Analysis of approaches for creating pipe connections in oil and gas equipment

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Abstract. The article deals with the problem of connecting pipelines in the oil and gas industry. One of the connection methods is resistance welding. Often, the use of this approach shows muted efficiency as it depends on the qualifications of the welder. A technique for creating flange (plane) connections with a pipe in the oil and gas industry is considered. The necessary equipment and types of welds within the considered area are considered. Thus, it is necessary to conduct a literature-patent review to find an alternative method for creating welded joints in oil and gas pipelines in order to increase the reliability of such joints and reduce the cost of production. The analysis of the subject area and the search for possible solutions to the problem posed were carried out. Various welding methods (manual electric arc, automatic submerged-arc welding, induction brazing, etc.) are considered and a comparison of the main welding methods is given, as well as the rationale for the use of electron beam welding to create such pipe joints.

1. Introduction

Flanges are commonly used to connect pipeline elements - its segments, fittings, instruments, including metering and control, various parts and much more [1]. Products of different types are in demand - threaded, welded, loose. A set of such a connection consists of the following parts: flanges, an O-ring or gasket, studs or bolts, nuts. The tightness of the joints at the joints is achieved due to the mechanical action on the seal - the gasket is deformed under the force transmitted by the bolts and studs.

This connection has certain advantages. First, it is possible, if necessary, to quickly dismantle a certain area. This is important when carrying out repair work, cleaning. Secondly, they provide a high level of tightness. Thirdly, the absence of welding seams on the line increases its useful life. Threaded flanges are also good because they can be used to mount pipeline elements and connect equipment in rooms where welding is prohibited [2].
These products have relative disadvantages. For example, the sealing elements need to be replaced periodically. The installation process can be referred to as laborious. In addition, it is necessary to monitor the condition of the welded joint of the flange itself and the pipe during operation, since due to pressure and temperature differences in the system, water hammer and other factors, it can weaken, which will lead to leakage [3].

The main method for welding a flange to a pipe is butt welding. The plane (flange) is docked with the pipe along the entire perimeter of the pipe end, tacks are made and then completely scalded. This welding process is rather complicated, since the welding process involves the use of all types of welding seams [4]:

- Horizontal.
- Ceiling.
- Vertical.

At the same time, in order to perform a high-quality connection, the welder requires a fairly high qualification.

Also, this welding method is not particularly reliable, since there is no way to weld the joint over the entire area of contact of the flange with the pipe, welding is performed only at the edges. Thus, the purpose of the work is to review welding methods for connecting pipes and choosing an alternative welding method to improve the quality of welded joints.

2. Materials and Methods
Consider the most used welding methods for connecting a flange to a pipe in the oil and gas industry.

2.1 Manual arc welding
Electric arc welding is currently the most important type of metal welding. The source of heat in this case is an electric arc between two electrodes, one of which is the workpieces being welded. An electric arc is a powerful discharge in a gas environment [5].

The arc ignition process consists of three stages: short-circuit of the electrode to the workpiece, withdrawal of the electrode by 3-5 mm. and the occurrence of a stable arc discharge. A short circuit is produced in order to heat the electrode (cathode) to the temperature of intense exo-electron emission.

At the second stage, electrons emitted by the electrode are accelerated in an electric field and cause ionization of the gas gap “cathode-anode”, which leads to the emergence of a stable arc discharge. The electric arc is a concentrated heat source with a temperature of up to 6000 °C. Welding currents reach 2-3 kA at arc voltage (10-50) V. The most used arc welding with a covered electrode.

Advantages of the method [5,6]: high level of manufacturability, the possibility of upgrading the process, a small heating zone during operation, ease of control, cheap consumables and high productivity.

Cons of electric arc welding [5,6]:
- It is necessary to use welding converters (rectifiers, inverters) and additional equipment (transformers for welding).
- Dependent on power sources (network, generator).
- Work can only be performed on cleaned and treated surfaces.
- Energy consumption for manual electric arc welding is 2-3 kA (10-50V).

2.2 Automatic submerged arc welding
Automatic submerged-arc consumable-electrode welding is widely used [7]. The flux is poured onto the product in a layer (50-60) mm thick, as a result of which the arc burns not in air, but in a gas, bubble located under the flux melted during welding and isolated from direct contact with air. This is sufficient to eliminate liquid metal splashing and disruption of the weld shape even at high currents. When welding
under a layer of flux, a current strength of up to (1000-1200) A is usually used, which is impossible with an open arc. Thus, in submerged arc welding, the welding current can be increased 4-8 times compared to open arc welding, while maintaining good welding quality at high productivity [8].

