Fracture of a gas pipeline manufactured by high frequency current welding

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Abstract. Fracture of an underground gas main with a diameter of 530 mm during the production of pneumatic tests along a factory longitudinal welded joint made by contact welding using high-frequency currents, is considered. Fracture research was carried out by analysis of the project and technical documentation of the object, visual and measuring control of the object, ultrasonic measurement of pipe wall thickness, fractographic, metallographic and chemical analyses, measurements of hardness and microhardness of pipe metal. It was established that fracture of the gas pipeline occurred as a result of the opening of one pipe along the entire length of the factory-made longitudinal welded joint during the propagation of cracks in the welded joint and the subsequent propagation of the main crack in both directions to adjacent pipes; the centers of fracture were numerous surface crack-like defects of the welded joint. It is shown that a fracture was caused by a violation of the welding technology of a longitudinal welded joint, a violation of heat treatment, an unacceptable thinning of the pipe wall in the weld zone.

1. Introduction
Ensuring the safety of oil and gas pipelines, equipment of the oil and gas industry is of great importance in the polar regions of Russia - the Arctic, where the elimination of the consequences of the accident requires significant material and time resources, in the full dependence of the life of the Arctic settlements on energy resources [1, 2, 3, 4].

The climatic conditions of the polar regions of Russia are characterized by low climatic temperatures and sharp continentality. The temperature period below 0°C is about 210 days and the minimum temperature reaches 60°C below zero, the difference in average temperatures is 100°C. Most of the territory belongs to the permafrost zones [3, 4, 5].

The causes of emergencies in pipelines, equipment of the oil and gas industry, their development into accidents and disasters are, as a rule, failures of technical systems due to design errors, violation of manufacturing technology, operating conditions and operating modes, degradation of material properties during long-term operation, natural phenomena such as earthquakes, tsunamis, etc. [1, 2]. The article provides an analysis of the causes of the catastrophic fracture of the main gas pipeline on the territory of the Republic of Sakha (Yakutia), as a result of violations of manufacturing and welding technology.
2. Equipment and materials
The analysis of the causes of fracture is based on the analysis of the design and technical documentation of the object, visual and measuring control of the object, ultrasonic measurement of pipe wall thickness, fractographic, metallographic and chemical analyzes, measurements of the hardness and microhardness of the pipe metal.

Fractographic analysis was carried out at the macro and micro levels using a set of visual measuring control and scanning electron microscope Philips XL 20 to identify the mechanisms of damage and destruction. Metallographic analysis was carried out on a Philips XL 20 scanning electron microscope to reveal the microstructure of the material. Spectral chemical analysis was carried out in order to determine the grade of steel using the Spectroport F instrument.

The wall thickness was measured by the VZLET-UT ultrasonic thickness gauge over sections in four planes. The hardness of the material was determined using the TEMP-2 portable hardness tester in places of thickness measurement.

3. Results and discussion
In the Republic of Sakha (Yakutia), in the winter of 2006, a section of the underground gas pipeline was destroyed during pneumatic tests with a pressure of $P=5.6$ MPa (design working pressure $P=5.5$ MPa) at an ambient temperature of $42^\circ$C, which was accompanied by soil discharge and gas pipeline opening. A general view of the destroyed section of the gas pipeline is shown in figure 1.

![Figure 1. General view of fracture of the gas pipeline.](image)

The underground gas pipeline consist of steel electric-welded straight-seam pipes with an outer diameter of 530 mm and a wall thickness of 7 mm, the pipes are connected by resistance welding using high-frequency currents. The calculation of ring stresses showed that at the time of fracture, stresses did not exceed the permissible values and met the condition $\sigma \leq 0.75\sigma_T$ according to RD 12-411-01 (Instructions for diagnosing the technical condition of underground steel pipelines) and Building code 2.05.06-85 (Trunk pipelines). According to the design documentation, chemical composition and hardness, the metal of the pipes corresponded to the steel grade 09G2S (GOST 19281-89).

The destroyed section consists of three pipes welded by two mounting ring joints (figure 2). The middle pipe was destroyed by the movement of the main crack along the axis of the longitudinal
factory welded joint rectilinearly with the opening along the entire length of the joint; at a distance of 530 mm along the gas direction from the mounting ring joint, a side crack 100 mm long, perpendicular to the fracture line, was found in the pipe body. The maximum opening of the lateral crack is observed at the factory longitudinal welded joint, and the radial scars on the open surface of the crack are normal to the pipe walls. These facts indicate that a lateral crack arose due to the opening of the pipe along the factory welded joint and propagated according to the transverse shear pattern. The fracture of the first and third pipes along the gas direction — cracks with a curved path that passed along the base metal and looped before stopping — was a continuation of the fracture of the middle pipe.

