Expansion of technological capabilities of the electron beam welding installation

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Abstract: The direction of electron beam technologies is promising and is rapidly developing. Quite recently, the electron beam was a tool for welding, and nowadays, electron-beam additive technologies and beam hardening technologies have become widespread. At the moment, there is no electron beam system that unites all these technologies. Expensive equipment has been developed to implement each technology. The article deals with expanding the technological capabilities of the 15E1000 electron-beam welding installation in order to implement new methods and techniques for processing metals with an electron beam.

1. Introduction

The intensive development of technology requires the development of new methods for the manufacture of parts. Even 10 years ago, electron beam welding was considered an advanced method, but now, to implement the ideas of developers, completely new technologies are required to realize the most daring ideas of designers.

Currently, there are no installations that combine all electron beam technologies (welding, additive growing, surface hardening). Each electron-beam technology has its own expensive equipment: for layer-by-layer growth using an electron beam, for example, an installation developed by «Tomsk Electronic Technologies Research and Production Company» LLC [3] or an «xBeam-01» installation developed by «NVO Chervona Khvilia» [5], for surface hardening of products - installation ELV-6 [4], for electron-beam welding - installation such as ELU, SUELS [1], which cannot be used for other types of technologies.

The purpose of this work is to create a universal complex for implementing the technology of synthesis of parts, joining them by welding with minimal deformations, surface modification of the mechanical properties of materials by means of an electron beam with minimal financial costs.

At the moment, preliminary work has been carried out to refine the technologies planned for implementation in a single universal electron-beam complex. The complex is implemented on the basis of the TETA 15E1000 electron beam welding unit (Figure 1).
The characteristics of this unit are presented in table 1.

| Parameter name                  | Meaning                      |
|---------------------------------|------------------------------|
| Vacuum chamber dimensions       | 8500х6500х3000 mm            |
| Accelerating voltage            | 30 kV                        |
| Beam current                    | 0-500 mA                     |
| Cathode type                    | Direct / indirect heating    |
| Evacuation time to working vacuum | 10 minutes                  |
| Faceplate rotation speed        | Up to 3 rp/m                 |

1.1 Electron beam welding of magnetic alloys

In the process of electron beam welding of products made of ferromagnetic steels (09G2S, 17G1S, 07H12NMBF-Sh, etc.), one of the reasons for the appearance of such unacceptable defects as lack of penetration is the deviation of the electron beam from the joint [1].

To exclude the formation of this defect on parts of small thickness (up to 10 mm), the magnetization is measured (the value should not exceed 0.2 A/cm) and subsequent demagnetization with a hand device (Figure 2). The principle of demagnetization by this device is as follows: the product is exposed to an alternating magnetic field with a decreasing amplitude.
For products with a thickness of more than 10 mm, the technology of electron beam welding without the use of filler wire has been developed and tested. The technology is implemented as follows: immediately before the joint is welded, the edges are demagnetized by an electron beam at a distance of 15-20 mm from the joint, after which electron-beam welding of the joint is performed (Figure 3). Demagnetization occurs due to the heating of the material above the Curie point (at this temperature, complete demagnetization occurs) [2].

In order to implement these methods of demagnetizing products before electron beam welding, the complex is equipped with a device for measuring magnetization (Figure 4).
1.2 Electron beam welding with filler wire

In electron beam welding, the highest quality welded joint and the most stable process occurs when welding "lock" joints without penetration. However, the "lock" joints increase the material consumption of the product, the labor intensity of manufacture associated with the machining of the "locks" for welding and after welding. Electron beam welding in the "lock" joint without the use of filler wire has been introduced at the enterprise for the following materials: steel; titanium alloys; aluminum alloys, etc.

Electron beam welding with through penetration allows avoiding these disadvantages, but with such a welding scheme, there is a high probability of understatement in welded joints due to sagging of the pool of molten metal. Often, such underestimation is an unacceptable product defect and must be corrected. Currently, external defects in the shape of the seam are eliminated by manual welding with a non-consumable electrode with filler wire feed in a shielded gas environment. Performing an additional pass of electron beam welding with filler wire feed will solve the problem of underestimation.

To implement the EBW technology with filler wire feed, the installation is equipped with a wire feed mechanism (Figure 5). The wire feeder is located outside the vacuum chamber and consists of three parts: a wire feeder driven by a stepper motor; vacuum injection system with intermediate pumping; wire feed system providing control of the feed angle.

![Figure 5. External wire feeder for the implementation of electron beam technologies: through-penetration welding and additive growth](image)

Also, the supply of filler wire in electron beam welding will allow introducing alloying elements into the weld pool, making seams with a narrow gap groove (for large thicknesses).

1.3 Electron beam additive cultivation

The process of electron-beam additive growing is as follows. An electron beam with a power density sufficient for melting is focused on the surface of the substrate or an already grown metal layer. A molten bath is formed at the processing site, into which the wire is introduced, thereby increasing the volume of the molten material. When the machining position is shifted by a 3-coordinate table or manipulator by turning or in the horizontal direction, the melt pool is displaced, as a result of which the metal deposited at the previous moment of time solidifies [3].

