V International Scientific and Technical Seminar

IMPROVEMENT OF RELIABILITY OF MAIN GAS PIPELINES SUBJECT TO STRESS CORROSION CRACKING

December 16–18, 2020

SCC 2020

CONFERENCE PROGRAM. ABSTRACTS

Gazprom VNIIGAZ,
Moscow

Public Joint Stock Company «Gazprom»
Limited Liability Company «Scientific & Research Institute of Natural Gases
and Gas Technologies – Gazprom VNIIGAZ»

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Moscow 2020

DEAR COLLEAGUES!

We are glad to welcome you at the V International Scientific and Technical Seminar “Improvement of Reliability of Trunk Gas Pipelines Subject to Stress-Corrosion Cracking”.

Within five years the seminar has become a unique industry-specific site for collaboration of gas pipeline operation specialists, scientists and producers of new equipment and technologies in the field of monitoring and preventive measures against stress corrosion cracking of truck gas pipelines.

Challenges of 2020 lead us to arrangement of an on-line event on the basis of webinar.ru platform, involving many representatives of Gazprom PJSC administration, subsidiary companies and organizations of Gazprom PJSC, academic researchers of universities and research institutes, specialists of diagnostic and repair organizations, as well as producers of innovation products and technologies.

Thanks to the support of Gazprom PJSC Department (O.E. Aksyutin) and Gazprom PJSC Department (E.B. Kasyan), our seminar may be considered an international industry-specific research event.

The seminar will host more than 30 reports and 150 representatives from Russia, Belarus, Kazakhstan, China, Kyrgyzstan, Korea and Germany.

Thanks to the support of Gazprom VNIIGAZ LLC Research and Educational Center, this seminar is included in the list of implementation activities in the framework of a corporate training system for scientific personnel employed at Gazprom PJSC and subsidiaries. For the first time, the seminar will include a comprehensive in-person career enhancement.

Special attention to the problem of stress corrosion cracking of trunk pipelines is given due to the large scale and multifactorial nature of this phenomena. This event is interesting for engineers and scientists in the field of pipe products, reliability and electrochemical corrosion specialists, diagnosticians and predictive modeling IT-specialists, mathematicians, mechanics, physicists, chemists and material engineers. Stress corrosion cracking has a direct influence on Gazprom PJSC gas pipeline system reliability, it is a key parameter of energy security in our country.

R.R. Kantyukov
Cand.Sci.Eng., Deputy Director General on Science, Chairman of Gas Transportation and Storage Section of Gazprom VNIIGAZ LLC Academic Council

I.V. Ryakhovskikh
Cand.Sci.Eng., Chairman of Seminar Organizing Committee, Deputy of Gazprom VNIIGAZ LLC Corporate Scientific Center for Corrosion Monitoring and Corrosion Protection

A.B. Arabey
Cand.Sci.Eng., Co-Chairman of Seminar Organizing Committee, Academic Director of Multidisciplinary Endeavour “Efficient Application of Pipe Products in Gas Industry”, Principal Researcher of Gazprom VNIIGAZ LLC

Economic challenges of our age complicate investigations in the field of low-cost repair technologies and computer models for life cycle and operability assessment of gas pipelines due to stress corrosion cracking. Therefore, there is a great demand for research investigations in the field of physical and chemical simulations and digitation of stress corrosion cracking process based on fundamental investigations of steel stress corrosion damage.

The seminar will host reports on the following relevant subjects:

– results of experimental investigations, physical, chemical and mathematical simulations of corrosion and stress corrosion fracture of trunk gas pipelines;

– development of a regulatory framework and operation experience of Gazprom PJSC trunk gas pipelines subject to stress corrosion cracking;

– development of technologies, materials and equipment for repair and technical diagnostics of trunk gas pipelines subject to stress corrosion cracking;

– implementation issues of the research aimed at preventive measures development of stress corrosion cracking and underfilm corrosion of trunk gas pipelines;

– implementation of technical diagnostic and truck gas pipeline damage data analysis.

Based on the results of the seminar the best reports will be recommended for the following international conference: GTS-2021 Gas Transport Systems. The Present and the Future. A topical issue of the Gas Science News scientific and technical collection will be published. It is on the list of the State Commission for Academic Degrees and Titles. The articles on stress corrosion cracking shall be forwarded to the official e-mail address of the seminar: SCC@vniigaz.gazprom.ru.

In conclusion we would like to wish success to all the participants of the seminar. We are certain that joint cooperation will help us to achieve significant progress in understanding of stress corrosion cracking mechanism and its separate aspects, as well as in regulatory control of corrosion stressed trunk gas pipeline operation and development of requirements to new types of pipeline products and protective coating, as well as technologies for diagnostics and repair of pipelines.

PROGRAM

V International Scientific and Technical Seminar

IMPROVEMENT OF RELIABILITY OF MAIN GAS PIPELINES SUBJECT TO STRESS CORROSION CRACKING

Online format

Gazprom VNIIGAZ LLC

16 December 2020, Wednesday

Moscow time
GMT+3

9.00–9.10	**Seminar participants connection**
9.10–9.30	**OPENING OF THE SEMINAR** **Rafael Kantyukov,** Deputy Director General on Science, Gazprom VNIIGAZ LLC **Ilya Ryakhovskikh** Deputy Head of the Corporate Scientific and Technical Center for Corrosion Monitoring and Corrosion Protection, Gazprom VNIIGAZ LLC **Natalia Anisimova** Deputy Head of the Scientific and Educational Center, Gazprom VNIIGAZ LLC
9.30–9.50	Stress corrosion cracking of main gas pipelines. Problems and prospects of solution **Ilya Ryakhovskikh** *(Gazprom VNIIGAZ LLC)*
9.50–10.10	Corrosion cracking of pipe metal on main gas pipelines: a retrospective and new challenges **Andrey Arabey** *(Gazprom VNIIGAZ LLC)*
10.10–10.30	Corrosion Behavior of HVDC Interference on Pipeline Steel **Han Yan** *(CNPC Tubular Goods Research Institute)*

10.30–10.50	Establishment of regulatory requirements for the design, construction and reconstruction of main gas pipelines in areas of potential occurrence of SCC defects **Igor Leonovich** *(Russian State University of Oil and Gas)*
10.50–11.10	Prevention of the development of corrosion and mechanical failure during re-insulation of the linear sections of main gas pipelines **Marina Terentyeva** *(Ukhta State Technical University)*
11.10–11.30	Application of machine learning methods for detection of anomalies, including SCC identified by using magnetic pipeline pigs and ultrasonic automated inspection systems **Adel Yarullin** *(Innopolis University)*
11.30–11.50	Application of mathematical automated algorithms for solving problems of predicting pipe damage by stress corrosion cracking defects and their development kinetics **Marina Maleeva** *(Institute of Physical Chemistry and Electrochemistry of the Russian Academy of Sciences)*
11.50–12.10	Prediction of the SCC defects in the linear sections of main gas pipelines based on the results of technical inspection **Nazar Kachura** *(Gazprom transgaz Surgut LLC)*
12.10–12.30	Stabilization of stress-corrosion cracks due to layer heterogeneity of the crystallographic texture and residual stresses in steel pipes of main gas pipelines **Olga Krymskaya** *(National Research Center Nuclear University MEPhI)*
12.30–13.30	**Break**

13.30–13.50	Impact of uneven distribution of residual and operational mechanical stresses in the pipes of main gas pipelines on the occurrence of SCC defects **Stepan Pogulaev** *(Gazprom Transgaz Ukhta LLC)*
13.50–14.10	Stress-corrosion on the linear part of the main gas pipelines. problematic issues **Mars Zakiryanov** *(Gazprom Transgaz Ufa LLC)*
14.10–14.30	Experience in accepting design decisions to prevent SCC **Aleksey Belyakov** *(Gazprom Proektirovanie LLC)*
14.30–14.50	Stress corrosion defects in JSC "Gazprom transgaz Belarus". First experience **Egor Mazhuha** *(Gazprom transgaz Belarus JSC)*
14.50–15.10	Evaluation of the impact of intra-wall stratifications on the performance of gas pipes **Roman Kashkovskiy** *(Gazprom VNIIGAZ LLC)*
15.10–15.30	Ensuring reliability of main gas pipelines under the conditions of stress-corrosion damage **Vitaliy Labyntsev** *(Gazprom transgaz Saint-Petersburg LLC)*
15.30–15.50	Impact of cyclic loading on the development of previously formed corrosion-mechanical cracks in low-carbon steel X70 **Sergey Zhedulov** *(Gazprom VNIIGAZ LLC)*
15.50–16.30	**Panel discussion «Modeling and Prediction of Stress Corrosion on Gas Pipelines».** **Formation of proposals for the protocol**