In submerged arc welding, the weld metal is formed due to the melting of the base metal (about 2/3) and only about 1/3 due to the electrode metal. The arc under the flux layer is more stable than with an open arc. Welding under a layer of flux is performed with bare electrode wire, which is fed from a coil to the arc burning zone by the welding head of the machine, which is moved along the seam [9]. Ahead of the head along the pipe, granular flux enters the seam groove, which, melting during the welding process, evenly covers the seam, forming a hard slag crust.

Advantages of the method [7-9]:

- Simple and reliable technology.
- The equipment is easy to transport.
- Flux is much cheaper than inert gas, which is used for gas welding.

Gas protects the weld pool, just like flux, but the price of gas is ten times more expensive. Minuses [7-9]:

- Low qualification of the welder can lead to the fact that the flux will be applied unevenly, which means that the weld will deteriorate, be uneven and fragile.
- Submerged arc welding is rarely used for delicate thin seams in process lines.
- Energy consumption for automatic floor welding with flux is 1000-1200 A.

2.3 Spot resistance welding

In spot welding, the parts to be joined are usually located between two electrodes. Under the action of the pressure mechanism, the electrodes tightly squeeze the parts to be welded, after which the current is turned on. Due to the passage of current, the parts to be welded are quickly heated to the welding temperature. The diameter of the molten core determines the diameter of the welded spot, usually equal to the diameter of the contact surface of the electrode [10].

Depending on the location of the electrodes in relation to the parts to be welded, spot welding can be two-sided and one-sided.

When spot welding parts of different thicknesses, the resulting asymmetric core is displaced towards the thicker part and, with a large difference in thickness, does not capture the thin part. Therefore, various technological methods are used that ensure the displacement of the core to the abutting surfaces, increase the heating of a thin sheet due to overlays, create a relief on a thin sheet, use more massive electrodes from the side of a thick part, etc. [11].

A type of spot welding is projection welding, when the initial contact of parts occurs along pre-prepared protrusions (reliefs). The current, passing through the place where all the reliefs touch the lower part, heats them up and partially melts them. Under pressure, the reliefs deform, and the top part becomes flat. This method is used for welding small parts. Table 1 shows the characteristics of machines for spot welding [10,11].

| Machine type | W, [kVA] | U па6, [V] | D, [mm] | F, [kN] | Welding per hour |
|--------------|----------|------------|---------|---------|-----------------|
| MT-809       | 20       | 1-3        | 0.2-3   | 3       | 150             |
| MT-1609      | 85       | 3-6        | 0.5-5   | 6       | 350             |
| MT-207       | 170      | 4-8        | 1-5     | 16      | 150             |
| TII-400      | 400      | 6-12       | Before 8| 32      | 40              |
Column designations: W - machine power, U work - operating voltage, D - electrode diameter, F - compression force of the parts to be welded, welds per hour - productivity.

Energy consumption of spot resistance welding is 1-12 V, 20-400 kVA.

2.4 Induction welding

This method predominantly welds longitudinal seams of pipes in the process of their manufacture on continuous mills, and hard alloys are deposited on steel bases in the manufacture of cutters, drill bits and other tools [12].

With this method, the metal is heated by passing high-frequency currents through it and squeezed. Figure 1 shows induction welding.

![Pipeline induction welding](image)

**Figure 1.** Pipeline induction welding.

Induction welding is convenient in that it is non-contact, high-frequency currents are localized near the surface of heated workpieces [13]. Such installations work as follows. The high frequency generator current is applied to an inductor, which induces eddy currents in the workpiece, and the pipe heats up. Mills of this type are successfully used for the manufacture of pipes with a diameter of (12-60) mm at a speed of up to 50 m / min. Power is supplied from lamp generators with a capacity of up to 260 kW at a frequency of 440 kHz and 880 kHz. Pipes of large diameters (325 mm and 426 mm) with a wall thickness of (7-8) mm, with a welding speed of up to (30-40) m / min are also manufactured.

Advantages of the method [12,13]:

- Fast heating.
- Long service life of the inductor.
- Absence of marks, scratches, etc. on the parts to be welded under the inductor.

Minuses [12,13]:

- Difficulty maintaining a uniform gap between the inductor and the surface of the parts to be welded.
- Relatively high-power consumption due to current spreading over the pipe surface outside the welding zone and the difficulty of concentrating heating in the welding zone.
Energy consumption for welding using induction heating is on average 260 kV.

2.5 Electron beam welding

Electron beam welding (EBW) is a process based on the use of heat generated during deceleration of a sharply focused beam of charged particles accelerated to high energies. This heating source acquired widespread use only with the development of vacuum technology and electronic optics, only after that it began to be used in metallurgical technology [14].

