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Abstracts

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The structure of the digest corresponds to the Program of the conference and includes the following sections: Plenary Session and Sessions (A, B, C, D, E, S).

The order of abstracts corresponds to the order of presentations at the conference.

PLENARY SESSION

New machinery and advanced technologies in trunk gas pipeline transportation

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Development and reconstruction of the gas transportation system of Gazprom PJSC are traditionally based on the achievements of modern technologies and gas transportation technology through trunk gas pipeline.

The report highlights technical and technological features of the new trunk gas pipelines and their basic elements:

- linear part, laid in difficult climatic conditions,
- compressor stations and gas transmission equipment,
- control and dispatching systems,
- energy-saving instruments.

Experience of Gazprom VNIIGAZ LLC in scientific foundation and research and engineering support of gas transportation system development and operation

*D.V. Lyugay, S.V. Nefedov
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For almost 70 years Gazprom VNIIGAZ LLC is a leading research center of Gazprom PJSC and is widely renowned in our country and abroad. The Institute provides scientific and engineering justification and support of the largest unprecedented projects shaping the gas industry of Russia. Research teams of the Institute perform designing for supergiant gas fields in Western Siberia, develop scientific foundations for creation and functioning of the unified gas supply system and underground gas storage network.

VNIIGAZ develops applied fields of fundamental science, new technological and technical solutions, determines scientifically justified technical policy of the industry in the long term.

Unique scientific competences of hydrocarbon transportation, storage and refining, accumulated in the previous years, allowed for significant extension of research range, comprehensive solution of urgent tasks of development, diversification and efficiency improvement through the whole process chain of the industry.

The following areas are still relevant for main pipeline transportation of natural gas:

- construction of highly reliable gas pipelines in arctic, offshore conditions, in areas of seismic, technological and man-caused activity, with underdeveloped infrastructure;
- ensuring working capacity, safety and efficiency of operating facilities subject to active physical and moral wear and tear.

Current trend of development of Russian gas transmission system involves diversification of export gas flows, forming gas production centers at Yamal and Arctic shelf, in the oil and gas bearing areas of the Eastern Siberia and the Far East. Strategic projects of Gazprom PJSC in development of LNG complexes, gas chemical production facilities, helium and complex hydrocarbon transportation and storage urge VNIIGAZ to search for innovative feasible comprehensive process solution, for the purpose of balanced development of UGSS and reliable gas supply to consumers as well.

Theoretical and experimental research and further pilot tests result in creation of design solutions, registers of construction technologies, materials and equipment authorized for use, regulatory documentation.

For all the projects, Gazprom VNIIGAZ LLC performs comprehensive scientific and technical supervision that involved development of Project Specific Technical Specifications (PSTS), technical requirements to pipes, coupling parts, welding and non-destructive testing, corrosion protection, ensures the use of the most efficient compressing and power equipment.

Functional stability and stability of gas supply to consumers are ensured by maintaining required level of reliability and safety of operated GTS facilities. Efficiency of the System of GTS Technical Condition and Integrity Control is

determined by optimized targeted application of modern methods and technologies of technical diagnostics, maintenance and repair.

Efficiency of research in the Institute is confirmed by implementation of the programs of current mains reconstruction and refurbishment, comprehensive overhaul of the linear part of main and utility pipelines of Gazprom PJSC's compressor stations. Introduction of innovative technologies in the newest investment projects of the recent years (Bovanenkovo–Ukhta gas mains system, Power of Siberia gas mains, etc.) has also enabled significant reduction of capital costs of the projects.

Geodynamic safety maintenance at main pipelines

B.V. Budzulyak (Self-regulated organization Association of gas and oil complex builders, A.A. Apostolov (Self-regulated organization Association of gas and oil complex builders), A.S. Lopatin (Gubkin Russian State University of Oil and Gas (NRU))

The paper studies challenging issues of the use of new aviation diagnostic means and organizational actions aimed to enhance operation safety of the linear parts of gas mains in areas of natural and technological hazards. Insufficiency of traditional methods used for monitoring of pipeline condition separately from condition of adjacent soils is demonstrated. A totally new technology for organization of correct geomonitoring of pipe-soil complex, allowing for actual objective evaluation of technical condition of oil pipelines and geodynamic safety assurance at potentially hazardous sites is offered.

Fundamental regularities of industry-related safety in justification of future gas transportation systems

N.A. Makhutov (Chairman of Working group for the analysis of risks and security issues under the RAS President)

Within the fundamental research program, the Russian Academy of Sciences has been developing theories of catastrophes, safety and risks for three decades already. These studies are focused on research of regularities, scenarios, criteria of industry-related safety in terms of physics, chemistry, emergency origins and progress mechanics. Russian Academy of Sciences and Gazprom PJSC have always been collaborating in the sphere of applied research, methodological and regulatory base using the results of fundamental academic studies. This collaboration is running more actively in the recent years. The Institute of Mechanical Engineering and Gazprom VNIIGAZ LLC have chosen formation of defining expression system and expression parameters for quantitative determination of man-caused risks viewed as functions of achieving specific limit conditions, and damage corresponding to those conditions, as a main subject of joint research and applied development. Justification of transition of operating and future gas transport systems from standard routine situations into damage, accident and catastrophic conditions requires substantial progress of specialized research in the field of non-linear stress-strain conditions, non-linear destruction mechanics. In addition to traditional strength, resource and fail-safety reserves of bearing elements in gas transportation system, analysis and regulations of industrial safety should include risk reserves, driving creation and operation of gas transportation systems into the acceptable risk area. To meet that provision, a whole set of compensatory actions should be developed with design economic costs directly related to actual and acceptable risks.

The report provides data on theoretical and applied bases of analysis, regulation, standardization, expert examination and supervision of industrial safety at gas transportation system facilities with the help of risk criteria.

Innovative technologies and production for use at Gazprom PJSC facilities

*S. V. Shtepa
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1. Monolayer anti-corrosion coating: advantages of application.
2. New technologies and materials for pipeline protection: UKM covering material.
3. Extended service life of surface pipelines: Litomet electric insulation cradle.
4. Cost optimization for pipeline construction: Balit lining system.
5. Gazprom PJSC contribution to the Year of Environment in Russia.

Prospects for development of Gazprom PJSC GTS CCTCI

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S.V. Nefedov, S.I. Dolgov, V.S. Safonov (Gazprom VNIIGAZ LLC)*

Gazprom PJSC has been dealing with issues of the Comprehensive Control over Technical Condition and Integrity (CCTCI) of the Gas Transport System (GTS) for a long time. By the moment, a methodology tool allowing to forecast and provide integrity of the linear portion of trunk gas pipelines (TGP) is implemented on practice. A methodology tool and algorithms to forecast and provide integrity of GTS site facilities such as compression and gas distribution stations have already been developed and are in the implementation stage.

GTS CCTCI concept takes into account system risks for problem-solving in system integrity estimation. The main mechanism to account for system risks assumes ranking of individual GTS subsystems, corridors, trunk gas pipelines, pipeline portions by the importance. This mechanism is implemented on the basis of accounting for prospect plans of gas transportation, assessment of pipeline portion loads, estimation of required technically feasible productive capacity of the portions and technically feasible throughput capacity of each UGSS element'. This approach proved its feasibility in the development of GTS overhaul plans over the last several years.

Modern conditions of UGSS functioning and development are characterized by correction of the structure of streams due to changes in export areas, shifting of base gas production regions and appearance of new ones. Besides, an active development of the spot segment in European and, possibly, Russian gas market would significantly impact the transport regimes. In total, new influences would result in complication of stream forecasting tasks and appearance of new influences that determine the target level of technical condition.

Preservation of a high efficiency of CCTCI system under such conditions assumes the next stage of development of a new methodology tool that would be less dependent on the credibility of streams forecast and would provide for shaping the target level of GTS technical condition based on probabilistic stream distribution, with regard to expectations of significant short-term fluctuations in gas consumption volumes and alternative solutions for real-time control over streams and gas transport regimes.

Improvement of compressor station design for natural gas pipelines

Zhang Wenwei (Chief engineer of China Petroleum Pipeline Engineering co., Ltd Engineering)

This paper introduced the development process and overall situation of natural gas pipelines and compressor stations which were constructed and managed by Petro China. The researches and related achievements in improving the reliability, economical efficiency and the environmental protection were discussed, including the optimization of compressor station design methods, the localization of compressor sets, the waste-heat utilization of gas turbines, and the enhancement of adaptability of assistant systems as well. Finally, the future research directions were proposed.

TECHNICAL SESSIONS

SESSION «A» TECHNOLOGIES OF MAIN GAS TRANSPORTATION

Reliability and efficiency of gas transportation through Yamal-Europe system

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Unified Gas Supply System (UGSS) is a unique, unprecedented organizational and industrial structure uniting gas production, processing, transportation, storage and distribution facilities in a single engineering and production complex. Gas is transported by a gas mains system included in UGSS of Gazprom PJSC, and by gas pipelines of eastern regions of the country, which operate independently yet. Gas pipeline length exceeds 180 thousands km.

Gas is transported to Nord Stream 1 and Nord Stream 2 export gas pipelines from Yamal Peninsula by 3 thousand km long Yamal–Europe gas mains system starting from Bovanenkovo field at Yamal Peninsula and running over the Russian territory to gas metering stations of Portovaya CS and Slavyanskaya CS. The System includes Bovanenkovo–Ukhta TGPS, section of Ukhta–Gryazovets TGPS, and Gryazovets–Portovaya and Gryazovets–Slavyanskaya sections.

The report considers issues of technology, systemic power efficiency, safety, and other basic parameters of a gas export system.

Systemic reliability of oil product mains

M.Kh. Sultanov
(NII Transneft NTTs LLC)

Reliability analysis includes the following key tasks:

- defining of reliability indicators and parameters range;
- selection of methods and means for reliability data obtainment, and methods of mathematical processing of reliability data;
- quantitative reliability evaluation and result analysis including classification of failures by same-type elements of oil product pipeline facilities and by failure causes, determination of the most significant factors (causes) affecting reliability of a facility reviewed, and time variation dynamics of those factors;
- decision-making regarding reliability of facilities reviewed.

Operation reliability assessment for oil product mains is based on the method of evaluation of actual reliability level in terms of main task performance, i.e. oil product supply to a customer in compliance with contract responsibilities (in specified scope and time period).

An oil product pipeline is viewed as a complicated engineering system with hierarchical structure in terms of reliability, i. e. consisting of single functional subsystems, failure of which can result in full or partial failure of the whole system. In their turn, the subsystems (depending on their purpose) can be divided into single elements (units, devices, aggregates, parts).

Assessment and analysis results for actual reliability of oil product pipelines may serve as an informational basis for technical condition control of oil product pipelines and assurance of guaranteed compliance with contractual responsibilities.

Long-term forecast of reconstruction and overhaul scope for Central gas transportation corridor systems

I.O. Stureyko
(NIIgazekonomika LLC)

Existing practice of planning and actual financing scopes of reconstruction and overhaul for the Central gas transportation corridor systems is discussed.

Comparative analysis of possible long-term forecast approaches and scope calculations by those approaches are presented.

On the basis of the approaches and calculations offered, their effect on long-term UGSS development plans is demonstrated and exemplified by implementation of large-scale projects, such as new construction route selection and abandonment or reconstruction of existing capacities.

LNG production at main pipelines gas distribution stations

*S.V. Lyugay
(Gazprom VNIIGAZ LLC)*

LNG production at gas distribution stations (GDS) is currently performed using differential pressure. The works for adaptation of such systems to GDS operation conditions have been carried out by Lentransgaz, VNIIGAZ and Uraltransgaz since the late 1990s, when the first technological solutions and pilot plants appeared. Currently such a plant is in trial operation at GDS-4 in Ekaterinburg. However, the implementation of even such a simple cycle at real GDSs is challenging particularly taking into consideration seasonal change of gas flow through GDS. Under these conditions, it is impossible to ensure stable production capacity of a plant throughout the whole year.

Currently Gazprom VNIIGAZ LLC has developed the technology of the second generation for LNG production at GDS. According to this technology, LNG production stability is ensured by use of additional auxiliary compressor equipment. In addition to this, specific energy consumption is much lower than existing level and other levels used in this class of LNG production technologies.

Modern technologies in domestic applied software of dispatching complexes

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(Gubkin Russian State University of Oil and Gas (NRU))*

For development of modern software and programming and computing suits included in dispatcher decisions support systems, it is typical to continuously increase the list of solvable tasks, the amount of simulated process systems and improvement of the existing models. Increase of solvable task complexity leads to the necessity to change over to computational models that can effectively use the capabilities of modern multiprocessor and distributed systems. The report covers the complex task of development distributed heterogeneous software calculation package (SCP), which solution is at intersection of some development areas in modern information technologies.

The application of parallelizing technologies enables effective solution of large-scale computational tasks, specific for hydrodynamic systems. In order to create a system capable to solve resource-intensive computational tasks it is advisable to use MPI and CUDA interfaces.

Use of productive and reliable reporting technology is a key factor for successful functioning of distributed service-oriented systems. Use of service-oriented architecture makes it natural to apply thin-client technologies as main approach to portability of application interface, originally developed for a specific system, simultaneously solving the problem of *cross-platform development*.

Use of tools ensuring arrangement of joint work, testing and development process organization in accordance with a chosen methodology enables transfer of software generation and development to a new technological level. Use of virtualization tools makes it possible to speed up software testing process and simplify developed software deployment by means of preliminary preparation of complete operational environment.

Method of calculation examples generation for implementation of dispatch control tasks

*K. Yu. Slobodchikov
(Gazprom Automation OJSC)*

The topic of calculation models generation is not new and is relevant both for dynamic processes and for complex multiparameter calculations, which the tasks conditionally assigned to "dispatcher calculator" group are abounded with.

Calculation example is not only a debugging tool for checking program code but is also a demonstration example which helps the personnel of gas transportation company to validate feasibility of operation program calculations in any software shell such as server system, SCADA system, PLC controller

The best fit to actual physical process is essential for any model. The set of input parameters for calculation of any tasks associated with gas transport can't be taken in arbitrary relation. The examples of calculations available in open sources, as a rule, abound with calculations rounding, using nomograms and application of obsolete methods in calculations.

It brings about the required sequence: generation of calculation example in modeling program based on available method, correlation of calculation results, identifying causes of discrepancy and correction of input data.

In some cases, during analysis of "dispatcher calculator" tasks, iteration resulted in adjustment of the method itself and representation of calculation recommendations.

The following tasks have been analyzed for operation demonstration: "Calculation of gas reserves in a single-strand gas pipeline", "Calculation of stationary non-isothermal gas flow parameters through the pipeline", "Determination of possible/actual hydrate formation points ", "Determination of emissions amount in case of emergency at single-strand gas pipeline".

Therefore, calculation examples have wide application field in simulation environment and their use is demanded at different life cycle stages of establishment production dispatching complexes as well as other automation means performing complex multiparameter calculations.

Procedural approaches to technological capability evaluation for UGSF required to compensate short-term gas consumption fluctuation

S.I. Dolgov
(Gazprom VNIIGAZ LLC)

In traditional opinion, main task of a UGSF is adjustment of seasonal consumption fluctuations and support during winter peak loads on the system. These UGSF tasks are mostly considered in justification of required gas stock volume and maximum daily recovery.

This report offers quite different vision of UGSF role in UGSS operation and relevant approaches to assessment of required daily recovery from an UGSF.

The authors have created a regional UGSS balance model allowing for evaluation of UGSF utilization capacities for compensation of short-term gas consumption fluctuations. Service zones of gas transportation companies were used as regional balance zones.

UGSF reaction for short-term daily gas consumption fluctuations related to temperature changes in different regions was estimated by this model.

By the estimation results, availability of local means of gas consumption fluctuation control was assessed (i. e., matching of UGSF capabilities with potential short-term gas consumption fluctuations). Depending on the availability level of probability control instruments, all zones were divided into three groups: without any UGSFs, deficit group, excess group ($\Delta Q_{osed} \leq 0$; $\Delta Q_{otb}^{max} > \Delta Q_{potr}^{max}$). Factors not considered in the article may include gas stock in the main gas pipelines, participation of production facilities in the processes of compensation of short-term gas consumption fluctuation, and possibility of arranging for dispatch services of gas flow and stock management in an UGSF. Yet despite the assumptions made, the described approach can be used for evaluation of potential UGSS stability to short-term gas consumption fluctuations from the systemic positions, as well as for development of proposals for underground gas storage subsystem and intersystem link design.

Safety justification for hazardous production facilities of mains

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of Moscow Engineering Physics Institute)*

The report covers issues of risk-oriented approach introduced by Rostekhnadzor for industrial safety assurance at HPFs. Procedures of risk analysis are a basis for design solution justification, industrial safety declaration of hazardous production facilities (HPF), development of special-purpose specifications (STU) and safety justification of HPF, fire hazard calculations and preparation of emergency response plans for HPF.

Specific features of safety justification procedure implementation at mains HPFs are considered, including typical mistakes in safety justification development, issues of state expert examination of projects containing safety justification and special-purpose specifications.

Accident rate at mains in Russia and abroad is analyzed.

Risk analysis methods (safety guidelines) approved by Rostekhnadzor are compared to the method of determining design fire hazard values for production facilities (approved by Order No. 404 of Emercom of Russia, July 10, 2009).

Practical cases of accident risk assessment at mains, performed within development of safety justification and special-purpose specifications, are presented.

Key areas of efficiency improvement for risk-oriented support of industrial safety are proposed and include development of:

- 1) Systems of remote collection and analysis of incident and accident rate data;
- 2) Domestic software (databases of incidents and accidents, risk assessment methods, including computation hydrodynamics) developed under import phase-out requirements;
- 3) Methodology of efficiency assessment for safety barriers (organizational and engineering safety measures).

Modern approaches to modeling of non-stationary gas-dynamic processes in gas transport system

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Development of modern computer technology provides the possibility for selection of detail level in modeling of a gas transport system and its components, based on variety of solvable tasks.

The gas dynamic simulator (GDS) developed by Gazprom VNIIGAZ LLC ensuring continuous transfer of telemetry data to SCADA system about natural gas flow in linear sections and compressor stations for functioning of smart training system (IST) for specialists of a dispatch service (DS), is based on solution of a complete system of non-stationary non-linear differential gas dynamics equations in a detailed difference grid.

The level of spatio-temporal details in GDS is chosen based on the need to demonstrate the development of non-stationary processes in real-time mode (at no more than 1-second intervals for the entire GTS of Gazprom Transgaz Ukhta LLC) and with localization in space with a scale of about the main pipe diameter. The simulated processes correspond to spatiotemporal development of unlimited number of both regular and abnormal emergency situations simulated through the entire length of the Company's GTS. When this happens, GDS should adequately response to the commands given by the DS specialist being trained through the interface available in DS for GTS components control (primarily using the capabilities of Transgaz regular SCADA PDS).

Computational models and algorithms provided non-stationary calculations in parallel mode on TESLA graphics accelerator with CUDA technology.

Improvement of corporate regulatory and methodological support in the area of technogeneous risk and industrial safety analysis for gas transportation mains

*S.V. Ovcharov, Yu.V. Gamera, Yu.Yu. Petrova, L.V. Yagupova,
I.N. Alekseyev (Gazprom VNIIGAZ LLC)*

In recent years, Gazprom VNIIGAZ LLC has developed a number of new corporate regulatory documents dedicated to various aspects of industrial safety indicator evaluation and assurance at hazardous production facilities (HPF) of gas and gas condensate transportation mains with account of the recent revisions of federal regulatory basis in the area of industrial safety, including the following standards and recommendations:

- STO Gazprom 2-2.3-1001-2015 “Industrial safety declaration of hazardous production facilities. Organization of industrial safety declaration development and update”;

- R Gazprom 2-2.3-1121-2017 “Industrial safety declaration of hazardous production facilities. Methodological recommendations for industrial safety declaration development for the facilities of gas and gas condensate transportation mains”;

- R Gazprom 2-2.3-1002-2015 “Development and approval of accident containment and response plan for linear sections of main pipelines”;

- R Gazprom 2-2.3-1094-2016 “Development and approval of accident containment and response plan gas distribution stations”;

- R Gazprom 2-2.3-1106-2017 “Regulatory documents for design, construction and operation of Gazprom JSC facilities. Assessment of estimated accident rate at compressor stations of gas mains at the design stage”.