17 December 2020, Thursday

Seminar Continuation Participants' reports	
9.00–9.10	**Seminar participants connection**
9.10–9.30	Examination of the possibility of estimation of the size of stress-corrosion defects by non-destructive testing methods. Approaches to categorizing pipes with defects in field conditions **Aleksandr Kaverin** *(Gazprom VNIIGAZ LLC)*
9.30–9.50	Prospects of application of technical condition monitoring systems for optimizing criteria for assessing cracklike defects of gas pipelines **Darya Nikulina** *(Russian State University of Oil and Gas)*
9.50–10.10	Implementation and operation of the system for identification of stress corrosion cracking defects in Gazprom transgas Moscow LLC **Denis Egudkin** *(Gazprom transgas Moscow LLC)*
10.10–10.30	Optimization of methods of inspection and evaluation of the technical condition of gas pipelines subject to stress corrosion cracking **Andrey Prisyazhny** *(Gazprom transgaz Yekaterinburg LLC)*
10.30–10.50	Possibility of detection of stress-corrosion defects under stress in main gas pipelines, conditions for their development **Dmitriy Komarov** *(Gazprom transgaz Samara LLC)*
10.50–11.10	Development of technology for the detection of corrosion on pipelines using neural networks **Nikolay Tsvetkov** *(Gazprom transgaz Saint-Petersburg LLC)*

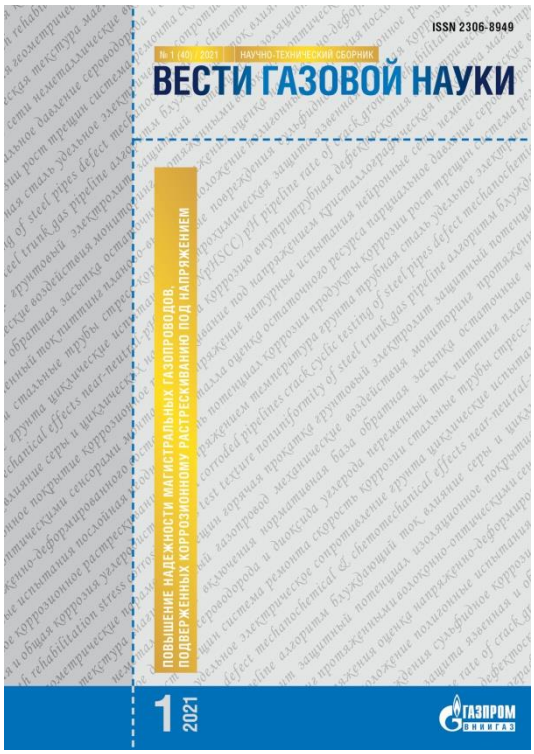
11.10–11.30	Implementation of new solutions aimed at identification and interpretation of crack-like anomalies at UGSS facilities ***Vedernikov Kirill*** *(«Gazproekt-DKR» Ltd)*
11.30–11.50	Identification and depth ranking of SCC defects during testing using the autonomous in-line inspection robotic scanner A2072 INTROSCAN **Ivan Tychinin** *(Introscan Technology JSC)*
11.50–12.10	A-line family of autonomous systems for integrated monitoring of main gas pipelines **Sergey Yelizarov** *(INTERUNIS-IT LLC)*
12.10–12.30	Predictive capabilities of the acoustic emission method for localization of potentially hazardous areas of the development of SCC defects **Aleksey Kuzmin** *(Strategia NK LLC)*
12.30–13.30	**Break**
13.30–13.50	Prevention of the development of processes of corrosion and stress corrosion fracturing of the unified gas supply system pipelines using risk-based magnetic tomography examination **Svetlana Kamaeva** *(STC «Transkor-K» LLC)*
13.50–14.10	An integrated approach to improving the reliability of main gas pipelines liable to stress corrosion cracking Alexander Naumenko («Gazprom transgaz Yugorsk» LLC)
14.10–14.30	Automated quality control of insulation works and post-repair eddy current flaw detection as a means of reducing the risk of accidents due to stress-corrosion cracking **Sergey Rybalko** *(«SPE «NEFTEGAZDIAGNOSTIKA» LLC)*

14.30–14.50	Improvement of the efficiency of gas transport system diagnostics through the use of electrical and eddy current testing methods **Olga Novokshonova** *(NPP Mashproject LLC)*
14.50–15.10	Ensuring safe operation of main gas pipelines in conditions of stress-corrosion damage **Sergey Savenya** *(Gazprom College Volgograd PPEI)*
15.10–15.30	Cold bent branches and their defects. problems of detection and assessment **Michael Kadylkin** *(Gazprom transgaz Kazan LLC)*
15.30–15.50	Automation of the corrosion mapping process **Alexey Desyatkov** *(Gazprom Transgaz Chaikovsky LLC)*
15.50–16.10	Results of the study of acoustic-emission parameters of fiberglass pipelines for the development of the inspection methodology **Kirill Medvedev** *(STC EgidA LLC)*
16.10–16.30	Detection and control of stress-corrosion cracks using eddy current matrices **Vladimir Pankov** *(Olympus Moscow LLC)*
16.30–16.50	Increase of stability of thermoelectric generators used for cathodic protection of gas pipelines **Michail Korzhuev** *(Institute of Metallurgy and Metallurgy of the Russian Academy of Sciences)*
16.50–17.20	**Panel discussion** **«Technical diagnostics of MG susceptible to SCC».** **Formation of proposals for the protocol**

18 December 2020, Friday

Seminar Continuation Refresher courses	
10.00–10.10	**Seminar participants connection**
10.00–11.30	**Lecture 1 Stress corrosion cracking of main gas pipelines** **Ilya Ryakhovskikh** Deputy Head of the Corporate Scientific and Technical Center for Corrosion Monitoring and Corrosion Protection, Gazprom VNIIGAZ LLC Cand. Sci (Eng.)
11.30–12.00	**Break**
12.00–13.00	**Lecture 2 Diagnostics of the corrosion state of gas supply system objects using non-destructive testing methods** **Aleksandr Kaverin** Head of the laboratory for predictive modeling of damage to linearly extended and area facilities of the UGSS Corporate Scientific and Technical Center for Corrosion Monitoring and Corrosion Protection, Gazprom VNIIGAZ LLC
13.00–13.45	**Lecture 3 Corrosion under delamination of the protective coating of main gas pipelines: mechanisms, patterns and prevention** **Roman Kashkovskiy** Leading Researcher Laboratory of physical and chemical modeling and prevention of corrosion and mechanical destruction of UGSS facilities Corporate Scientific and Technical Center for Corrosion Monitoring and Corrosion Protection Gazprom VNIIGAZ LLC, Cand. Sci. (Chem.)
13.45–14.00	**Summing up the Seminar**
CLOSING SEMINAR	

A specialized issue of the scientific and technical journal «Vesti Gazovoy Nauki» on the topic **“Improving reliability of gas mains subject to stress corrosion cracking”** is planned for 2021.



Based on the results of the seminar, the best reports will be recommended for publication.

Material submission deadline

Correspondent manuscripts aimed at publication in the Vesti Gazovoy Nauki journal should be sent by the end of April 2021 to the official address of the workshop:

SCC@vniigaz.gazprom.ru

Manuscript size

Recommended volume of printed work – 12 pages (MS Word editor, 1.5 spacing, 14 point size) including figures (no more than 5), tables, bibliographic list.

