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DEVELOPMENT OF AN OPTIMAL PLACEMENT ALGORITHM FOR ELECTROCHEMICAL PROTECTION OF UNDERGROUND STEEL GAS PIPELINES

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Statement of the problem. The paper considers the process of complex periodic corrosion inspection in order to assess the effectiveness and improve the operational reliability of the corrosion protection system (CPS) using the example of on-site technological networks of the underground gas storage Elshanskaya.
Results. The technical condition of the electrochemical protection means, the level of active protection and the technical condition of pipelines of the underground gas storage were assessed, the object was protected by its length and time, and zones of negative influence of constant and stray currents were identified. A method is proposed for determining the optimal number and locations of cathodic protection stations (CPS).
Conclusions. Based on the research results, a commissioning method is proposed that provides the optimal technological mode of operation of electrochemical protection means (EChP), and proposals have been developed to ensure the effectiveness of diagnostics and the safety of further operation of gas distribution pipelines. The implementation of this approach in the design of EChP facilities can lead to a significant reduction in energy consumption during operation.

Keywords: underground gas storage, anticorrosive protection systems, gas pipeline, direct current, stray current, safety.

Introduction. The gas industry is one of the essential sectors of the Russian economy. Russia is the global power supply leader with the most powerful gas transportation system and a management object not to be found elsewhere in the world. According to the PJSC Gazprom, the length of gas networks is over 172.6 thousand km.

An important way of ensuring the reliability and safety of the functioning of existing gas distribution systems is the introduction of new progressive technologies, materials, technological equipment, measuring instruments and metrology for a higher economic efficiency, reliability and safety.

At underground gas storages (UGS), the pipeline transport system is a complex structure which includes underground gas pipelines with welded joints, bends, transitions mostly made of steel and anti-corrosion protection of the system — active (electrochemical protection) and passive (insulation surfacing) [1, 8, 13, 20, 23].

Active protection, which is fairly easy to maintain and repair, and passive protection of underground gas pipelines of UGS facilities are aimed at resisting corrosion of the pipeline material which is evaluated based on its reliability [9, 11, 17, 19].

Currently corrosion protection of engineering structures is a major technical and economic issue. Corrosion resistance of underground engineering networks plays a considerable role in the construction and operation of gas transportation facilities. In accordance with the regulatory documents (GOST R 51164-98 (ГОСТ) Steel Main Pipelines. General Requirements for Corrosion Protection and GOST (ГОСТ) 9.602-2016). A unified system of protection against corrosion and aging) to ensure the efficiency of corrosion protection, the following requirements must be met:

— value of the polarization potential (protective potential without an ohmic component) for operating steel structures should range from (–0.85) to (–1.15) V for the copper-sulfate reference electrode during the entire service life of the object;

— depending on the diameter and specific operating conditions, a reinforced type of protective surfacing with quality control of anti-corrosion materials, surfacing technology, properties of the finished surfacing, etc. should be employed on pipelines in areas of heightened corrosion hazard.

The major issue that arises in evaluating the economic efficiency of complex protection against corrosion is the optimization of the parameters of electrochemical protection, since the data on the choice of effective anti-corrosion surfacings is broadly presented in relevant literature [5]. Based on the analysis of the structure of the directions of use of electricity at the facilities of gas distribution systems, the specific consumption of electricity by ECP plants per 1 m^2 of a gas pipeline area is 0.8—0.85 (kWatt·h)/m^2.

The purpose of the study is to assess the potential of energy saving and efficiency of its implementation from the introduction of new technologies and materials in relation to the technological consumers of electrical energy prevailing in gas distribution, i.e. electrochemical protection tools, using the example of on-site technological networks of a compressor shop of the Yelshanskaya UGSF.

The major goals are:

— to analyze the sources of hazard during long-term operation of pipelines of the gas distribution network;

— to justify the methods and technology for the reconstruction of electrochemical protection tools;

— to develop guidelines for reducing energy consumption for the operation of electrochemical protection tools to ensure the efficiency and safety of further operation of the gas distribution system.

