Application of electron beam welding as an alternative approach for connecting pipelines in oil and gas equipment

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Abstract. The article discusses electron beam welding for connecting pipelines. This approach has been reviewed in the literature. The technology of creating flange connections in the oil and gas industry is considered. The analysis and selection of the most suitable equipment for the creation of permanent joints of complex structures has been carried out. Thus, a literature-patent review of the current state and methods of using electron beam welding for various designs and control methods has been carried out. The analysis of the subject area showed that there is equipment, in particular, the TETA 6E400 installation and a turntable for creating such connections in the area under consideration. The proposed approach will improve the quality of flange-pipeline welded joints and reduce the cost.

1. Introduction

A significant expansion of the industrial use of electron beam welding (EBW) is associated with the possibility of efficient production with its help of products from structural metals and alloys of large thicknesses (up to 300 mm) [1-3]:

- Pressure vessels, nuclear and chemical reactor casings, containers for nuclear waste, underwater vehicle casings, steam turbine rotors, supersonic aircraft supporting structures. Another advantage of EBW is its ability to be a finishing operation when welding metals up to 80 mm thick. However, this requires a highly efficient and highly reliable manufacturing process that meets the best quality standards. In this regard, there are a number of problems in the theory, technology and technology of EBW, the successful solution of which often requires the combined efforts of many research centers.
In the field of theory, the most important task is to create computational models of the welding process under various conditions and electron-optical systems of welding electron guns, which would allow predicting with good accuracy the parameters of welded seams, welding modes, parameters of electron beams and the optimal configuration of elements of electron-optical systems [4-6].

In the field of EBW technology, the most important problems are the improvement of methods: closing circular seams, repairing defective sections of seams, demagnetizing products before welding, removing an electron beam into an atmosphere of inert gases (out-of-vacuum welding), welding in low vacuum, welding dissimilar materials; in-depth study of the effect of neutron irradiation on the characteristics of welded joints. It is also necessary to develop expert and information computer systems. In the field of creating equipment for EBW, the main problem is to reduce the cost of equipment while increasing its productivity [7-9]. To solve these problems, it is necessary:

- To develop powerful inverter (with a control frequency of more than 10 kHz) power sources for welding electron guns.
- Improve pumping systems for vacuum chambers, providing oil-free vacuum and short evacuation time (less than 5 minutes for large vacuum chambers).
- Using the latest hardware components and Internet technologies, to develop more advanced software-automatic control systems with self-diagnostics of the entire complex of equipment.

Improvement of organizational forms of development of such an expensive welding method as ELW is also of great importance. The existence of technology firms at large research centers is quite justified, where paid services for welding with an electron beam of products of customers in this region are performed. To ensure the economic independence of such firms, they should also organize small-scale production of unique products [10-12].

There are many ways of tracking the EBW process, introducing the EBW process, to obtain high quality welded joints. Consider several ways to obtain a strong, reliable and deep seam:

1. The most widespread systems of automatic guidance of the beam to the joint in the process of electron-beam welding, require the presence of scanning beam movements, which has a positive effect on the quality of the joints obtained from homogeneous materials. Guidance systems based on the secondary emission signal and X-ray radiation are especially widely used. The operation of these systems is based on signal detection when scanning the product joint with an electron beam. When welding in the atmosphere, the design of the electron-beam gun does not provide for search movements of the beam, and, as a consequence, in the absence of movement of the beam, these tracking systems will not function. Nevertheless, when welding dissimilar materials, it is possible to use a control system based on the registration of changes in the vertical component of the magnetic field above the welded area. A flux gate can be used as a magnetic field sensor, which, in comparison with a Hall sensor, is more sensitive to weak magnetic fields and makes it possible to implement a system at a carrier frequency. The sensor, mounted on an electron beam gun, is installed above the welded joint. The fluxgate sensitivity axis is oriented in the plane of the joint passing through the electron beam parallel to the joint and perpendicular to the surfaces to be welded. The use of a measuring device with a flux-gate sensor allows you to determine the actual value and direction of deflection of the electron beam relative to the joint of the welded product by changing the parameters of the magnetic field of the current in the parts being welded and thereby control the position of the electron beam during EBW, which is of no small importance when welding dissimilar materials [13].

2. Currently, the simplest and most affordable way to control the penetration is the use of a collector of penetrating electrons located on the inner side of the weld. The principle of operation of such a system is to control the collector current caused by the through current of electrons passing through the molten metal. The operator must adjust the beam current so that the collector current ranges from 2 to 3 mA. The problem is that the collector current is pulsed,
which greatly complicates the operator's work and increases the risk of rejects and all kinds of defects.

