing a more precise positioning of the hand tool in a position, perpendicular to the workpiece during welding, despite small irregularities of the surface of the workpiece.

The advantages of the layout model, shown in Fig. 8 are as following:

- the presence of a system of limiting switches,
- a presence of a system, capable of protecting the operator from laser radiation.

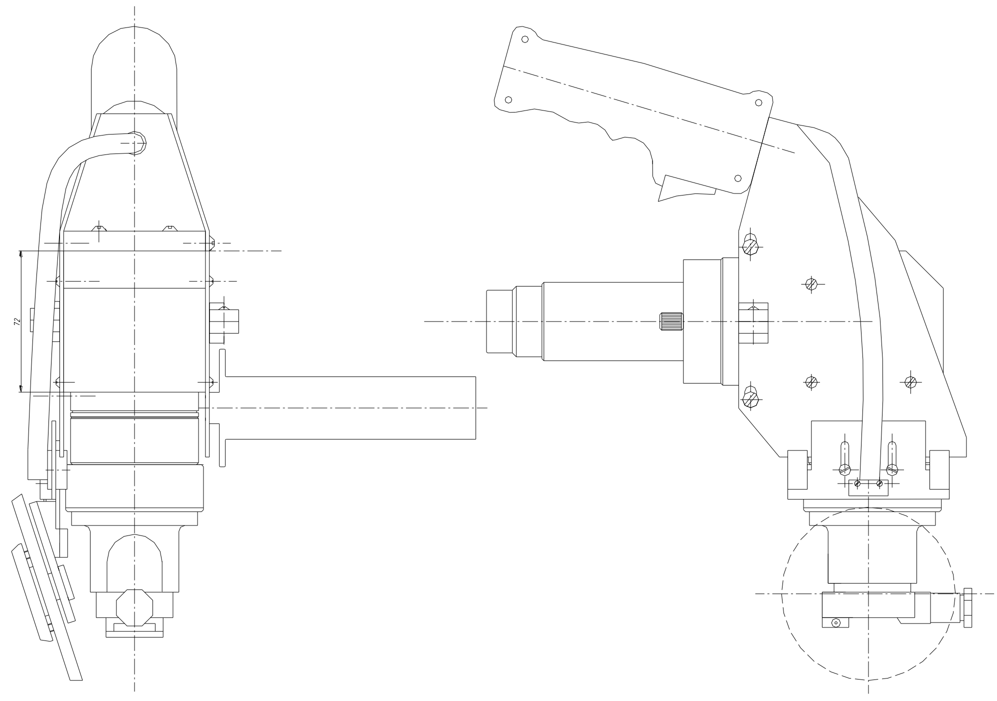

Fig. 9 The chosen layout of the created mockup of a hand-held laser tool.

In the end, a model of a handheld laser tool with a rotating mirror and a wheel, made for clamping the workpiece as well as keeping it in the focus of the lens, was chosen. Its finalized layout scheme is shown on

Fig, 9. On the final layout, a set of limiter off-switches are located on the wheel for the safety of the operator, made for turning off the laser radiation, upon lifting of the tool away from the work plane. An additional handle, placed on the side wall of the tool, adds stability to it relative to the processing surface. The system of protection of optics from splashes and metal vapors of the welding bath, made in the form of a copper cross-jet. With the help of air pressure, emissions from the welding bath are blown away from the path of the laser beam. A system of gas protection of the welding bath is provided. Visualization of the process and preliminary adjustment is carried out with the help of video surveillance, placed coaxially to the laser radiation source. The signal from the video camera is output to a small CCD screen, which is placed in the field of view of the operator.

Simultaneous supply of shielding gas and laser radiation is handled by pressing the trigger on the handle. The surface of the handle, which is grasped by the hand, is made taking into account anthropometric characteristics and fits comfortably in a person's hand. The trigger is placed under the index finger of the right hand. Design also accounts for a possible replacement of the position of the auxiliary holding handle for left-handed people.