1. Analysis of factors affecting the technology of reconstruction of ECP facilities. According to the current regulatory documents (GOST (ГОСТ) 9.602-2016. Unified System of Corrosion Protection), the major issue of reconstruction is to provide underground structures with cathodic polarization of the required level along the entire length of the gas network and in terms of electrochemical protection. When selecting methods for ECP reconstruction, directions of achieving a greater efficiency in the operation of cathodic protection stations can be the optimization of their placement at facilities in relation to the routes of underground gas pipelines for a technologically sound minimum number of electrochemical protection tools, the required degree of redundancy and a guaranteed level of corrosion protection of underground steel gas pipelines and structures as well as a decrease in the total operating costs and a possible decrease in energy consumption of ECP facilities by changing the initial installation scheme of devices [2, 4, 5, 14, 15, 18, 19, 25]. This should take into account [3, 6, 17, 21]:

— resistivity of soils at the site of laying steel gas pipelines considering the boundaries of zones of different corrosive aggressiveness of soils;

— resistance of insulating surfacing of steel gas pipelines;

— magnitude of stray currents;

— location of ECP facilities;

— availability of adjacent underground communications and information on the parameters of their electrochemical protection;

— total power losses of the RMS consisting of productive (natural losses of the cathodic protection station determined by the difference of 100 % and the efficiency of the RMS) and non-productive losses including losses in drainage cables; losses in contact nodes of the cathodic protection installation; power losses associated with high resistance to spreading of currents of the anode ground electrode; losses from longitudinal resistance of the protected gas pipeline; power losses associated with an increase in the output current and voltage of the RMS with a deterioration in the quality of the insulation surfacing of the pipeline.

The choice of directions, methods and technologies for the reconstruction of ECP facilities including the development of proposals on the prospects for the development of the gas distribution network should be carried out based on a detailed analysis of the design schemes of the existing corrosion protection system and analysis of the operation of the ECP facilities [12, 22, etc.].

Solutions for the reconstruction of ECP facilities can be the following:

— use of a viable scheme for the allocation of tools of VCZ and ECP;

— replacement of ECP means according to the principle of operation and the criteria of efficiency and power;

— conditional sectioning of the gas pipeline;

— introduction of tools of regulation of operating modes and telemechanics [7].

The low efficiency of ECP for gas pipelines that have been in operation for more than 20 years is accounted for by a decrease in the protective potential and thus high costs for maintaining it within the required boundaries. An increase in the number or capacity of cathode stations may be required under the below conditions:

— a significant increase in the length of the gas network due to the connection of new consumers;

— damage to the insulating coating of gas pipelines as well as the impossibility or inexpediency of their restoration;

— introduction of adjoining communications and their inclusion in the system of joint protection;

— necessity to carry out the removal of gas pipelines beyond the boundaries of new construction facilities (gas pipeline bypasses of production sites).

The experience of practical diagnostics of gas distribution networks enables us to highlight a number of features [10, 24]:

— due to deterioration of insulation and wear of anodes designed for 20 years cathode stations gradually reduce the protection arm and thus over time an increase in their number is required;

— in the areas of stray currents and biological corrosion (soils of complex biogenicity), the highest efficiency of active electrochemical protection is achieved;

— even in soils with low corrosiveness, the absence of ECP leads to the formation of galvanic pairs, that is, to the appearance of corrosion damage.

Use of new technologies and materials to improve the energy efficiency of the RCC and ensure the saving of electrical energy requires significant capital expenditures. At the same time, energy inspections of gas facilities carried out by JSC Giproniigaz indicate that other areas of energy efficiency improvement do not considerably reduce annual electricity consumption.

2. Performing corrosion inspection of objects. The survey is conducted in accordance with Guidelines (CTO) Gazprom 9.4-052-2016 "Organization of Corrosion Surveys of PJSC Facilities of Gazprom. Major Requirements". The aim of the complex periodic corrosion survey is to assess the efficiency and increase the operational reliability of the PKZ system.

The survey tasks are the following:

— identifying the safety of an object in terms of length and time;

— identifying zones of negative influence of constant and alternating stray currents;

— specification of the location and classification of areas of various corrosion hazards also considering the results of diagnostics;

— identifying the technical condition of ECP facilities;

— local and integral assessment of the state of protective surfacings;

— optimization of operating modes of ECP facilities and designing recommendations for the operation of the ECP system;

— development of recommendations for repairs of ECP equipment and protective surfacings.

Through the course of the survey, zones of increased corrosion hazard (ICH) are identified; the state of all electrical protection and control tools is evaluated, the safety of the site in terms of length and time is identified; based on the study the optimal operating modes of the ECP facilities are determined, recommendations for improving the operational reliability are provided; the places of insulation defects are identified; an integral assessment of the insulation of extended sections is performed, pipe insulation and pipeline metal in control pits is evaluated.