More information is available at the link:

http://vesti-gas.ru/en/authors/requirements-articles

You can find works of past years here:

http://vesti-gas.ru/en/content/home/v-3-27-2016-improving-reliability-gas-mains-subject-stress-corrosion-cracking

http://vesti-gas.ru/en/content/home/v-3-40-2019-improving-reliability-gas-mains-subject-stress-corrosion-cracking

ABSTRACTS

Stress corrosion cracking of main gas pipelines. Problems and prospects of solution

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An important element of Russia's energy security is the world's largest Gas Transport System of Gazprom PJSC (GTS), which extends over 170 thousand km across the country. Around 80 % of large diameter main gas pipelines of the GTS are operated with protective coatings with expired service life. When a corrosive medium reaches the surface of pipes in sections where protective coatings are detached the operational defects are formed and developed some of which are attributable to stress corrosion cracking (SCC) and subsequently become the main cause of the main gas pipeline accidents.

The report presents a panorama of modern views on improvement of the efficiency of operation and maintaining the integrity of main gas pipelines under the risks of stress corrosion cracking. The paper covers problematic issues of improvement of diagnostic systems related to the contradiction between the requirements of regulatory documents for repair and the actual conditions of operation of main gas pipelines exposed to stress corrosion cracking.

Based on the modern understanding of the kinetics of SCC of pipelines in near-neutral electrolytes the paper presents a concept of development of balanced requirements for technical inspection and repair of main gas pipelines based on assessment of their lifespan which is gradually implemented in GTS technical condition and integrity management system.

The paper presents the plans of development of the corporate experimental complex of Gazprom PJSC for the assessment of service life of pipes with SCC defects and testing of the repaired structures. Perspective areas of innovative development of technologies, materials and equipment for repair and inspection of main gas pipelines are shown. The prospects of predictive modeling of the stress-corrosion process and its software implementation in relation to the problems of operation and repair of main gas pipelines are highlighted.

Corrosion cracking of pipe metal on main gas pipelines: a retrospective and new challenges

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The problem of corrosion cracking of metal pipes of main gas pipelines (SCC, stress corrosion) remains one of the main risk factors of emergency failures of underground pipelines of main gas pipelines, accounting for at least 50 % of the total number of causes of accidents, reaching up to 70–80 % in some years.

The results of our work made allowed ensuring already in the first decade of the 2000s the *LOW* level of failure flow density per gas pipeline as defined by the world community or no more than 0.2 accidents/1000 km per year. Despite the constant expansion of the range of gas pipelines affected by SCC, this level remains constant owing to the introduction of new and more effective measures based on increasing knowledge about the nature of SCC.

The initial cause for the SCC in the main gas pipelines was a wrong technical decision of the organizers of the creation of gas transmission networks in North America (USA, Canada) which was later adopted in the USSR to protect pipelines from corrosion with adhesive polymer tapes which were mechanically applied in the field conditions.

For example,at least 100 thousand km of Gazprom's main gas pipelines (176 thousand km) have such insulation coating.

The loss of insulating properties and degradation of coatings made of adhesive polymer tapes after 10–15 years of operation led to contact of bare metal with soil electrolyte, which "started" the mechanism of stress corrosion, which has become a global phenomenon, a problem for all the world's leading gas transmission companies: in North and South America, Australia, Europe).

Stress-corrosion damage in the form of individual, and more often multiple colonies of cracks develop for a long time from 15 to 25–30 years. Consolidation of the colony into the main crack is slow, and emergency failure occurs unexpectedly.

The accumulated data allow saying about local anodic dissolution at imperfections of the metal surface of pipes and welded joints, as the cause of the origin of multiple microdefects. Subsequently they develop into stress-corrosion cracks along the pipeline axis across the direction of the vector of the main tensile stresses. In rare cases of increased bending or combined loads on the pipeline, cracks are observed across the pipeline axis.

The main preventive measure is timely detection and repair of hazardous stress-corrosion damage. So far, based on the level of knowledge achieved in the previous period, all pipes where defect inspection showed the presence of cracks, regardless of their depth, are replaced with new ones. The purchase of new pipes accounts for main expenses for the repair of such sections.

We proved scientifically the possibility to keep in service the pipes with a crack depth of less than 0.10 of wall thickness, the proportion of which is up to 50 % of the length of the repaired section, provided that such pipes are re-insulated with a special coating with a SCC inhibitor. The introduction of this technology will reduce the cost of purchasing new pipes and increase the length of gas pipeline sections that are repaired annually.

In the foreseeable future, more and more widespread use of hydrogen technologies in the energy sector is expected. Europe is planning a gradual transition to a carbon-free economy by 2050, which will require the use of existing pipeline systems for the main transport of methane-hydrogen, later hydrogen-methane mixtures and possibly pure hydrogen.

In this regard, the task of assessment of the hydrogen degradation of the metal of pipes of existing gas pipelines as a risk factor for aggravating the stress-corrosion damage accumulated by the system becomes practically significant.

Corrosion Behavior of HVDC Interference on Pipeline Steel

Fu Anqing, Han Yan, Yuan Juntao, Li He

CNPC Tubular Goods Researcher Institute

With the application of HVDC transmission technology in long-distance transmission projects, the interference between pipelines and high-voltage transmission lines has become a problem that cannot be ignored. Therefore, we have carried out the research on the influence of high voltage interference on X80 pipeline. The results showed that with the increase of interference voltage, the corrosion rate of anode increased obviously, and the hydrogen embrittlement sensitivity of cathode increased significantly. The maximum corrosion rate and hydrogen embrittlement damage occurred under the 100V interference.

Establishment of regulatory requirements for the design, construction and reconstruction of main gas pipelines in areas of potential occurrence of SCC defects

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Over the past 20 years, stress corrosion cracking (CRN) has become one of the main causes of accidents and failures of main gas pipeline transport facilities. The number of detected and repaired SCC defects increases annually, and in some operating subsidiaries, the inspection and repair of such defects becomes the main task of the system for maintaining the operational reliability of pipelines.

In this situation, an urgent task is to establish special requirements for the design, construction and reconstruction of pipeline sections located on the territory that contributes to the occurrence and development of SCC defects. For such sections, both complex and individual requirements can be set for groups of factors that affect SCC defects: the external environment, mechanical stresses in the metal of the pipe wall, anti-corrosion insulation of the pipeline and metallurgical characteristics of the metal.

The existing mechanism for establishing mandatory requirements for the design, construction and reconstruction processes is based on the requirements of the Technical Regulations on the safety of buildings and structures, which allows establishing separate requirements for types of safety, including the mechanical safety of a capital construction facility by virtue of reference to the requirements of codes of rules and national standards.

Prevention of the development of corrosion and mechanical failure during re-insulation of the linear sections of main gas pipelines

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When the work is performed in field conditions the the insulation coating is replaced mechanically using specialized machines that form an insulation column.

One of the key operations during re-insulation in field conditions is cleaning of the defective insulation the quality of which will determine the lifespan of the new insulation and the pipeline as a whole.

Today, the most commonly used complex of machines is based on the mechanical method of cleaning with self-propelled systems using scrapers and brushes. But as the experience of their usage has proven these systems are quite cumbersome for use in the field conditions, they require a significant amount of consumables, do not ensure high quality of cleaning, damage the pipe surface and in addition, the environment is polluted by cleaning waste.

A modern and rapidly developing method of metal treatment is laser stripping of insulation from the metal based on the use of short laser pulses, which are directed to the surface to be cleaned, while evaporating the insulation and simultaneously warming the surface.

When working with a laser system, there is no need to purchase two cleaning machines and one heating machine within the same column. The treated material is not destroyed during laser exposure, a higher degree of cleaning compared to equivalent methods, low operating cost and environmental safety is ensured.

Application of machine learning methods for detection of anomalies, including stress corrosion cracking identified by using magnetic pipeline pigs and ultrasonic automated inspection systems

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The examples of results based on the application of machine learning algorithms for the analysis of data of in-line inspection by using magnetic pipeline pigs and ultrasonic automated inspection systems are presented.

Approaches to the development and verification of quality metrics for a convolutional neural network model for recognizing and determining the geometric dimensions of anomalies are shown. Examples of recognition results based on route data are provided to confirm the validity of using these metrics.

