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Construction of Long-Distance Oil Pipelines

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ABSTRACT

This article analyzes the classes of oil and petroleum product pipelines, classification of pipes for long-distance oil pipelines is presented, welding of long-distance pipelines for transportation of oil and petroleum products in severe climatic environment using conventional procedures is described, advantages and disadvantages of these procedures are highlighted. Possible application of hybrid laser arc welding is considered regarding oil pipelines of structural alloy steels, its advantages are determined as well as factors limiting its wide scale application. The technology of hybrid laser arc welding of seams of thick-walled pipe ends is considered with simultaneous application of two laser beams from external surface of joint of pipe ends. Its advantages are highlighted. Automated combined full wire welding of root weld layer in carbon dioxide and gas-shielded flux-cored wire welding of filling and facing runs are discussed which provide minimization of the influence of human factor on welding, promotion of welding operator trainings, improvement of mechanical properties of weld joints, which has been exemplified by comparative tests.

Key words: welding, oil pipeline, transportation, hybrid laser arc welding, root seam, blind gap.

1. INTRODUCTION

Pipeline systems for transportation of natural gas, oil and petroleum products are an important control instrument of economy and national security as well as an important constituent of international policy.

Russia at present is a leader of global oil market. Minor, moderate, and large-scale deposits are spread all over the country, thus, the transportation issue of petroleum products is very important. Pipeline transportation is the most advantageous for oil and various petroleum products. Numerous pipeline projects in Russia have been constructed and operate in the territory with unique climatic conditions: Far North, permafrost areas, marshlands, heavy ice in the sea. Several advantages of pipeline transportation of oil and petroleum products can be highlighted: low operation expenditures; low prime cost of pumping; possibility to pump several types of petroleum products simultaneously; uninterrupted supplies irrespective of climatic conditions, etc. More than 90% of oil produced in Russia are transported via pipelines. Production wells are connected with oil field infrastructure by oil pipelines [1]. The main drawback of pipeline transportation is huge capital expenditures at construction stage of long-distance pipeline. Successful construction of pipelines under severe conditions is based on advanced engineering solutions, innovative technologies, high qualification of personnel.

2. METHODS

Theoretical (studies, analysis and synthesis of publications devoted to the considered issue; analysis of research subject; generalization of the obtained results), empirical (analysis of regulative documenting, analysis of results of mechanical tests) and experimental (mechanical tests of weld joints) methods have been used.

3. RESULTS ANS DISCUSSION

Pipelines are intended for transportation of oil and petroleum products as well as for pumping of diesel fuel, gasoline, fuel oil, etc. Depending on conventional diameter, the long-distance oil and petroleum pipelines are classified [2] according to Table 1.

Table 1: Classes of oil and petroleum product pipelines

No.	Pipe diameter, mm	Class	Pipeline depth	Remarks
1	from 1,000 to 1,400 mm	I	at least 1 m	- in the marshlands and peaty soils intended for drainage: 1.1 m
2	from 500 to 1,000 mm	II	at least 0.8 m	
3	from 300 to 500 mm	III	at least 0.8 m	- in the marshlands without vehicle passage: 0.6 m
4	less than 300 mm	IV	at least 0.8 m	

The pipes for long-distance oil pipelines are made of carbon and low alloy steel which is a firm, reliable, cost efficient material characterized by good engineering properties including good weldability (Fig. 1).

Figure 1: Construction of long-distance oil pipeline.

The pipes for long-distance oil pipelines are classified as follows:

1. Production method:

- seamless pipes (diameter up to 529 mm);

- welded pipes with spiral weld (diameter of 219 mm and higher);

- welded pipes with longitudinal weld (flux welding and high frequency welding are used for pipe diameters of 508–1,420 mm, external anticorrosion coating is applied).

2.Climatic conditions upon construction and operation:

- northern versions (for Far North, operation temperature: +20°C…-40°C);

- regular version (for the central part of Russia, operation temperature: 0°C and above).

The wall thickness of seamless pipes can be from 4 to 32 mm depending on their diameter. It means that such pipes should be supported by bearing frame, which increases the cost of construction, thus, seamless pipes are rarely used for construction of long-distance oil pipelines.

Welding methods of oil pipelines are as follows:

- thermal welding (arc, flux, plasma, gas, laser, and others);

- thermomechanical (contact welding with magnetically operated arc);

- specialized methods (explosive welding, friction welding).

