Automated Installation for Modification Surface Properties of Details and Units of the Metallurgical Equipment by the Electron Beam Facing

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Abstract – The electron-beam facing installation is designed for the production of coatings on the surface of metal articles. The coatings have protective, wear-resistive, and heat-resistive properties. The installation is capable of creating coatings on large-area surfaces with high efficiency. The technological process is automated.

There are two plasma-cathode e-guns in the facing installation. This makes it possible to increase the facing efficiency and productivity. The guns are placed in a vacuum chamber on a two-rectilinear manipulator and can operate simultaneously.

This installation is used in metallurgy for creating wear-resistant coatings on aerial and oxygen lances, on crystallizers of continuous casting of steel, on rolls, etc.

1. Introduction

Electron-beam facing in vacuum [1, 2] allows coatings with unique properties to be produced. With this method of coating deposition there is no adhesion problem. The materials which can be treated by this method and the coatings which can be produced on their surfaces are widely diversified. The high repeatability of results in combination with the adaptable control of the technological process make it possible to produce coatings of required structure and preassigned properties.

We have developed an installation intended for deposition of heat-resistant coatings on crystallizers and aerial blast-furnace lances with the purpose of increasing their operational durability and also for restoration of various machine parts and metallurgical equipment. It can also be used for welding various metals and alloys, including high-melting ones.

The installation makes it possible to produce mono- and multilayer coatings of various purposes (hardening, wear-resistant, heat-resistant, temperature-resistant, etc.) depending on the composition of the facing powder on the surface of articles made of any metals, steels, and cast iron.

With this installation it is possible to deposit coatings on plane surfaces of workpieces of length up to 2100 mm, width up to 900 mm, and thickness up to 200 mm and on bodies of revolution of diameter up to 1200 mm and length up to 2100 mm.

The technological process of coating deposition is full-automatic.

2. Electron-beam facing

The principle of electron-beam facing is shown in Fig. 1. The electron beam creates a molten metal pool on the surface of the workpiece. The powder whose particles form a coating with required properties on the surface is supplied to the molten metal by a dispenser. The workpiece is moved inside the vacuum chamber relative to the (immobile) e-gun and dispenser or the e-gun with the dispenser are moved relative to the (immobile) workpiece.

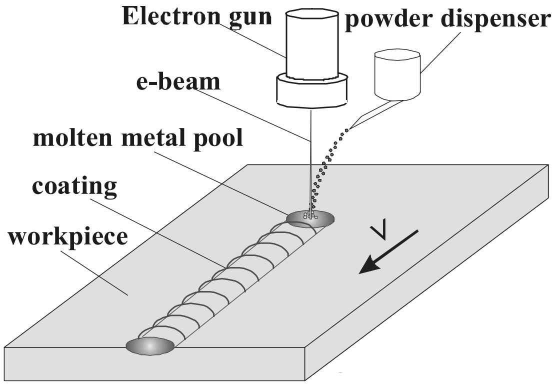


Fig.1.

The technology of multipass electron-beam facing is based on the phenomenon of "freezing" a powder into a melt pool. In every subsequent pass, a new portion of the powder is "frozen" and the previous portion is melted. The powder supplied to the pool speeds up the crystallization of the melt, thus promoting the formation of a fine grain structure and moderating the residual stresses in the deposited coating. The required thickness of the deposited layer is obtained by varying the rate of powder supply or by increasing the number of passes.

The process of facing is characterized by the following parameters: the accelerating voltage, the electron beam current, the distance from the focusing system to the surface of the workpiece, the electron beam scanning diameter and length, the velocity of motion of the workpiece, and the rate of powder supply.

3. Electron guns

The facing process is accompanied by intense ejection of vapors and gases from the facing zone. Therefore, to produce an electron beam, plasma-cathode guns are used [3, 4]. These guns do not contain hot electrodes or components which would be heated in operation, and this makes them insensitive to reactive and high-melting vapors of the materials under treatment. They are capable of operating under the conditions of facing not taking special measures for protection of the emitter.

The electron emission in the guns occurs from the plasma of a hollow cathode low-voltage reflected discharge [4]. The electrons outgoing from the plasma get in a high-voltage electric field where they are accelerated, collected in a beam, and focused by the magnetic field of the focusing system. The electron emission current from the plasma is controlled by varying the discharge current.