3. The study of welds obtained during welding with oscillations of the electron beam across and along the seam, as well as with the rotation of the electron beam, showed that the indicated trajectories of the electron beam scan do not provide a significant increase in the structural homogeneity of the weld metal, and the absence of root defects is achieved only when large oscillation amplitude, which leads to a significant decrease in the penetration depth and an increase in the width of the weld.

4. In electron beam welding (EBW) in the atmosphere, traditional methods of automatic positioning of the beam along the joint of the parts to be welded are unacceptable due to the strong scattering of electrons in the air and the impossibility of deflecting the electron beam in the volume of the electron beam gun due to the airlock structure of the latter [14]. To track the joint in the EBW process, it is proposed to use the magnetic fields of currents in the parts formed by the current of the electron beam.

5. On the basis of a joint study of the stability of hydrodynamic and thermal processes in the weld pool, a model was developed for the formation of undercuts and cusps on the surface of welds with out-of-vacuum EBW. Theoretical analysis and simulation results showed that the reason for the formation of undercuts is surface phenomena, and the reason for the appearance of bumps is the development of instability of the thermocapillary flow of the melt in the weld pool.

- The thresholds for the speed of bumping and undercutting were determined depending on the beam current and working distance. It was found that with an increase in the beam current, the instability of the weld pool increases. As the working distance decreases, the beam intensity increases, so the beam current must be reduced to maintain the required penetration depth. In this case, the profile of the seam becomes narrower and the threshold for the rate of tubercle formation changes slightly.
- Thresholds of the rate of formation of bumps for various materials have been experimentally determined. As the thickness of the material increases, the threshold for the rate of formation of bumps decreases. The reason for this is the change in the conditions for the heat and mass transfer of the melt. It was found that the leading role is played by the Marangoni effect.
- The use of surfactants helps to suppress the formation of bumps by changing the coefficient of surface tension.
- High-speed video recording made it possible to estimate the rate of flow of the melt in the weld pool, the dynamics of growth and the size of individual bumps.
- Due to the use of nickel indicator material in the weld pool, horizontal flows and the absence of vertical ones were revealed, which was also confirmed by the results of microprobe analysis of thin sections in longitudinal and transverse thin sections.

Based on all of the above, we can say that EBW is the most effective welding method. Also, from an economic point of view, the method of welding is very convenient and practical, due to the reduction of both material and financial investments. A wide range of welding possibilities in various industries is clearly visible [13-15]. Welding can be carried out both in closed spaces such as vacuum and in open spaces (in the atmosphere). EBW can be carried out in various ways of welding, we can also control the process of the depth and width of the seam, in the course of work observe how the structure of materials changes, what defects occur, adjust the position of the beam, adjust the speed of the beam. The electron beam holds great promise and promise in the construction industries.

2. Materials and methods
The most important characteristic of electron beam welding is the high quality of welded joints and a wide range of thicknesses of the welded parts from fractions of a millimeter to 100 mm or more.
Having studied this issue, in the course of the literature and patent review, it was decided to use EBW using the TETA 6E400 unit at the development facilities of oil and gas treatment units. The TETA installation is shown in figure 1.

![Figure 1. Installation TETA 6E400. 1 - vacuum chamber, 2 - electron-beam gun, 3 - auxiliary mechanisms and supporting metal structures, 4 - high-voltage power supply, 5 - control and monitoring system. Internal dimensions of the vacuum chamber 800x800x800 mm.](image)

Figure 2 shows a schematic diagram of the TETA 6E400 installation.

![Figure 2. Installation diagram of TETA 6E400.](image)

To use the TETA installation for welding flange joints at the development sites of oil and gas treatment plants, it was proposed to design revolving nozzles for a turntable, which make it possible to weld several flanges of different diameters at once. The turntable is shown in figure 3.

![Figure 3. Rotary table.](image)
3. Result and discussion

The essence of the work of the TETA plant with the designed nozzles is to improve the quality of welded joints between the flange and the pipe.

The nozzle consists of two round plates with a diameter of 700 mm (upper and lower), between which there is an ACD-B1 asynchronous displacement motor, the upper plate is held by means of welded legs, which are inserted into special grooves in the lower plate. On the top plate there are so-called cartridges, into which the pipe is inserted and held in an upright position, a flange is put on the pipe and fixed in the desired position. The chucks in the top plate are mounted on bearings and have one pulley each through which the drive belt runs. A drive pulley is brought up from the displacement motor, which is flush with the rest of the pulleys and drives the cartridges, substituting the junction of the flange and pipe under the beam for welding.