Thermal welding is mostly applied. The arc welding (Fig. 2) makes it possible to weld pipes in all spatial positions; in the case of manual welding, the electrode travel speed across joint diameter reaches 20 m/h, in automated mode –60 m/h [1].

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a b

Figure 2: Thermal welding: a – manual arc welding; b – gas welding

Sections comprised of two and more pipes of higher diameters are assembled by mechanized welding. Automated flux welding, flux-cored welding with forced seam formation are applied most often. Flux-cored wire performs the functions of shielding gas. Welding head with fixed dam moves along pipe joint promoting formation of weld joint.

When assembling pipes of minor diameter, it would be reasonable to apply automated welding with magnetically operated arc known also as arc-contact welding. The impact of magnetic field along the ends of joined pipes activates high-speed arc rotation promoting heating of joined ends. The welding is performed in automated mode according to preset algorithm with continuous fusion of pipe ends, thus providing high quality weld joint [5].

Prior to assembling activities, the pipes and constituents are tested for conformity of parameters with specifications, the shapes of all joining items should coincide with the pipe ends. During construction of long-distance oil pipelines, the pipes are delivered from factories with ends prepared for arc welding. Prior to assembling, the pipes are cleaned of impurities, the pipe ends and adjacent parts (more than by 1 cm) are cleaned stripped to metallic appearance.

The pipes are assembled with strict perpendicularity of pipeline axes and joints, the allowable deviation is not higher than 2 mm, the gap uniformity across all joint perimeter is also monitored. The pipes are assembled using specialized pipe clamps, the allowance between the diameters of welded pipes should not exceed 1 cm (Fig. 3).

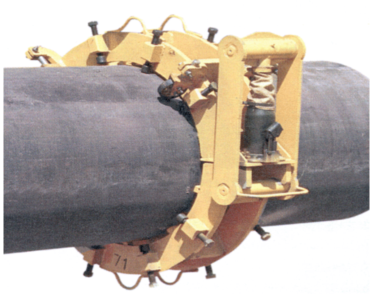

Figure 3: Pipe clamp

Preliminary heating is applied to adjust welding thermal cycle, to avoid formation of cold cracks (especially for low alloyed steels with carbon equivalent of 0.43% and above). Heating is carried out using special devices by homogeneous treatment of ends to the width of about 7.5 cm to the left and to the right from the seam over the total length.

Pipelines are butt welded. Welding is carried out from bottom to top with transversal oscillating movements of electrodes, the oscillation amplitude is determined by the distance between the pipe joints.

Deeper root penetration and higher density of weld joint can be obtained by manual arc welding in 2–4 layers. The surface of the first applied layer, which provides root penetration, is concave. The subsequent layers are imposed onto the previous ones overlapping them and fusing with joint ends. The facing run is the last, it provides smooth transition to the main metal, it has flaky surface and acts as decoration.

Pipes can be welded simultaneously by several operators, the process is continuous up to complete filling of join groove. Inline segmented welding of pipes assumes that each operator works at one isolated seam segment. Positions along the seams depend on the number of operators at each joint. If two operators are involved, then the welding is performed from bottom to top, from start in opposite directions along the perimeter. The pipelines are welded at the temperatures not lower than –20°C in order to avoid defects in the seams.

The welding is accompanied by generation of reinforcing bead, also known as flash, which can interfere with outer insulation and penetrability inside pipeline. After welding, the flash is removed using special trimmers [6].

It should be mentioned that the widely applied procedures of manual arc and mechanized welding are characterized by low process rate which slows down pipeline construction, herewith, the quality of weld joint depends on experience and qualification of operators, on assembling quality, on preliminary preparation, and other factors.

Time of pipeline construction is reduced due to application of sections produced by flux welding or butt welding at factory instead of separate pipes.

Nowadays, in the course of construction of long-distance oil pipelines, a current site is subdivided into 10–20 segments, the crews start operation at the distance of 1 km from each other, this provides the pipeline lay rate of 5–6 km per day.

The quality of weld seams is preliminary checked visually, then by radiation or ultrasound control. Installation of a segment of oil pipeline is completed by pressure leakage tests. Upon construction of long-distance oil pipelines, it is considered that oil moving at the speed of 3–6 km/h can destroy pipe in the case of unscheduled pump shutdown. The impact of shock wave is compensated by means of pipeline surge relief system which protects pipeline and minimizes release of working fluid.