The main component is an electron beam, which is created by a special device - an electron gun.

In order to reduce the loss of kinetic energy of electrons due to collisions with air gas molecules, as well as for chemical and thermal protection of the cathode, a vacuum of about \(10^{-4} \text{–} 10^{-6} \text{ mm Hg}\) is created in the gun. Such a high concentration of beam energy (up to \(10^9 \text{ W/cm}^2\)) with a minimal area of the heating point (up to \(10^{-7} \text{ cm}^2\)) leads to a decrease in thermal deformations during welding and the formation of a seam with a dagger-shaped penetration.

The energy consumption for welding using an electron beam is on average 18-20 kV. However, installations with a capacity of 30 kW and 60 kW are also used, depending on the thickness of the product and the required shape of the welded joint.

Electron beam welding has several significant advantages, including [14,15]:

- Small amount of heat input. In most cases, to obtain the same penetration depth in this type of welding, heat will be required 5 times less than in the arc form, which significantly reduces the warpage of products.
- Possibility of welding ceramics and refractory metals (tantalum, tungsten), ceramics, etc. With precise focusing of the beam, it becomes possible to heat a surface with a diameter of less than a millimeter. This, in turn, makes it possible to simultaneously weld metals with a thickness of tenths of a millimeter.
- High quality welded joints of chemically active metals and alloys: molybdenum, titanium, niobium, zirconium. As a rule, in many cases degassing of the weld metal occurs and, at the same time, an increase in its plastic characteristics. EBW is also indispensable for joining low-carbon, corrosion-resistant, copper, nickel steels, aluminum alloys.

But, despite the large number of advantages, EBW also has disadvantages [14,15]:

- Time spent when creating a vacuum in the working chamber after loading the products.
- Possibility of the formation of lack of fusion, hollow holes in the root of the seam when welding metals with high thermal conductivity, as well as seams with a large depth-to-width ratio.

3. Result and discussion

For a visual representation of welding, in the oil and gas field, in a tabular form, we compare the types of welding by parameters: dimensions of welding of materials, energy consumption, cost, human participation, field of application, features of welding.

Based on the table, we will draw the appropriate conclusions about the welding methods. Among the types of welding considered, it is possible to single out methods, the use of which is associated with the melting of a large amount of the base material.:

- Manual electric arc welding.
- Automatic submerged arc welding.
- Electroslag welding.
- Plasma welding.
- Seam welding.
- Spot resistance welding.
• Spot capacitor welding.

Comparison of welding methods is given in table 2.

Table 2. Comparison of welding methods.

| Welding Type            | Dimensions of materials to be welded | The cost | Human participation                          | Application area                                      | Features of the+                          |
|-------------------------|--------------------------------------|----------|---------------------------------------------|------------------------------------------------------|------------------------------------------|
| Manual electric arc     | 1 to 60 mm                           | Low      | With the participation of the master        | Steel sheets, pipelines, drills, chisels, etc.        | Mobility, profitability.                 |
| Automatic submerged arc | 1.5 to 150 mm                        | High     | Automatic welding                          | Pipelines, steel sheets.                              | Profitability.                           |
| Electro slag            | Up to 600 mm                         | High     | With the participation of the master.       | Thick-walled boilers and drums.                      | High productivity, cost-effectiveness of the welded process. |
| Butt contact            | Up to 5 mm                           | Low      | Automatic welding                          | Pipes, fittings, details of drilling elements.        | Short welding time.                      |
| Induction               | 0.5 to 15 mm                         | Low      | Automatic welding                          | Pipes and other closed (hollow) steel profiles.       | Mobility, time saving.                   |
| EBW                     | up to 0.1 ... 400 mm                 | High     | Automatic welding                          | Elements of pipes, frames, bits, drills, etc.         | A wide range of welding elements, mobility. |

Types such as diffusion welding, butt resistance welding, induction and electron beam welding, have most of the fluidity in the melting zone of the material.

Thus, the use of electron beam welding in the oil and gas industry is rational and promising.

4. Conclusion

The article examined the problem of connecting pipelines in the oil and gas industry. Application of the used approach shows low efficiency, since it depends on the qualifications of the welder. The technology of creating flanged (flat) joints with a pipe in the oil and gas industry is considered. The necessary equipment and types of welds in the area under consideration are considered. Thus, the analysis of the subject area and the search for an alternative method for creating welded joints on oil and gas pipelines was carried out in order to increase the reliability of such joints and reduce the cost of production. Various welding methods are considered (manual electric arc welding, automatic submerged arc welding, induction brazing, etc.), Comparison of the main welding methods is given, as well as the rationale for using electron beam welding to create such joints.

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