TESTING OF THE DEVELOPED MOCK-UP OF A HANDHELD LASER TOOL

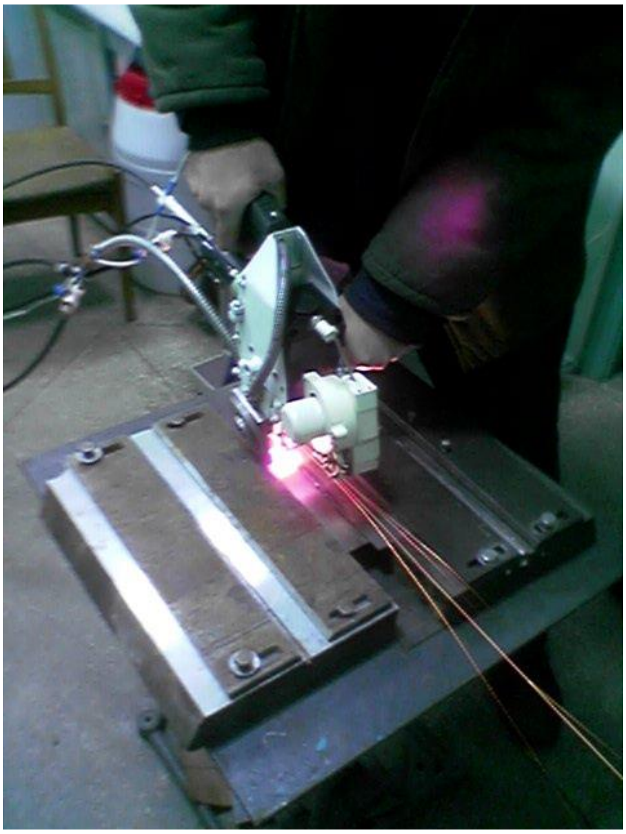

Fig. 10 The process of laser welding of thin black steels by an employee of the Paton Electric Welding Institute during the testing of the welding tool mock-up. The tool is paired with a 2 kW diode laser.

During the tests, it was established that a characteristic defect of the welding process using a handheld laser tool is the formation of wormholes and additions. This is the case due to the fact that the operator needs to change his position evenly with respect to the workpiece during the process of welding, which is not always applicable. Therefore, welding with such a tool should be carried out with short seams, 50...60 mm long (if the technology allows), or with the help of a semi-automatic tool that will monitor the position of the laser beam relative to the surface of the product and monitor the joint during welding. It is also very important to train the operator to ensure uniform welding speed. The tested prototype turned out to be too heavy (about 3.5...4.0 kg) for proper maneuvering of the tool during welding. To reduce weight, steel structural elements were replaced with aluminum ones. In addition, communications that are connected to the manual welding head (optical fiber, water cooling hoses, supply of protective gas) are a certain inconvenience. As a result, the manual laser tool was improved, and its ergonomics were improved.

The specific results of the test usage of the handheld laser tool allow us to distinguish three areas of its further development:

1. Improvement of individual components of the created ergonomic manual laser tool and technological equipment.
2. Development of a handheld laser tool for stationary work (with a minimum of functional units and auxiliary measures).
3. Development of a handheld laser tool for carrying out work in semi-automatic mode, coupled with a position monitoring system, responsible for the control of the laser beam position relative to the surface of the product as well as monitoring the joint during the welding process.

IV. CONCLUSION

As a result of the study, the main requirements for the design of a portable handheld laser tool, coupled with a 2 kW diode laser, were determined. After that, the layouts of the handheld laser tool were modeled and a model, on the basis of which a working mockup was built, was chosen. Afterwards, from a series of tests, it was established that a characteristic defect of the welding process when using a handheld laser tool is the formation of wormholes and harmful additions. This is the case due to the fact that the operator needs to change his position evenly with respect to the workpiece during the process of welding, which is not always applicable. The tested prototype has turned out to be too heavy (about 3.5...4.0 kg) for proper maneuvering of the tool during welding. As a result, the manual laser tool was improved, and its ergonomics were improved. The specific results of the test usage of the handheld laser tool allow us to distinguish three areas of its further development:

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