The developed documents include improved methodological approaches, adapted to corporate requirements, to development, execution and expert examination of industrial safety declarations of HPFs of gas and gas condensate mains, to development of accident containment and response action plans at such HPFs with account of their process specifics, new design schemes based on fault trees for assessment of accident rates at the CS designed. The report provides a brief description of the main provisions of those documents.

Assessment of decommissioning possibilities for excessive gas transportation capacities

*I.O. Stureyko, R.Ya. Gryb
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Challenges of unutilized capacity decommissioning are overviewed. It is demonstrated that, unlike the task of development, the problem of decommissioning does not have a clear solution and requires additional restrictions.

Extreme cases are examined, and general results for possibilities of compressor capacity and linear part abandonment depending on the operational load of the gas transportation corridor are shown.

A calculation procedure for capacity required for operation of a gas transportation corridor with declining gas flow is described.

An example of excessive capacity calculation for a Central gas transportation corridor under different scenarios is provided.

Methodological approaches to substantiation of LNG center parameter allocation and evaluation for short-term gas consumption fluctuation control

S.I. Dolgov
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Analysis of daily gas consumption dynamics by RF subjects has shown that deviations from mean monthly volumes of gas consumption, as a rule, are directed opposite and compensate each other with a month. Deviation amplitude can reach 30–40% of gas consumption volume in a subject in proportional terms and up to 10 mln. cubic m/day in absolute values. Upon abrupt simultaneous temperature drops or increases at the territory of several adjoining RF subjects, those deviations can reach 100–110 mln. cubic m/day and more in total for that territory. For daily gas consumption fluctuations, gas balance in the system is maintained mainly by changing stored gas volume in the pipes and gas tapping from UGSFs.

Irregularity of gas consumption varies in a wide range due to differences in the gas consumption structure and diversity in weather conditions in RF subjects. And capacities of territorial UGSS subsystems for regulations of irregularities are also unequal due to different gas transportation volume, availability of underground gas storage facilities and their possible daily volumes of gas recovery and loading. The study offers an approach for assessment of demand in territorial UGSS subsystems for gas consumption fluctuation controls and availability of fluctuation controls. Those assessments are proposed to be used to form an offer for allocation and evaluation of required LNG center parameters intended to control short-term fluctuations of gas consumption.

Enhanced utilization efficiency of gas distribution station reserves within Gazprom PJSC due to justification of feasible throughput capacity and low-cost technical refurbishment

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Currently Gazprom PJSC operates a lot of gas distribution stations (GDS) with gas flow rate reaching design performance of the GRS. At such “filled-up” stations, gas transportation companies have to deny gas supply increase to existing customers and connection to the gas transportation system to new customers according to legislative requirements of industrial safety. It is evidently holding back implementation of regional social and commercial projects and development of domestic gas market. Restrictions on gas supply can be removed only after GDS reconstruction with design performance boosted. Yet reconstruction requires significant investment and is time-consuming.

Methodological approach overviewed in this report offers two solutions to filled-up GDS problem. The first one involves determination of technologically feasible GDS throughput (TFT) on the basis of computer simulation, which is often much higher than rated design performance, and justification of safe operation of the GDS with increased gas flow rate. GDS TFT justification would allow for timely elimination of restrictions of gas supply to customers, while no station refurbishment is required (the method deals only with detection of underutilized throughput reserves and their involvement on gas supplies by taking some organizational and technical actions). The second method involves detection of “bottlenecks” (single elements of equipment and piping) delimiting GDS TFT, and elimination of the bottlenecks by low-cost technical refurbishment.

The study reviews basic stages of the method offered, mathematical GDS models developed, and dedicated software suites. Results of the approach tests exemplified by existing pilot GDS’s are demonstrated. Issues of project support of low-cost technical refurbishment are reviewed. Advantages of the method as a promising investment area of Gazprom PJSC are discussed.

Proposed approach can serve as a way to utilize production facilities of Gazprom PJSC more efficiently and to optimize investment in production facility development.

Digital transformation tools of Gazprom PJSC

*Yu.V. Mikheyev, A.A. Yegorova, Ye.V. Dubova
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Intensifying global sectoral and intersectoral competition defines the need for continuous innovations and improvements in Gazprom PJSC activities in terms of process performance and economic efficiency. One of the most efficient tools for solution of such issues and transformation into the target state is digital technologies.

The report describes some tools of sustainable digital production system design in Gazprom PJSC. A digital production system is designed on the basis of cyber physical production system concept integrating physical and virtual processes and assets and using model-oriented approach through all stages of the life cycle.

Cyber physical systems represent a natural development of integrated production systems (such as Toyota Production System, Brilliant Manufacturing (General Electric), Airbus Production System, etc.). Transition to a smart cyber physical company is impossible without deep re-engineering and optimization of technological and business processes, vertical and horizontal integration, design of a comprehensive production system, process platform of the company.

Elements of sustainable production system were developing and proving their efficiency within pilot projects at a number of gas transportation companies of Gazprom PJSC. The report discusses implementation of digital transformation with involvement of such efficient approaches as lean, agile, QRM, etc.

New quality of the production system is ensured by up-to-date digital transformation tools (PDM/PLM, IoT, Big Data, etc.).

Assurance of operational reliability of offshore pipelines in severe geotechnical conditions of continental shelf

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Promising offshore oil and gas fields are located in regions with underdeveloped infrastructure, low geological exploration maturity and severe natural and climate conditions. Currently, development and implementation of field development projects is considered with several (geological, engineering, and financial) uncertainty levels if a probability of events cannot be determined in advance, or some events cannot be prevented by traditional methods while hazard potential grows in direct proportion to sophistication of the project, thus enhancing hazards and adverse factors of project implementation. It is seen most clearly at early development stages when uncertainty factors are especially high.

Failure to account for such factors as submarine permafrost in transit zone of continental shelf, increase in seawater density due to dredging works, terrain irregularities along a pipeline route, can have serious implications up to an emergency situation caused by loss of containment in an offshore pipeline. Cost of compensation actions (such as buildup of pipeline concrete coating wall thickness, or of overlaying ground over upper generating line of a pipe) is incomparably less than cost of repair and reconstruction works at an offshore pipeline in case of loss of containment.

This report considers issues of operational reliability assurance at offshore pipelines by development of a theoretical apparatus and relevant methodological basis that would allow for assessment of design and operating reliability of offshore pipelines in severe geotechnical conditions of continental shelf.

Gazprom transgaz Ukhta LLC test facility as a base for computational and experimental estimation of innovative solutions and technologies

*I. V. Maksyutin
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In the process of gas transfer systems operation Gazprom transgaz Ukhta LLC make efforts to maintain them in operation condition. One of the guidelines for maintenance of the existing facilities is to assess their technical condition and define the period of their safe operation. In this regard, the issues related to suitability of the existing rejection rates and repair procedures for structural elements of main gas pipelines (MGP) with different defects are of the highest importance.

Change of rejection rates and selection of optimal repair procedure for structural elements of MGP with different defects can be done based on the results of field and laboratory tests performed by Subsidiary Companies in cooperation with Gazprom VNIIGAZ LLC.

Taking the above mentioned into consideration, Gazprom transgaz Ukhta LLC has begun working on establishment of pilot facility to test materials, machinery, technologies and equipment used at main gas lines and their surroundings on the basis of our Company.

The testing facility should combine:

- laboratories (of destructive and non-destructive testing) available in engineering and technical center of the Company;
- testing site to conduct full-scale static and durability tests of MGP structural elements and equipment;
- testing site for tests of MGP sections (with temporary assigned "research" status).

The test facility is considered as a basis for future dedicated research and technology development center of Gazprom transgaz Ukhta LLC for solving scientific and technical problems of Gazprom PJSC. The development of the test facility will facilitate prompt performance of computational and experimental evaluation of structural elements efficiency for MGP with different defects and will contribute to effective integration and replication of new technologies.

Labor safety briefings with 3D model complex visualizing safe work procedures for equipment operation, repair and maintenance at oil and oil product mains' facilities

*A.I. Trifonov
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It is better to prevent some errors than to deal with their consequences. This approach is especially relevant in issues dealing with life and health of employees, and occupational health and labor safety policy should be continuously supported and improved, and briefings should be arranged regularly.

Briefings can be prepared and held in many variants, e. g. in a text or graphic form. Research has proven that graphic information is memorized and reproduced easier than text.

Basic training is performed by reading technical textbooks and corporate regulations, viewing of information posters, coaching sessions, video guides, and observation of a work process in real environment.

To improve information delivery and memorization quality, all training methods should be combined in a single briefing method with possible imitation of actual activities. Therefore, a decision was made to use interactive briefings.

Interactive briefing has been developed to improve briefing quality by demonstration of conditions, prohibitions and other safety requirements with the help of advanced technologies, focusing on interaction with other process participants, availability of training material, higher information content of briefing.

Understanding of the way employees comprehend the information presented (both text and graphics) allows for improvement of briefing efficiency. Studies of work experience of a qualified employee, introduction of 3D visualization and interactive components into a training program would ensure deeper involvement in the training process, which would enhance efficiency of personnel health and life safety during work operations.

Comparative economic parameters for technologies of natural gas transportation in compressed, liquefied and hydrated forms

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Hydrocarbon market at the background of economic boost on a both global and regional scale can grow only by continuous creation of new gas technologies and equipment expanding versatility of gas market tools, including technologies of gas delivery to the markets. One of urgent issues for Gazprom PJSC is improvement of existing gas transportation technologies and creation of new competitive technologies for natural gas delivery to customers and storage in different states.

Variants of LNG, CNG and HNG technologies application in specific gas transportation projects are evaluated by engineering and economic feasibility, reasonability and practicability of engineering solutions for natural gas transportation and storage. It is reasonable to compare economical parameters of LNG, CNG and HNG transportation technologies used in different projects in order to understand development prospects for each technology, their applicability for solution of gas transportation tasks. Analysis of potential competitiveness of the technologies in question can be performed on the basis of project profitability calculations, determined largely by the natural gas price in the delivery region.

Analysis of contents and technical parameters of equipment and vehicles required to implement LNG, CNG and HNG transportation technologies within a gas transportation project was used as a basis for development of an economic model for the technologies. Economic efficiency of natural gas transportation technologies was assessed. Areas of efficient application for LNG, CNG and HNG technologies were defined as a function of natural gas volume and transportation distance on the basis of economic profitability assessment of projects.

Innovative engineering projects of BT SVAP LLC

*A.P. Svechkopalov
(BT SVAP LLC)*

BT SVAP engineering center has developed step-ahead modifications and hybrid designs of pipes with protective and weight coatings ZUB which extend the scope of application:

- Pipes with protective composite and concrete weight coatings with pre-installed systems and elements of electrochemical protection – with bracelet protectors and cable cathode terminals;

- Pipes with protective composite and concrete weight coatings with pre-installed systems for monitoring of design position, stress and strain state, corrosion state, and emergency alarm;

- Pipes with protective composite and concrete weight coatings with pre-installed cable conduits for laying of fiber-optical communication lines;

- Thermal-insulating pipes with protective composite and concrete weight coatings with skin-effect system for above-ground pipeline laying in earthen berms;

- Thermal-insulating pipes with protective composite and concrete weight coatings for the laying in multiyear frozen ground, underwater crossings constructed by the trench and trenchless methods;

- Strengthened pipe designs with concrete coatings for use as compensating actions in areas of excessive approach.

SVAP Engineering LLC in close cooperation with specialists of design companies is developing engineering solutions based on the analysis of the project conditions, feasibility study of alternative technical solutions, and systematic work with experts of Gazprom VNIIGAZ LLC.

Calculation complex for technological risk indicators of linear section of gas mains

*Yu.Yu. Petrova, Yu.V. Gamera, L.V. Yagupova, S.V. Ovcharov,
S.V. Nefedov (Gazprom VNIIGAZ LLC)*

Risk-oriented approach introduced by Rostekhnadzor for regulation of industrial safety of hazardous production facilities, and quantitative risk analysis used within operation of progressing automated decision-making support systems make calculation of technological risk indicators at gas mains (TGP) of Gazprom PJSC most relevant.

In Gazprom VNIIGAZ LLC, a complex of computing software and methodological approaches is developed and used actively for calculation of key technological risk indicators at TGP sections (anticipated accident rate, anticipated direct damage of a single accident, total technological risk). Its functions include data preparation for risk calculation (including spatial data on TGP environment objects), calculation of operational risk indicators, TGP site ranging by risk indicator level, and visual representation of results. The complex was assembled within creation of a Technical State and Integrity Control System, adopted for operation in compliance with its methodology, and tested at actual facilities.

The complex provides territorial distribution of potential, individual, collective, social risks and calculations of estimated rates of accidents involving at least one death for TGP sites. These indicators are fundamental for the risk-oriented approach of Rostekhnadzor.

Functions of the complex can be used for quantitative risk analysis at TGP sites, including development of industrial safety declaration or special-purpose specifications, or action plans for accident containment and response and specific documents of risk analysis, as well as within implementation and testing of promising data and control systems, such as technical condition control systems, remote control systems of industrial safety, risk management systems, etc.

Occupational risk management at Gazprom PJSC facilities with high noise levels

A.L. Terekhov
(Gazprom VNIIGAZ LLC)

The report overviews labor conditions at gas transportation facilities of Gazprom PJSC in terms of noise. Information on negative effect of noise on employees, occupational risk level, and risk management actions is provided. A development algorithm for actions reducing process equipment noise level and for anticipation of implementation results is included. Cases of implementing such actions and gas transportation enterprises are described.

This report concludes long history of Gazprom VNIIGAZ LLC operations in the sphere of noise protection under methodological guidance and with participation of and funding from Gazprom Gas Operations Safety Ltd., Directorate 307/10.

Model of industrial safety monitoring based on risk-oriented approach for a linear section of gas mains

*Yu.V. Gamera, Yu.Yu. Petrova
(Gazprom VNIIGAZ LLC)*

An important aspect of gas transportation system (GTS) operation is an accident hazard at hazardous production facilities (HPF). According to a risk-oriented approach approved by Rostekhnadzor, accident hazard grade of a single GTS HPF is defined by main and auxiliary accident hazard indicators determined by a quantitative or qualitative analysis. Quantitative Risk Analysis is the most complete and hence most labor-consuming method.

Quantitative Risk Analysis is performed at the operation stage of a HPF during development of an Industrial Safety Declaration (ISD). Yet the existing procedure of ISD development does not allow for prompt estimate of accident hazard grade at a HPF despite regularity of the procedure. In this study, the following approach is suggested for its monitoring at gas mains sections. The state described in the latest valid ISD is considered as the basic state. Deviation from the basic state is determined by relative changes in potential and individual risks due to failure to keep minimum allowable clearances, pipe aging, activation of hazardous natural processes and operating pressure fluctuation. As per results of analytical calculations, a trend in changes of both potential and individual risks can be represented as a three-level indicator (traffic light scheme). Variations in accident hazard grade of the site may be estimated prudently by the maximum indication.

This model of accident hazard grade monitoring can be used as an element of remote industrial safety monitoring system for a linear section of a gas main.

Development of efficient pressure pulsation dampers for gas pressure reduction lines

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Delivery of natural gas to the consumers requires gas pressure reduction performed at the gas distribution stations (GDS). GDS operations involve intensive gas dynamics and mechanical vibrations spreading through the working medium and the structure, and noise emitted into environment through structure body elements. Main sources of vibration and noise are gas pressure regulators reducing pressure from 5–7 MPa in the mains to 0.5–1 MPa in consumer pipeline networks. Monitoring of a number of GRS of Gazprom transgaz Samara LLC showed that noise level in pressure reduction premises, as well as at the internal adjoining territory at some stations, comprised 105–120 dB(A), exceeding established sanitary standards of SanPiN 2.2.4.3359-16 by 25–40 dB(A).

The authors have developed a calculation and test method and heavy-duty pressure pulsation dampers (PPD) based on it and installed at the outlet of pressure regulators. PPD is significantly reducing dynamic gas pressure pulsation excited by a high-speed jet. PPD installation does not cause decrease in GDS distribution capacity or regulator operability, and does not require major build-up of the pressure reduction line.

The report describes a test PPD ensuring sound pressure reduction over 30 dB(A) with mass flow rate of 2.2 kgps, input pressure 4.5 MPa and output pressure of 0.6 MPa, ensuring compliance with the sanitary rules of SanPiN 2.2.4.3359-16. In this parameter, the PPD developed is on par with the best similar products in the world (Tartarini, Samson, Hannywell, Mesoneilan, etc.).

An invention patent No. 2622679 is obtained for the developed PPD. Test operation of the PPD has been run for more than 3 years already. Currently, PPD introduction activities are being performed.

SESSION «B» DESIGN, CONSTRUCTION AND OPERATION OF COMPRESSOR STATIONS

Assurance of operability of existing gas compressor pool of Gazprom PJSC

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Specific features of contemporary environment of UGSS development:

- Shift of production centers to Yamal and offshore shelf;
- Creation of gas supply system of Eastern Siberia and the Far East;
- Diversification of export gas flows;
- Depletion of Nadym-Pur-Taz Region sources;
- Intense ambient stresses (environment protection and industrial safety);
- Independent gas suppliers;
- Competition of LNG and gas-to-chemicals;
- Sectoral Sanctions and dependence on imports.

In such circumstances, operability of compressor pool is maintained on the basis of various interconnected areas of activities:

- Process and technical condition of CS;
- Reliability;
- Maintenance and repair (including diagnostics);
- Import phase-out;
- Upgrade, reconstruction, conservation;
- Industrial safety and hazards;
- Environment protection and energy efficiency;
- Innovative activities.

The report overviews the state and perspectives of technical and process aspect development in the areas listed.

Energy efficiency solutions; case of Volga GPU-16

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Currently, over 1000 GPUs are operated at oil and gas facilities of the Russian Federation. One of the major tasks for the manufacturers is enhancement of GPU energy efficiency. Energy efficiency can be boosted by using an ejection effect and recirculation cycle in turbo unit heating and ventilation system. Energy efficiency and independence can also be increased by using a utility generator within the GPU.

The paper describes methods of GPU energy efficiency improvement:

- 1) Schematic diagram and operation algorithm of heating and ventilation system with recirculation cycle and ejection scroll for engine unit are shown;
- 2) A variant of utility generator plant and GPU power supply scheme with switching to power supply via an inverter within the GPU are offered.

Compressor equipment of NPO Iskra – advanced developments

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In the last 20 years, NPO Iskra has supplied over 500 gas pumping units for the oil and gas system of Russia. Most of Ural series GPUs feature centrifugal compressors of the company's own manufacture.

With account of gas market dynamics, great attention is paid to reliability, energy efficiency and cost efficiency parameters during development of new equipment.

For that purpose, parameters of operating equipment produced earlier are monitored continuously.

Based on the experience of compressors optimization and research works, the enterprise continuously conducts new developments to ensure advanced efficiency, quality and reliability of its products.

All newly-developed equipment involves application of advanced science-intensive technologies allowing for reduction of production costs, costs of equipment maintenance, and for increase in the efficiency of gas transportation.

Currently, new dimension ranges of compressors are developed, support and packing units are being developed, parts and units using additive technologies and composite materials are tested.

For linear compressors the polytropic operational efficiency is increased by 2...3% as compared to their analogues previously produced by NPO Iskra, while the cost-effective operation zone is increased by 10...30%. Moreover, dynamic stability of the rotor is ensured.