The paper covers significant features for solving the recognition problem, considerations related to the feasibility of combining groups of defects, as well as their classification for application of machine algorithms. Solutions to problems of unbalanced sampling and training of a convolutional neural network model on "noisy layout" are considered. For the optimum of training of machine algorithms, suggestions are given regarding the approach to the marking of anomalous areas based on the results of analysis of a set of flaw patterns.

Thus, the study proves the efficiency and applicability of machine algorithms for solving the problem of identification, localization and determination of the geometric dimensions of anomalous areas using the data of in-line diagnostics with magnetic pipeline pigs and ultrasonic automated inspection systems, as well as the advantage in terms of processing speed.

Application of mathematical automated algorithms for solving problems of predicting pipe damage by stress corrosion cracking defects and their development kinetics

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Gazprom has the world's largest gas transmission system. The task of efficient and safe operation of main pipelines is one of the priorities, at the same time, the occurrence and development of operational defects, the most hazardous of which are stress corrosion cracking fractures on the outer wall of the pipeline, have a significant impact on the performance of main gas pipelines. Therefore, it is important to predict the damage to pipes by such defects, as well as the rates of their development.

This work provides justification for the choice and algorithmization of the optimum method for predicting the development of various types of operational defects, namely, corrosion defects, SCC and fatigue based on physical and chemical models of their development, taking into account the data of operational documentation and process parameters of main gas pipelines, the results of complex corrosion inspections, including soil aggressiveness in relation to SCC and corrosion, the results of analysis of domestic and international regulatory documents and standards. A Python software package was created for online calculation and visualization of the acquired data, which will simplify the work of engineers when choosing the optimum strategy for pipeline protection.

The main gas pipelines are also regularly inspected using in-line inspection tools to detect various types of defects in order to monitor the technical condition of gas pipelines and forecast the scope of pipe replacement during major repairs. However, the accuracy of the forecast based on in-line inspection tool data is not always satisfactory. In particular, SCC defects with a depth of less than 20 % of the pipe wall thickness are detected with insufficient accuracy.

To improve the results of the forecast of the length of replacement of pipes in case of major repairs, including sections exposed to SCC, the forecast based on ILI model using only in-line inspection tool data and the forecast based on "gas pipeline – peer model" using in-line inspection tool data, correlation relationships of the impact of six main factors on SCC, as well as the results of additional pits were automated and tested. The simulation statistical and probabilistic modeling of the forecast of damage of main gas pipeline sections using these models was performed and the forecast accuracy of each model was calculated. An equation for calculating the optimum number of additional pits was proposed to refine the model forecast. It is shown that the number of pits is determined by the length of the studied section and the estimated proportion of pipes with the studied defects.

Literature used

1. DIN 50929 part 3. Probability of corrosion of metallic materials when subject to corrosion from the outside. Buried and underwater pipelines and structural components.

2. V.E. Gmurman. Theory of probability and mathematical statistics. 12th edition. Moscow, Urait, 2015,479 pp.

3. S.K. THOMPSON Sampling. 3rd edition. Wiley, 2012. 445 p.

Prediction of the SCC defects in the linear sections of main gas pipelines based on the results of technical inspection

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Stress corrosion cracking (SCC) of the linear part of main gas pipelines is one of the main causes of their failure. Due to the priority of ensuring and managing the industrial safety of hazardous facilities, there is a need for periodic diagnostic inspection of main gas pipelines. Identification of hazardous stress-corrosion areas that can affect the safe operation of the pipeline is one of the most significant factors in determining the need for technical inspection and major repairs of the linear part of main gas pipelines.

This paper covers a method of automation of the process of determination of the areas of linear part of main gas pipelines with the highest probability of SCC. The scheduling of the technical inspection of the section of the linear part of main gas pipelines is based on aggregate assessment of the considered sections and determination of the specific expected number of failures. The score summarizes the most significant factors that affect the probability of pipeline integrity losses based on the results of analysis of data of the last technical inspection: field surveys, in-line inspection (ILI), technical inspection in pits, performance assessment, as well as data from lists of corrected defects within the framework of major repairs.

Comparison of the results of ILI and field inspection in the pits during major repairs of sections of the main gas pipeline revealed a low sensitivity of the sensor system of magnetic flaw detectors used in ILI to detect crack-like defects. This leads to the conclusion that the results of ILI cannot be used as an objective source of data for statistical processing of stress-corrosion defects. According to the results of studies of the last decades the technology and quality of manufacturing of pipes, the presence of watercourses on the route of linear parts of main gas pipelines and increased groundwater level, condition of insulation coating, high temperature of pipes (proximity to the compressor station), corrosiveness of the soil are significant factors contributing to the development of SCC in the linear parts of main gas pipelines. Thus, the stress-corrosion score rating is determined by the combined effect of tensile stresses in the pipe wall and aggressive conditions of external and internal (relative to the pipe) media determined based on the results of complex technical inspection.

When a sufficient amount of statistical data is accumulated based on the results of the studies such as ILI, ground survey, non-destructive testing during major repairs and other inspections it will be possible to increase the reliability of determination of the sections of linear parts of main gas pipelines with SCC by using neural network modeling technology. The use of such technologies will make it possible to rank the sections of linear parts of main gas pipelines by the category of probability of SCC. The accuracy of forecasting increases with the clarification and expansion of the number of factors that initiate the SCC process and with the constant accumulation and analysis of data based on the results of technical diagnostics.

Stabilization of stress-corrosion cracks due to layer heterogeneity of the crystallographic texture and residual stresses in steel pipes of main gas pipelines

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The paper demonstrates the impact of heterogeneity of quantitative textural and structural parameters over the wall thickness of pipes made of steel of strength category X70 on their SCC exposure. The crystallographic texture, structure, and residual stresses of the base material of pipes after long-term operation as part of main gas pipelines were studied, as well as various zones of process welds. The study revealed the mechanisms of reduction of the rate of development of stress corrosion cracks when reaching a layer within which the texture parameters significantly change. Based on the analysis of the obtained data, a criterion for pipe classification was developed: if the degree of texture on the outer surface of the pipe is higher than 3, most cracks with a high probability (90 %) do not develop deeper than 15 % of the pipe wall thickness. Based on experimental data it was demonstrated that the distribution of residual macrostresses over the wall thickness of various pipes is almost identical: the tangential component stretching on the outer surface linearly decreases to almost zero in the area of 20 % of the wall thickness.

Based on the results obtained, recommendations were proposed for taking into account quantitative textural and structural parameters, as well as residual macrostresses for evaluation of the rates development of stress corrosion cracks and their stabilization.

Impact of uneven distribution of residual and operational mechanical stresses in the pipes of main gas pipelines on the occurrence of SCC defects

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Large-diameter pipes used for the construction of main gas pipelines are made by forming of the sheet steel. Zones of residual stresses are inevitably formed during bending of sheets and subsequent welding and these zones are unevenly distributed along the perimeter of the pipes. In addition, the profile of such a pipe itself differs from an ideal circle with a variation of the local radius of curvature upward or downward close to the average value equal to the nominal value. This variability of the local radius of curvature allows describing a pipe as a polygon with smoothed corners. Different circumferential stresses occur in different zones of a non-ideal pipe profile due to the internal pressure of the pipe. Uneven distribution of the combined residual and operational stresses can both accelerate and slow down the process of occurrence and development of stress corrosion-cracking defects (SCC).

The above is confirmed by measurements of the local radius of curvature along the perimeter before and after cutting the rings cut from the pipes of the main gas pipelines. In addition, the results of electrotensometry during hydraulic testing of pipes also showed different levels of elastic deformations at the places of sensor installation sites in areas that differ in the curvature of the profile. An analysis of the distribution of zones of crack-like defects was performed using the data of in-line inspection and diagnostics in pits conducted by external flaw scanners for assessment of the impact of uneven distribution of residual and operational stresses on the occurrence and growth of stress corrosion cracks. The results of the analysis for single-seam and double-seam pipes revealed zones with high probability of SCC, these zones are located both near longitudinal weld in the area of edge bending and at some distance from it.

