Design of an electron beam welding installation based on the existing equipment for connecting pipelines without using a vacuum

A A Stupina1,2,3, I A Panfilov1,2,3, O A Antamoshkin1,2,3, E L Vaitekunene1,2, N V Fedorova1,2 and D V Eremeev2

1 Siberian Federal University, Svobodny pr., 79, Krasnoyarsk, 660041, Russian Federation
2 Reshetnev Siberian State University of Science and Technology, Krasnoyarsk, Rabochy Av., 31, Krasnoyarsk, 660037, Russian Federation
3 Krasnoyarsk State Agrarian University, Kirenskogo, 2, Krasnoyarsk, 660074, Russian Federation

E-mail: h677hm@gmail.com

Abstract. The article is aimed at solving the problem of connecting pipelines using electron beam welding. During the presented study, the analysis of the object of study - the main oil pipeline was carried out, during which the main shortcomings in the formed welded joints were identified. The authors also analyzed the methods of forming welded joints, which showed the advantages of electron-beam technology. The means of electron beam welding were selected: a generator, an electron beam gun. The electrical characteristics of the installation have been calculated, which make it possible to formulate the requirements for the purchased equipment. As a result, the authors have designed an installation for electron-beam welding of joints of the main pipeline elements, which makes it possible to form welded seams up to 400 mm deep and 1 mm wide.

1. Introduction
Today, there are guns for electron beam welding (EBW) that allow welding products at normal atmospheric pressure, without the need to create a vacuum [1-3].

The focusing of the beam is impeded by the magnetic field in which the reflective discharge burns. This field is concentrated in the discharge chamber; there is also a leakage field, which is closed through the gaps between the magnetically conductive elements of the source structure. This field can also be present in the electron-optical system of the source. The magnetic field penetrating into the electron-optical system will change the conditions for the formation of the electron beam. In articles [4-6], the results of calculations of the configuration and magnitude of the magnetic field in the regions of formation, acceleration and transport of electrons in the electron-optical system of the plasma electron source were presented. It was shown that the configuration and magnitude of the magnetic field in these regions can be significantly changed by choosing the material of the electrodes that form the magnetic circuit. The creation of a quasi-uniform magnetic field in the electron-optical system of the plasma electron source can significantly improve the focusing of the beam.
The brightness (current density per unit solid angle) of a focused electron beam is one of the most important parameters of the gun. High values of this parameter make it possible to use guns in devices for extracting beams into the atmosphere through gas-dynamic windows. In addition, the guns can be used in such non-mass technologies as cutting, creating calibrated holes, etc. According to the results that were carried out in articles [7-9], the brightness of a focused electron beam generated by a gun with a plasma emitter was measured. The measurements were performed for a beam with a power of up to 4 kV and an electron energy of 60 kV, focused at a distance of 0.5 m from the focusing lens. It is shown for the first time that the brightness of a focused beam of a gun with a plasma emitter is not inferior to the brightness of beams obtained in hot cathode guns [10,11].

As a result of the analysis of scientific literature, it is possible to pick up the electron guns already available in our time, which are represented by the company “ELION” LLC. At the moment, there are three types of guns that differ from each other by the consumed energy: Gun with plasma cathode 60kV is shown in figure 1.

![Figure 1. Plasma cathode gun 40kV.](image)

Cannon characteristics:

1. Electron beam current 0 to 200 mA.
2. Accelerating voltage range: from 10 to 30 kV; from 20 to 40 kV; from 20 (30) to 50 kV; from 30 to 60 kV; from 30 to 75 kV; from 90 to 120 kV.
3. Overall dimensions of the gun:
   - Height no more than 550 mm.
   - Outside diameter: 335 mm (ISO 250) or 285 (ISO 200).
4. The mass of the gun without a high-voltage cable should not exceed:
   - 50 kg for guns up to 60 kV.
   - 110 kg for guns up to 120 kV.

By agreement with the customer, the range of accelerating voltages, gun dimensions, gun weight can be changed.
Depending on the thickness of the materials to be welded, we will choose a gun with a voltage of 60 kV, because it meets our parameters of welded product thicknesses in terms of power.

Main technical characteristics of 60kV plasma cathode gun:

- Operating mode - continuous, impulse.
- Working pressure in the vacuum chamber 10-4 Topp.
- Accelerating voltage up to 60 kV.
- Beam current up to 200 mA.
- Maximum beam power 12 kW.
- Beam diameter at focus 0.3 - 0.6 mm.
- Beam deflection angle, not less than 7 degrees.
- The amount of gas (air) inlet into the discharge chamber is 12-20 cm³ atm/hour.
- Weight of the gun with a plasma cathode 60 kg.

2. Materials and methods

Let's calculate the required minimum engine power to move the unit around the axis. At the beginning, we find out the work being done (1) of our engine:

\[ A = N \cdot t \]  

where \( N \) – power [W]; \( t \) – time [s]; \( A \) – Work [J].