Dynamic strength and resource indicators of CCM in operation conditions

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In centrifugal compressor machines (CCM) with synchronous drives, intensive resonance torsion oscillation is observed during launch. It is caused by coincidence of natural frequency of torsion oscillation in a shaft train and frequency of alternate torque in the drive rotor during launch. Alternate torque frequency equals double slip frequency, i. e. it varies from 100 to 0 Hz during launch. In some cases, shafts were breaking, and bushings were displaced in machine joint parts.

Analysis of attenuation by the results of torsion oscillation strain-gauging in natural machines showed that dynamic factor λ of 2.8...3.0 can be used. Maximum torsion stress level in shafts is assessed by rated torque of the drive, stress concentration factor in a fillet, and dynamic factor of the launch mode. To estimate allowable number of machine launches, low-cycle fatigue limit of shafts is calculated, or results of torsion fatigue tests of shafts are used. Many CCMs feature drive gear multipliers. In terms of gear cog strength, dynamic loads caused by cyclic engagement wear that may evolve in the course of long-term operation is one of the most dangerous. Design and experimental frequencies of cyclical wear of multipliers in a number of operated machines are presented. Vibration level at the specified frequencies is strongly connected with gear cog wear amount. Cyclic wear frequency is determined for evaluation of remaining life of gears. Vibration levels at the cyclic wear frequency are determined by actual spectra for each operation stage, and dynamic factors are estimated. Remaining life is determined by stresses exerted in different operation periods using a linear damage addition principle. Proposed approaches allow for quite objective assessment of operational reliability of CCMs on the basis of test data.

Selection of centrifugal compressor parameters for future GPUs and an example of compressor project

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Within contractual responsibilities to Iskra-Avigaz United Gas Industry Technologies CJSC, the laboratory of Turbine Aggregate Gas Dynamics of SPbPU has developed a procedure and software for design of future compressors with high-flow stages. Developed programs are used for gas dynamic design of future ЦК-25/101-1,44 compressor for a linear GPU pipeline with 9.91 MPa pressure. Technical assignment for gas dynamics project was issued in compliance with initial requirements provided (Giprospetsgaz).

Analysis shows that optimum ratios are not available with two compressor stages in conditions of high injection pressure and current GTE speed rates. The task is solved by changing to three-stage design. In it, axial/radial impellers should be used in all compressor stages.

Primary design was made with computer software: variants with different rotor rpm, number of stages and theoretical head coefficients of impellers were compared, and flow part dimensions were determined. Further on, impeller blades were profiled in non-viscous quasi-3D calculation software, flow part dimensions and shape were adjusted with account of CFD calculations as well. In the end, gas dynamic properties were calculated, and flow parameters in the flow part were determined.

Compressor body features tangential outlet pipe and radial inlet pipe. Up to 4 impellers with compression degree up to 1.8 can be used. The design allows for both oil and magnetic bearings.

25 MW compressor project with final pressure of 9.91 MPa promises high performance characteristics and can serve as a basis for a new compressor family.

Laboratory of gas dynamics in turbo-machines – development of scholar tradition of turbo compressor engineering in LPI-SPbPU, results of collaboration with compressor manufacturers

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Research laboratory Gas Dynamics of Turbo-Machines was founded in September 2013. The whole team of Yu. Galerkin from Department of Compressor, Vacuum and Cooling Equipment and research team of positive displacement compressors of Prof. Khrustalev were assigned to the laboratory. Currently the laboratory staff includes 13 researchers with higher technical education, including three professors – Doctors, and four Candidates of Engineering Sciences.

Activity areas of the Laboratory:

- Research of gas dynamic processes in the flow section of turbo-machines by computational gas dynamics methods;
- Development of gas dynamic design methods;
- Implementation of gas dynamic design in software suites for optimum design of flow parts and calculation of gas dynamic characteristics (engineering methods);
- Investigative studies of promising power machines by assignments of power machine consumer and manufacturer companies;
- Research and development works on positive displacement compressors, similar to the ones listed above;
- Education of research staff through research degrees and doctorates;
- Research and administrative work in the Association of Compressor and Pneumatic Engineers.

Within a project under the Resolution No. 218 of the Government, a new version of Multipurpose Simulation Method software was developed, which was used in design of three-stage compressor for a 25 MW linear GPU with 101 atm. final pressure and projects of model stages based on axial/radial spatial impellers. Twenty simulation stages are currently at the phase of manufacturing and preparation for tests.

Development of mathematical models for calculation and design of centrifugal compressors by multipurpose simulation method

*A.A. Drozdov, Yu.B. Galerkin
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Fast and reliable design of centrifugal compressors requires up-to-date and tested techniques. One of successful and reputable procedures is a Multipurpose Simulation Method developed in St. Petersburg Polytechnic University. Over 50 compressor types with a total power exceeding 5 mln kW has been developed by that method. Mathematical models at the bottom of the Multipurpose Simulation Method are developing and improving along with data and experience accumulation and upon the need to account for various factors.

Analysis of results on non-viscous quasi-3D and CFD calculations with calculations by a mathematical model allowed for development and implementation of a new flow restructuring scheme at the inlet of impeller blade system, accounting for gas movement character in more detail.

With further development, mathematical models include gas dynamic functions for determination of flow parameters in control sections of flow part of a centrifugal compressor. Instead of multiple iterations in equation system solution for calculation of gas density in control sections by enumeration, a continuity equation is solved. It increases calculation rate and prevents potential convergence problems in iteration processes.

Flow parameters in axial/radial impellers are calculated in 5 axial symmetry planes. It simplified head loss calculation greatly and provides extra information on the flow.

Development of mathematical models maintains relevance and efficiency of the Multipurpose Simulation Method for calculation and design of centrifugal compressors and compressor stages.

Unified parametrical diagnostics technology for GPUs

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Technical condition identification and monitoring tasks for gas pumping units (GPUs) by capacity and power efficiency are implemented within various operational procedures (diagnostics, information and analysis control systems, maintenance & repair, quality and technical level evaluation, etc.), thus stimulating the need for development of unified technical condition criteria and parameters for GPUs, available to all participants of the processes listed above.

Criteria of parameter and indicator stability for gas turbine units (GTUs) and centrifugal gas compressors are represented by the technical condition factors (TCF) or values of actual rated reduced capacity and performance (which are basically interchangeable).

Up-to-date equipment of automation systems, together with equipment “degradation” nature and level, allow for monitoring of GTU and centrifugal compressor parameters with a certain accuracy.

A unified system of efficiency and technical condition parameters, methods and calculation algorithms ensures unified, comparable results in different areas of GPU operation support (tests, diagnostics, design and control calculations, etc.).

Analysis of operating and transitional modes in design of high pressure gas compressor station

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The object of the research is a gas compressor station (GCS) maintaining reservoir pressure. GCS includes three compressor units (CUs) connected in parallel, each consisting of a gas-pumping unit with centrifugal compressor (CC) consisting of low (LPS) and high (HPS) pressure sections; air coolers (AC) and separators. Recirculation lines for each section feature blow-off valves (“cold” bypass); in addition, a “hot” bypass is provided for with gas offtake to AC.

Problematic points arising during development of technical and process solutions in GCS design have been considered. Namely, operational parameter limits for joint operation of sections with account of restrictions imposed were determined; auxiliary process equipment and CU configuration with account of meeting the requirements of existing regulatory and technical documentation, analysis of starting and transition processes and emergencies was selected.

Calculation has defined limit off-design operating modes of CC where LPS works at the maximum end pressure possible while HPS works in the bypass mode. Processes with the “cold” blow-off valve and with “hot” bypass valve have been overviewed. Solution of this task provided proof of design pressure PN80 selection for pipelines and equipment instead of formally believed PN100.

Process of an emergency CC shutdown without gas drain was simulated. Solution of a non-stationary task is a value of equilibrium pressure in LPS and HPS circuits, as well as in the general CU circuit and time of pressure balancing. Dynamic characteristics of blow-off and shutoff valves, inertia characteristics of shaft train were taken into account.

Results obtained are used for assessment of probability of surges and return promotion of a rotor, determination of reliability of dynamic gas seal system operation. If necessary, layout solutions of CU are changed: additional valves of “hot” or “cold” bypass, change of an installation site of check valves, changes in volumes of section circuit connections.

Cost reduction for GPUs based on unified design solutions

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1. Analysis of designs of gas pumping units used;
2. Criteria of GPU design project evaluation;
3. New materials and designs for newly developed GPUs;
4. Reduction of installation work period due to the use of prefabricated units;
5. Optimization of transportation costs due to the use of standard sizes of structures;
6. Application of up-to-date data exchange systems and electronic forms of scheduled maintenance works;
7. Adjustment of new structures based on pilot gas pumping units.

Enhancement of GPU operation reliability and efficiency using equipment life cycle control tools

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Cost of gas pumping unit (GPU) life cycle affects efficiency of gas transportation directly and is a constituent of gas transportation costs. GPU life cycle cost control provides for cost reduction for GPU operation participants through all the life cycle stages.

Generally, GPU life cycle cost reduction requires implementation of the following action plan:

- analysis of GPU operation cost;
- development of an automated information system collecting and analyzing GPU operation data, that would allow for organization of interfaces between GPU operation participants for implementation of new optimum methods and tools of maintenance and repair;
- GPU operation cost optimization on the basis of cooperation with the operation project participants, with definition of operator's requirements to GPU life cycle cost.

At the first stage, cost reduction is planned in relation to development of Gazprom PJSC relations with the suppliers, aimed to reduce operation costs and improve GPU operation reliability on the basis of unified information environment, with a pilot project implemented at Gazprom transgaz Samara LLC.

Increased equipment reliability at Bovanenkovo OGCF due to improvement of maintenance and repair system by using PBL contract concept

*Ye. V. Vasilyev
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According to the Energy Strategy of the Russian Federation up to 2035, Bovanenkovo OGCF is listed among facilities providing production potential build-up of gas industry production potential. Bovanenkovo OGCF is a system with complex structure and functional links, requiring high reliability level.

Reliable operation depends mainly on efficiency and resource of maintenance and repair system. Efficient maintenance and repair system should ensure equipment reliability through its whole operation life at minimum costs.

Existing maintenance and repair system has proved its efficiency, yet the strategic importance of Bovanenkovo OGCF makes it desirable to make it even more reliability-oriented.

The global practice shows that among major steps in that direction are development and implementation of PBL (Performance Based Lifecycle Product Support) concept. This concept is used as a basis for execution of long-term mutually beneficial agreements (PBL contracts) for maintenance with fixed price. Subject of such agreements are standardized parameters of the end maintenance result – mean time between failures, availability factor, technical utilization factor.

In such conditions, a Contractor is directly interested in achieving a maximum possible result. On the one side, a Contractor aspires to ensure continuous equipment availability and minimize down time for scheduled and unscheduled repair. On the other side, a Contractor does everything possible to enhance reliability of material assets and increase time between overhaul. Thus, equipment reliability is increased, and total costs of the Customers are reduced at the same time.

Improvement of operational efficiency for gas turbine gas pumping units

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About 90 % of expenses of fuel and power resources at gas transportation facilities of Gazprom PJSC are attributable to gas turbine unit (GTU) operation support in the scope of gas pumping units. Therefore a key area in implementation of power efficiency improvement program is reduction of specific fuel gas consumption by driven GTUs.

For that purpose, energy-saving actions aimed to improve operation efficiency of main equipment in compressor shops – GTUs and CGCs (centrifugal gas compressors) – are being developed in implemented in affiliate companies. Such studies are performed jointly with research and engineering organizations and educational institutions as well.

The following projects should be noted in terms of improvement of cost and performance efficiency of GTU:

- New removable flow part of axial compressor of one of the most commonly used units, GTK-10-4;
- Search for solutions for prevention of blade damage in axial compressor of GPA-25(DN) unit with converted motor manufactured in Ukraine;
- Development and introduction of a new optimized control program of GTK-25I(R) plant;
- Development of compressor shop operation optimization system with account of technical condition of main equipment;
- Test of water injection system upstream of regenerator, for regenerative GTUs etc.

Increase in performance efficiency of centrifugal gas compressor is equally important. In this connection, the following projects should be mentioned:

- Development of a new removable flow part for CGC of N-370 NZL type for compression grade 1.18;
- Development of CFC for NTs-16/76 centrifugal compressor for compression grade 1.35, etc.

As a whole, such comprehensive approach to implementation of energy-saving actions allows for significant reduction in fuel and energy resource consumption for gas transportation.

Estimation of combined version for configuration of gas air cooling units at line and booster compressor stations

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Increase in efficiency of temperature modes of cooling of gas at linear and booster compressor stations (CS) is connected with operation optimization for respective process sites where structure and features of optimum operation depend on a number of factors including configuration of the equipment.

Currently, general shop and modular configuration of CS and, in particular, gas-pumping unit (GPU) and air cooling unit for gas (gas cooler) are well-known and widely applied. Advantage of modular configuration in comparison with general shop one consists mainly of decrease in gas dynamic losses in pipelines, in improved utilization efficiency of power equipment, reduced cost and time of CS construction, reduced operational expenses. However, this version has also shortcomings which include greatly increased number of required gas cooling devices.

In some cases, for example, if performance of a single GPU is low, combined configuration of air cooling units of gas at a linear CS can be used, where two (and more) GPUs can be united in a single module with a common gas cooler.

Besides, combined configuration can also be used in case of a transition of a booster compressor station (BCS) to two and more compression stages with account of decreasing compression volumes.

Recommended gas cooling temperature in coolers, and other optimization parameters have been determined in accordance with the developed procedure at the stage of energy optimization for a given part of the process area.

The analysis performed shows that for combined configuration can maintain required cooling modes at the number of coolers reduced by 10–25% with small increase in operational expenses.

Energy-efficient equipment manufactured by GAZKHOLODTEKHNICA LLC

Yu.V. Belousov
(GAZKHOLODTEKHNICA LLC)

GAZKHOLODTEKHNICA LLC has been producing equipment for oil and gas industry since 1994. Range of its production is topped by air cooling devices for oil (oil coolers) manufactured both in general industrial and explosion-proof design (TU 3612-004-29464111-2014 and 3612-040-29464111-2014, respectively).

Currently, operation of oil coolers is completely automated and meets most up-to-date operational requirements, such as minimum cost of oil or oil and air mix heating and cooling in operation ambience from +60 to 40 °C, minimized weight and dimensions, reduced electric energy consumption due to application of fans with electronic switching.

Since 2009, GAZKHOLODTEKHNICA LLC manufactures GMT oil/gas heat exchangers (as per TU 3612-060-29464111-2010). These devices allow returning heat to GPU operation cycle and thus enhancing gas turbine engine performance and reducing energy consumption owing to dismissed need for an oil cooler and a fuel gas heater.

Starting from 2013, GAZKHOLODTEKHNICA LLC has started development of an electronically commutated motor for own production in both explosion-proof and general industrial design for use within gas and oil coolers. Replacement of asynchronous motors with electronically commuted ones enables energy consumption reduction for equipment operation up to 40%.

The latest innovation of GAZKHOLODTEKHNICA LLC is a gas/oil unit combining fuel gas preparation, motor and GPU compressor oil cooling, fuel gas heating and commercial metering of fuel gas in a single prefabricated unit. Currently a gas/oil unit with an expander generator aggregate allowing for energy self-sufficiency of GPU is under development.

Technical and process solutions for development of booster complex of Gazprom dobycha Noyabrsk LLC

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Gazprom dobycha Noyabrsk LLC performs gas production and treatment at the fields in different development phases, from continuous production period to operation completion stage.

Most of operating fields go through declining production stage already; for others, this stage is anticipated in the nearest future.

Late operation stages of fields are characterized by inefficient operation modes of treatment and compression equipment under low loads. Upgrade potential of the equipment installed is almost exhausted.

Booster complex should undergo changes of its process scheme and be transformed according to the field development stages. In addition, technical solutions ensuring efficient and complete field development should be provided for at the stage of planning of new booster capacity commissioning.

The report will overview technical and process solutions for booster complex development at Gazprom dobycha Noyabrsk LLC allowing for efficient production of design gas volumes through all stages of the field development.

Booster complex development is considered as a single unit with field and intrafield transportation systems and gas treatment equipment.

Development of TAKAT packaged helical compressor unit used in compression systems of low-productivity wells of Gazprom PJSC

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Within the frame of import phase-out program of Gazprom PJSC in 2016, NIIturbokompressor JSC named after V. B. Shnepp has developed, and Kazankompressormash has supplied TAKAT 78.2-7 M3a XJ11 packaged compressor unit (PCU) based on helical oil-filled compressor for the use in distributed compression technology for oil and gas condensate fields.

The PCU developed is designed to boost pressure of unprepared gas supplied from cluster of gas wells No. 611 (7 wells) in the flow lines of gas collecting system of Yamburg oil and gas condensate field and at other facilities of Gazprom PJSC. The PCU is fully prefabricated and completed, highly mobile, and features optimized weight and dimension parameters, minimized installation and commissioning period, and independent unattended operation mode.

By using TAKAT packaged compressor units manufactured by Kazankompressormash JSC, Gazprom PJSC would be able to opt out of purchase of similar foreign equipment. Use of a PCU would ensure: stable gas production from previously inactive wells; maintenance of positive thermal operation mode in gas collection flow lines; prevention of ice plugs, reduced consumption of methanol in a gas collection system; improved gas recovery in a well with low reservoir pressure; increased well operation time; liquid returns from bottom hole; commissioning of previously inactive wells.

As of September 2017, the PCU has passed factory tests successfully and goes through final stage of installation on site.

Solutions of Tsentrotekh LLC for Gazprom PJSC

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– *Independent power plants* – Fueled by solid oxide fuel elements (e. g. for cathodic protection). A pilot sample has been manufactured and passed tests in Gazprom Transgaz Yekaterinburg. Power: 2 kW. Reliable operation in automatic mode for more than 9,700 hours, with 20 shutdowns and launches.

– *Filters* – Process gas treatment, treatment efficiency up to 99.99999% for particle up to submicronic size. The elements are unified with products of global manufacturers (over 200 designs). For use in various industrial engineering areas.

– *Droplet separators* – No mobile, replacement and consumable parts. Regular drain of liquids to a drain pipeline through condensate pot in manual or automatic mode. Working fluid: natural and other gases inert with respect to the body materials. Working fluid temperature: minus 50 to plus 130 °C.

– *Helical oil-free compressor* – It can be used as a basis for engineering of compressor units for associated petroleum gas and gas mix compression, including aggressive mixes free of oil traces.

– *Helical expanders* – Based on helical oil-free compressor. Compared to conventional turbo expanders and reciprocating expanders: possible operation with higher degrees of gas expansion (2 to 7 instead of 1.8 to 2.7 in a conventional turbo expander); helical expander can be used as a basis for design of electric power sources fueled with secondary energy resources (compressed gas and low-potential heat).

New concept of gas metering station design

*G.A. Derevyagin
(SPA Vympel LLC)*

1. Introduction. Metering unit based on ultrasonic gas flow meters.
2. Vympel-500 ultrasonic metering system DN50 – DN1400 Technical characteristics.
3. The concept involves design of a single-line GMS based on Vympel-500 of large diameter Features and Benefits.
4. Metering unit verification procedure:
 - 4.1. Primary verification with Vympel-80000 test bench;
 - 4.2. Regular verification by a verification unit at the operation site with Vympel-500 comparison reference DN1000.
5. Monitoring unit for physical and chemical gas properties.
6. Results of pilot operation of a single-line GMS.
7. Conclusion. Relevance of implementation of a new GMS concept in Gazprom PJSC.

Practical development and introduction of promising lubricants for Gazprom PJSC

A. V. Kitanin
(Gazpromneft-SM LLC)

1. Currently, Gazpromneft-SM LLC owns six production sites in different countries. Gazpromneft-SM LLC produces a wide range of high-tech lubricants for industrial equipment and motor vehicle operation.

2. In collaboration with Gazprom VNIIGAZ LLC, the Company is developing and introducing new lubricants for gas pumping units and liquids for pipeline shutoff valves.