3. Problem of identifying the optimal distances between cathodic protection stations. Analysis of the existing mathematical models of the ECP system made it possible to assume that by reducing the number of SCZs it is possible to cut down the total energy consumption for the operation of the ECP and at the same time to achieve complete protection of the pipeline with worn-out insulation.

Table 1 presents data on energy consumption (W, kWatt) for cathodic protection of gas pipelines Ø114×4 mm and Ø219×5 mm with a length of 100 km with an average integral transient insulation resistance R = 500 Ohm·m^2 depending on the distance between cathodic protection stations ΔL, km [19].

Table 1

Energy consumption for the cathodic protection

Energy consumption for the cathodic protection of the pipelines, W, kWatt	Distance between the stations of the cathodic protection ΔL, km											
	1	2	3	4	5	6	7	8	9	10	11	12
pipeline Ø 114×4 mm												
$W^{114\times4}$	0.06	0.065	0.075	0.083	0.092	0.12	0.14	0.165	0.225			
pipeline Ø 219×5 mm												
$W^{219\times5}$	0.115	0.125	0.133	0.15	0.16	0.195	0.23	0.27	0.33	0.41		

Table 2 shows the values of energy consumption for the cathodic protection of a Ø530×6 mm gas pipeline with a length of 100 km depending on the average integral transient insulation resistance and the distance between the cathodic protection stations.

Table 2

Energy consumption for the cathodic protection of the pipelines of Ø 530x6 mm

Energy consumption for the cathodic protection of the pipelines, W, kWatt	Distance between the stations of the cathodic protection ΔL, km											
	1	2	3	4	5	6	7	8	9	10	11	12
Average integral transient resistance of the insulation R = 50 Ohm·m^2												
$W^{530\times6}$	3.1	4.45	7.45	—	—	—	—	—	—	—	—	—
Average integral transient resistance of the insulation R = 100 Ohm·m^2												
$W^{530\times6}$	1.41	1.72	2.32	3.45	5.12	—	—	—	—	—	—	—
Average integral transient resistance of the insulation R = 200 Ohm·m^2												
$W^{530\times6}$	0.65	0.8	0.9	1.05	1.45	1.91	2.5	—	—	—	—	—
Average integral transient resistance of the insulation R = 500 Ohm·m^2												
W^{530x6}	0.27	0.29	0.31	0.37	0.47	0.49	0.51	0.57	0.64	0.77	0.98	—

Furthermore, by means of calculations, it is possible to identify the maximum permissible distance between the cathodic protection stations, which provides the required level of protective potentials within the regulatory limits throughout the entire section of the underground pipeline. This distance decreases as does the diameter, transient insulation resistance and pipeline wall thickness.

Therefore, e.g., for a gas pipeline Ø 530×6 mm with a length of 100 km, the value of the maximum permissible distance between the CPS is 3.6 km (at R = 50 Ohm·m^2); 5.2 km (at R = 100 Ohm·m^2); 7.3 km (at R = 200 Ohm·m^2); 11.4 km (at R = 500 Ohm·m^2) [19].

The objective function of the task of identifying the optimal (maximum permissible) distances between cathodic protection stations (CPS), which provides the level of protective potentials within the normative limits throughout the entire pipeline section which are the integral costs in the construction and operation of stations, the optimality criterion is the minimum costs for calculated (specified) time period:

$$З = \sum_{t=0}^{T} \left(Э_i \cdot c_{эi} + K_{скз} \cdot \left(n_{скз} + \varphi_{скз} \right) \mu_0 + \mu \cdot \mu_t \right) \cdot \frac{1}{\left(1+E\right)^t},$$

where $Э_i$ is the annual energy consumption, kWatt·h; $c_{эi}$ are the energy costs, rouble/(kWatt·h); $K_{скз}$ are the capital costs of the cathodic stations including assembly, rouble/item; $n_{скз}$ is the number of cathodic stations; $\frac{1}{\left(1+E\right)^t} = \alpha_t$ is the discount coefficient; μ is the maintenance costs of the station; $\varphi_{скз}$ is the percentage of annual costs of the station operation; T is the life cycle of the system; t is the calculated life cycle of the system; μ_0, μ_t is the coefficient of an increase in costs of resources for a year of the station construction at $t = 0$ and for a current year of operation t respectively; E is the efficiency coefficient of the capital costs, year^{-1}.