In the design of the guns, metal-ceramic units are used whose hermeticity and mechanical strength are provided by electron-beam welding. The gun housings are of in-chamber construction. The design of the housing provides easy and convenient access to the cathode assembly for periodic maintenance. Figure 2 presents the appearance of a gun mounted on the manipulator of the installation.

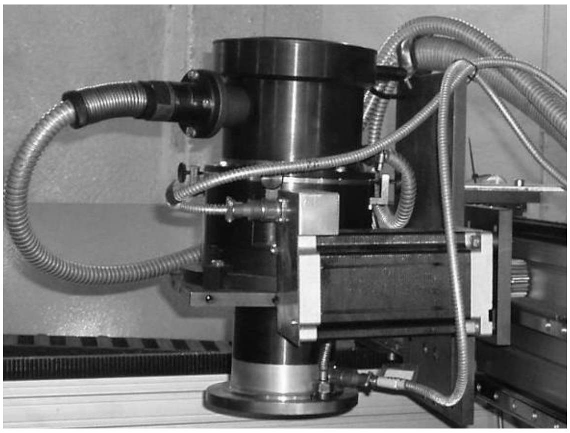


Fig. 2

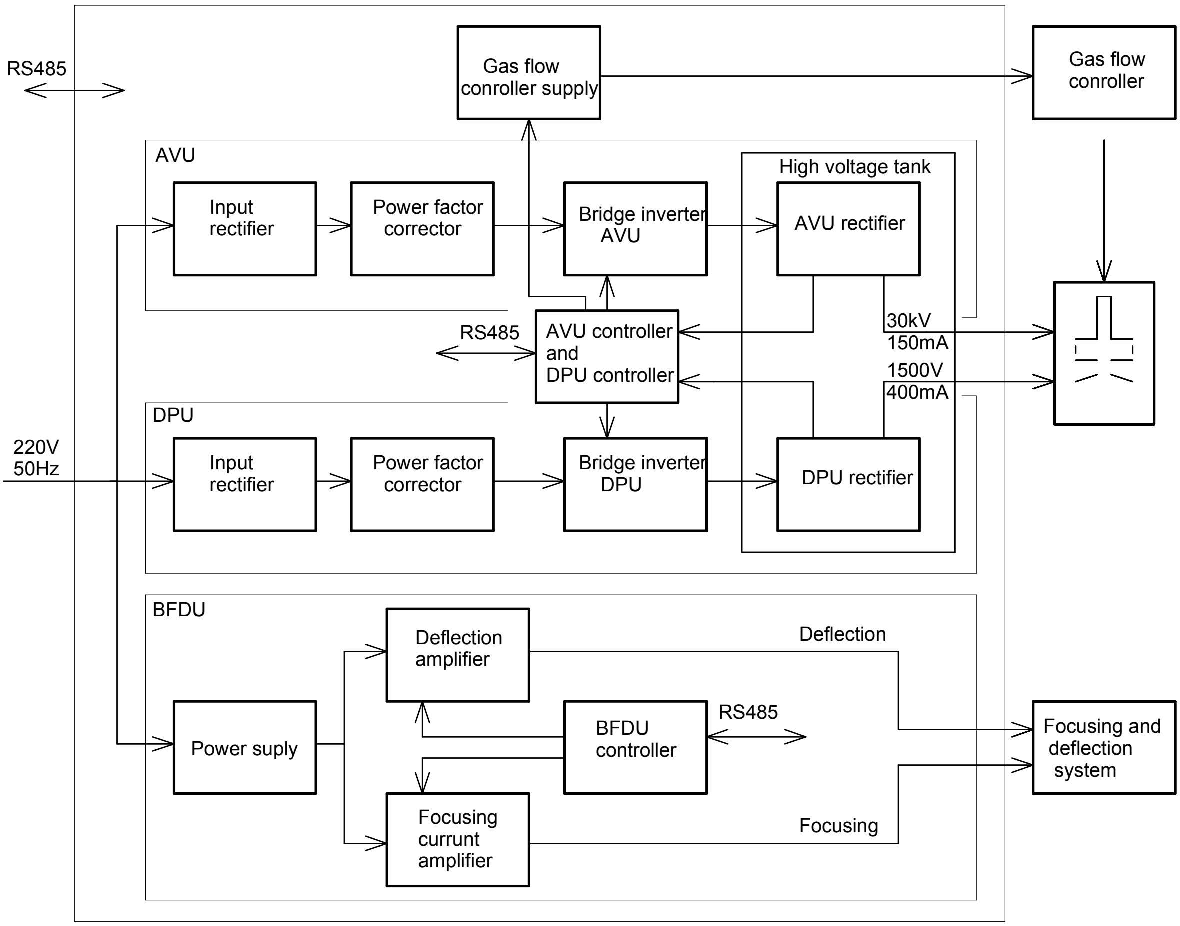


Fig. 3

4. Power supply module

The power supply system of the equipment (Fig. 3) consists of an accelerating voltage unit (AVU), a discharge power supply unit (DPU), a beam focusing and deflection control unit (BFDU), and a control unit of the gas flow controller. The units are controlled by a computer via an optical or an RS485 interface.

The accelerating voltage and discharge power supply units are made by the classical circuit design of a bridge inverter with the phase-shift control circuit. In the inverter, the resonance method of switching MOSFET transistors is realized that provides a low level of electromagnetic noise and reduced dynamic losses in switching power transistors. The high conversion frequency (30 kHz) makes it possible to reduce the output capacitance of the power supplies to 10 nF and to increase the rate of processing of control signals.

The accelerating voltage unit can operate in one of the two modes: stabilization of the accelerating voltage and limitation of the output current. In the first mode, a given accelerating voltage is stabilized as the load current increases from 0 to 150 mA. This is the normal operation of the unit. As the load current increases to more than 150 mA, the accelerating voltage unit goes over to the current limitation mode within 50 μs. This makes it possible to protect the load and to prevent the development of an arc discharge in case of breakdown in the electron gun. As the load current decreases, the accelerating voltage unit is back to normal operation. If the load current does not decrease, the unit is switched off for 20–100 ms and then returns to normal operation. This algorithm provides fault-free operation in extreme transient and arcing environments.