3. Key tasks to be solved by development of new lubricants is improvement of process equipment operation reliability. An important factor of a new product development is substitution of imported lubricants with domestic lubricants.

4. New products undergo qualification tests in the scope of mandatory bench and laboratory tests. Next step is a pilot production test of the lubricants in process equipment of a customer.

5. In the recent years, Gazpromneft-SM LLC together with Gazprom VNIIGAZ LLC have implemented projects of introduction of the following lubricants:

- МГД-20М motor oil of gas motor compressors. Supervised operation was performed with МК-8М gas motor compressor;
- ТП-22С ГП turbine oil for Ladoga GPU;
- G-Profi PSN 40 motor oil for reciprocal gas motors.

6. Currently, supervised operation of ИПМ-12ГП oil for gas turbine engines is in the completion phase. The tests are performed at АЛ-31СТ engine. This oil will be produced with the help of poly alpha olefin base oils providing high performance properties.

7. Gazpromneft Hydraulic Nord GP fluid for shutoff valves is developed and is currently undergoing qualification tests. This fluid is developed for import product phase-out with a domestic one.

Muffler parameter influence on dynamics and acoustic characteristics of gas pressure regulator

*K.M. Afanasyev, Ye.V. Shakhmatov, A.A. Igolkin, D.M. Stadnik,
V.Ya. Sverbilov (S.P. Korolev Samara National Research Technological
University)*

The main noise source in gas distribution systems is reduction of the natural gas pressure in regulators of the system aggregates. Special mufflers in the form of a set of throttle plates are used for pressure regulator noise reduction. However, installation of such devices may cause malfunction of the unit. That is why there is a need to study characteristics of a regulator with a muffler in order to select the parameters at which the desired pressure reduction is retained and the noise is reduced.

This paper studies a regulator equivalent to a reduction valve similar to a muffler installed in the outlet line. A mathematical model of this system was implemented in the Simulink software in order to analyze muffler impact on static and dynamic characteristics of a pressure relief valve. A program in Matlab software was also developed for determination of the noise generated by the system.

Dependencies between the main system operation parameters and the muffler flow area were obtained by this simulation. Muffler influence on the transient process quality was analyzed. The areas of stability in the regulator and muffler parameter space were calculated. Muffler impact on stability reserve of the system was estimated. The muffler flow area values providing the lowest level of the noise generated by the system were determined.

Experimental research using a pneumatic test bench was carried out for verification of a mathematical model. The theoretical results have good correlation with experimental data.

Occupational hazard assessment at compressor stations in Arctic climate zone

*I.N. Alekseyev, A.L. Terekhov
(Gazprom VNIIGAZ LLC)*

Currently, oil and gas stock has to be replenished from fields located in the northern regions of our country. As a result, the issue of oil and gas transportation in the extreme conditions of the Arctic climate is now relevant and urging. Operations in Arctic Region run in extremely severe climate and geotechnical conditions. They include irregular light conditions of Arctic day and night, different geomagnetic intensity, increased level of non-ionizing cosmic radiation, steep fluctuations of air pressure, reduced partial oxygen pressure in air, polar stress syndrome, etc., leading to increased chance of accidents, injuries and occupational diseases among personnel. Annual total damage of technological accidents and cost of accident response and accident consequence elimination sum up to dozens of billions of rubles in the Russian Federation. Most of those costs are attributed to accidents at hazardous production facilities (HPF). Under such conditions, assessment and management of occupational risks through a systemic analysis of possible causes of occupational diseases and accidents at work, predicting their consequences and taking necessary appropriate technical and organizational decisions are necessary to ensure safety at the workplace. The report reviews main definitions of occupational hazard theory, and a novel concept is proposed for calculation of equivalent occupational hazard, existing methods of qualitative and quantitative risk assessment are overviewed, results of occupational hazard assessment at gas transportation facilities in Arctic and Subarctic environment and recommendations for occupational hazard control with account of specific labor conditions are provided.

SESSION «C» MANAGEMENT OF GTS TECHNICAL CONDITION AND INTEGRITY

Main gaslines: technical condition studies

*V.V. Kharionovskiy
(Aerospace Monitoring and Technologies CJSC)*

Results of technical condition studies at gas mains, and of field and in situ tests in particular, are presented. Current diagnostic methods are overviewed, including inspection methods for challenging sites and analysis of stress-strain condition of potentially hazardous sites identified by diagnostics. It is shown that in situ studies have a key role for gas pipelines constructed in severe environment and climate conditions, and examples of such studies in the Far North and at process pipelines of compressor stations are provided. Experience of field tests was used to develop a concept of field R&D works in the industry with account of site reorganization to an up-to-date level.

A new criterion of operational pipeline strength is offered on the basis of actual properties of pipe metal and loads, allowing for more precise assessment of flawed site diagnostic results compared to the construction standards used. The problem of gas pipeline operability at long terms of operation is studied, on the basis of technical and economical estimates as well. An approach to general gas pipeline reliability assessment is examined, and methodology of its application in Gazprom PJSC is formulated.

Pipeline integrity practice and development of Petrochina oil and gas pipeline

*Feng Wenxing
(PetroChina Pipeline Company)*

Oil and gas pipeline integrity practice in PetroChina pipeline company is introduced in the presentation, including the background, process and main issues of the pipeline integrity development. PetroChina pipeline company carried out pipeline integrity management in the past 10 years, established the management programs and complete technology systems to support the integrity policy and strategy. The safety environmental output is significant and the pipeline leak frequency is much lower than before. A new China national standard about pipeline integrity management based on PetroChina pipeline experiences is written and released. It will contribute to China oil and gas pipeline industry to implement pipeline integrity management and improve sustained safety and environmental performance.

Ensuring safe operation of trunk gas pipelines subject to stress corrosion cracking

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(Gazprom VNIIGAZ LLC), A.B. Arabey, O.N. Melekhin,
O.V. Burutin (Gazprom PJSC)*

In the conditions of increased operating life of the main production facilities in gas transportation organizations of Gazprom PJSC, particularly for trunk gas pipelines (TGP), the need for optimization of overhaul costs is significantly increasing.

One of the reasons of high overhaul cost for continuously operated TGP is the need for cutting-out of pipes with SCC damage regardless of their geometrical dimensions and development stage in compliance with the effective regulatory documentation. Thereat, the share of pipes with SCC damage of insignificant depth may reach 90% of the whole length of the TGP section subject to overhaul.

Considering the fact that at present the current capabilities of diagnostic complexes do not ensure acceptable reliability of revelation of cracks with depth less than 10 % of the rated pipe wall thickness, most SCC defects remain in the gas pipeline after the scheduled inspection and are revealed only during TGP technical diagnostics during repair, which hinders the planning of resources and work execution periods in advance.

The results of the conducted integrated tests and studies of pipe stress-corrosion damage revealed that fatigue development of cracks is not observed when the corrosive medium has no access to the pipe metal surface having SCC damage with depth less than 10% of the pipe wall thickness.

The calculation procedure for strength assessment of pipes with SCC damage allowed for establishing the regions of permissible values and elaborating suggestions for standardization of limit depths of stress-corrosion damage for pipes made of controlled rolling steels with account of shape, orientation, and location in relation to the welded joint and mechanical properties of pipe steel.

Analysis of nature and reasons for defects causing process pipeline depressurization

*Ye. Ye. Zorin, D.A. Neganov
(NII Transneft LLC)*

Development of deep hydrocarbon deposits is characterized by a high formation pressure and temperature, as well as ever-growing corrosive activity of the extracted product. Thereat, in different wells even on one section hydrocarbons' aggressiveness to process pipeline metal may vary in a wide range: from active anodic dissolution, in the presence of high-concentration CO₂, to hydrogen embrittlement.

Transportation of multiphase media via process pipelines under a high pressure and with a high well yield induces the effect of wall corrosion/erosion damage according to the "rill corrosion" type, but with completely different damage morphology.

The use of conventional materials such as 09G2S steel for high-pressure solid-drawn pipes does not allow at present for even short-term reliability (2–3 years of operation) of process pipelines.

The use of corrosion inhibitors for the open loop is expensive and inefficient, which raises the question of ranking of the currently used materials depending on characteristics of extracted hydrocarbons and the need for development of new steels for process pipelines.

Aerospace monitoring of main pipelines

*M.A. Bolsunovskiy
(Sovzond Company)*

Technology of aerospace pipeline monitoring developed by Sovzond Company enables identification of sites of adverse geological engineering factors promoting accidents at mains; assessment of natural and man-caused factor impact on administrative decision-making regarding actions aimed at reduction of their negative impact on the technical condition of mains; reduction of accident hazard.

Aerial shooting from unmanned aerial vehicles (UAV) allows for continuous monitoring of pipeline condition, construction and repair progress, and space survey in high and ultrahigh resolution can be used to monitor dangerous natural events. Automated frame decoding allows for identification of:

- Sites subject to karstic and suffosion processes;
 - Swamped and waterlogged sites;
 - Man-made objects within protective zone and minimum allowable distance zone, including illegal objects;
 - Significant elevation drops as a source of rockslide sites
- etc.

Aerospace methods hold a vast potential for a wide use in pipeline operation. Comprehensive use of aerial shooting from UAV and space survey data for pipeline monitoring provides highly detailed forecasts of accident areas evolving under effect of natural and man-caused factors. In its turn, it would enhance efficiency of gas mains protection and repair planning and actions.

Calculating in-field tie-ins in the trunk gas pipeline

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V.P. Cherniy (Gazprom VNIIGAZ LLC)*

An analytical method for calculation of the wall thickness of in-field tie-ins in trunk gas pipelines is developed. The method is based on the principle of substitution of areas, compensating the trunk pipeline opening area with “additional” areas in longitudinal sections of the trunk pipeline and the branch.

Nonlinear relations for determination of the branch thickness are derived as a function of the coefficient of load carrying capacity of the trunk pipeline and the branch/trunk pipeline diameter ratio. Fulfillment of the strength conditions for tie-ins designed in accordance with the proposed method is verified by the results of numerical stress-strain analysis of the tie-in using the finite element method.

Experience of creation and use of spatial data in the GTS technical state and integrity control system of Gazprom Transgaz Belarus JSC

*S.V. Grib
(Gazprom Transgaz Belarus JSC)*

One of the functioning areas of the GTS technical state and integrity control system is the formation of a spatial geodata base, comprising data both on facilities of the gas transportation system and data on facilities in their vicinity.

GTS facilities can be mapped using different information sources: geodetic positioning, open satellite data, aerial photography from UAV, and design documentation.

The formed geodata base is also used in some other activity areas, in particular, it serves as a data source for the Infotech ISTS, allows for monitoring of protected zones, minimum distance zones; and accelerates the making of managerial decisions.

The paper presents the experience of formation of a spatial geodata base for facilities of trunk gas pipelines and illustrates the results of its use at Gazprom Transgas Belarus JSC.

System for accounting, monitoring and analysis of fulfillment of recommendations and response to remarks found during diagnostics of the facilities of Gazprom Transgaz Nizhny Novgorod JSC

A.V. Saburin

(Engineering Department – Branch of Gazprom Transgaz Nizhny Novgorod LLC)

The project is aimed at creation of a system for monitoring the timely response to remarks and fulfillment of recommendations, found during diagnostic examinations (hereinafter referred to as DE).

The following tasks were solved to fulfill this goal:

1. An algorithm for processing of diagnostic work results was developed;
2. All remarks and recommendations issued according to the results of diagnostic works are accounted;
3. Quality of planning of response to remarks and fulfillment of recommendations was increased;
4. Timely monitoring of response to remarks and fulfillment of recommendations was organized.

Implementation of the listed tasks became possible thanks to the creation of a system in the unified information space. The information system operation results in generation of reports for each process participant, measures with elimination deadlines are assigned to each remark.

The implementation of the set tasks has the following results:

- creation of a database of Company facilities DE in the intranet network with the possibility of information entry and quick processing;
- automated monitoring of timely response to remarks, fulfillment of DE recommendations, search of the best elimination method;
- forming DE plans and checking their fulfillment.

The result of operation of the presented information system due to its implementation in the Company's Intranet network was the exclusion of accident and incident risks, risks of equipment reliability decrease and punitive sanctions of supervision bodies due to failure to respond to remarks and fulfill the recommendations found according to DE results.

Enhancement of indicator calculation precision and program generation accuracy in technical condition and integrity control systems of GTS by integration with CP MCS

*V. Yu. Semikin (Gazprom Avtomatizatsiya PJSC), M.B. Basin,
B.V. Basin (Gazavtomatika Magistralnye Systemy LLC)*

Subsystem of corrosion protection monitoring and control (CP MCS) is developed by Gazavtomatika Magistralnye Systemy LLC and introduced at the branches of gas transportation facilities and in Kasimov and Moscow UGS. CP MCS are intended to monitor technical condition of corrosion protection systems at the linear parts of gas mains and at infrastructure sites, including compressor stations and underground gas storages. CP MCS holds detailed data on actual corrosion flaw progress rate, on the state of protection coating at the linear parts of gas mains, on the demand for corrosion protection means for diagnostic inspections, maintenance and repair.

This information is used in existing and newly introduced information systems in Gazprom PJSC and its affiliates, functionality of which includes generation of medium- and long-term programs of technical condition and integrity monitoring (hereinafter TCIM) at the gas transportation system facilities, yet at the moment integration of CP MCS with such systems is not implemented or designed.

To minimize the risks of interference with functionality of existing information systems and deadline breach in newly introduced ones, it is reasonable to implement and test all decisions of information system integration with CP MCS and changes in functionality with account of new information flows in a test system. TCIM calculation suite applied successfully in 2014–2016 for generation and update of Comprehensive Overhaul Program 2016–2020 for linear part of gas mains of Gazprom PJSC may be used as such test system.

Implementation of the proposed approach would ensure improvement of informational support for TCIM planning processes in Gazprom PJSC.

Prospects of using means for intra-pipe diagnostics of the linear part of trunk gas pipelines based on integration of non-destructive inspection kinds and methods

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V.V. Lopatin (NPTs VTD LLC)*

At present, most intra-pipe flaw detectors, making part of intra-pipe inspection instruments (IPII) intended for monitoring of the linear part of trunk gas pipelines (TGP LP), is based on using the magnetic kind of non-destructive inspection. At the same time, the physical peculiarities of magnetic non-destructive inspection impose certain restrictions on technical improvement of the magnetic system and the system of IPII data recording.

The paper presents the results of domestic developments of intra-pipe flaw detectors, providing the possibility of integrated use of the magnetic and acoustic kinds of non-destructive inspection.

The following is also considered:

- the main requirements of Gazprom PJSC to acoustic and combined means for intra-pipe technical diagnostics (ITD);
- results of full-scale tests of the prototype of the combined complex for IPD of Gazprom PJSC TGP LP;
- prospects for use of combined IPD means on Gazprom PJSC TGP LP.

Intra-pipe technical diagnostics of gas pipelines using remotely operated automated complexes – modern state, tasks and development prospects

*I.L. Vyalykh, A.A. Kaverin, I.V. Nedopad
(Gazprom VNIIGAZ LLC)*

The paper considers the retrospective experience of using automated remotely operated complexes for ITD. The attained level of modern development of the existing equipment for ITD of Gazprom PJSC facilities is shown.

The changes and systematization of Gazprom PJSC technical requirements to diagnostic complexes for ITD of CS process pipelines are outlined. The results of certification and pilot operation of equipment for ITD of CS process pipelines in compliance with Gazprom PJSC requirements are given.

The experience of ITD equipment use at local sections of the linear part of trunk gas pipelines is considered.

The prospective tasks and areas for development of capabilities of ITD diagnostic equipment for increased reliability of pipeline technical state assessment are given.

System for assurance of departmental functional tests in assessment of diagnostic equipment compliance with Gazprom PJSC technical requirements

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(Gazprom VNIIGAZ LLC)*

One of the most important components of the technical diagnostics system for Gazprom PJSC facilities is the structure of departmental tests of diagnostic equipment, carried out in addition to the GOST requirements, for assessment of compliance of the diagnostic tools' main purpose indicators with Gazprom PJSC requirements before their admission to use.

The testing system includes experimental assessments of technical, flaw detection and operating characteristics of diagnostic equipment for compliance with the effective requirements of Gazprom PJSC.

The paper considers the methodical, organizational and technical features of testing of diagnostic tools. The developed unified structure of test phases is presented, which allows for checking the compliance of actually achieved characteristics of diagnostic equipment with technical specifications and requirements of Gazprom PJSC, including the possibility to operate in real conditions, taking into account technological features of monitored facilities. The main technical requirements to testing benches and testing equipment are given. The technical capabilities and structure of the existing testing grounds, necessary for fulfillment of the full package of departmental tests of diagnostic equipment used at Gazprom PJSC facilities, are given.

Innovative robot-aided diagnostic complexes as an element of energy supply security system

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Yu.A. Sedelev (CJSC IntroScan Technology),
I.V. Ryakhovskikh (Gazprom VNIIGAZ LLC)*

One of the methods of energy security assurance is maintenance of a required reliability level for the main assets of the Fuel and Energy Complex. Current trends in integrity control in long-term operation of gas transportation systems assume long-term planning of main gas pipelines (MGP) maintenance and repair activities. Existing approaches to long-term planning of maintenance and repair are based on information on actual technical condition of MGPs, and regular technical diagnostics using in-line inspection equipment is the most informative tool for obtainment of such data.

A significant part of MGPs within the gas transportation system (GTS) of Gazprom PJSC features a complex configuration, its design intrinsically not suitable for a classic in-line diagnostics. Such gas pipelines include pipeline passages over water bodies, connection unit pipelines, tapping gas pipelines, process pipelines of compressor stations, etc. Absence of monitoring of corrosion and stress corrosion damage development at uninspected sections of MGP can affect operation reliability of the whole GTS.

The report describes a method to solve this issue with the help of innovative A2072 IntroScan robot-aided diagnostic complex, experience of its application at Gazprom PJSC facilities, and key development prospects.

Proactive control of technical condition of production assets

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L.I. Grigoryev (Gubkin Russian State University of Oil and Gas (NRU))*

Costs of technical condition and integrity control of production assets take up a significant portion of the production cost and can reach 40 % for funding-intensive enterprises with continuous production cycle. Optimization of costs of production asset operation support is one of the key tasks, and its solution would affect efficiency and competitiveness directly.

One of the ways to increase efficiency of equipment utilization and maintenance and repair optimization is a technology of proactive control of technical condition of production assets, implemented recently in practice in aviation, aerospace, nuclear power industries, military and other fields.

Application experience of the technology proposed shows that significant direct effect is achieved with relatively low costs, and joint application with traditional maintenance and repair methods produces a synergistic effect.

Principles and methodology of early technical condition diagnostics at process facilities

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Development of early diagnostics system is an urgent issue of safety and operation efficiency assurance at sophisticated process facilities. Comparison of monitored parameter measurements with limit values or use of single independent methods of information analysis are not always an efficient solution for accurate information provision for field control.

We propose integration of the following innovative and efficient methods in an early diagnostics system:

- Smart analysis of data with possible utilization of accumulated experience formed during process facility operation;
- Forecasts and detection of trends in monitored parameter changes for early detection of extraordinary situations;
- Data pre-processing (search of connections among data, recovery of missing values, detection of incorrect values, allocation of informative features, etc.).

Integration of the total of efficient methods into a single system would ensure a new qualitative level of solutions for issues of technical condition identification and forecasting at sophisticated process facilities.

Experience of operation of the contingency management system at Gazprom Transgaz Surgut JSC

*M.Yu. Karnaukhov, A.M. Rudenko, S.V. Zhorov
(Gazprom Transgaz Surgut JSC)*

One of the main areas of industrial plant development is the search of new methods for efficiency increase, downtime reduction and productivity increase. The implementation of automatic process complexes at all production process stages allows for attaining the above-mentioned goals in most cases. At the same time, given the multiple increase of controlled parameters and warning signals of process equipment malfunctions, visual monitoring of data reliability and timely response to occurring contingencies becomes impossible. A contingency is any deviation from the normal operation mode of an automated process complex or a process control object. The tasks of revealing and processing of contingencies at an early stage with increased controlled parameters turned out to be one of the most requested ones but, along with that, insufficiently worked-out aspects. Up to now proper attention was not paid to such systems and the necessary resources, which would guarantee the efficient task solving, were not allocated.