The top view is shown in figure 4.

![Figure 4. Top view nozzle.](image)

The result of the design is the creation of a structure that will increase the productivity of the installation by several times, since the main disadvantage of the installation is the time it takes to create a vacuum in the working chamber after loading the products. The creation of a working vacuum lasts 20-40 minutes, depending on the size of the vacuum chamber, while the process of welding the flange with the pipe itself lasts no more than one minute.

With the help of this development, we will be able to weld several flanges at once in just one cycle of equipment operation, which in turn will increase its productivity several times.

4. Conclusion

The article discussed in detail the electron-beam welding method. An analysis of the equipment used for EBW was also carried out. TETA 6E400 was chosen as the main device for the use of EBW in the oil and gas industry, as well as a rotary table provided by the manufacturer for connecting the flange and the pipeline. Thus, the applicability of electron beam welding in this approach was substantiated. And a nozzle was selected that allows the use of EBW for connecting pipelines of the oil and gas industry.

References

[1] Węglowski M S, Błacha, S and Phillips A 2016 Electron beam welding – techniques and trends – review Vacuum 130 72-92
[2] Lacki P and Adamus K 2011 Numerical simulation of the electron beam welding process Computers & Structures 89(11-2) 977-85
[3] Tynchenko V S, Kurashkin S O, Tynchenko V V, Bukhtoyarov V V, Kukartsev V V, Sergienko R B, Tynchenko S V and Bashmur K A Software to Predict the Process Parameters of Electron
Beam Welding *IEEE Access* 9 92483-99

[4] Chiumenti M, Cervera M, Dialami N, Wu B, Jinwei L and de Saracibar C A 2016 Numerical modeling of the electron beam welding and its experimental validation *Finite Elements in Analysis and Design* 121 118-33

[5] Dey V, Pratihar D K, Datta G L, Jha M N, Saha T K and Bapat A V 2009 Optimization of bead geometry in electron beam welding using a genetic algorithm *Journal of Materials Processing Technology* 209(3) 1151-7

[6] Kurashkin S O, Seregin Y N, Tynchenko V S, Petrenko V E and Murygin A V 2020 Mathematical functional for thermal distribution calculating during the electron-beam welding process *Journal of Physics: Conference Series* 1515(5) 052049

[7] Guo S, Zhou Q, Kong J, Peng Y, Xiang Y, Luo T and Zhu J 2016 Effect of beam offset on the characteristics of copper/304 stainless steel electron beam welding *Vacuum* 128 205-12

[8] Kar J, Roy S K and Roy G G 2016 Effect of beam oscillation on electron beam welding of copper with AISI-304 stainless steel *Journal of Materials Processing Technology* 233 174-85

[9] Tynchenko V S, Kurashkin S O, Murygin A V and Tynchenko Y A 2021 Energy distribution modelling in the weld zone for various electron beam current values in COMSOL Multiphysics *Journal of Physics: Conference Series* 1889(4) 042058

[10] Lu W, Shi Y, Lei Y and Li X 2012 Effect of electron beam welding on the microstructures and mechanical properties of thick TC4-DT alloy *Materials & Design* 34 509-15

[11] Wang S and Wu X 2012 Investigation on the microstructure and mechanical properties of Ti–6Al–4V alloy joints with electron beam welding. *Materials & Design (1980-2015)* 36 663-70

[12] Rodgers T M, Madison J D, Tikare V and Maguire M C 2016 Predicting mesoscale microstructural evolution in electron beam welding *Jom* 68(5) 1419-26

[13] Trushnikov D, Belenkiy V, Shchavlev V, Piskunov A, Abdullin A and Mladenov G 2012 Plasma charge current for controlling and monitoring electron beam welding with beam oscillation *Sensors* 12(12) 17433-45

[14] Murygin A V, Kurashkin S O, Tynchenko V S and Rogova D V 2021 The use of ANSYS for modelling the energy distribution in steady mode with electron beam welding *Journal of Physics: Conference Series* 1889(4) 042061

[15] Kurashkin S O, Tynchenko V S, Seregin Y N, Murygin A V, Kukartsev V V and Tynchenko V V 2020 The model of energy distribution during electron beam input in welding process *Journal of Physics: Conference Series* 1679(4) 042036