The practical significance of the performed analysis comprises the identification of potentially hazardous areas of SCC defects on the pipe surface for optimization of the inspections. In addition, better study of the level of stress state in these zones will allow for a reliable expert assessment of the load-bearing capacity of a pipe with SCC defects.

Stress-corrosion on the linear part of the main gas pipelines. Problematic issues

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LLC «Gazprom transgas Ufa» operates more than 4,700 km of main gas pipelines and branch pipelines, out of which 1,630 km are gas pipelines with a diameter of 1020–1420 mm. Most large-diameter gas pipelines are operate for more than 30 years with an insulting film coating of route application, the service life of which is an average of 8–12 years.

The report provides data from in-lines and borehole surveys carried out for 2019–2020 years on gas pipelines DN 1220–1420 mm, notes that the largest number of stress corrosion cracking (here and after SCC) cases were identified on pipes, during the manufacture of which a high level of residual stresses is formed, in particular, on spiral-seam and double-seam pipes.

In general, for the effective solution of issues related to urgent industry problem of formation and development of SCC defects, as well as increasing the reliability of gas pipelines, we consider it necessary:

1) to improve the accuracy of identification detected by in-line inspection of defects and their parameters in order to optimize operating costs and make informed choices repair of defective pipelines methods;

2) to perform the revision of regulations in terms of evaluating the strength of pipes with cracks transverse direction (in STO Gazprom 2-2.3-173-2007);

3) to develop recommendations for the forecast (5–10 years ahead) assessment of the technical condition of pipeline sections exposed to SCC.

Experience in accepting design decisions to prevent SCC

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The safety of the main gas pipeline is a priority for all organizations that are part of the Company, including design organizations.

Stress corrosion cracking (hereinafter referred to as SCC) is one of the main causes of accidents on main gas pipelines, along with the defects of construction.

Despite the existing questions about the nature of this phenomenon it constitutes a corrosion and mechanical destruction of the outer surface of the pipes of main gas pipelines due to the long-term impact of ground water with specific corrosion properties on the metal of as well as the impact of tensile external loads caused by gas pressure and the impact of internal loads produced during the manufacture and operation of pipes.

Based on the analysis of the conducted studies sections exposed to SCC are characterized by the following features:

– sections are associated with negative landforms (depressions, potholes, erosional incisions in the of ravines and hydrographic network);

– the prevalence of binder soil (loam, clay) in the geological section in the interval of the depth of the gas pipeline which is characterized by a very high water capacity with low water yield;

– variable wetting of the laid gas pipeline due to seasonal fluctuations of the water table.

The task of the designer is to minimize the impact of this phenomenon on a gas pipeline by developing a set of measures and technical solutions in accordance with the requirements of regulatory documents, as well as based on the experience of designing, analyzing the detection of stress-corrosion defects, etc.

Stress corrosion defects in JSC "Gazprom transgaz Belarus". First experience

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In 2020, JSC “Gazprom transgaz Belarus” first discovered defects of stress-corrosion origin (hereinafter referred to as SCC). In the linear part of main gas pipelines stress corrosion defects were found in the the result of the scheduled in-line inspection of the output loop and the section between safety valves No. 320 and No. 321 of compressor station in the result of the scheduled local survey of CS process piping in the pits.

Based on the results of the analysis of the results of local survey and laboratory studies of pipe templets with the SCC the following patterns were revealed:

– maximum concentration and depth of cracks is observed on heat-strengthened spiral welded pipes of strength class K60;

– cracks are mainly located in the supporting part of the gas pipeline, including on double-seam pipes along the longitudinal seam;

– a significant number of pipes were found where cracks intersect the factory spiral welds or are located in the heat affected zone of the circumferential weld;

– stress corrosion defects are found on pipes with weak adhesion of the protective coating, in the areas with buckling and folds;

– pipes with SCC are found mainly in woodlands with clay soils;

– sections of main gas pipelines at the distance starting 10–15 km from compressor stations were the most susceptible to the stress corrosion defects.

Evaluation of the impact of intra-wall stratifications on the performance of gas pipes

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This paper studies the impact of intra-wall stratifications on the performance of pipes that operated for more than 45 years as part of an existing main gas pipeline. The gas pipeline under the study was constructed in 1971 using imported pipes of strength class X53 and X56. Stratifications on the inner pipe walls were first discovered in the late 1980s, to date, the number of detected pipes with stratifications does not exceed 1 % of the total number of main gas pipeline pipes.

Laboratory studies of pipe steel demonstrated that its chemical composition and standard mechanical properties correspond to the rated values. It was noted that the content of non-metallic inclusions in steel increased but is acceptable for pipes with a diameter of 1020 mm.

Based on the analysis of gas transport conditions along the pipeline in 2009–2019, a model of its operation was developed which includes alternately repeated combinations of amplitude and pulsation loading cycles. For evaluation of the pipe performance a test bench was built containing pipe fragments with extended zones of intra-wall stratifications. The bench was subjected to cyclic internal pressure tests simulating 20 years of operation of this gas pipeline according to the calculated loading model.

A step-up increase in the internal pressure of the test bench demonstrated that plastic deformation of the pipe occurs at twofold design pressure of the main gas pipeline. The plastic deformation zones of the test bench were located directly between the stratification zones and the welds, which indicates the need to repair pipes with stratifications near the welds. An additional factor for stricter requirements for pipe rejection can be the presence of combined types of defects, such as "lamination + internal crack".

The criteria for selective repair of pipes in the studied section of the main gas pipeline were determined based on the results of the complex of studies and recommendations were given for optimization of the methods of inspection of main gas pipelines and improvement of the the detection of stratifications by in-line inspection.

Ensuring reliability of main gas pipelines under the conditions of stress-corrosion damage

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The paper covers the problems of ensuring the reliability of the main gas pipelines of the unified gas supply system under the conditions of stress-corrosion damage.

At the moment, gas losses and material damage in case of accidents caused by stress corrosion exceed those from accidents caused by all other reasons.

An important factor in the development of stress-corrosion processes is the level of tensile stresses in pipeline structures and the aggressiveness of soils in the near-pipe space that affect the defective structure of pipe steels. Stress corrosion manifests itself in the form of crack colonies, the development of which leads to an extended rupture.

Accordingly, the methods used to assess and prevent stress-corrosion damage of pipelines should first of all be aimed at identifying factors specific to the given type of damage, including the impact of stresses and microbiological activity.

The arguments, facts and justifications presented in the paper based on the authors' practical studies allow stating the following:

– the problem of stress corrosion in operating gas pipelines primarily pertains to one of the problems of corrosion-mechanical failure of steels and alloys and should be solved taking into account the laws of degradation and failure of structural materials operating under variable loads and exposed to aggressive media;

– the authors propose using generalizing coefficients that characterize the total impact of the main negative factors (stress-strain state, soil corrosion aggressiveness, and the state of the insulation coating) to ensure the allocation of potentially hazardous sections of a gas pipeline that are most susceptible to stress corrosion;

– work on the prevention of stress-corrosion failure should be included in the mandatory set of surveys for design institutes when choosing the route of new gas pipelines.

Impact of cyclic loading on the development of previously formed corrosion-mechanical cracks in low-carbon steel X70

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The problem of stress corrosion cracking is relevant for a wide range of structural materials that are operated under the impact of tensile stresses and a corrosive environment. In Russia this process is most common at the world's largest Gas Transportation System of Gazprom PJSC.

Most of main gas pipelines of the GTS are operated with protective coatings with expired service life. As a result, when the corrosive medium reaches the metal of pipes crack-like damage caused by stress corrosion cracking mechanism develops.

This paper defines the relationships of the impact of cyclic loading on the development of cracks in pipes made of low-carbon steel X70 during long-term operation as part of the main gas pipeline.

A device was developed and manufactured in the course of the work for testing pipe metal on model samples. The results of cyclic testing of steel samples with natural SCC cracks and artificial defects (cuts) of various depths are presented. Natural cracks with a depth of up to 34 % of the pipe wall thickness began to develop at a stress of 484 MPa after 11750 cycles. When the defect depth was 50 % of the pipe wall thickness the defect development is observed after 3600 cycles and a load of 396 MPa. All natural SCC cracks grew evenly without brittle failure of the material in the direction perpendicular to the pipe axis. The development of cracks from artificial cuts with a depth of 40 % of the pipe wall thickness begins after 3500 cycles and a load of 484 MPa, which is 1.5 times higher than the design loads.