The more identical are CPS to each other, the lower the total energy consumption for the electrochemical protection of the gas pipeline and the greater the integral costs are for the CPS system.

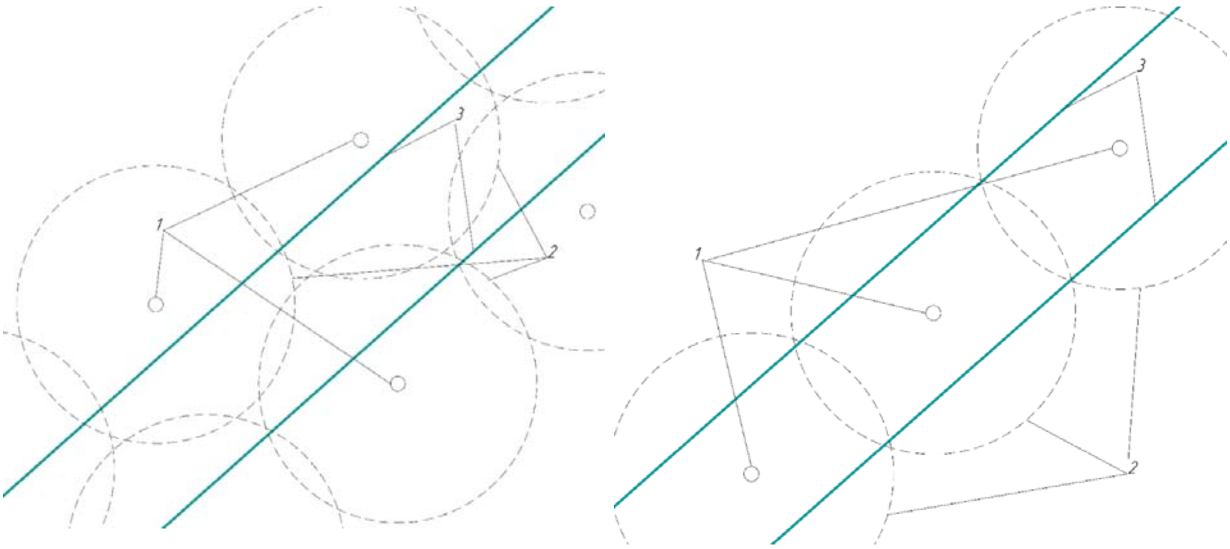
4. Development of a viable layout of ECP facilities. The special feature of the location of underground gas pipelines of UGS facilities is their accuracy over a relatively small area. The presence of a large number of gas-collecting reservoirs and welling loops and their intersections are conducive to special conditions for the distribution of ECP funds in a more efficient manner.

There are two main scenarios for applying a viable scheme for placing ECP tools (or optimizing the operation of electrochemical protection tools by means of changing the original scheme):

— if the gas supply scheme under discussion consists of several underground pipelines designed in accordance to different projects where for one reason or another, it is not considered whether they belong to a single corrosion protection system or not, it is necessary to change the location of the ECP tools or points of input of the protection current depending on the state, saturation and mutual arrangement of pipelines;

— if the gas supply scheme under discussion contains “old” (operated for a long time) and newly built gas pipelines that require a different level of protective potential, it is essential to change the location of ECP tools or protection current input points according to the integral state of the insulation coating (depending on the type and life cycle).