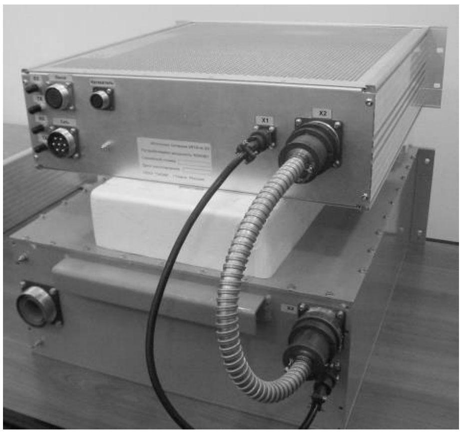


Fig. 4

The discharge power supply unit is a current source with the output voltage ranging between 50 and 1500 V. It operates in the current stabilization mode throughout the output voltage range.

Structurally, the accelerating voltage and discharge power supply units are made as two sections: a low-voltage section containing inverters and an oil-filled high-voltage tank in which the output stages are housed (Fig. 4).

The control and stabilization of the beam current are performed by varying the discharge current with a control time constant no more than 0.1 s.

5. Arrangement and operation of the installation

Deposition of coatings is carried out in the vacuum chamber of the installation. Two e-guns mounted on the two-rectilinear manipulator are placed in the chamber. The manipulator, providing independent horizontal movement of the guns, is intended for deposition of coatings on large-area plane surfaces. The use of two simultaneously operating guns increases the productivity of the installation. For deposition of coatings on ring surfaces an additional manipulator is used which provides rotation of the workpieces. The appearance of the installation is shown in Fig. 5.

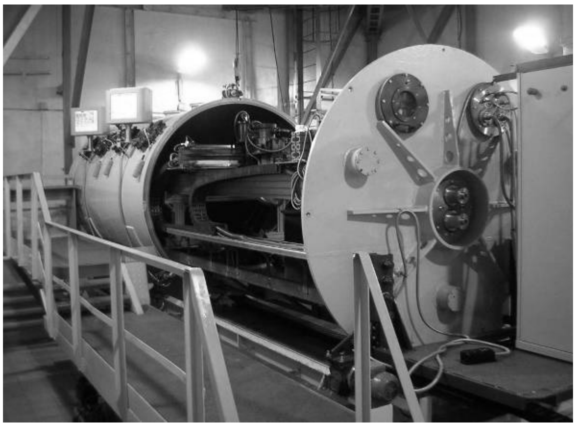


Fig. 5

The operation of the vacuum system, the power supply, the movement of the guns, and the technological process are controlled with an automated computer system. The choice of the mode of operation and the monitoring of technological parameters are performed with the help of commercial displays. To change the mode or a parameter, it suffices to press the graphical label of controls on the display with a finger.