If a pipeline is installed in the ground, then it is affected by soil corrosion, if a pipeline is installed above the ground, then it is affected by atmospheric corrosion. The following methods and tools are used for protection against corrosion:

- passive – insulating coatings based on bituminous compositions, epoxy primer, polymer adhesive bands, etc.;

- active – electrochemical protection by cathode polarization of pipelines. Insulting monolith couplings are being used now [7].

In order to increase construction efficiency of oil pipelines, great attention is paid to investigations into new procedures of pipe welding. Herewith, the emphasis is on reducing the number of passes during welding, that is, on increase in welding rate. The hybrid laser arc welding is a challenging approach based on development of fiber laser [13].

Hybrid laser arc is the method where weld pool is formed by simultaneous action of laser radiation and weld arc. The process can be carried out using nonconsumable or consumable electrode. The arc heats metal, melts its upper layer, thus providing wide seam filling gaps; the laser beam provides deep penetration into the metal (Fig. 4).

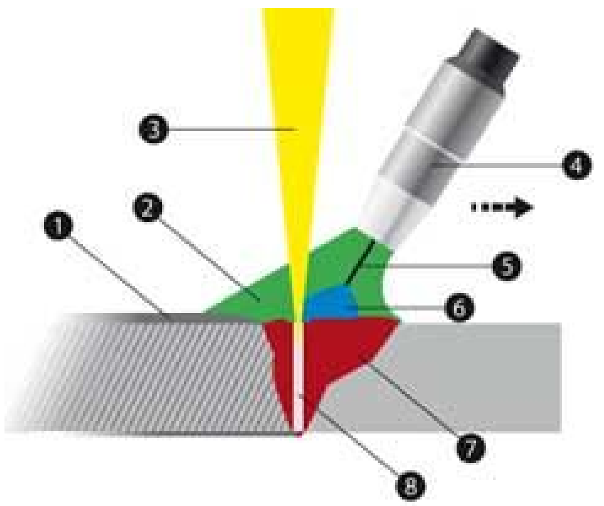

Figure 4: Laser hybrid welding:
1 - weld joint; 2 - inert shielding gas; 3 - directional laser beam; 4 - burner; 5 - weld wire; 6 - electric arc; 7 - weld pool; 8 – bore.

This welding procedure makes it possible to apply structural alloyed steels for oil pipelines, which are characterized by high mechanical properties. Initial experiments of girth joint welding were performed by Gullco International. Optic fiber laser was used as a source of laser radiation. A 4.5 kW laser was used at the width of root face up to 6 mm, and at higher width – a 10 kW SLV Mecklenburg–Vorpommern laser [3]. The experiments determined the hardness distribution in the seam, the maximum hardness was detected in seam root, which allowed to weld up the root seam without overlapping pass.

While testing the welded pipe joints, they were located and fixed in various positions which enabled determination of allowances peculiar for pipeline construction. The quality of weld joints was controlled by ultrasound, the obtained results confirmed advantages of the hybrid procedure upon welding of oil pipelines in severe climatic environment.

Welding of fixed joints of oil pipelines by hybrid laser arc procedure is performed by mobile process systems (Fig. 5) based on improved welding tractors comprised of:

- laser arc module (optic fiber laser with laser head);
- welding head guidance system;
- electrode feeding machine;
- invertor – as an arc source.

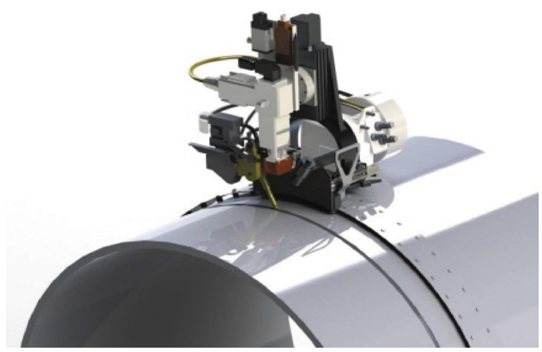

Figure 5: Mobile process system.

Economic efficiency of these approach is based on:

- increase in process rate;
- process automation;
- improved quality of weld seam;
- lower production expenses.