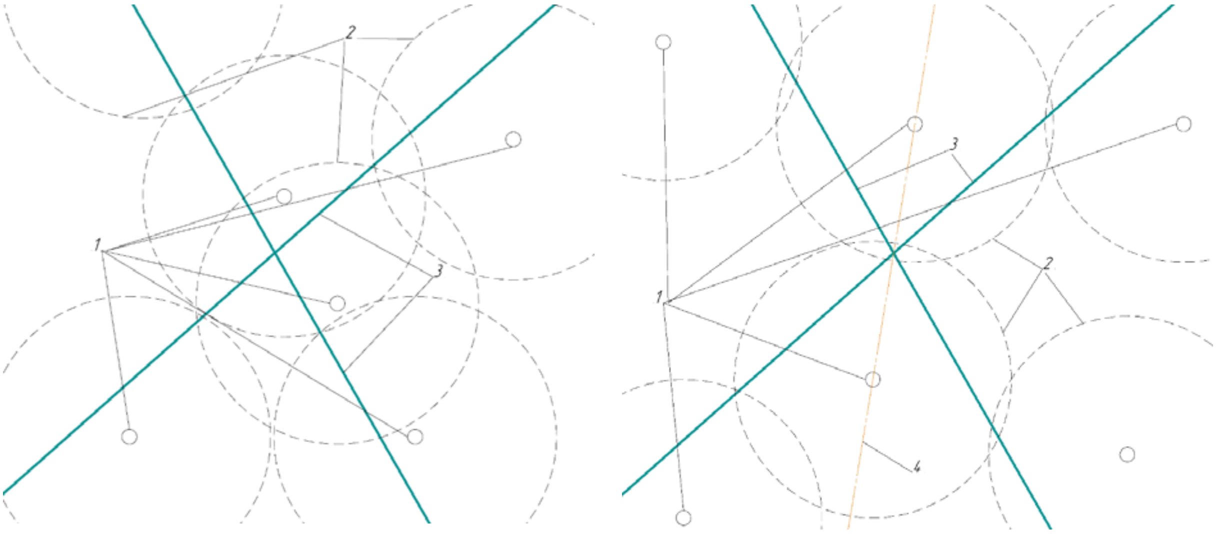
Let us look at an underground steel gas pipeline of an underground gas storage facility. A detailed examination shows that the gas-collecting collectors are located in parallel at a slight distance away. Thus, through the course of the reconstruction of the ECP system, it is possible to reduce the number of CPS by placing them at an equal distance from the adjoining gas pipelines. This will ensure that both of the pipelines are covered with a protective potential (Fig. 1).



a) **b)**

Fig. 1. Location of ECP facilities prior and following the reconstruction on parallel gas pipelines: a) prior to the reconstruction of the ECP; b) following the reconstruction of the ECP; 1 are cathodic protection stations, 2 is a protective potential surfacing, 3 is an underground gas pipeline

Also, for underground gas pipelines of underground gas storages, intersection of welling loops is typical, which might pose extra difficulties when placing ECP facilities. This is most likely to occur where intersecting gas pipelines were laid at different times. In the case of reconstruction of ECP tools of such pipeline sections, the most viable way of placing ECP tools will be the installation of an ECP on the bisector of the intersection angle of the gas pipelines (Fig. 2).



a) **b)**

Fig. 2. Location of ECP facilities prior to and following the reconstruction on the intersecting gas pipelines: a) prior to the reconstruction of ECP; b) following the reconstruction of the ECP; 1 are cathodic protection stations, 2 is a protective potential surfacing, 3 is an underground gas pipeline, 4 is a bisector of the angle of intersecting gas pipelines

Such an arrangement of ECP tools will not only reduce the number of CPS and thus the cost of capital costs and maintenance of the ECP facilities, but it also prevents hydrogen saturation of steel pipelines where the protective potentials of the adjoining cathodic protection stations overlap.

The practical implementation of the suggested algorithm was considered under the conditions of on-site technological networks of the compressor plant of the compressor station of the Yelshanskaya UGS compressor station. The optimization results are provided in the technical report of the complex periodic corrosion inspection of the facilities of the PJSC Gazprom [16]. In Fig. 3 are the results of a survey of one of the sections of the pipeline network.

According to the data of the report on the results of the corrosion survey, following the reconstruction of the ECP system and the reduction in the number of ECP stations, there is no hydrogenation of steel pipelines, while the required standards of pipeline protection are met.