The control system can operate in one of the three modes: Vacuum System, E-Gun, and Manipulator.

In the Vacuum System mode, it is possible to switch the pumps on and off and to open and close the valves of the vacuum system. The display shows the readings of the vacuum meters at different points of the vacuum system and the state of the pump cooling system. In this mode, it is possible to program all sequences of switchings of the valves and pumps for automated pumpdown of the vacuum chamber.

The power supply of the electron-beam guns is controlled in the E-Gun mode (Fig. 6). In this mo-

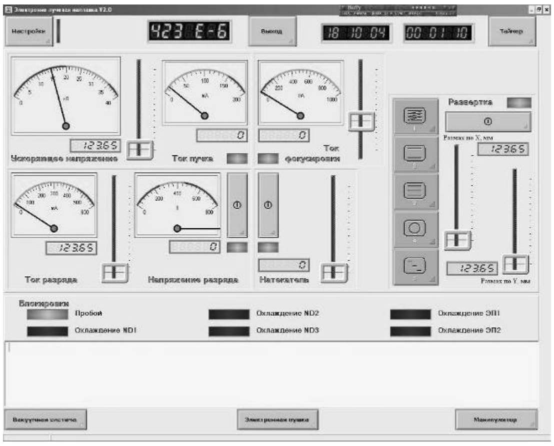
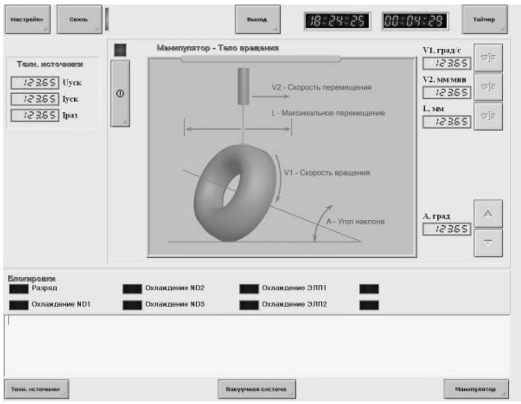


Fig. 6



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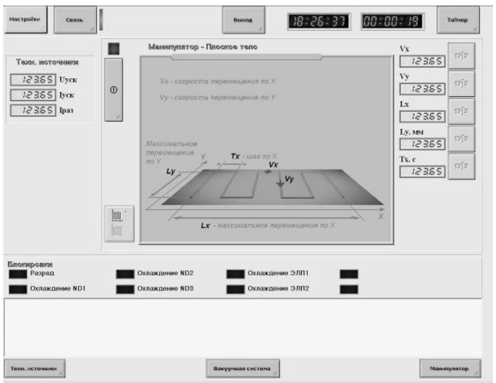

b

Fig. 7

de, it is possible to control the accelerating voltage, to change the magnitude of the beam current, and to control the gas flow rate and the parameters of the beam scanning over the surface of the workpiece.

The Manipulator mode (Fig. 7, *a*, *b*) is intended to control the movement of the workpiece and e-guns. Depending on the properties of the workpieces, two modes of operation of the manipulator are possible. For deposition of coatings on large-area plane surfaces the Manipulator – Plane Body mode (Fig. 7, *a*) is intended. In this mode, the workpiece is immobile, and two e-guns are moved simultaneously above its surface along a prescribed trajectory.

The Manipulator – Body of Revolution mode (Fig. 7, *b*) is intended for deposition of coatings on axisymmetric surfaces. In this mode, the gun is immobile, and the workpiece is rotated at a certain angle with a given velocity.

Table. Principal characteristics of the installation

Voltage of the supply line, V	380±5%
Power input, kW	30
Limiting pressure in the vacuum chamber, Pa	10^{-2}
Number of simultaneously operating e-guns	2
Rate of powder supply by the dispenser, g/min.	10–50
Accelerating voltage, kV	up to 30
Beam current, mA	up to 150
Dimensions of the vacuum chamber: diameter, mm length, mm	 2020 3500

Conclusion

The installation created by us is used on one of the world's largest metallurgical works – the West Siberian Iron and Steel Plant – for deposition of wear-resistant coatings on aerial and oxygen lances, on crystallizers of continuous casting of steel, and on rolls.

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