It should be mentioned that implementation of laser welding is restricted by high requirements to preparation of welded ends. Hybrid laser arc welding makes it possible to reduce requirements to preparation of welded ends, which at present constrains application of laser welding for oil pipelines [12].

Laser arc welding is characterized by certain drawbacks, such as:

- increased transversal sizes of weld seam promote overheating of main metal;

- increased arc pressure on weld pool [11], which is stipulated by increase in heat input required for provision of fusing capacity of hybrid heat source in comparison with laser welding [9].

Peculiar defects occur during welding such as undercutting on one or both sides of upper bead, internal pores, sea, slackening. These drawbacks can be eliminated by simultaneous modulation of consumable electrode arc and laser radiation. In addition, the weld seam is narrowed (seam shape coefficient is 0.87), as well as the seam dendrite structure is refined [10].

Hybrid laser arc welding can be applied for longitudinal seam of thick-walled pipe ends both with maximum allowable gap and with higher gap, herewith, the quality of weld seam is improved. In addition, for seam welding of thick-walled pipe ends, two laser beams are used simultaneously from the side of external surface of pipe ends.

Defocused beams are directed to opposite joints of pipe ends. This becomes possible when the regions of beam propagation are not overlapped and are positioned at maximum close distance which is selected on the basis of conditions of welding possibility. The laser beams are crossed in the areas of minimum diameter of each beam, this results in summation of laser radiation energy. The same angle of laser beam with regard to the vertical promotes fusion of pipe ends and generation of weld seam.

Filler wire is fed to the welding area and is melted in shielding gas by electric arc, thus forming single weld pool. A gas or gas mixtures, such as argon and carbon dioxide, are used as shielding gas of weld pool. The electric arc is positioned behind the beams of filling of prepared pipe ends. The beam axes are positioned in one plane perpendicular to welding direction and at equal angles from vertical axis with their crossing in focus area. The focus is located above the processed surface and the defocusing regions are located so that to provide beam onto appropriate opposite joint end. This approach provides seam welding in one pass, thus decreasing energy and labor consumptions [4].

A new stage of welding of fixed pope joint is automation of root weld layer by conversion from mechanized welding by consumable electrode in active gases on factory preparation of pipe ends to automated gas-shielded full wire welding on specialized narrow preparation of pipe ends assembled with blind gap.

This approach promotes:

- decrease in joint assembling time;
- decrease in welding time;
- decrease in amount of filling layers, minimization of bead welding, improvement of the quality of weld joints (Fig. 6).

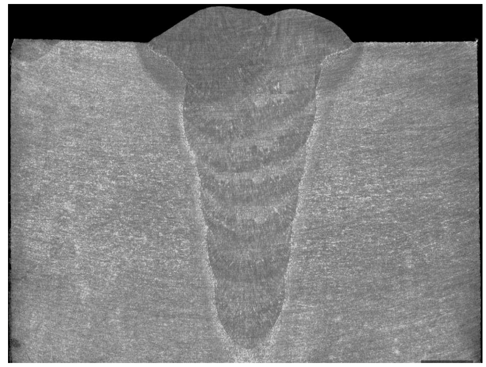

Figure 6: Weld joint

The advantages of this procedure in comparison with conventional welding of fixed pipe joints of long-distance oil/gas pipelines are as follows:

- automation of the process;
- moderate cost of equipment (in comparison with fully automated systems);
- easy training (retraining) of welding operators;
- reduced time of joint assembling and welding;
- decrease in amount of fused metal due to decreased surface area of prepared section;
- saving of weld materials;
- high and steady mechanical properties of weld joints.

Mechanized welding by consumable electrode of root weld layer in active gases with subsequent filling by automated gas-shielded flux-cored welding was selected as the basic procedure.

Automation of root weld layer is achieved by conversion from mechanized welding by consumable electrode in active gases on standard factory preparation of pipe ends to automated gas-shielded full wire welding on specialized narrow preparation of pipe ends assembled with blind gap which is performed by SST method in automated mode. This allows to obtain guaranteed height of root layer of 4−5 mm and complete fusion of welded ends with the height of temper bead in the range of 0–±3 mm and the width of 3–±6 mm. Upon welding of pipe ends, the ends should not be displaced more than by 3 mm [8].