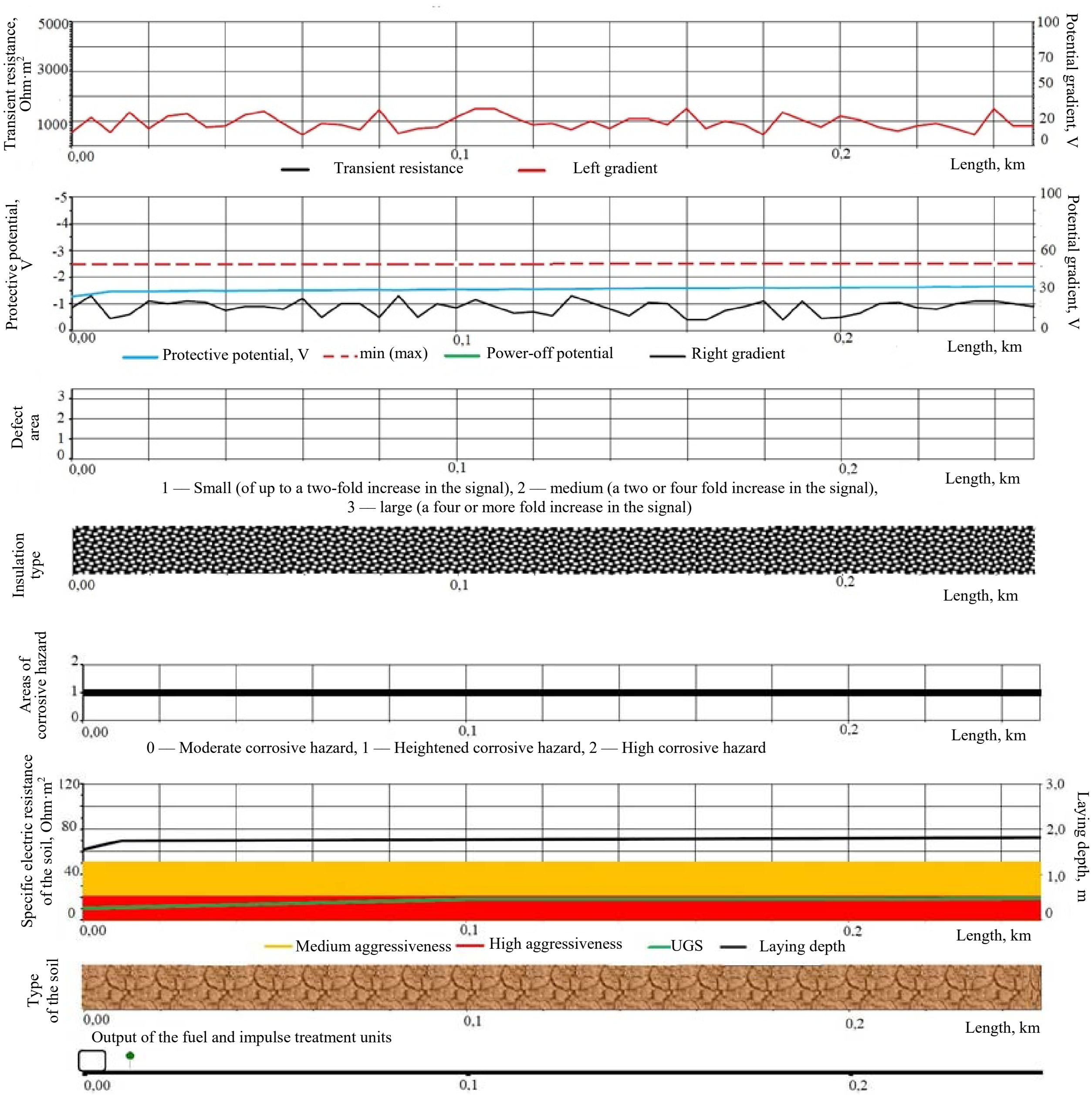


Fig. 3. Corrosion map of the pipeline

Conclusions. The article analyzes and lists the major factors impacting the current consumption and power loss by the ECP system during the cathodic corrosion protection of gas distribution system objects.

The issues of reconstruction of the system of electrochemical protection of gas pipelines from the standpoint of energy efficiency are discussed. The on-site technological networks of the compressor plant of the Yelshanskaya underground gas storage station were selected for investigation.

Practical measures are suggested in order to reduce the power losses of the ECP system. The above approach to designing a computational model of the ECP system made it possible to assume that as a result of the optimal location of CPS, more efficient protection of both newly commissioned pipelines and those with worn-out insulation is achieved. At the same time, according to the results of measurements and verification calculation, the suggested principle of the location of ECP tools on parallel and intersecting gas pipelines allows one not only to reduce the cost of installation and operation of ECP tools, but also to prevent hydrogen saturation of the gas pipeline sections. Based on the results of the measurements of the average integral transient insulation resistance, it was argued that there is a maximum permissible distance between the cathodic protection stations making it possible to ensure the standard level of protective potentials throughout the entire section of the protected underground pipeline.

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