An external difference in the development of SCC and artificial cracks was also observed. The SCC defects tend to branch in contrast to the natural cracks.

The microstructure, texture and fracture surface of the samples were studied. The revealed relationships of the impact of cyclic loading on the development of previously formed SCC cracks can be used in the development of a multi-stage kinetic model for the formation and development of SCC under the main gas pipeline operating conditions.

Examination of the possibility of estimation of the size of stress-corrosion defects by non-destructive testing methods. Approaches to categorizing pipes with defects in field conditions

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Deterioration of the main gas pipelines (MGP) of Gazptom PJSC highlights the problems of planning and effective distribution of funds for inspection and repair of pipelines. The development of low-cost technologies for repairing gas pipelines with stress corrosion cracking (SCC) defects is especially relevant when the most important aspect is the classification of defects according to the degree of hazard based on the results of instrument inspection of pipes. These pipe repair technologies require to solve the problems of accurate localization of the deepest cracks and reliable estimation of their size in stress corrosion crack by nondestructive testing (NDT) methods in field conditions.

The paper provides the main results of the tests of NDT tools with respect to the problem of estimation of the size of colonies of stress-corrosion cracks on the surface of pipes operated as part of main gas pipelines that differ in size, properties and chemical composition. The established relationships between the readings of tools that employ ultrasonic, eddy current and electric non-destructive testing methods and the actual crack sizes are provided. The reliability of the test results and conclusions was confirmed by standardized methods of optical electron microscopy and x-ray tomography applied for verification of the size of cracks in the areas of maximum readings of instruments.

The paper provides practical recommendations for application of non-destructive testing tools for assessment of the depth of stress-corrosion cracks and the capabilities of this approach to the problem of categorization and rejection of main gas pipeline pipes.

Prospects of application of technical condition monitoring systems for optimizing criteria for assessing cracklike defects of gas pipelines

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The influence of the complex stress-strain state (SSS) of pipe metal on the initiation and development of defects in gas pipelines, including stress corrosion cracking (SCC) defects, is well studied, at the same time, when assessing the performance of pipes with defects, conservative criteria obtained for the worst combinations of loads and impacts on a defective section of a gas pipeline.

The current level of development of monitoring technologies makes it possible to assess the stress-strain state of the metal of pipes and fittings of gas pipelines with high accuracy, as well as to record the chronology of its changes during operation. The volume and completeness of data obtained during long-term continuous monitoring allows one to apply modern methods of fracture mechanics to assess the performance of pipes with defects and switch to the use of evaluation criteria that depend not only on the geometric dimensions of the defects, but also on the actual stress-strain state of gas pipelines, as well as the chronology of its change.

In addition, the introduction of continuous monitoring tools will optimize the technical requirements for diagnostic equipment designed to search and identify defects, in particular, the requirements for the minimum size of identified defects for gas pipelines with various stress-strain states.

The application of this approach will allow to optimize the costs of maintenance and repair of gas pipelines, which largely determine the cost of gas transportation.

Implementation and operation of the system for identification of stress corrosion cracking defects in Gazprom transgas Moscow LLC

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Reasons for implementation of the System.
The concept of the System functioning.
Goals and objectives of the System.
System business process.
Organizational and methodological support of the System functioning.
Principles of ensuring single approaches to the implementation of the main activities of the System functioning.
Interim results.

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Optimization of methods of inspection and evaluation of the technical condition of gas pipelines subject to stress corrosion cracking

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Stress corrosion cracking is one of the main causes of accidents on gas pipelines. The existing regulatory document (STO Gazprom 2-2.3-173-2007) regulating inspections of gas pipelines subject to SCC does not allow identifying with a sufficient degree of reliability the boundaries of sections damaged by SCC and their ranking, as a result, information about the technical condition of gas pipelines subject to SCC is interpreted incorrectly.

The analysis and generalization of factors contributing to the development of SCC allowed developing a model of "SCC situation" (hereinafter referred to as the model) in which the occurrence and subsequent development of stress-corrosion defects is possible. The model is based on the coincidence of system-forming factors of the stress corrosion cracking. Based on the model, a methodological approach is proposed to identify potentially hazardous stress-corrosion sections. In addition, the ranking factors provided in STO Gazprom 2-2.3-173-2007 were revised in order to obtain more reliable indicators of stress corrosion risk factors.

The proposed methodological approach enables to more accurately identify and rank sections damaged by the SCC.

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2. Company’s standard Gazprom 2-2.3-760-2013
3. Company’s standard Gazprom 2-2.3-412-2010

Possibility of detection of stress-corrosion defects under stress in main gas pipelines, conditions for their development

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The paper presents statistics of stress-corrosion defects under stress (SCC) found in the facilities of Gazprom transgaz Samara LLC. The diagnostic possibilities of detection of these defects by in-line magnetic inspection pigs and NDT methods in pits are considered. The analysis of factors affecting the development of SCC defects is performed based on the rejection materials obtained during major repairs of the linear section of the main gas pipeline (DN1400, the length of the section: 25 km, operating time at the time of repair: 34 years). The relationship between the geometric parameters of defects is described, which allows estimating the depth of cracks based on external parameters [1]. Mechanical tests of samples containing cracks were performed under cyclic loading [2], as well as micro-X-ray spectral analysis of metal and corrosion products.

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Development of technology for the detection of corrosion on pipelines using neural networks

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In addition to the scoring system for assessing the predisposition of a pipeline section to corrosion, there is a development by AMT, commissioned by VNIIGAZ, based on data from the site of the Punginsky LPU MG, owned by Gazprom transgaz Yugorsk LLC. Despite the attempt to use neural network moderation to solve the problem and create a prototype of the software package, this development has a number of significant drawbacks related to the technology and methods underlying it.

The proposed solution is based on the use of modern modeling methods. An experienced choice of the most appropriate neural network architecture or machine learning method is assumed, and a combination of different methods is also possible. It is planned to create a software package that will combine all the necessary information to determine the possibility of corrosion on the site and as a result of the program, the probability of corrosion formations on the pipeline will be obtained.

It is necessary to collect and process data from various sections of pipelines. You need to create a database of input parameters from completely different sections, which will allow you to apply the technology to different sections with different characteristics.

Thus, the proposed solution to the problem of detecting corrosion formations on pipelines has a great potential for successful implementation.

Implementation of new solutions aimed at identification and interpretation of crack-like anomalies at UGSS facilities

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Currently, JSC "Diakont" is developing the new generation inspection units, the purpose of which is to ensure full compliance to the current edition of the Technical Requirements for Automated Inspection Tools for ILI of PJSC «Gazprom» compressor stations technological pipelines.

Application of the new generation automated inspection tools provides increasing of inspection efficiency by performing the types of NDT that were not previously performed using the existing gas compressor stations ILI inspection tools included in the existing register of ILI robotic inspection solutions on PJSC «Gazprom» facilities.

Thus, the capabilities of the new generation automated inspection tools developed by JSC "Diakont" is carrying out a comprehensive continuous (in accordance with the requirements of STO Gazprom 2-2.3-328-2009) pipeline inspection: visual in-line examination, visual measuring inspection of girth welds, visual measuring inspection of seam welds, pipes wall visual measuring inspection, visual measuring inspection of pipeline fittings, UT inspection and thickness measurement of pipes wall, UT inspection and thickness measurement of pipeline fittings, pipe wall adhesion inspection, pipeline fittings adhesion inspection, pipe walls and pipeline fittings profilometery – for a single run of the tool. And also UT inspection of girth and seam welds, determination of pipelines spatial position.

In October 2020, prototypes of new inspection units were presented at the testing mockup stage of departmental tests of PJSC «Gazprom», the capabilities of which are (in relation to crack-like anomalies):

1) Detection and interpretation/classification of «crack-like anomalies» of a pipe wall oriented along the pipelines axiso;

2) Detection and interpretation/classification of «crack-like anomalies» of a pipe wall oriented perpendicular to the pipelines axis (in the annular direction);

3) Detection and interpretation/classification of plane anomalies on girth welds.