The paper presents the experience of Gazprom Transgaz Surgut JSC in synthesis of the system for detection of malfunctions in automated process complexes, process facilities of management and ITIL library. Solutions are suggested for implementation of this approach in the form of a soft- and hardware package "Integrated automated system for monitoring and operability control of process facilities of management," which implements the technologies for contingency revealing, operational management of contingency elimination, as well as analysis of archive information and its inclusion into process of efficient management of process facility operation for support of managerial decision-making. These solutions make it possible to implement the transition to proactive control of process equipment and its maintenance and repair according to technical state.

Mobile geomonitoring of hazardous soil activations on the linear part of trunk gas pipelines

*M.M. Zaderigolova (Altumgeo LLC),
A.S. Lopatin (Gubkin Russian State University of Oil and Gas (NRU))*

The paper presents new author developments of radio-wave mobile-based hardware intended for geotechnical monitoring of the linear part of trunk gas pipelines in areas of natural and technogenic risks and assurance of safe gas transportation.

Development of technical requirements to monitoring systems of trunk gas pipeline based on fiber optic sensors

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Nowadays in the world practice, the monitoring systems based on distributed fiber optic sensors have become widespread for the purposes of monitoring the deformed state of long critical objects, such as bridges, dams, dikes, as well as individual elements of aircrafts and power units.

Depending on the type of a facility, such systems are usually used to control deformed condition, temperature and access control.

The use of such systems at Gazprom PJSC facilities requires implementation of unified approaches to assessment of technical and functional capabilities of various manufacturers systems. "Technical requirements to geotechnical monitoring systems using distributed fiber optic sensors located at gas transportation facilities in zones of active tectonic faults, landslide processes, caverns, permafrost and weak soils" have been developed to ensure a unified technical policy in the field of geotechnical monitoring systems application.

The "Technical requirements..." cover technical capabilities, specific application of GMS water treatment systems, as well as the results of laboratory and bench tests of the system components. Specific features revealed during installation and operation of the systems at Gazprom PJSC facilities are taken into account.

The "Technical requirements..." include the provisions aimed at the system improvement in terms of providing construction and operational serviceability.

Limiting conditions criteria included in the Technical Requirements are stated taking into consideration technical capabilities of the system, as well as targets and objectives of its application.

The structure and the scope of the requirements help to reduce the cost of the system ownership by means of the system components optimization and application of open components and data formats.

Problems of monitoring the stress and strain state of oil and gas pipelines and their solving using the metal magnetic memory method

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Rostekhnadzor Order dated July 28, 2016 No. 316 has entered into force on January 1, 2017; this Order made alterations to Federal Standards and Rules in the industrial safety area “Rules for Expert Review of Industrial Safety”, approved by Rostekhnadzor Order dated November 14, 2013 No. 538 (hereinafter, the “Rules”).

In compliance with the said Rules, during expert review of hardware the need for monitoring (study) of their stress and strain state (SSS) is established.

At present, all the leading diagnostic centers in the world are dealing with the problem of monitoring mechanical stresses in operating structures and pipelines for assessment of their state. However, up to now no efficient methods of stress monitoring, suitable in practice, were suggested.

Problems arising in practice during stress monitoring cannot be solved within the framework of the existing concepts of internal stresses. The ideological basis for development of the topic “Stress monitoring” shall be the energy concept reflecting the objective processes of redistribution of material’s intrinsic energy in response to external impact.

It should be noted that the metal magnetic memory method is a method for diagnostics of material’s energy state.

At present, non-contact magnetometric diagnostics (NMD) is all the more frequently used in practice for assessment of the actual SSS of oil and gas pipelines laid under the ground. NMD is based on measuring distortions of the Earth magnetic field along the oil and gas pipeline route, conditioned by the change in pipe material magnetization in the stress concentration zone and in zones of developing stresses. Pipeline NMD is performed using the magnetic parameters developed in the metal magnetic memory method.

The report presents examples of monitoring of the actual SSS of long sections of oil and gas pipelines. NMD is used in the express monitoring method to determine the most stressed sections, and after opening of such sections, additional monitoring by the metal magnetic memory method and ultrasonic method is performed. The efficiency of such integrated monitoring is shown.

**Split tees by INTRAFIT for hot tapping works.
INTRA Service Company readiness to perform works**

*Yu.S. Kolenova
(INTRA Service Company LLC)*

The paper presents the results of the work on import substitution of equipment for work on non-stop repair (leakage sealing, hot tapping and pressurized pipeline shut-down) and describes the capabilities of the INTRAFIT production complex (part of INTRA Service Company LLC). Until a few years ago the Russian market of this equipment and spare parts depended on foreign suppliers for 90%. Today INTRAFIT produces pipeline parts, equipment and spare parts for hot tapping and pressurized pipeline shutdown and other non-standard products up to DN 1440 mm. It covers the whole range of necessary equipment for 100% and eliminates the dependence on equipment import.

The paper also considers the actions taken by INTRA Service Company for upgrade of production capacities, improvement of the quality management system, as well as confirmation of compliance with the international standard of the American Society of Mechanical Engineers (ASME) and industry standards of PJSC "Gazprom".

SESSION «D» LINE PIPE PRODUCTION, WELDING AND ALLIED TECHNOLOGIES, PROTECTIVE COATING OF PLANT EXTRUSION

Technical requirements to highly-deformable pipes to be operated within active tectonic fault, high seismic activity and permafrost areas

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V.O. Makhanev (Gazprom VNIIGAZ LLC)*

Current stage of main pipeline system development in Russia is connected with projects of construction in regions with weak soils, in areas of high seismic activity, at the sites overlying active tectonic faults. In this connection, a new requirement should be set to the applied pipes in regard of high deformability.

To fulfill this comprehensive requirement, it is needed to ensure: standardization of longitudinal metal properties; smoothness of “strain-deformation” curve; “low” value of yield limit and tensile strength ratio; “high” value of uniform deformation; “small” deviations of cross-section shape; ageing and low-cycle fatigue resistivity.

Together with RosNITI OJSC and within R&D works with Gazprom PJSC, Gazprom VNIIGAZ LLC has developed a draft of Technical Requirements to the pipes of K60, K65 strength class designed for operation in extreme conditions, where a number of criteria defining high deformability of pipes and controlled at the stage of manufacturing is given.

Technical Requirements suggest assessing deformability of pipes by the results of unified lab test of metal specimens and bench tests of full-scale pipe specimens. At the moment, the part of requirements based on lab tests is considered as mandatory. As the results of lab (delivery) tests of production pipe batches, study results, information on operation of pipeline sections get accumulated, it would be possible to implement the requirement for comprehensive evaluation of pipe deformability, including bench tests of full-scale specimens and analysis of their results.

Basic standards of Gazprom PJSC for welding and quality NDT technologies for weld joints of main gas pipelines

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S.P. Sevostyanov, D.A. Kopylov, Yu.A. Solovyev (Gazprom VNIIGAZ
LLC)*

The report describes a development procedure, categories and types of Gazprom PJSC standards, including basic standards defining general organizational and methodological provisions and requirements ensuring mutual understanding, technical uniformity and alignment in the sphere of welding and NDT of weld joint quality at the design, construction and operation stages of Gazprom PJSC facilities. Key requirements to development, review, coordination, approval and cancellation of regulatory documents on welding and weld joint quality control. Main Sections of the primary Gazprom STO “Welding and non-destructive testing of weld joints. Main provisions”, as well as the structure of standardization document body “Welding and non-destructive testing of weld joints”, classification of subgroups in the standardization document body “Welding and non-destructive testing of weld joints” are described. Content and main sections of the primary Gazprom STO “Welding and non-destructive testing of weld joints. Welding technologies for field and main gas pipelines”, STO Gazprom “Welding and non-destructive testing of weld joints. Welding technologies for repair of field and main gas pipelines”, STO Gazprom “Welding and non-destructive testing of weld joints. Non-destructive test methods for weld joint quality in field and main gas pipelines” are studied.

Organization of works for development of Gazprom PJSC technical requirements to split tees used for tie-in and blanking of pressurized pipelines

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Pressurized gas pipelines repair and rebuilding, connection of elbows, jump-over lines, loop lines, reducing pieces to pressurized gas pipelines require the use of hot tapping technology. This technology ensures uninterrupted gas supply to consumers, allows for significant reduction of gas losses and avoiding of environmental problems associated with gas release into atmosphere during repair and construction works.

The special equipment for hot tapping includes split tees through which tie-in and gas pipeline cavity blanking are directly made. After the work is completed, the split tees remain in the gas pipeline and are subsequently serviced by the Owner.

For hot tapping the facilities of Gazprom PJSC use the equipment and split tees made by foreign manufacturers of T.D. Williamson (USA). For example, the workshop producing split tees of this company is located in Belgium and some other foreign countries.

Due to the current economic situation in the country and within the frames of import substitution program, split tees have been included in the list of the most important types of products for import substitution and production localization targeted at technological development of Gazprom PJSC.

Gazprom PJSC has instructed Gazprom VNIIGAZ to organize works for elaboration of Gazprom PJSC technical requirements to split tees and testing prototypes of split tees made in Russia.

Gazprom VNIIGAZ LLC developed a draft technical specification for split tees, a strength calculation method, and a "Program and procedure of split tees full-scale tests" (hereinafter referred to as the Program), according to which, the first trials of Russian split tees jointly produced by ETERNO LLC and Delta Engineering LLC were performed for the purpose of:

- evaluation of split tees serviceability and compatibility with tie-in and blanking equipment manufactured by T.D. Williamson (USA);
- checking tightness and evaluation of structural strength of split tees made in Russia.

The report presents the results of arrangements for development of technical requirements and the results of testing the split tees made in Russia.

Split tees for hot tapping at Eterno LLC

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The report discloses principles of hot tapping of pipelines. Main advantages and disadvantages of the technology are defined.

A history of Eterno LLC is presented: its foundation, process equipment range, production range.

The report describes a history of introduction an import phase-out product, split tees for hot tapping, at Eterno LLC.

Brief description of split tee unit and unit part manufacturing technology is given.

The report provides results for split tee tests performed by Eterno LLC according to the Program and Methodology of acceptance tests of split tees, developed by Gazprom VNIIGAZ LLC.

Eterno LLC is a winner of “Promising Production Development for Gazprom PJSC Facilities 2017” contest with its project of split tee production for hot tapping.

Hybrid laser welding of large-diameter pipes at ChTPZ PJSC

M.A. Fedorov
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The report describes an essence of laser and hybrid laser and electric arc welding technology (hereinafter HLW). Main advantages and disadvantages of the technology are defined. Global level of HLW technology development is shown.

Key advantages for a pipeline assembled out of HLW-welded pipes are listed.

In addition, the report provides main test results for steel plates and tubular products manufactured with the use of HLW:

- Mechanical tests of 21.6 mm thick plates out of steel of K60 strength class (X70);
- Mechanical tests of 23 mm thick plates out of steel of K65 strength class (X80);
- Mechanical and hydraulic tests of Ø 720x21.6 mm pipes out of steel of K60 strength class (X70);
- Mechanical tests of Ø 1420x21.7 mm pipes out of steel of K60 strength class (X70).

The report describes major actions implemented within a roadmap executed between Chelyabinsk Pipe-Rolling Plant PJSC (ChTPZ PJSC) and Gazprom PJSC for development of new generation pipe production with the use of laser welding. Also, operation schedule within the roadmap is described, and intermediate results are summarized.

The report presents parameters of a new generation pipeline out of steel of X100 strength class, welded with the use of laser technologies only.

Laser welding technology for fixed circumferential joints of large diameter pipes

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The report provides information on the development of laser welding technology for non-rotating circumferential butt joints of large diameter pipes and the machine for welding non-rotating circumferential ULST-1 pipe joints.

It has been noted that high requirements to weld joints of main pipelines, as well as growing progress rate of pipelines construction lead to the necessity to develop new welding technologies and welding equipment.

Application of a fiber laser as a source of radiation for pipes welding makes it possible to use the narrowest cutting of edges for welding and obtain the required mechanical properties of a weld joint

Laser welding technology for non-rotating circumferential pipes joints is based on two processes:

- Welding of root run with deep penetration;
- Welding of filling run and facing run with feeding filler wire.

The report includes information on qualification tests of ULST-1 laser welding machine, reference weld joints (test weld joints) of steel spool pieces samples having strength category K60 with outer diameter of 1420 mm and a wall thickness of 25.8 mm.

It provides the results of weld joints tests on the basis of testing center "POLITEHTEST" (St. Petersburg).

Based on the results of automatic laser welding qualification for non-rotating circumferential butt joints of gas pipelines with ULST-1 machine, the technology was included in the register of welding procedures used in construction, reconstruction and repair of Gazprom PJSC facilities.

The report provides the information on the development of self-propelled laser welding machine based on automatic laser welding technology for non-rotating circumferential butt joints of main pipelines using ULST-1.

Laser multi-pass welding of spool pieces samples based on the self-propelled laser welding machine, including ULST-1, was demonstrated at the exhibition "Welding" in St. Petersburg held on the 25–28th of April, 2017.

Thermal impact of laser welding source on microstructure and hardness of weld joint metal

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The study includes research of thermal impact of a laser welding source on microstructure and hardness of weld joint steel for pipes of K60 strength class.

Registration of thermal cycle parameters showed that during laser welding, some sites of heat affected zone (HAZ) in weld joints feature cooling rates at the level of 100–120 °C/s (welding without pre-heating) and 80–90 °C/s (welding with pre-heating; root weld).

According to anisothermal diagrams of austenite decomposition, hardening structures with martensitic phase should be formed in the indicated range of cooling rates.

In the first fill pass, the HAZ metal was heated to complete recrystallization temperatures, and its cooling rate shifted to 40–60 °C/s range. Such regimen allowed for formation of a microstructure consisting mainly of ferrite and carbide mix with different dispersion values, in the full absence of ferrite phase. Low amount of martensite in the joint metal structure has no significant effect on hardness of weld joints, and hardness changes still fall into the values defined in regulatory documents.

Development of new types of pipe products for production fields with higher content of hydrogen sulfide and carbon dioxide in the obtained product

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Gazprom VNIIGAZ experts conducted inspection and control tests for corrosion-resistance of domestic manufacturers' pipe products to control stability of the products quality and possibility to use them in wells of Gazprom PJSC gas/gas condensate and oil fields, which products contain hydrogen sulfide and carbon dioxide.

During the work performance Gazprom VNIIGAZ experts made in-process control, inspection of domestic manufacturers' pipe products mechanical, corrosion and performance properties.

The programs of scientific and technical cooperation with domestic manufacturers developed by Gazprom PJSC, which were the basis for works performance, demonstrated their effectiveness in attracting industrial potential of the leading Russian pipe plants in solving the problems targeted at development of pipe products intended for deployment of Astrakhan MMC, resistant to corrosive environments with increased content of hydrogen sulphide and carbon dioxide.

For the first time, assimilated pipe products made in Russia demonstrated a number of competitive advantages in comparison with their foreign analogues, which allows avoiding dependence on foreign deliveries of pipe products intended for operation in environments with high content of hydrogen sulfide and carbon dioxide.

Production of casing string pipes with welded connectors at ChTPZ PJSC

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Currently, Chelyabinsk Pipe-Rolling Plant PJSC (ChTPZ PJSC) is actively involved in import phase-out of tubular products in the oil and gas industry. Thus, a project of casing string pipes with welded snap-together Lynx SA2 and HDHT connectors for well construction at offshore shelf together with Rosshelf CJSC within an import phase-out program.

Ø508–914 mm casing string pipes with snap-together connectors are widely used by Russian oil and gas companies for well holing and surface casing pipe formation in offshore field development. Currently, the whole scope of such products used in Russia is purchased abroad. In this connection, ChTPZ PJSC together with Rosshelf CJSC (official exclusive supplier of Lynx connectors in the Russian Federation) are mastering production of this pipe type since 2016.

Currently, a welding process for a single-seam Ø508x15.9 mm casing string pipe manufactured by ChTPZ and Lynx SA2 and HDHT connectors is undergoing qualification. These connections have proved to be reliable, do not require special tools and special training in assembly and disassembly for personnel, and are widely used throughout the whole world. A specific feature of the connector welding technology used at ChTPZ is an absence of post-welding thermal treatment of the weld and possibility of full X-ray test of the weld. It should be noted that in September 2017, this welding technology was qualified by Gazprom VNIIGAZ LLC.

Next stage of production qualifications is a bench test of case string pipes in FSUE Krylov State Research Center (St. Petersburg).

In the future, ChTPZ PJSC plans to localize Lynx SA2 and HDHT connectors in Russia and develop production of the most widely used size types of casing string pipes with connectors.

**Specific features of pipe-bending equipment jiggling
and manufacturing process of cold-bent branches to meet
requirements of STO Gazprom 2-4.1-713-2013
and STO Gazprom 2-3.5-1076-2016. Up-to-date devices
for branch bending angle monitoring**

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(Kropotkinsky Machine-building Plant OJSC)*

In STO Gazprom 2-4.1-713-2013 and STO Gazprom 2-3.5-1076-2016, requirements to cold-bent branch quality are increased.

Participation of the plant in Gazprom PJSC programs for bending of highly-deformable pipes with 1420 mm diameter, in Turkish Stream project (bending of 813x39 mm pipes) and other operations enabled the Company to accumulate experience and test new equipment for cold bending of pipes.

To obtain required quality of cold-bent branch ends, a special-purpose process jiggling and changes in bending process are recommended.

The issue of obtainment of chord head describing the minimum acceptable radius of pipe bending is especially relevant for bending of pipes with 1220 and 1420 mm diameter to 5 and 6 degree angles.

To obtain required bending radius of cold-bent branches, a new process jiggling and changes in bending process are recommended.

To improve performance, quality, stability and convenience for pipe-bending machine operator, an advanced device PDI-3 for remote angle measurement is proposed.

In manufacturing of 2nd type branches, edge treatment after extension cutting is performed quickly and properly by edge treatment machines of SPK1023 and SPK1423 models.

Studying twofold and multiple loading of rod samples of pipe steel

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A.S. Chaban, A.Yu. Rakin (Gazprom VNIIGAZ LLC)*

In strength testing of trunk pipelines by internal pressure, the test pressure value is taken equal to 1.1 of the operating value for normal-category sections and 1.25 or 1.5 for higher-category sections. The given values were adopted in domestic practice since the 1960s and reflect the safety factor traditionally established in different technical fields.

The goal of the research is to find the optimal value of the safety factor in strength testing of trunk pipelines with account of pipe material, as well as based on the statistics of breakdown force change at multiple loading of samples. The obtained results will allow for either confirming or revising the existing approach to pressure assignment during strength testing of trunk pipelines and elaborating a theoretical justification of the observed phenomena. In practice, this will allow for establishing the optimal gas pipeline testing parameters ensuring the necessary reliability and safety.

The research is topical given the constant improvement of pipe steels, as well as in the light of development of innovative materials (including composite ones) intended for pipe manufacture.

The analysis of foreign and domestic experimental studies of twofold loading of steel samples until failure shows the possibility of breakdown force reduction at the second loading up to 90% of the first force value. At that, the statistical sample of foreign and domestic experiments is small while the procedure is complex.

In this respect, the specialists of Gazprom VNIIGAZ LLC have elaborated an original procedure used for experiments in twofold loading of steel samples until breakdown and a statistical analysis of the results was performed.

Possibility of using electroslag melting pipes for connecting parts of high-pressure pipelines

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This year, Belgorod Plant of Power Engineering Industry has turned 78 years old. In its history it has accumulated unique production experience in pipeline manufacture.