Automated combined full wire welding of root weld layer in carbon dioxide and gas-shielded flux-cored welding of filling and facing runs minimize the influence of human factors on welding; simplify training of welding operators; improve quality of mechanical properties of weld joints.Automated gas-shielded full wire welding with special tapered preparation of pipe ends assembled with blind gap improves geometry of welded pipe ends (Fig. 7).

Figure 7: External view of pipe end preparation.

Preparation of ends used upon this procedure provides optimum combination of weld joint quality, welding rate, and properties of seam metal. This is achieved by means of decrease of joint assembling, which is less labor consuming in the case of blind gap welding rather than in the case of standard preparation of ends; decrease in time consumed for welding of root weld layer as well as welding time of filling and facing runs. Herewith, decrease in welding time of filling layers is related both with reduction of their total number and with minimization of bead weld (when it is eliminated, the quality of weld joints is improved). Application of this procedure decreases width of facing run (Fig. 8).

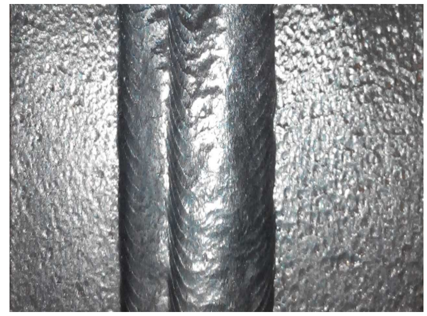

Figure 8: Facing run.

The results of mechanical tests of weld joints obtained by the considered procedure demonstrate high their mechanical properties, namely: improved impact strength. The experimental data are summarized in Table 2 [8].

Table 2: Comparative tests of mechanical properties of weld joints on ends of Ø1420 mm × 25.8 mm steel pipes, strength grade K60

No.	Description of tests	Mechanized welding by consumable electrode of root weld layer in active gases with subsequent filling by automated gas-shielded flux-cored welding		Combined welding of root weld layer using automated gas-shielded full wire welding in carbon dioxide and gas-shielded flux-cored welding of filling and facing runs	
1	Static tension, [MPa]	651		642	
		649		640	
		644		639	
		647		641	
2	Hardness, [HV10]	Upper layers of weld joint			
		min	max	min	max
3	Main metal	230	241	214	229
4	Heat affected area	217	229	200	268
5	Seam metal	221	236	211	222
Lower layers of weld joint					
6	Main metal	235	249	202	212
7	Heat affected area	205	222	200	218
8	Seam metal	223	228	195	202
9	Impact bending, KCV [J/cm^2]	-20°C	-40°C	-20°C	-40°C
10	Notch groove, upper layers of weld joint	102	66	156	104
		109	71	159	120
		104	83	162	116
11	Notch groove, lower layers of weld joint	72	51	131	111
		77	55	135	118
		81	47	141	109
12	Notch, weld fusion line, upper layers of weld joint	173	112	156	128
		179	98	165	174
		186	134	143	163
13	Notch, weld fusion line, lower layers of weld joint	127	102	161	174
		155	89	94	101
		167	71	179	98

It should be mentioned that the technology of automated full wire welding of root weld layer in carbon dioxide and gas-shielded flux-cored welding of filling and facing runs was qualified and included into welding specifications of OAO Gazprom [Welding procedure specification. Automatic full wire welding of root layer in carbon dioxide by SST method and gas-shielded flux-cored wire welding of filling and facing runs using M-300C welding head aiming at preparation of edges of fixed girth joints. OAO Gazprom, 2012].

Economic efficiency of implementation of this procedure is 26 million rubles per 100 km of construction: 21 million rubles are saved due to decrease in the amount of consumed wire by 56 tons, and 5 million rubles are saved due to decrease in the amount of applied shielding gases by 2,600 bottles [8].

4. CONCLUSION

Welding of long-distance pipelines is a hi-tech process which should be based on high qualification of welding operators and compliance with specifications providing high quality weld joints. Development and implementation of new welding procedures applied upon construction of oil and gas pipelines are stipulated by the necessity to decrease current and investment expenditures, the reduction of welding cycle duration, and the improvement of product quality. The considered procedures make it possible to perform welding of oil and gas pipelines under Far North conditions using thick walled pipes with resulted high quality of weld joint with required mechanical properties and minimum weld deformations.

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