Basing on the results of post-processing of the primary UT inspection information performed with the multichannel unit that is possible to perform detection and identification of various types of defects, including crack-like anomalies / mechanical damage.

Existing technologies do not allow to unambiguously identify the type of defect in relation to crack-like anomalies and mechanical damage.

In order to separate crack-like anomalies and mechanical damages having the same reflective surface for UT inspection of angle beam input channels and identification of a specific type of defect, the Diakont Group of Companies carried out complex experimental studies and formed requirements to methods,

equipment and technologies aimed at separating defects into "crack-like defects" and "mechanical damage". Based on the results of these works, an MPD unit was presented, containing ultrasonic direct beam channels with a narrow aperture, designed to measure the residual thickness in the area of the "crack-like anomaly / mechanical damage" defect (in the area of the crack-like anomaly, the change in the pipe wall thickness will not be recorded) parameter of a specific defect type.

The mentioned above capabilities of detecting and interpreting defects are realized by analyzing reliable primary inspection information coming from the inspection tools complex without additional mathematical processing and do not require additional pits digging on real objects to recalibrate the primary data.

It should be noted, that simultaneously with the development of new units and inspection methods, «Gazproekt-DKR» Ltd together with «Innopolis University» carry out works within the R&D project “Development of an intelligent system for inspecting the technical condition of compressor stations using a complex of robotic means and real-time data transmission” of PJSC «Gazprom».

One of the most expected results of this work is the capability of identifying crack-like anomalies using primary inspection information with no need in human participation in the process. That will allow eliminating the influence of the human factor in data processing, identification and interpretation of crack-like anomalies.

Identification and depth ranking of SCC defects during testing using the autonomous in-line inspection robotic scanner A2072 IntroSCAN

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The innovative in-line scanner and flaw locator A2072 IntroScan was developed for assessment of the technical condition of in-service pipeline systems. In addition to detection and localization tasks, it is necessary to evaluate the type and depth of defects. The work is underway to upgrade the flaw detector scanner to address the above tasks.

As of the upgrading A2072 IntroScan was tested in various sensing modes (LF – 65 kHz, MF – 300 kHz), in bench and field conditions.

The defect zones were localized, the types of defects were evaluated and the localized defect zones were evaluated/ranked by depth during testing.

Based on the test results the quality of detection and identification of SCC defects was evaluated during in-line inspection of process pipelines using the in-line autonomous robotic scanner and flaw locator A2072 IntroScan in various sensing modes.

A-line family of autonomous systems for integrated monitoring of main gas pipelines

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The current level of development of telecommunications technologies and NDT tools allows receiving and processing a large array of diagnostic data from various facilities in real time, including facilities operated in harsh weather conditions on remote areas. Our company offers a broad range of monitoring solutions, including autonomous systems for diagnostics and monitoring of main gas pipelines. The monitoring should be construed as a specially organized systematic monitoring of both the pipeline itself and related utility structures. This monitoring is carried out continuously using a broad range of different types of sensors that record the characteristics of processes occurring in the material of structures and in the surrounding space. The monitoring system performs the following tasks: timely detection of defects in pipelines, their localization and tracking of the development of strain-stress state of pipelines and its monitoring in the areas of maximum stress concentration; monitoring of the efficiency of electrochemical protection of underground pipelines; acquisition and storage of data, the output of operational information to the control room, automation of data analysis and reduction of the role of the human factor in the evaluation of the results of the inspection, generation of an alarm about the upcoming abnormal situation and the need of unscheduled shutdown of pipelines.

Predictive capabilities of the acoustic emission method for localization of potentially hazardous areas of the development of SCC defects

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Digitalization of inspection systems along with the use of artificial intelligence is a modern global trend. In particular, the analysis of inspection results in the multidimensional space of diagnostic features allows identifying hazardous defects that develop during prolonged operation. The problem of detection of stress corrosion cracking defects in main gas pipelines at an early stage of development is of particular interest.

One of the methods that enables to acquire direct information about the stages of development and growth rate of stress corrosion cracking defects is the acoustic emission (AE) method. It is known that the occurrence and growth of SCC defects is directly related to the increased values of local stress fields that occur in gas pipeline sections as a result of the prolonged operation. In particular, this fact determines the high potential for the development of the AE method, primarily from the point of view of assessment of the probability of occurrence of the limit state of the object.

The aim of this work was the practical justification of the use of acoustic emission method for identification of potentially hazardous areas of initiation of SCC in operating pipelines and for development of a technology for automated monitoring of such sections on this basis. The main problem of development of the technology is the creation of a set of diagnostic features based on the results of complex diagnostics of the inspected facility.

The paper presents the main innovative principles of the new testing technology, which include the use of digital filtering systems for processing of AE data, the subsequent procedure for detecting and isolating a useful signal from a defect, the formation of a multidimensional space of defect signatures and the development of a decision support system based on the principles of machine learning. A conclusion the complex technical diagnostics of main gas pipeline section using the AE method provides an additional opportunity to identify with a high degree of probability potentially hazardous zones of stress corrosion cracking initiation long before reaching the limit state of the inspected facility. This method of assessment of the stress strain state using the AE method can be used both for scheduled inspections and for monitoring of the technical condition of gas pipeline sections.

Prevention of the development of processes of corrosion and stress corrosion fracturing of the unified gas supply system pipelines using risk-based magnetic tomography (MTM) examination)

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The problem of mitigation of the consequences of possible accidents caused by the stress corrosion cracking (CRN/SCC) is still very relevant across the world. The prevailing solution in the oil and gas sector is the application of the inline inspection pigs (ILI). However, there are still challenges in both identification and correct assessment of the degree of hazard of SCC defects, which often have insignificant geometric dimensions and develop non-linearly until the failure. It is difficult to resolve this problem for a number of reasons.

The main problem is the inability to accurately account for the level of local stresses in a particular section of the pipeline, especially when it is impossible to carry out inline inspection. Such pipelines include pipelines of gas compressor and oil pumping stations, UGS, chemical and petrochemical plants, as well as a number of field pipelines. The share of the length of such pipelines can reach up to 70 % of the total length of the systems. A technology patented in the Russian Federation, the United States and Canada using the magnetic tomography method (MTM) regulated by the Russian regulation RD 102-008-2002 is designed to solve this problem.

The recent years have shown that the most promising innovative methods for detecting areas of increased mechanical stress are contactless magnetic methods based on the Villari effect, in particular, the MTM.

The prospects for using MTM to prevent such risks are due to a number of advantages, including the following:

1. MTM does not require special preparation of the pipeline, shutdown or changing of the operation mode;
2. the external inspection enables to examine features that are cannot be detected by inline inspection and contact testing;
3. it guarantees a sufficiently high reliability of detection of areas with crack-like defects and stress-strain anomalies (at least 75 %);
4. it demonstrates high performance (up to 7 km or more per day for 1 crew of specialists with portable equipment);
5. it has a wide range of detectable defects in the base and welded metal and ensures high accuracy of assessment of the degree of their hazards taking into account the applied loads;
6. It allows automatic monitoring of the development of crack-like defects in sections of any length and at any time interval with building of an interactive three-dimensional digital model so-called "digital twin" at all stages of the pipeline infrastructure life cycle.

Thus, MTM is a promising tool for identifying SCC risks and improving the reliability of pipelines not subject to in-line inspection. The risk-based maintenance methodology or RBI (Risk Based Inspection) based on MTM in the future will serve as the basis of best available technique (BAT) for prevention of the risks of explosive fracturing of pipelines including extremely critical ones located in the underwater Arctic zones.