In 2005 it organized the pipe manufacture which at present fully meets the plant's own demand for large-diameter thick-walled seamless pipes. Seamless pipes are manufactured by two methods: forging with subsequent drilling-out of the core (TU 1310-030-00212179-2007, TU 1317-001-38948552-2015) and by the electroslag melting method (ESM) TU 1301-039-00212179-2010.

The electroslag melting technology is used for over 50 years already for making the stock workpiece, as well as manufacture of pipeline valve semi-housings. The novelty of the process implemented at Belenergomash-BZEM LLC is in the use of this process for making a pipe shell with geometry maximum close to that of the finished pipe.

In 2012, the shop for pipe manufacture by the electroslag melting method with the design capacity of 6 thousand tons of pipe per annum was commissioned. The commissioned production capacities allow for making pipes with a diameter of 245 to 920 mm, wall thickness from 17 to 100 mm and length up to 6,000 mm.

For development of the ESM pipe manufacture technology for TPP and NPP pipelines, our plant has received the 2013 award of the Russian Federation Government for science and technology.

At present, works are being carried out for mastering of the technology of pipe shell manufacture for connecting parts of pipelines for the oil and gas complex (OGC) of steels 09G2S-Sh, 10G2FBYu-Sh, 13KhFA-Sh, 20A-Sh, 20FA-Sh. Satisfactory results have been obtained, an agreement with VNIIGAZ LLC, Samara ITC LLC and Gazprom-Snabzheniye LLC will be signed in the near future for pipe certification.

Implementation of the technology of workpiece manufacture of ESM pipes will allow for reducing the production period of pipeline connecting parts for OGC and will increase product quality level.

Influence of layer-by-layer inhomogeneity of crystallographic texture on arresting of stress-corrosion cracks in steel pipes of trunk gas pipelines

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When considering stress-corrosion cracking processes in TGP pipes one should take it into account that in rolled plates used for pipe manufacture there are factors arresting the movement of cracks propagating from the surface side. The main such factor is the layer-by-layer inhomogeneity of the plate's crystallographic structure. Transgranular cracks propagate in metal only along certain crystallographic planes. That's why, having reached the boundary between the plate layers with different textures, i.e. with different predominant grain orientations, the crack is arrested because it has to change its direction, which requires additional energy or additional stress increase. The texture forms in plates, which are a material for manufacturing of TGP pipes, due to the action of plastic deformation mechanisms during hot rolling. When the plate surface contacts the cold mill rolls, the plate is cooled and a temperature gradient occurs in it, depending on which deformation in the plate's surface and central layers may proceed differently, with involvement of different mechanisms. Depending on whether the temperature of plate hot rolling is higher or lower than the temperature of phase transition $\gamma \rightarrow \alpha$, i. e. the transition of austenite to ferrite, deformation in the plate's central and surface layers may develop in different phases with formation of different types of textures. Typical textures are provided by the processes of dynamic stress aging in the α -phase and dynamical recrystallization, occurring in a certain temperature interval. Moreover, layered rolling texture forms in the ferrite due to the prevailing of grains with two different rolling planes in successive layers. Knowledge of the details of the plate hot rolling process allows for forecasting the pipes' behavior in stress-corrosion cracking conditions, as well as in further operation of previously built TGP with revealed defects.

Quality control of small-diameter pipeline weld joints made by contact flashing welding

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Contact flashing welding (contact welding) is a promising welding method used in construction of gas and oil pipelines.

Until recently, absence of NDT technologies and means ensuring reliable detection of method-specific flaws (discontinuities with completely or partly missing metal connection) hindered wide introduction of this method. Detection of discontinuities with partially missing metal connection, the so called “collapsed spots” poses the greatest challenge.

Together with Ultracraft CJSC, FSAI Scientific Training Center “Welding and Control” at the Bauman Moscow Technical University have found solutions to this issue and developed technologies and instruments of automated US testing of weld joints in large and small diameter pipelines. The technology is based on ultrasonic diffraction amplitude-time (DAT) method implemented on the basis of phased-array antenna technique. Today, the technologies developed and relevant equipment (Avtokon AR(M)-type flaw detecting scanner) are applied successfully at the facilities of Irkutsk Oil Company LLC in construction of production pipelines with 159 to 325 mm diameter and 8 to 30 mm wall thickness, using K-584-M welding aggregate.

Calculation and test evaluation of thermal processes for different methods of main pipeline welding

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Changes of material properties during welding are mainly determined by heating and cooling conditions. In practice, it is important to have a possibility to substitute test evaluation of thermal cycle parameters with a calculation method. Thus, this study is aimed to select and justify calculation schemes for temperature and time parameter determination for high-performance pipe welding methods and construction of main pipelines.

The paper describes the process and results of test studies performed for automatic submerged multi-arc welding of longitudinal pipe joints and for laser welding of pipeline end joints with filler wire.

Analysis of the curves obtained for thermal welding cycle enabled determination of metal cooling rate within temperature interval of austenite diffusion decomposition. At the same time, metal cooling rates in adjoining HAZ areas were assessed for those specific welding processes by calculation.

Comparison of the test and calculation data showed good convergence of the results. At the low cooling rates, namely for automatic submerged multi-arc welding, difference between test and calculation values varies within 5–10%. At higher cooling rates, namely for laser welding with filler wire, the difference is larger and comprises 15–18%.

New methodology of residual welding stress assessment in construction and repair of main pipelines

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Residual welding stress fields appear in the welding areas during welding erection works in construction and repair of main pipelines. Maximum tension stress can reach the regulatory yield stress limits for pipe steel. Currently, such stresses are not considered in calculations of pipeline load-bearing capacity. In case high-strength low-ductility pipe steel grades are used, or under high loading speed, stress is not relieved, which can cause fracturing and structure collapse. Gazprom PJSC regulatory documents regulate application of various actions aimed to reduce residual welding stress level in gas pipelines (e. g. high-temperature tempering). Yet the documents do not include any monitoring of efficiency of such operations.

This study offers a comprehensive methodology of residual welding stress assessment in pipeline weld joints (including repair welding sites) with account of the minimum impact of measurements on the structure. The method is based on laser interferometry and is used for registration of deformations and displacements at the external pipe wall surface by drilling of a small probing hole. This method belongs to mechanical methods of residual welding stress tests in welded structures (“cutting methods”) and thus can be considered more accurate than physical methods based on measurement of any indirect parameters.

Equipment designed on the basis of this technology has passed field tests during practical tests of welding technology for Bovanenkovo–Ukhta gas mains, as well as in development of surface flaw repair technology for gas pipelines of Gazprom transgaz Yugorsk LLC.

Use of press welding methods for different types of corrosion-resistant pipes in construction of field pipelines

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Currently, an issue of corrosion resistance for both the pipes and field weld joints is extremely relevant in construction of field pipelines. To solve this problem, various types of corrosion-resistant pipes are used or planned for use, including: pipes with internal polymer, glass-lined or metal coating; pipes out of corrosion-resistant steel grades.

Challenges of internal protection of field weld joints in coated pipes are well-known. The report states that rotation friction welding or contact flash welding allow for installation of nipping up of austenite stainless steel bushing with application of protection coating layer on crossover joint inside the pipe at the factory. Erection of a pipeline out of such pipes would reduce itself to welding of stainless bushing to each other, such joints not requiring application of protective coating.

Use of stainless steel pipe in pipeline construction has the following features. Austenite steel easily weldable by electric arc methods is costly due to high nickel content. Nickel-free steels (chrome-containing or lightly nickel-doped duplex grades) are known for their restrictions for electric arc welding. The report shows that contact flash welding is a rather simple and efficient solution for pipeline construction out of stainless chrome-containing or duplex steel; besides, this method has much better economic parameters than electric arc fuse welding.

Application of high strain line pipes to fabricate cold bends with a large bending angle

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It has been well known that high-strain line pipes manufactured by JFE Steel Corporation, HIPER, own high strain capacity in compression or bending compared to that of standard line pipes. Therefore a number of HIPER pipes have been delivered to customers all over the world to ensure pipeline integrity in harsh environments like as seismic zones, fault zones, liquefiable zones, unstable slopes, mountainous areas, and cold regions.

The outstanding strain capacity in compression or bending of HIPER has also been utilized to fabricate cold bends with a large bending angle compared to that obtained using standard line pipes. Therefore, in this paper, the excellent workability of the high strain line pipe, HIPER, on fabricating cold bends is described and the cost effectiveness of the cold bends having a large bending angle is discussed. Cold bends with a total bending angle of 12 degrees were fabricated using 24", 12 m long HIPER pipes. Variations of the pipe strain during the bending works were measured and the surface profiles of the cold bends were measured.

A series of finite element analyses were also conducted to establish a finite element model. The 24" HIPER pipes exhibited the excellent workability on cold bending and no harmful local deformations were observed. The results imply that large diameter HIPER pipes shall also be applicable to fabricate cold bends with a large bending angle. The cost effectiveness of the cold bends is discussed taking into account a hypothetical pipeline route. The results explain that the number of cold bends decreases with increasing total bending angle. Consequently the costs of labor and transportation can be diminished.

Studying the variation of mechanical properties of large-diameter pipes with increased deformation capacity at heating from coating application and subsequent plastic deformation during manufacture of cold-bent branches

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Large-diameter pipes (LDP) within pipelines are used with an anticorrosion coating (ACC), application whereof is accompanied with low-temperature heating. Steels (X70–X80) for LDP with a ferritic-bainitic structure have increased ageing tendency. By now, pipes with an increased deformation capacities have been developed (for APR zones), which, thanks to the steel structure peculiarities, have guaranteed strain-hardening characteristics (incl. $\sigma_T(R_{t0.5})/\sigma_B$, δ_p) both in the initial state and after ACC application. This made it possible to manufacture cold-bent branches (GO) with an increased bending angle (reduced radius) in relation to the requirements of GOST 24950-81 with satisfactory shape parameters.

The change of mechanical properties at extension of the pipe base metal K60 with increased deformation capacity under successive impact of heating ($\approx 200\text{--}230\text{ }^\circ\text{C}$, $\approx 5\text{ min}$) from ACC application and plastic deformations ($\epsilon_p = 2\text{--}3\%$) in the longitudinal direction during manufacture of bent branches with an increased bending angle and $R = 20\text{--}25 D_H$ was analyzed.

Heating during ACC application causes for the pipe metal with an increased deformation capacity a relatively small increase in values of $\sigma_T(R_{t0.5})$ and $\sigma_T(R_{t0.5})/\sigma_B$, but plasticity indices (δ_5 and δ_p) on the whole remain unchanged. Deformation due to bending of branches causes a change in values of $\sigma_T(R_{t0.5})$ and $\sigma_T(R_{t0.5})/\sigma_B$, more in the longitudinal direction, but in the transverse and longitudinal direction plasticity decreases by $\approx 2\text{--}4\%$. The metal of the branch straight section after deformation is characterized by decreased plasticity (δ_5 and δ_p by $\approx 1.0\text{--}2.5\%$), i.e. the branch straight section also suffers deformation.

On the whole, the base metal of branches with bending radius in the transverse direction reduced to $R = 20 D_H$ has strength exceeding the pipe properties, while in the longitudinal direction it retains a margin of plastic deformation until failure with the value of $\delta_p \geq 5\text{--}7\%$.

Assessment of residual stress and strain state of cold-bent branches with increased bending angle

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At present there is the prospect of manufacture of cold-bent branches with an increased bending angle (GOU) of pipes with a high deformation capacity (HDC). Cold-bent branches (GO) are installed on trunk gas pipelines in case of rugged topography, which complicates the routing and requires a correct checking strength calculation. Plastic deformation of the stock pipe wall metal during formation of the bent branch and the occurring stress-corrosion cracking on the route show the need for precise determination of residual stress and strain state (SSS) of GOU.

To determine residual SSS of GOU, a three-dimensional mathematical finite-element (FE) model of GOU formation in standard pipe bending machines with a parameterized pipe geometry and machine's working parts. Result accuracy is ensured by the accounting of physical and geometric non-linearity of the problem using the actual properties of the stock pipe material, differing from the bilinear Prandtl deformation diagram, as well as accounting of the actual interaction between the stock pipe and the working parts of the pipe-bending machine via contact interaction.

The modeling results allowed for assessing the SSS of GOU, revealing the high level of residual stresses up to 0.8 of the material yield strength in the neutral line zone and on straight sections, including in the circular direction, revealing plastic deformation of the GOU wall metal on straight sections, as well as assessing the degree of GOU manufacturing process influence on its SSS.

**Innovative equipment for assembly of the pipes to be welded.
Application experience in construction of gas pipeline
“Siberian power”**

*I.A. Koroleva
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Regardless of welding system used in construction of pipelines, the basis of a high quality and safe weld joint is precise and efficient pipes assembly for welding. Innovative, fundamentally new internal RedRam centralizer was specially designed for large-diameter pipes. Powerful expanding force is ensured by hydraulic system which allows for complete avoiding of edges displacement and straightening of pipes ovality, making perfect basis for modern automatic welding systems.

JSC “Lengazspetsstroy” performs welding of the pipes with the diameter of 1420 mm at TGP “Power of Siberia” on site of “Belogorsk–Blagoveshchensk 1970.45 km – 2154.20 km” using complex of one-sided automatic welding “Veraweld Torch System D”, pipes assembly for welding is made by RedRam centralizer.

Application of RedRam centralizer solves the problems of operational loss of time, which improves productivity of the works and leads to reduction of the project total cost.

Repair of circumferential joints using INTRATOOL equipment

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The paper presents the method for repair of circumferential welded joints on the gas pipeline – full perimeter welding of circumferential butt-welded joints on gas pipelines with unallowable internal defects using the Clamshell pipe lathe. A method for repair of welded joints without disturbance of pipeline connecting elements and shut-off & control valves, applicable in all climate conditions, is proposed. It solves the problem of timely repair work performance with absence of new joint parts or valves of required size, which is typical when a defect is detected during work.

Efficiency of the performed work package is considered by comparing the technologies for repairing the full perimeter of a welded joint with complete removal of the T-pipe with adjoining pipes and an alternative method – cutting and beveling of a defective welded joint using the CLAMSHELL machine.

Development of estimates for connection of main pipelines and pipeline branches by the method of cold cutting and overlapping under pressure

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TDV Evrasia LLC is a developer of innovative technology for pipeline repairs under pressure with no disconnection of consumers.

As per FZ-369 dd. 03.07.2016 “On Amending Town-Planning Code of the Russian Federation” and Articles 11 and 14 of the Federal Law “On Investment Activities in the Russian Federation in the Form of Capital Investments”, TDV Evrasia LLC supported by the Government of Yaroslavl Region, within the framework of the program “Engineering and Economic Standardization of T.D. Williamson Technology in Design Solutions”, develops State Itemized Estimates of the Collected Volume 25 “Main and Field Pipelines”, Section 27 “Estimates for Connection of Main Pipelines and Pipeline Branches by the Method of Cold Cutting and Overlapping under Pressure” and the associated regulatory technical documentation:

1. Unified Design Solutions (USD hereinafter) for re-laying main pipelines and pipeline branches with the use of cutting under pressure have been developed and passed the expert review: VOLUME I “Instructions for Design Documentation Sections Development” and VOLUME II “Drawings”;

2. USD VOLUME III “Unified Operation Process Charts” have been developed and passed the expert review, according to MDS 12-29.2006 “Guidelines for Process Chart Development and Preparation”;

3. USD VOLUME IV “Itemized Estimates” is under development;

4. USD VOLUME IV “Logistic Support for Cutting under Pressure by the Technology of T.D. Williamson” is under development;

5. VOLUME of calculations “Cost of Engine Hour of Machine and Tool Set Used for Cutting under Pressure by the Technology of T.D. Williamson” is under development;

6. STO “Re-laying Main Pipelines and Pipeline Branches by the Technology of T.D. Williamson. Design Rules and Process Solutions” has been developed and is passing the Federal Expert Review of FAU FTsS;

7. RTD development would be followed by materials adaptation for low distribution mains.

Severkor corrosion-proof rolled pipes. Introduction prospects

D.V. Kuznetsov, S.M. Tikhonov, A.A. Komissarov, Ye.P. Sidorova, Yu.V. Komissarova, G.V. Serov (MISiS National Research Technological University), A.V. Mitrofanov (Severstal PJSC), I.G. Rodionova (FSUE TsNIIchermet named after I.P. Bardin)

With high demand for cold-resistant and corrosion-proof tubular products at the metal article market, including field pipes for linear pipelines (oil and water pipelines), MISiS and Severstal PJSC, supported by the Ministry of Education and Science of the Russian Federation (Decree No. 218 of the Government of the Russian Federation dated 09.04.10, Contract No. 02.G25.31.0141 dd. 2016) have initiated a project to develop a new pipe steel grade, Severkor, with improved performance parameters. Within the project, special attention is paid to enhancement of resistance to general and local corrosion that is the main cause, primarily in the form of through washouts, of drastic operation life reduction in tubular products and hence the increased cost of pipeline ownership in total.

To improve corrosion resistance of rolled metal, several microalloy variants were tried, and methods of melting and casting technology optimization were developed to reduce foreign matter content in the metal, including corrosion-active non-metal impurities of type 1 (calcium aluminates), 2 (calcium aluminates in sulfide shell), and 3 (magnesium aluminate-based). Research performed resulted in obtainment of lightly alloyed rolled sheets in rolls with improved corrosion resistance corresponding to K52–K56 strength category, and practical test of pipe blank molding and welding out of the said rolled stock.

At this project stage, new-generation coil stock undergoes comprehensive corrosion tests including corrosive/erosive wear, corrosion resistance in compliance with NACE standards, corrosion resistance assessment in H₂S and CO₂ environments, and studies by the procedure of Severstal PJSC and Institute of Non-organic and Physical Chemistry named after L.Ya. Karpov (KANV 1 and KANV 2), and by a procedure of FSUE TsNIIchermet named after I.P. Bardin (KANV 3). Preliminary study results allows for anticipation of over 10 years of guaranteed accident-free operation of direct-seam field pipes out of Severkor rolled stock.

Development of methods for structure measurements and structural steel destruction

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Scale of structures in steels, including pipe steels, is wide: from nano- to macro-sizes. Their end pattern reflects features of evolution of structures and defects within the technology. Understanding of the destruction mechanisms of heterogeneous structures is important to assess the reasons for metal viscosity drops, remaining lifetime of items, search for best possible structures according to given properties. Successful reaching these goals is determined by availability of unbiased methods for observing structures, deformation and destruction (*in situ*, by acoustic emission, and *post mortem*, by the type of fractures).

Wide-scale introduction of modern computers and digital image recording means in the material science made it possible to obtain quantitative assessments of structures and fractures (contrary to comparison with a reference image), e.g., when ranking metal by quality. However, wide range of observation and metering devices and software for image processing increases the importance of metrology support for computerized procedures.

Measurement statistics play an important role. With insufficient area of the fields of view, occasional fluctuations of numerical values of structure and fractures characteristics are possible, but when they are comparable with specimen dimensions they would explain the reasons for a spread in values of characteristics and sometimes their consistency. E.g., representative statistics of fracture geometry measurements was the one to show that the fracture was not a fractal.

Scales of structure heterogeneity must be taken into account for the assessment of mechanical properties, in particular, when building up and assessing differences of series curves. For various metal compositions and structures (forgings, sections, sheets), an efficiency of series curves approximation was shown based on the principle of maximum credibility with identification of independent parameters and their errors. With developed heterogeneity of structures – prospects of local cold shortness technique, by acoustic emission measurements upon destruction of micro specimens the dimensions of which are commensurable with the scale of their heterogeneity.

Development of quantitative methods for structures and destruction measurement may be helpful to develop a brand new range of standards for their determination. This would finally allow to standardize the requirements to the structures.