![Figure 2](image)

**Figure 2.** The scheme of fracture of the gas pipeline.

Far from the crack kink, an unacceptable thinning of the walls of the gas pipeline was not found, but almost all the measurements of the kink thickness do not meet the requirements of TU 14-3R-1471-2002, SP 101-34-96 (Set of rules. The choice of pipes for the construction of trunk pipelines): the pipe walls have a thinning beyond the minus tolerance, which not associated with local plastic deformation during fracture, and is the result of thinning of the pipe wall in the weld zone when removing the inner burr.

Microstructural studies of a thin section made along a plane normal to the surface being welded and to the pipe wall were carried out (etching 5% HNO₃ in ethanol using a Philips XL-20 scanning electron microscope). Three zones are distinguished by structure: the zone of the weld, the zone of thermal influence and the base metal.

The base metal has a ferrite-pearlite structure, fine-grained, a grain score of 10-11 and contains inclusions whose sizes are comparable to the grain score; perlite stitching along the direction perpendicular to the axis of the pipe. The weld zone with a width of 0.75 mm has a hardening structure and consists of two areas. The first region with a width of 0.5 mm has a martensitic structure, the second, transitional to the zone of thermal influence, an area with a width of 0.25 mm is an inhomogeneous structure consisting of martensite and ferrite precipitates. The thermal influence zone with a width of 0.5 mm has a ferrite-pearlite, fine-grained structure with an average grain size of about 5 μm, which is probably due to the fine-grained initial austenite and the occurrence of ferrite-pearlite transformation under conditions of overheating. Thus, in the zone of the welded joint of the middle pipe, a martensitic structure has formed, which causes a tendency in the welded joint to form brittle quenching cracks.

Upon visual inspection of the fracture surface of the middle pipe, three types of areas are distinguished (figure 3 (a)). Microfractographic analysis of these areas was carried out using a Philips XL-20 scanning electron microscope in the secondary electron mode.
Figure 3. Fracture surfaces of the middle pipe: (a) general view; (b) type I area; (c) type II area.

Areas of type I, 2-10 mm wide, are characterized by a brilliant crystalline fracture, a fibrous relief, occupy all or part of the thickness of the destroyed pipe surface, are distributed irregularly along the entire length of the destroyed surface, and are fibrous zones of the fracture surface corresponding to regions of slow growth of cracks from the fracture centers. The fracture surface in type I area consists of flat facets of brittle cleavage along martensitic plates, whose orientation is determined by the direction of the acting maximum stresses (figure 3 (b)).

Type II areas are characterized by a gray crystalline fracture, a rough relief, occupy the main part of the fracture surface and represent the radial zones of the fracture surface corresponding to regions of rapid crack propagation (figure 3 (c)). Radial scars indicating the direction of propagation of the crack emanate from the fibrous zones. The large number of fibrous zones (type I area) on the fracture surface and the multidirectional radial scars in various type II areas indicate the propagation of cracks from many centers distributed along the length of the destroyed surface.

Areas of type III - visually dark, covered with an oxide film, sickle-shaped, with a fibrous relief, are found in 28 areas of type I, located at the outer or inner surface of the pipe. The fracture surface is characterized by a quasi-split fracture characteristic of brittle fracture of quenching structures. Fibrous circular grooves in areas III extend from the linear portion of the free surface of the weld joint and extend concentrically deep into the weld joint. Oxidation of the surfaces of open cracks, as a rule, occurs when they form until the weld joint have completely cooled after welding. These facts indicate that the centers of fracture were surface crack-like defects of the welded joint that formed before the welded joint had completely cooled after welding.

4. Conclusion
Thus, the fracture of the gas pipeline occurred as a result of the opening of one pipe along the entire length of the factory-made longitudinal welded joint during the propagation of cracks in the welded joint and the subsequent propagation of the main crack in both directions to adjacent pipes; the centers of fracture were numerous surface crack-like defects of the welded joint. The pipeline fracture was caused by the following violations: a violation of the welding technology of a longitudinal welded
joint, as indicated by the presence of crack-like defects in the welded joint formed in it until complete cooling after welding; a violation of heat treatment, as indicated by the formation of quenching structures; an unacceptable thinning of the pipe wall in the weld zone when removing the inner burr.

References

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