Automated quality control of insulation works and post-repair eddy current flaw detection as a means of reducing the risk of accidents due to stress-corrosion cracking

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Accidents due to stress corrosion cracking is one of the most serious problems of the gas transmission companies. Based on statistics, similar defects occur in places of the layer separation of the film type protective coating applied during gas pipelines construction. Associated factors for the occurrence of the under film corrosion: pipe poor surface preparation before protective coating application, presence of highly corrosive environment at the place of layer separation. It is impossible to detect such problems with the help of electrometric inspections, electrochemical protection as the main method of corrosion processes control is also in effective. There are several methods of quality control of protective coatings and the variety of instruments for its implementation. However, the approaches currently used have been developed without considering the features of continuous insulation of gas pipelines long sections, up-to-date insulation materials and technologies for their application, therefore, effective control is not always possible. The authors of the article have created the concept of the quality control automated complex for the insulation works based on existing experience in the development, production and testing of portable flaw detectors. The project provides for the combination of eddy current control of the insulation coating thickness and acoustic impedance method. Upgraded acoustic impedance and eddy current sensors are integrated into quick-change cartridges of the measuring unit. In addition, it is possible to installed by current repair diagnostics sensors for searching defects of general corrosion and stress-corrosion cracking.

Improvement of the efficiency of gas transport system diagnostics through the use of electrical and eddy current testing methods

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The importance of the gas industry in the Russian Federation is undisputable. Since the resource is not distributed everywhere, production enterprises are located in the places where it is localized, and it is the large-scale gas transportation system that makes it accessible and ensures gas delivery to both the households and enterprises in Russia and abroad. This fact confers a great importance upon gas pipelines that are part of the gas transmission system, and brings to the fore the problem of cracking under the combined impact of tensile stress and corrosion of the medium.

Given the length of gas pipelines, searching for and reliable determination of the depth of stress-corrosion cracks is a long and labor-intensive procedure. To save resources of service organizations, we offer equipment manufactured by NPP Mashproject LLC: magnetic eddy current flaw detector VID-345 and electrical crack detector 281M.

These devices demonstrated high quality measurements during testing of samples from the library of VNIIGAZ which allows recommending them as significantly more accurate (crack detector 281M determines the crack depth from 1.5 mm more reliably than eddy current instruments) and allowing for more rapid inspection (sensor VID-345 has a larger contact surface than the majority of similar devices, and also allows monitoring facilities without cleaning them).

Ensuring safe operation of main gas pipelines in conditions of stress-corrosion damage

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The paper deals with the problems of safe operation of main gas pipelines of the unified gas supply system in conditions of stress-corrosion damage.

An important factor in the development of stress-corrosion processes is the level of tensile stresses in pipeline structures and the aggressiveness of soils in the near-tube space that affect the defective structure of pipe steels.

The author suggests using generalizing coefficients that characterize the total impact of the main negative factors (stress-strain state, soil corrosion aggressiveness, and the state of the insulation coating) to ensure the allocation of potentially dangerous sections of the gas pipeline that are most susceptible to stress corrosion.

Cold bent branches and their defects. Problems of detection and assessment

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The designing and construction of the linear parts of main gas pipelines comprises the laying of straight sections and turns made in the form of elastic-plastic bends (hereinafter referred to as EPB) or using bends made usually by cold bending (hereinafter referred to as CBB).

The in-line inspection (hereinafter referred to as ILI) identifies EPB zones that exceed the design values with a ranking according to the degree of hazard. At the same time, such stresses and the degree of their hazard are not evaluated on the cold bent bends.

For example, this year, according to the ILI report 2 pipes with transverse cracks up to 58 % deep were identified on the 59 and 59.3 km of the gas pipeline branch connection to NKPU at the ravine crossing. The detected defects were outside the EPB zone, and therefore, the stress on the sections was not evaluated. Given that the threshold of detection of cracks by ILI equipment is more than 20 % of the wall thickness, there is no probability of early detection of such defects.

In case of high level of bending stresses on the cold bent bends, the rate of crack development increases. Currently, there is a known method for early detection of such defects by analyzing and comparing the data of ILI with design and as-built documentation, in order to determine deviations from the design parameters, defects of construction and other factors where there are conditions for settling (deflection) of the main gas pipeline during operation. The practical experience has shown that this process is time-consuming and not all the information available in the documentation is sufficient to identify these deviations.

It is necessary to include the assessment of the stresses on the cold bent bends and the assessment of the degree of their hazard at the ILI stage.

Automation of the corrosion mapping process

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Problem description: The process of drawing up a corrosion map takes quite a long time. The filling in the fields of the corrosion map with illustrations of the items in the field conditions, soil types and drawing up a single report accounts for the major portion of the work scope.

The project summary: Inspection of the insulation coating of the pipeline using the diagnostic meter "DIAKOR" is performed. The pipe-ground potential, polarization potential, depth and axis of the pipeline, AC voltage gradients in the ground is measured, the wave shapes of the cathodic protection system are studied and the coordinates are determined in the GPS system. The ability to record the measured data in internal flash memory and then transfer it to a computer is the advantage of this device. However, the form and type of transferred measurements are not suitable for creating a visual corrosion map.

To solve this problem and speed up the report preparation process, we suggest developing a program that converts the measured data into the form we need, which will significantly reduce the time for preparing the report.

Our program will store all data from surveys in a single database. The program interface allows obtaining reports for any period in a convenient format displaying them on the screen in a convenient form for analysis. Also, with the help of our solution it will be possible to automate the process of analysis of corrosion maps with further identification of problem areas.

The program will be developed in the C# programming language in conjunction with Access databases.

Results of the study of acoustic-emission parameters of fiberglass pipelines for the development of the inspection methodology

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During 2019 STC EgidA LLC and INTERUNIS-IT LLC with the participation of the NCO Association Rostechexpertiza conducted a number of tests in the sites of Tatneft-Presskomposite LLC for development of a method of AE testing of in-service fiberglass pipelines.

The following results were obtained based on the results of the tests.

The acoustic parameters of fiberglass pipelines were determined: the attenuation coefficient is 2.96 dB/m, the velocity of AE signals is 1304 m/s and the recommended value of the amplitude discrimination threshold is 42 dB.

60-80 % of cases of leakage of fiberglass pipelines are preceded by a strong excess of AE activity level 100 imp./s. In different experiments the duration of such excess ranged from 0 to 300 s depending on the loading rate but also on how close the holding pressure selected in increments of 25 % approached the failure pressure.

Amplitudes exceeding 60–80 dB correspond to the failure of a single fiber with a diameter of 20 microns.

The most informative parameter for assessment of the technical condition of fiberglass pipeline is the AE activity. Therefore, it is recommended to carry out loading without holding. Continuous AE should be considered a signature of a hazard class IV source. If the AE activity exceeds the level of 100 imp/s for 3–5 seconds, it should be considered as a signature of the presence of a class III source and the linear increase in AE activity under a load with activity values ranging from 10 to 100 imp/s should be considered as a source of hazard class II. The presence of signals with an amplitude higher than 60 dB should be considered a signature of the presence of a hazard class I source.

The above results are provided in the author's presentation.

Increase of stability of thermoelectric generators used for cathodic protection of gas pipelines

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Now thermoelectric generators (TEG) made on the basis of intermediate temperature interval thermoelectric materials (TEM) (n-PbTe, p-GeTe) are widely used in systems of cathodic protection (CP) of the main gas pipelines. Characteristic parametres of the TEG for CP are: the temperature of hot and cold contacts T_{hot} = 700- 800 K, T_{cold} = 400 K, working voltage U = 10–12 V, currents to I = 1–1,2 A, power till A = 10–16 W. Thus heating hot contacts of the TEG is carried out at the expense of burning of the gas which is selected from a gas pipeline. However, alloys GeTe at the Curie temperature T_c = 630–700 K undergo polymorphic transformation $\alpha \leftrightarrow \beta$ with change of volume δV ~ 1 % that conducts to destruction of TEG branches at heating and cooling close T_c. The reason of destruction is connected by that transition of the GeTe from fragile destruction to plasticity occurs at $T > T_c > T_T \sim 0{,}8\ T_m \sim 800$ K. T (Here T_m = 998 K is the temperature of fusion GeTe, and T_T is the temperature of Tamman at which superficial diffusion of atoms of a material on borders of crystal grains is activated, thus the material becomes plastic).

In work it is shown that at doping GeTe with some quickly moving impurity (Cu, Ag, La, Y, etc.) in the alloys it is observed a parity $T_T < T_c$, thus the material becomes superplastic and does not collapse at heating and cooling close T_c. Accordingly the resource of work of system CP raises.

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