SESSION «E»

CONSTRUCTION, REPAIR AND CORROSION PROTECTION OF GAS TRANSPORTATION FACILITIES

Concerning applicability of the method to determine polarization potential of underground structure using fixed mounted potential sensor

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The report reviews the main principles of the methodology to measure polarization potential of underground structure by the method of disconnection of auxiliary electrode polarization current, that are based on equivalence of the processes occurring at underground structure metal in an insulation defect and on the operating surface of potential sensor.

The report reviews the results of field measurements and comprehensive full-scale and lab tests of long-acting reference electrodes (with auxiliary electrodes, AE) after their dismantling from underground pipeline sections. The influences leading to incorrect functioning of fixed copper-sulfate reference electrodes with potential sensors (LARE hereinafter) are analyzed. Based on the results of analysis of electrometric measurement data using LARE, it was noted that steady potential of AE at the linear portion of trunk gas pipelines is in most cases shifted towards the domain of negative values, and at compression stations, GDS – towards the domain of positive values. At polarization of AE, steady potential of which is shifted towards the domain of negative values, AE polarization potential would be more negative than the protected structure potential. Therefore, an “under-protection” of the structure would occur at the control of ECP parameters by polarization potential. And vice versa, in case steady potential of AE is shifted towards the positive domain and, correspondingly, polarization potential doesn’t match the lower limit of standardized value, an “over-protection” would occur at the protected structure.

Based on the results of studies conducted with participation of Khimservis CJSC, the reasons for deviation of auxiliary electrode potential beyond the domain of admissible values were determined and the conditions for best possible parameters of operation of fixed copper-sulfate reference electrodes with potential sensors were determined.

Main aspects of improvement of Gazprom PJSC construction activity

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Construction, upgrading and technical re-equipment of UGSS facilities are one of the most important work areas facilitating the long-term development of Gazprom PJSC and the energy complex of RF. The main works are aimed at constructing the linear part of trunk gas pipelines.

Construction works of Gazprom PJSC make up 10 % of the total construction works volume in RF. From 2011 till 2016, over 9 thous. km of TGP and branches have been commissioned, which is 5% of the total length of the trunk gas pipelines operated by Gazprom PJSC.

Large-scale work was organized and is being carried out for improvement of Gazprom PJSC construction activity, the aspects of which are outlined in the paper.

At present a number of normative legal documents of the Russian Federation, aimed at regulation of town-building activity, have been adopted. The paper assesses the risks of Gazprom PJSC conditioned by changes in town-planning activity and increase of government control, determines the main areas of Gazprom PJSC interaction with the Ministry of Construction of Russia for their minimization (Interface Agreement and Roadmap for 2017), under which the necessary changes will be made to the RF town-building legislation, including as regards the preparation of criteria for design documentation acknowledgment as modified design documentation, incorporation of departmental cost estimates into the federal register, application of the industry-specific principle of SRO formation for builders, technical customers of facilities of the power (incl. oil and gas) complex.

The paper also deals with the issues of elaboration and implementation of a voluntary certification system INTERGAZSERT, aimed at improving the quality of products and services, used by Gazprom PJSC, and the Association of Building Organizations in the Gas Industry was created, which joins the major customers and contractors of Gazprom PJSC in order to create unified approaches in the construction of gas facilities and assurance of protection of Association members' interests.

Modern development of pipeline ballasting area, international experience, requirements and comparisons

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Pipeline Coatings and Technologies LLC company presents a production system for application of outer concrete weight coating (OCWC) and outer ballasting protection coating (OBPC) on the pipes of 219–1420 mm diameter. Applied method of “splashing” upon protective coating application gained the worldwide acceptance; it guarantees economic and process feasibility of use.

This technology corresponds to Russian and international standards, including DNV-OS-F101.

Technical and economic efficiency drivers of possible results of concrete-coated pipes use for main pipeline oil and oil products transportation:

1. Preventing a possibility of damaging anti-corrosion coating at the stages of transportation, construction or repair works and pipeline operation due to the concrete coating of pipes, providing for facility service life increase;
2. Preventing a possibility of losing the ballasting ability of coating throughout the entire period of pipeline operation, regardless of external impacts;
3. Preventing risks of ballasting means shifting and protective coating and pipeline damage;
4. Ballasting ability of concrete-coated pipe coating is created under plant (industrial) conditions and doesn't depend on the quality of pipeline ballasting works under route conditions, and reduces the periods for construction or repair in general;
5. Lesser resistivity upon pulling due to a lengthy cylindrical surface as compared with single ballast weights;
6. High level of industrial safety;
7. No man-made environmental impacts.

Trunk gas pipelines under intensive mechanical impacts: peculiarities of construction and corrosion protection

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The paper deals with the aspects of assessment of external mechanical impacts on gas pipelines during construction and operation, conditioned by the interaction of solid soil fractions and the external pipeline surface.

The paper analyzes the factors of occurrence and parameters of such impacts on the insulating protective coating and the base metal of pipes in case of trench and trenchless laying. Impacts on the gas pipeline from soil containing separate large inclusions, being sources of concentrated loads acting on the steel pipe wall, may cause its inadmissible local deformations with dents on the surface.

The paper suggests variants of technical and process solutions for limitation and minimization of consequences of such impacts with account of the used construction technologies, including in the conditions of restricted use of imported soil and parameters of rock fragmentation.

The issues of mechanical impact protection of ECP equipment elements and gas pipeline corrosion monitoring (extended anodes, reference electrodes, corrosion sensors, switching elements) in rocky soil conditions are considered.

Based on the results of studies and tests of the pipe surface protection means, carried out with participation of Gazprom VNIIGAZ LLC, the possibilities of their use in selection of design and construction solutions are evaluated. The package of necessary studies and tests for establishing and systematizing the requirements to the optimal parameters and conditions of coating use for gas pipeline protection against mechanical impacts with account of soils' properties is determined.

Choosing a method for construction of trunk oil pipeline underwater passages

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Trunk pipelines are systems of increased risk. Assurance of their strength, useful life, durability and safety is an important task for researchers, designers, developers of structural materials and technologies, specialists in operation, inspection, monitoring and supervision.

Underwater passages are among the most critical pipeline sections, therefore special requirements are presented to their operability, because even insignificant damage of underwater passages with loss of tightness may cause severe environmental consequences, from which arises the need for considering the operability of trunk pipeline underwater passages (TPUP) from the viewpoint of safety assurance and management.

Thereat, it should be noted that the solving of TPUP safety issue shall base on solving of the following issues: durability → reliability → useful life → stiffness → stability → strength, through their interaction with stricter requirements to the TPUP normal operation with transition to each next level [1].

The key elements of TPUP safety are as follows: selecting the laying methods, state monitoring and inspection, prevention of emergencies and readiness to eliminate them.

This paper deals with safety assurance on condition of construction method selection. The causes of emergencies, dependent on construction method, are conditioned by the impact of natural factors, such as seismic activity, natural conditions of river bed and bank reconfiguration bed, and technogenic factors such as violations of the construction and repair technology, errors in designing, works at hydraulic structures and agrotechnical measures on river catchment areas.

Methods for assessing geological-engineering conditions for enhancing efficiency of the directional drilling method in construction of trunk pipeline underground passages

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An integrated assessment of engineering geological conditions is necessary for selection of a technology of drilling operations on the underwater passage well. The used assessment methods in designing of underwater passages cannot fully perform such assessment, because they do not take into account some significant values affecting the drilling operations technology.

The integrated assessment of engineering geological conditions includes the following:

- determining the category of technological complexity of underwater passage construction by the directional drilling method. Based on the selected category it becomes possible to ensure the necessary scope of geological engineering surveys, to determine the requirements to the drilling technology and rock-cutting tools (hereinafter RCT), and construction time;

- developing a geomechanical model jointly with a hydrodynamic model. The developed models make it possible to determine the following: zones of stable state of the well bore, soil hydrofracturing, drilling mud filtration into permeable formations, traction forces of pulling and the possibility of pipeline pulling into the underwater passage well. The obtained data make it possible to determine the complication zones, to correct the underwater passage profile, to determine the necessary drilling mud properties and to form a flushing program, to select RCT.

The absence of calculation data in underwater passage designing significantly complicates the selection of a well bore construction technology, in determination of sections with possible complications and emergencies related to well bore path deviation, well wall collapse, drilling mud absorption by permeable deposits, as well as breakage and increased wear of drilling tools.

Comparative analysis of the use of directional drilling and carrier pipe microtunneling technologies

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Podzemburstroy LLC developed an innovative domestic technology for repair and construction of underwater crossings – “Method of Curves”, also known as the method of carrier pipe microtunneling. This method includes the advantages of trench-free technologies for directional drilling and microtunneling.

The essence of this method is laying pre-bent tubes along the given crossing route, which, in turn, allows reducing the radius of laid pipeline bending and, respectively, reduce the crossing length.

This method has a number of significant engineering and economic advantages: the channel part of water body remains intact, including the coastline integrity; no bentonite outcrops, there is no need to dispose of it; the pipeline would never “float up” or “fall down” in the course of operation, since the route of constructed crossing has an arc-type structure; safety of operation due to possibility of a deep pipeline setting from the surface; high process efficiency of the method is caused by a high level of work mechanization, small amount of machinery and equipment for the main and auxiliary operations, as well as absence of process cycle components with a weight over 18 t; the possibility to lay down the pipeline in strict accordance with the given design route is achieved through the use of location system, the base of which is gyro sensors not exposed to electromagnetic impact; the possibility to lay down pipelines at almost any soil conditions - from loose soils to rocks; the method implementation cost is comparable with the cost of the trench method for construction of crossings over water obstacles; the average rate of pipe laying is up to 20 meters per day with regard to welding and insulation works.

Developing a test bench for concrete-coated pipes

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The paper outlines the prerequisites for creation of a test bench for determining mechanical properties of steel concrete-coated pipes for construction of trunk gas pipelines and describes the bench operation principle.

Pipes with a concrete weight coating are widely used when constructing pipelines on sections of intersection with water barriers, bottomland areas, in marsh-ridden and waterlogged area, as well as for marine pipelines. However, as distinct from other ballasting means, the concrete coating affects the stiffness of concrete-coated pipe, which causes the need for adopting special technical solutions in designing of pipelines made of concrete-coated pipes.

Theoretical determination of stiffness of concrete-coated pipes is complicated by the features of their design and variability of concrete properties. This conditions the need for experimental confirmation of the characteristics of concrete-coated pipes of different designs.

Jointly with concrete-coated pipe manufacturers, various test bench designs were tried and, considering the obtained experience, Gazprom VNIIGAZ LLC specialists have developed a bench mounted at the production base of Pipeline Coatings and Technologies LLC in Volzhsky (Volgograd Region).

The distinctive feature of the developed test bench is the possibility to test steel concrete-coated pipes for elasticity at loading with the bending moment acting in the conditions of real operation of trunk gas pipelines. As a result of testing of a specific type of concrete-coated pipes, the empirical dependence of stiffness of the tested concrete-coated pipe on bending moment, as well as dynamics of pipe concrete coating state during bending can be obtained experimentally.

The bench was used for tests to determine the elastic bending parameters of a pipe with diameter up to 1,400 mm, wall thickness 27 mm, strength class K65 with an external weight concrete coating 150 mm thick.

Chemical cleaning of gas pipelines

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At present, the main method for assessment of gas pipeline cleaning degree is the measurement of the amount of deposits carried out by the cleaning pig. The remainder of hard-to-remove admixtures cannot be assessed by this method. On the other hand, incomplete cleaning causes reduced sensitivity of pipeline pigs and, consequently, reduced reliability of TGP LP. On the other hand, hard-to-reach admixtures cause significant increase of IPD prime cost.

Hard-to-reach admixtures may include deposits of compressor oil and hydrogen-sulfide corrosion products – pyrophoric iron. However, a significant aspect in the course of chemical cleaning of such deposits is the cost of this procedure and guaranteed maintenance of the commercial characteristics of transported product.

We suggested methods for reduction of expenses on cleaning due to the use of a lesser amount of chemicals, as well as the use of temporary gas-liquid separators.

Underground supports of process pipelines and shutoff/control valves

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The paper considers the issues of designing and construction of underground pipelines installed on supports and studied in the field of pipeline interaction with the soil conducted at Gazprom VNIIGAZ LLC.

Construction of new-generation trunk pipelines having increased weight and stiffness characteristics have conditioned the need for development of new approaches to designing and construction of underground pipelines with the use of supporting structures, as well as requirements to manufacture of underground pipeline supporting structures.

The following results have been obtained in the course of calculation and simulation studies of pipeline interaction with soil:

- a unified system of technical requirements for underground supports of process pipelines and shutoff/control valves was established, which allows for using the corresponding products in gas pipeline construction and repair;
- the predominant use of precast reinforced concrete supports was suggested;
- new procedures for support designing, technologies for their mounting, as well as special measures during construction monitoring were established;
- special attention was paid to the requirements for construction and assembly works in winter.

The studies yielded the results allowing for elaboration of the following regulatory documents:

- R Gazprom 2-4.1-988-2015 “Underground supports of process pipelines and shutoff/control valves. Technical requirements”;
- R Gazprom 2-4.1-989-2015 “Underground supports of process pipelines and shutoff/control valves. Application procedures.”

Application of support and reinforcement structures at Gazprom PJSC facilities

*A.L. Kalugin
(CJSC Gazprom StroyTEK Salavat)*

1. Use of multiblade screw piles.
2. New technologies and materials for heat insulation.
3. All-in supplier: advantages and optimization.
4. Contribution of CJSC Gazprom StroyTEK Salavat for the Year of Environment in the Russian Federation.

Development of frost heaving calculation algorithm

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Nowadays Tomsk Polytechnic University, Institute of Oil Chemistry of Siberian Branch of the RAS and Tomsk State Architectural and Building University are actively working to establish the fundamental relations between the soil, construction gel and pipeline and regularities of their variation depending on the manufacture technology and influence of operating factors in Arctic conditions, and scientific bases of process solutions are being elaborated. This approach is fundamentally new in the field of subsoil development and formation of the underground space. TPU and Institute of Oil Chemistry of Siberian Branch of the RAS are leaders of research in this area and for many years, in cooperation with TNK-BP OJSC (Nizhnevartovsk), Gazprom Transgaz Tomsk LLC (Tomsk), LUKOIL OJSC (Moscow), West-Siberian Industrial Group LLC (Novy Urengoy, Yamal-Nenets Autonomous District) are searching for approaches to development of fundamentally new technologies for calculations and creation of a new kind of construction gels. In the work period: an idea was suggested and tested—to consider joint calculation as a two-stage procedure for analysis of pipeline stress and strain state using the FEM; elements of mathematical model of pipeline interaction with the geo-environment were developed; 4 monographs and over 40 articles were published; USA letters patent No. 5.072.992 and a positive resolution for patent issue in Germany, Japan, PRC, etc., 15 author's certificates of the USSR and RF patents were obtained; experimental samples of a new kind of construction gels were developed and manufactured. The regulatory documents, specifying the procedure for calculation of pressure pipelines, give the requirements to joint calculation of the pipeline and soil mass. Thus, the creation of a calculation algorithm will eliminate the uncertainty of regulatory documentation and ensure correct fulfillment of nonlinear analysis. The developed algorithm for calculation of freezing soil frost heaving using construction gels in the natural conditions will allow for designing with guaranteed reliability and durability of trunk and field pipelines in natural Arctic conditions.

Using mobile compressor stations on trunk gas pipelines

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Pipeline maintenance and repair works usually require pipeline pressure reduction for gas removal from the damaged pipeline sections and assurance of work safety. One of the variants for pressure reduction is cutting-off of the damaged section and gas bleeding from it to the atmosphere. Moreover, the operating organization may use the technology of gas pumping for reduction of pipeline gas pressure before bleeding. Using the gas pumping technology allows for retaining the natural gas volume for sale to the customer and reducing methane emissions to the atmosphere, thus reducing the environmental pollution.

To implement the technology of gas pumping from the gas pipeline under repair, operating organizations use linear compressor equipment installed on compressor stations and mobile compressor stations (MCS). Depending on situation, the operating organization may use only linear compressor equipment or linear compressor equipment together with MCS.

The paper describes the worldwide experience in MCS use, gives the results of analytics and considers the prospects of their use as booster compressors for strength testing of newly built and repaired sections of trunk gas pipelines.

Requirements were elaborated for MCS process parameters, for methods and procedure of their monitoring, testing procedure, environmental requirements, as well as technical requirements for MCS connection and use on trunk gas pipelines.

Based on the conducted research, Gazprom VNIIGAZ LLC has elaborated interstate standards GOST 34070-2017 "Gas Supply System. Trunk Pipeline Gas Transportation. Mobile Compressor Station. Technical Requirements" and GOST 34069-2017 "Gas Supply System. Trunk Pipeline Gas Transportation. Mobile Compressor Station. Technical Requirements".

Materials and technologies of corrosion protection for berthing structures operated in the intermittent immersion zone

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Reliability of corrosion protection of berthing structures is particularly important in zones of intermittent and full immersion, where repair of anticorrosion coatings (ACC) requires significant financial expenses due to the need for expensive diving operations.

Nowadays the most widespread method of corrosion protection method in the intermittent immersion zone is the use of epoxy- and polyurethane-based ACC. Such ACC are applied on the dry surface of the hydrotechnical structure by way of preliminary caisson mounting.

As an alternative to such ACC, it is suggested to use anticorrosion structures and sprayed-metal coatings. An anticorrosion structure means a structure consisting of one or several layers of polymeric materials, protecting the pile (pipe/sheet-pile and sheet-pile wall, large-diameter shell) against corrosion and ice load.

The paper deals with the results of laboratory tests of anticorrosion structures of different designs, as well as the technological features of their application and operation. Anticorrosion structures of different manufacturers, available on the Russian market, are studied.

The results of laboratory tests of sprayed-metal coatings, applied by the electric-arc spraying method, made of various metals and alloys (Zn, Al, ZnAl, AlMn, AlMg), are presented. Corrosion resistance of sprayed-metal coatings under the impact of marine atmosphere, intermittent and full immersion is analyzed. Sprayed-metal coatings with the least decrease of coating thickness in marine atmosphere, in intermittent and full immersion zones were determined.

Technology for manufacturing of cold-bending branches of highly-deformable pipes

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Pursuant to the order of A.B. Miller (CEO of Gazprom PJSC), the Department (V.A.) Mikhalenko) and Gazprom VNIIGAZ LLC provided scientific and methodological support for tests and try-out of technologies for manufacture of cold-bending branches with an increased bending angle of highly-deformable pipes produced in Russia. The paper gives the main research results. In particular, it overviews:

- Key aspects of the technology for manufacture of cold-bending branches;
- Influence of various process factors on geometrical characteristics of branches with an increased bending angle;
- Influence of large plastic deformations on integrity of the external protective and internal smooth coating.

The research results were used to determine requirements to parent pipes and produced branches, and a technology for manufacture of cold-bending branches with an increased bending angle was developed.

Complex of equipment for corrosion monitoring of marine pipeline systems

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The use of means for remote corrosion monitoring of underwater sea pipelines is an important component of the system of facility technical state assessment to ensure their safe (fail-safe) operation due to corrosion. A package of technical and methodical solutions for a system of remote corrosion monitoring of Gazprom PJSC marine facilities was suggested, results of prototype development were presented, the package of tests at equipment pilot operation was successfully completed. For harmonization of industry-specific regulatory documents with foreign norms, Recommendations of Gazprom PJSC for corrosion monitoring of offshore facilities were elaborated and areas of development of corrosion monitoring means for offshore pipelines were determined.

Optimizing the cathode protection of the gas transportation system using equipment of TST CJSC

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Corrosion protection is an essential element of the system of gas transportation system technical state management, is intended for restriction of corrosion rate and is performed by way of pipeline isolation from the environment and application of cathode protection current. To reduce the corrosion rate of gas transportation system pipelines to an acceptable level, cathode protection must be arranged with the optimal parameters at all sections of the facility under protection. The optimal parameters of pipeline cathode protection can be attained when electrical energy is spent only for suppression of corrosion processes.