At the moment, the technology for growing samples from the following materials has been worked out: heat-resistant steel (07Kh12NMBF-Sh) and titanium alloy (VT-6) with obtaining positive results
on the mechanical properties of the grown material. The mechanical properties of heat resistant steel are shown in Table 2.

### Table 2. Mechanical properties of 07H12NMBF-Sh

|                  | Ultimate tensile strength, MPa | Yield strength, MPa | Relative extension, % | Relative narrowing, % | Impact strength, J/cm² |
|------------------|--------------------------------|---------------------|-----------------------|-----------------------|------------------------|
| Main material    | No less 910                    | No less 785         | No less 10            | No less 50            | 75                     |
| Grown sample     | 1163                           | 986                 | 13,5                  | 53,3                  | 126,6                  |

For this material, a chemical analysis of the grown sample was carried out. The result of the analysis showed that in the process of electron-beam growing, no critical changes in the composition of heat-resistant steel were revealed, the content of all chemical elements is within tolerance and corresponds to the starting material 07Kh12NMBF-Sh. Table 3 shows the chemical composition of the base material and the grown material.

### Table 3 - Chemical composition of the grown metal

|                  | C %   | Cr %   | Mo %  | Nb %   | V %   | Ni %  | Si %  | Mn %  | S %   | P %   |
|------------------|-------|--------|-------|--------|-------|-------|-------|-------|-------|-------|
| Main material    | 0,05- | 10,5-  | 0,35- | 0,05-  | 0,15- | 1,4-  | ≤0,6  | ≤0,6  | ≤0,020| ≤0,030|
|                  | 0,09  | 12,0   | 0,50  | 0,15   | 0,25  | 1,8   |       |       |       |       |
| Grown sample     | 0,071 | 11,0   | 0,47  | 0,09   | 0,22  | 1,65  | 0,29  | 0,109 | 0,0015| 0,013 |

For the implementation of this technology, as well as for the implementation of electron beam welding with through penetration, it is necessary to introduce an external wire feed mechanism into the installation. Growing flat products is possible only with a 3-coordinate water cooling table in order to avoid overheating of the deposited metal. An example of this table is shown in Figure 6.

![Figure 6. 3-axis table for additive growth of flat parts](image_url)

In addition to the wire feeder, a new plant control system is required with options to control the 3-axis table and the additive growing process. An example of this system is shown in Figure 7.
Figure 7. An example of a control system for the process of layer-by-layer growing using an electron beam

This control system allows:
- visualize future printing with the ability to view the stacking of material on any area or layer and, if necessary, change the slicing parameters;
- visualize the printing process with an estimate of the remaining time;
- interrupt, pause and resume a long printing process;
- change the main parameters during printing: beam power, wire feed speed.

The growing process begins with the preparation of a 3D model of the product (STL format). The file with the constructed model is loaded into the control program, where it is sliced: splitting into layers, creating an algorithm for filling the layers with wire material (the algorithms for the operation of the manipulator drives and the wire feeder are set), and the commands for controlling the electron beam are embedded. Next comes the growing process.

1.4 Electron beam hardening and local heat treatment

Quenching with a laser or electron beam is one of the methods for hardening the surface layer of metals and alloys. The use of these energy sources provides a short heating and cooling cycle and leads to the formation of a finely dispersed hardened structure with high hardness and wear resistance [4]. Surface hardening is possible for tool steels (Kh12MF, 9KhS, etc.). Some materials require post-weld heat treatment to reduce internal stresses (e.g., titanium alloys, high-alloy heat-resistant steels, etc.). With small thicknesses, it is possible to perform local heat treatment with an electron beam in order to reduce material and labor costs.

To implement these technologies, the following set of equipment is required (Figure 8): a pyrometer, thermocouples, thermocouples (for measuring the temperature of the processed surface of the product) and equipment for connection. It also requires a change in the design of the camera body - replacement with a new flange with a viewing window for a non-contact pyrometer (Figure 9).
Currently, work is underway on surface hardening of parts made of tool steels (Kh12MF, 9KhS, etc.) by an electron beam and local heat treatment after electron beam welding (titanium alloy VT6).

Strengthening with an electron beam is carried out as follows: the required surface of the sample is scanned at the same speed, ensuring that the branches of the scanning trajectory do not intersect. Oscillatory movements of the scanning field in two mutually perpendicular directions make it possible to carry out a line-by-line scanning trajectory. In the process of sweeping, the scanning field moves in the horizontal direction and simultaneously shifts downward depending on the speed of movement of the part. Having passed one line, the scanned electron beam quickly returns back, after which it begins to move again, but along another line.

2. Conclusion

The modernized electron-beam installation TETA 15E1000 made it possible to:
1. Use the latest developments of scientists and specialists in the field of beam technologies.
2. Significantly reduce costs (20 times) for the purchase of new equipment for each electron beam technology.
3. Transfer the manufacture of parts from magnetic alloys to electron beam welding and carry out demagnetization with a device or by imposing blank passes by electron beam welding (patent 2739931 was obtained for this method).
4. After the introduction of an external wire feed mechanism, in most products, switch to through-penetration welding, perform both fragmentary growing of parts of parts, and complete growing of workpieces.

5. Perform surface hardening of tool steel products with an electron beam and local heat treatment after electron beam welding.

3. References

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