We do not know the power from formula (1). Find power (2):

\[ N = \frac{A}{t} \]  

To find the capacity, we also do not know the job, we will find a job (3):

\[ A = F \cdot S \]  

where \( F \) – force (4) [N]; \( S \) is the distance at which the work will be performed [m];

\[ F = m \cdot a \]  

According to the law of free fall, \( a = g = 9.8 \text{ m/s}^2 \). Figure 1 shows a diagram of the movement of the engine.

![Figure 2. Engine movement diagram.](image)

The work will be carried out along the length of the semicircle of the pipe section (5).

\[ S = \frac{2 \cdot \pi \cdot r}{2} = \pi \cdot r \]  

(5)
where $\pi$ – mathematical constant; $r$ - pipe radius [m].

In practice, oil trunk pipelines are divided into four classes depending on the diameter:

- I - with a diameter of 1000-1200 mm.
- II - 500-1000 mm.
- III - 300-500 mm.
- IV - less than 300 mm.

From (3) and (4) follows equation (6):

$$A = m \cdot a \cdot S,$$

where $m$ – weight [kg]; $a$ - free fall acceleration [m/s$^2$]; $S$ - pipe radius [m].

Substituting (5), we obtain the equation (7):

$$A = m \cdot a \cdot \pi \cdot r,$$

Then, substituting (6) into (2), we obtain the formula for calculating the minimum required power for the engine to move the installation during operation (8):

$$N = \frac{m \cdot a \cdot \pi \cdot r}{t},$$

Since the recommended values of the process speed for the installation of electron beam welding, the formula (8) can be changed taking into account the following (9), (10):

$$S = V \cdot t,$$

$$t = \frac{s}{v} = \frac{\pi \cdot r}{v},$$

Formula (8) takes the form (11):

$$N = \frac{m \cdot g \cdot \pi \cdot r \cdot v}{\pi \cdot r} = m \cdot g \cdot v.$$

Welded steel pipes for main gas pipelines, oil pipelines and oil product pipelines GOST 31447-2012.

Power values for different pipe diameters are presented in Table 1.

| Pipe diameter, mm | Wall thickness, mm | Speed m/h | Power, W |
|------------------|-------------------|-----------|----------|
| 159              | 17                | 50        | 15       |
| 168              | 15                | 45        | 14.7     |
| 178              | 13                | 43        | 13.9     |
| 219              | 10                | 38        | 11.7     |
| 630              | 9                 | 32        | 9.4      |
| 720              | 8                 | 30        | 9.2      |
| 1400             | 6                 | 25        | 7        |

Let’s calculate the required power, [W] for a pipe with a diameter of 159 mm and a wall thickness of 17 mm at a speed of 50 m/h:

$$N = m \cdot g \cdot v = 120 \cdot 9.8 \cdot 0.013 = 15$$
The required net motor power for will be 15 W. These calculations show the adequacy and applicability of the method proposed by the authors. Based on these calculations, a mobile installation of electron beam welding will be designed.

3. **Result and discussion**
Before starting welding, let's pay attention to the pipe diameter and wall thickness. After the analysis, you need to set a certain pipe diameter to the guide belt, then connect the ends of the guide belt with clamps. We put the platform with rollers on the guide belt, use the release lever to squeeze the rollers on the guide belt so that they are securely fixed. On the platform there will be horizontal motors and vertical motors, which are attached to the platform by bolts and nuts. A plate is attached to the horizontal motor, which moves the electron beam gun. The electron beam gun is attached to the plate by levers with holders. The holders are bolted to the plate, and on the other hand, hold the gun with clamps. To the gun, one side is connected under a copper cable, and the other side goes from the generator. In turn, we can rotate the generator, depending on the welding, to certain places.

![Figure 3. General view of the EBW installation. 1 - pipe; 2 - guiding belt; 3,4 - displacement motors; 5 - release lever; 6 - rollers of movement; 7 - electron beam gun; 8 - seam; 9 - holders; 10 - cable; 11 - concrete racks; 12 - generator.](image)

4. **Conclusion**
The analysis of the object of research - the main oil pipeline, was carried out, during which the main shortcomings in the formed welded joints were identified. The analysis of the methods for the formation of welded joints, which showed the advantages of the electron-beam technology. The means of electron beam welding were selected: a generator, an electron beam gun. An installation for electron-beam welding of the joints of the main pipeline elements was designed, which makes it possible to form welded seams up to 400 mm deep and 1 mm wide. The electrical characteristics of the installation are calculated, which make it possible to formulate requirements for the purchased equipment.

**References**
[1] Kornilov S Yu, Osipov I V and Rempe N G 2009 Obtaining sharply focused beams in electron guns with a plasma cathode *Devices and experimental techniques* **3** 104-9
[2] 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

[3] 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

[4] Kornilov S Yu and Rempe N G 2012 Formation and focusing of electron beams in an electron-optical system with a plasma emitter in a magnetic field Technical Physics Journal 82(3) 79-84

[5] 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

[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] Kornilov S Yu and Rempe N G 2013 On the parameters of the electron beam of a gun with a plasma emitter Letters to the Journal of Technical Physics 39(19) 1-8

[8] 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

[9] 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

[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] 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