The equipment manufactured by TST CJSC allows for implementing the optimal cathode protection layout in full:

- insulating monolithic sleeve (electrical insulating joint) IMS, allowing for pipeline sectionalizing into separate sections to ensure their optimal protection;
- protective-threshold device PTD, which is a separation device based on semiconductor elements and intended for reduction of cathode protection current leaks into the grounding system of equipment having a galvanic coupling with the protected structure, due to blocking of cathode protection current passage in the range of the specified potential thresholds;
- polarizing element of cathode protection PEKZ-TST, which is a low-power cathode protection station with power up to 300 W with the possibility of making in the rack of the test station, powered from standalone energy sources, which allows for ensuring the specific parameters of section protection with the minimum costs;
- corrosion monitoring subsystem PKM-TST, allowing for monitoring all the necessary cathode protection parameters, as well as revealing the factors affecting the pipeline's corrosion state.

Given the modern development level of the corrosion monitoring system and CP equipment, it is easy to implement the optimal layout of GTS cathode protection with the minimum capital and operating costs.

Repair of pipe polyethylene coatings in factory and field conditions

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Pursuant to the Pipe Products Register, published on the Gazprom PJSC website, as of September 10, 2017 the Gazprom PJSC Standing Commission for acceptance of new pipe product kinds has certified 20 Russian manufacturers of polyethylene-coated pipes for compliance with the technical requirements. In total, these plants, in terms of average diameter (720 mm), annually make about 10 thous. km of insulated pipes.

Modern application of three-layer polyethylene coatings on pipes is a highly-automated process, which is equipped with a multilevel diagnostics and troubleshooting system, minimizing the probability of defects. However, complete avoidance of product quality gaps is yet impossible.

Based on the results of research of the regularities of pipe polyethylene coating damageability, analysis of the existing factory and field repair procedures, study of experience of repair works and effective regulatory documentation, Gazprom VNIIGAZ LLC plans to elaborate the document R Gazprom 9.1-XXX-2018 "Instruction for Repair of Damage of Pipe Factory Polyethylene Coating. Technical Requirements."

The instruction shall include the following provisions:

- classification of visually detected through and part-through defects of the polyethylene coating, caused during factory insulation or during transportation and storage of insulated pipes;
- quantitative criteria used to solve the issue of the need for repair works and selection of repair procedures depending on defect type and size;
- technical requirements to materials and equipment for coating repair;
- requirements to the procedure for pipe coating repair in field conditions;
- requirements to quality control of coating repair works.

TTL MAK-2. Description and purpose

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Standard process train of autonomous packaged unit (TTL MAK-2) is a semimobile repair base for repair of used pipes, that can be stationed in direct vicinity of a pipeline overhaul location. The standard process train is designed for repair and insulation renovation on 8–12 m long pipes with diameter of 1020 to 1420 mm. The train is rigged up in 2–4 month time in field.

Scope of TTL MAK-2 application

TTL MAK-2 is deployed near main pipeline repair sites in order to reduce logistic costs compared to the pipe repair at factory, and allowing for improvement of repair quality compared to the field method.

Process train content by sites

The process train consists of 4 main sites: finishing pipe cleaning site; pipe diagnostics, defect identification and repair site; edge trimming site; and insulation site. The sites are fully equipped to perform all scope of pipe repair and insulation renovation works.

Pneumo-framed structure (PFS)

PFS serves to maintain required microclimate in the zone of process equipment operation. PFS is made of arch-type air-filled balloons attached to a foundation. PFS ends are covered by walls with gates for motor vehicles and a gate for pipe input and output. Dimensions are 75x35x18 m.

Automation and control system of TTL MAK-2

Most of TTL MAK-2 units are equipped with automatic control system, reducing human factor impact on the work results and lowering the probability of defects.

Advantages of TTL MAK-2 Conclusion

TTL MAK-2 combines advantages of a stationary plant and mobility. Quality of applied coating is on par with a factory coating and exceeds quality of coating applied in the field. The train maintains pipe transport rate up to 40 mph and insulation application rate up to 30 mph. Quick relocation between base sites is possible.

The process train is a unique solution combining mobility and high quality of pipe insulation. The process train does not have a fixed type of insulation and can be equipped for any necessary coating type.

Prevention of corrosion cracking and corrosion of steel gas pipelines under delaminated coating as an element of corrosion protection system

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The multi-line gas transportation system (GTS) of Gazprom PJSC was built from the beginning of the 70-ies till the middle of the 90-ies of large-diameter pipes insulated chiefly with a field-applied film protective coating with the average service life of about 10 years. The said factor later became one of the main causes of increased corrosion and stress-corrosion damage of trunk gas pipelines (TGP). Due to continuing aging of the GTS (over 80 % of TGPs have been operated for over 20 years) the issues of planning and rational allocation of funds for gas pipeline operability assurance become more and more important.

By now considerable progress has been made in the solving of the issue of TGP stress-corrosion cracking (SCC). In particular, the possibility of long-term operation of TGP sections with insignificant stress-corrosion damage of the pipe surface, re-insulated with materials containing SCC inhibitors, has been proved.

According to contemporary conceptions, SCC processes may occur only on pipe sections contacting the soil electrolyte under the delaminated coating. Thereat, the areas of initial corrosion spots (pitting, pits) are local stress raises on the pipe surface, where microcracks may develop in future.

In this respect, a promising task is the prevention and control of corrosion cracking and various kinds of pipe metal corrosion (including microbiological corrosion) under the delaminated protective coating of TGP. Within the framework of the outlined issues, it is of practical interest to improve the properties of various kinds of protective coatings due to addition of various additives to them, which have an integrated inhibiting and bactericidal action, for use on TGP, as well as elaboration and development of methods for forecasting and monitoring of various corrosion kinds.

The paper shows the promising areas in the field of prevention of formation and development of TGP corrosion processes under protective coating delaminations.

Lamellar zinc coating as the most efficient method of corrosion protection

*D.N. Merkin
(DÜRER Group of Companies)*

Advantages of lamellar zinc coating over other types of metal coatings are evident.

Low corrosion resistance of fasteners is a weak spot for uninterrupted operation of critical equipment.

Operation cost for wellhead equipment maintenance is reduced due to the use of lamellar zinc-coated fasteners.

Lamellar zinc coating applied in new technical solutions of DÜRER Group of Companies.

GOST R ISO 10683 is used in regulatory documents for oil and gas equipment.

Sectoral companies provide feedback regarding issues of corrosion protection of fasteners and equipment elements, which can serve as technical assignment for our research center.

Joint insulation under route conditions. Technologies for re-insulation of pipelines

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(Selmers Technology B.V.)*

Quality of welded connection insulation under route conditions is critical for integrity of pipeline insulation coating. At the moment there is no ideal solution that would allow to have compatible coatings of the main pipe body and welded connection. Selmers solutions in this field allow to get closer to resolving this problem and significantly improve the existing technologies.

Despite a reasonably high cost of initial investments into such systems, their use can be justified for certain applications requiring a high quality when performing joint insulation works.

The technology for route re-insulation of pipes and the trend of pipe repairs in plant conditions that has been developed during the recent years assume using modern methods for cleaning and high-quality application of new coatings. Route repair and repeated use of dismantled pipes gives a positive economic effect since the cost of recovered pipes may be significantly lower than that of the same new pipes with equal operational characteristics.

Technology for arc pin soldering of ECP terminals with safetrack equipment use

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(TK Gazstroysevis LLC)*

The report contains a review of the technology for arc pin soldering and equipment:

- technology principles;
- processes upon soldering connection appearance are described;
- main properties of obtained connection are given;
- purpose and technical characteristics of ECONECT unit;
- internal design.

Results of technology application at GAZPROM PJSC enterprises over 5 years are given.

SESSION «S»

Analyzing the causes of delamination and damage of factory-applied polyolefin coatings

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Two- and three-layer factory-applied protective coatings based on extruded polyolefins are nowadays the most advanced form of corrosion protection for trunk gas pipelines. However, it is impossible to completely avoid cases of non-compliance of quality of pipe external protective coating with the existing technical requirements. The internal statistics kept at large Russian manufacturers of pipes with polyethylene/polypropylene (PE/PP) coating shows that the number of rejected pipes with such coating (which are to be re-insulated) is about 0.3–0.5 %, while the number of pipes subject to local repair is from 0.5 to 1.5 % of the total quantity of insulated pipes.

During storage, transportation and operation of pipes with external PE/PP coating there occur such defects as insulation delamination on the pipe ends and breakdown/cracking of insulation on the pipe body.

In the process of PE/PP insulation application, the coating experiences internal stresses which under certain conditions may cause either coating rupture or its displacement in relation to the pipe, accompanied with irreversible disruption of coating adhesion to the metal.

This paper analyzes the causes of delamination and damage of factory-applied polyolefin coatings, measures internal stresses of individual layers in a model three-layer insulation system.

Development of automated software suite for calculation of reciprocating compressors of mobile truck gas filling compressor stations

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Gas car market is actively developing in Russia. Production and sale of compressed natural gas (CNG) as a motor fuel is a priority area of gas industry.

Extensive work of natural gas utilization as a motor fuel has been performed already in late 80-ies and early 90-ies. Regulatory document system was developed, and 450 NGV-refueling compressor stations of high and medium capacity were constructed. Yet in the next eight years (1991–1998), CNG demand has dropped almost by 10 times in Russia. Demand decrease resulted in reduction of production, and research in this area has almost stalled. Later, when motor gas fuel demand started growing again, Russian industry came unprepared to it and could not ensure supply of compressors for the gas industry.

This study is aimed at development of domestic automated software suite for calculation of reciprocal compressors used at gas-filling compressor stations. The software suite is based on advanced design methods and uses mathematical simulation of work processes in a compressor.

Several key issues related to reciprocal compressor calculation were solved during the software suite development: determination of intermediate pressure, calculation of actual gas parameters, optimization of compressor valve and unit parameters, compressor operation analysis with account of probability characteristics of suction parameters (pressure, temperature).

The software suite enables evaluation of reciprocal compressor operation efficiency in a wide range of gas parameter variation both at the suction and at injection side, simplifies selection of valves, compressor base, drive, etc., allows determining optimum compressor parameters for reliable work in all operation modes.

Development of reciprocating compressor with vertical shaft for car gas-filling compressor stations

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A.A. Kotlov (FSAEI SPbPU)*

Kompessor JSC is a plant producing high-tech compressor equipment on a commercial scale. Close direct cooperation with operator companies allows for quick response to the market demands by developing improved analogs of foreign equipment and creating competitive products.

Thus, Kompessor JSC has developed a reciprocating compressor with vertical crankshaft for gas-filling stations. The compressor is designed for methane or natural gas compression to final pressure of 24.5 MPa after drying and treatment to required parameters.

Unique vertical design of the compressor is developed specifically for gas compression systems and installation at the facilities with limited area for equipment mounting.

The compressor is designed for different inlet pressures (0.4 to 0.7 MPa) and is highly energy-efficient. It was designed by dedicated mathematical models accounting for properties of compressed real gas and optimizing compressor elements.

The compressor is air-tight, fully automated, easily serviceable, well-balanced, and has low noise level. Both air and water-type cooling can be used. A compact natural gas treatment and drying unit is developed for gas preparation to required parameters. Drying unit design is simple, reliable, compact and easily serviceable.

Kompessor JSC produces NGV-refueling compressor stations based on the compact compressor developed and a drying unit, according to required parameters, at minimum cost and in shortest time.

Together with the Peter the Great Polytechnic University, Kompessor JSC runs research for improvement and optimization of reciprocating compressors.

Assessment of stress-strain state of underground pipelines

S.A. Shotskiy (GEOTEK PJSC),
S.L. Golofast (Gazprom Proyektirovaniye LLC)

Internal overpressure and temperature difference cause longitudinal and transverse movement in an underground pipeline that can be reduced by concrete coating. Specific feature of minor transverse movement of a pipeline is a proportional increase of ground fill resistance. The authors have analyzed stress-strain state of a concrete-coated pipeline section with a turning angle over a raising terrain.

A differential equation of bending and axial compression of a bar was used to solve the task. Maximum bending moment M , pipeline deflection v , longitudinal force N at the section of transverse movement, bent section length l are determined by the formulas:

$$M = \bar{M} q_0 \sqrt[3]{\left(\frac{EJ}{q_T} \operatorname{tg} \varphi\right)^2}; N = \bar{N} \sqrt[3]{EJ \left(\frac{q_T}{\operatorname{tg} \varphi}\right)^2}; v = \tilde{v} \frac{q_0}{q_T} \sqrt[3]{\frac{EJ}{q_T} \operatorname{tg}^4 \varphi}; l = 2 \tilde{l} \sqrt[3]{\frac{EJ}{q_T} \operatorname{tg} \varphi}, \quad (1)$$

where \bar{M} , \tilde{v} , \bar{N} , \tilde{l} are numerical parameters of bending moment, deflection, longitudinal force and bent section length of the pipeline. E is a metal resiliency parameter; J is inertia moment of the pipe cross-section; q_T is weight of a pipeline length unit together with a product; φ is a half of pipeline turning angle; q_0 is intensity of solid surcharge (of the concrete coating).

To determine numeric parameters \bar{M} , \tilde{v} , \bar{N} , and \tilde{l} , calculation formulas are obtained, differing depending on the ratio of N and $(4k_0DEJ)^{0.5}$, values where k_0 is a proportionality constant of soil compression; D is outer diameter of the pipeline.

E. g., for $N > (4k_0DEJ)^{0.5}$, the formula for numeric parameter \bar{M} takes the following form:

$$\bar{M} = \frac{1}{\sqrt[3]{\alpha^2}} \left\{ \frac{a\alpha}{\varepsilon(\xi_2^2 - \xi_1^2)} (\xi_1 \operatorname{tg} \xi_1 - \xi_2 \operatorname{tg} \xi_2) + \frac{a^2(1 + \varepsilon)(\cos \xi_1 - \cos \xi_2)}{\varepsilon(\xi_2^2 - \xi_1^2) \cos \xi_1 \cos \xi_2} \right\}. \quad (2)$$

Parameters a , ξ_1 , and ξ_2 are determined depending on longitudinal force in the pipeline, its geometrical parameters, mechanical properties and ground properties, $\varepsilon = q_0 / q_T$.

The formulas obtained allow for analysis of stress-strain state of concrete-coated underground pipelines at turning points, and for selection of quantitative parameters of solid surcharge in order to reduce pipeline stress to acceptable level.

Impact of operation conditions on probabilistic estimate of gas pipeline safety margin

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Currently, a variant of pipeline safety factor (n_σ) calculation is reduced to terminating algorithms by the methods of non-parameterical statistics, with a function of distribution density $f_n(n_\sigma)$ of the factor reestablished on the basis of stress σ and ultimate stress s in the pipeline wall, characterizing strength properties of the pipe material. Here, σ and s variables are random and have distribution functions $f_\sigma(\sigma)$ and $f_s(s)$. Function $f_n(n_\sigma)$ enables calculation of any quantile values n_σ^α for n_σ by solution of the following equation against n_σ^α (with definite probability value $\alpha = \text{const}$):

$$\int_0^{n_\sigma^\alpha} f_n(n_\sigma) dn_\sigma = \alpha. \quad (1)$$

The study overviews effect of temperature and gas pumping pressure on the safety factor distribution function $f_n(n_\sigma)$ for linear sections of mains, and quantile estimates n_σ^α are calculated by the equation (1).

Calculation basis: pipe diameter 1420 mm; wall thickness 20 mm; steel 17ГC; the pipe features a corrosion flaw with the length of 300 mm and depth of 10 mm. Ultimate strength (s) of the pipe material follows Gram-Charlier expansion law, its density function $f_s(s)$ taking the form of:

$$f_s(s) = \frac{1}{\lambda_2 \sqrt{2\pi}} \exp\left[-\frac{(u_s)^2}{2}\right] \left\{ 1 + \frac{\lambda_3}{6} [(u_s)^3 - (u_s)] - \frac{\lambda_4}{24} [(u_s)^4 - 5(u_s)^2 + 3] \right\} \frac{1}{c_s}. \quad (2)$$

Law (2) parameter values: $\lambda_1 = 570.9$ MPa; $\lambda_2 = 19.3$ MPa; $\lambda_3 = 0.1480$; $\lambda_4 = 0.0209$; $s_{\min} = 53$ MPa; $s_{\max} = 600$ MPa.

Impact of corrosion flaw on the stress in the pipe is accounted for via a stress concentration factor equal to 1.46754.

Distribution density functions $f_n(n_\sigma)$ and safety factor values are obtained for linear sections of operating gas mains.

Analysis and comparison of the data obtained and rated safety factor value allow for identification of linear sections where actual safety factor exceeds rated value of $n = 1.2$, equals to it, or is lower at a definite probability $\alpha = 0.01$.

By the algorithms developed and data obtained, a list of actual indicators for mains strength reliability assessment can be extended, and hazardous linear sections can be identified and rated.

Wear resistance assessment for aramid fibers used to remove waterproof coating from gas pipeline surface

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As of today, over 50% of main gas pipelines of Gazprom PJSC are in operation for more than 30 years, and therefore need replacement of waterproof coating, which loses durability and adhesion strength gradually.

Mechanical methods of defective insulation removal from a pipe surface bear a risk of damage due to possible cutting off of weld joints and corrugations. To eliminate this problem, it was suggested to use high-strength non-metal fiber of both domestic and foreign manufacture (Arselon, Tvaron, Nomex, Kevlar, Armos, Rusar) as a cutting tool of insulation removal machines.

One of the main criteria of fiber type selection for a cutting tool is wear resistance. To assess wear resistance of aramid fibers, test studies were performed with equipment design for that purpose.

Wear resistance of aramid fiber samples was tested by fiber interaction with one pipe of $D = 219$ mm diameter in a process of insulation coating removal (surface coverage angle $\alpha = 210^\circ$, wear site length $l = 410$ mm). The pipe is made of 17Г1С-Y steel. Tests were performed at 20 °C.

Processing of test results for samples out of different aramid fiber lots by disperse analysis method provided a conclusion that fiber wear resistance did not depend on properties dispersion among fibers of different manufacture, caused by manufacturing process specifics (maximum coefficient of variation for all types of tested fibers comprised 3.7 % for Kevlar fibers).

Functions of probability density $F_l(l)$ for wear resistance of aramid fibers of different types were recovered, and quantile estimates l^α of this parameter at different significance levels ($\alpha = 0.01$, $\alpha = 0.05$ and $\alpha = 0.1$) were calculated on the basis of statistic processing of the test data.

The study results provided a conclusion that *Tvaron* non-metal fibers had the maximum wear resistance during insulation coating removal from a pipe in operation, and can be recommended as a work tool for machines for waterproof coating removal from a gas pipeline surface.

Methodological basis of acoustic diagnostics of process equipment in oil and gas industry

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The report overviews issues of the necessity to expand a range of tank diagnostic methods with the acoustic diagnostics method. In the absence of automatic noise processing methods, subjective factors played a key role in diagnostics of equipment failures, and acoustic diagnostic method could not compete with other methods evolving, such as X-ray inspection, US and magnetic-field testing, vibroacoustic and thermal diagnostics, and went out of use. Yet this method returned its relevance and practicability after development of a new generation of imported acoustic instruments, systems of digital real-time processing of large data arrays and wide application of such instruments in defense, aviation, shipbuilding industries. Acoustic diagnostics method becomes relevant for diagnostics of complex and costly devices.

Advantages of the method:

- Real-time information on an engineering object;
- Monitoring without interference with operation of the engineering object;
- Large set of diagnostic data on almost all mobile elements of an engineering object;
- High resolution capability of the method;
- Cheap hardware available (microphones, stethoscopes), possibility to digitize almost all types of technical noise.

Up-to-date development level of acoustic sensors and digital signal processing systems allows for bringing this method to the most advanced level, eliminate subjective factors and ensuring continuous multiparametrical monitoring of work processes.

This report is the first in the oil and gas industry to encourage sectoral experts to perform studies aimed to revive this method and spread practical results of its application.

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