PROVIDING RELIABILITY OF TRUNK GAS PIPELINES OPERATION ON THE BASIS OF IN-LINE INSPECTION RESULTS

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ABSTRACT

This Paper deals with the topical problem of providing safety of trunk gas pipelines on the basis of in-line inspection results, and consists of the following Sections:

Pipeline Failures and Diagnostics
In this Section data are cited on the length and failure incidence of Russia’s trunk gas pipelines. It presents Russian highly efficient technologies and equipment for ILI to ensure such technological operations as inner pipe-surface cleaning, caliper logging, defect detection by MFL and TFI tools, and defect measurement. It also cites the scopes of diagnostics carried out in Russia and abroad.

Diagnostics Results
The Section contains generalization of the experience and presents results of the diagnostics of above 100 thousand km of trunk gas pipelines. Cited here are results of the statistical data processing of detected defect parameters as well as rated assessments of defects danger. The high potential danger is shown of stress-corrosion damages due to the high crack growth rates, as well as the possibilities of applying EMA technologies to detect and identify cracks at an early stage of their development.

The Section also presents models for optimizing periodicity and scopes of repairs, and demonstrates the effectiveness of ILI to provide reliable trunk gas pipeline operation.

Repairs with Composite Sleeves
A model has been designed to describe the deformation and destruction of a pipe length having metal-loss corrosion defects, with due regard for elastic - plastic properties of the metal and sleeve material. The Section also deals with areas of effective application of the composite sleeve repair technology.

Conclusion
The ILI results have provided a reliable basis for safety and efficiency of the Gazprom trunk gas pipelines operation and ensured a 50% reduction in the failure incidence in general, while reducing 2.5 – 3 times the incidence of the stress corrosion-related failures in particular.
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1. PIPELINE FAILURES AND DIAGNOSTICS

The total length of Russia's trunk gas pipelines exceeds 150 thousand kilometers. Above 90% of the gas pipelines have been in service for 15 or more years. By that time, the number of pipeline failures starts increasing. Ever more attention has to be devoted to diagnostic surveys and repairs.

Corrosion damages are the main cause of failures and emergency breakdowns of trunk gas pipelines. Stress-corrosion cracking (SCC) defects are the most dangerous ones. Emergencies caused by SCC usually result in the rupture of a gas pipeline defected zone without the “gas-leakage-prior-to-rupture” stage. Relative number of emergencies caused by SCC in gas pipelines with a 1000 to 1400 mm diameter operated for 12 to 16 years is several times higher than the number of emergencies caused by general corrosion.

Development and introduction of in-line inspection (ILI) technologies and intelligent pigs became a drastic measure in increasing safety and reliability of trunk gas pipelines. Nowadays efficient provision of the Gazprom trunk gas pipeline system operation reliability is practically impossible without modern in-line inspection equipment and technology.

Spetsneftegaz has created highly efficient technologies and complete sets of intelligent pigs for ILI of trunk pipelines having 500 - 1400 mm in diameter. Technology of comprehensive in-line inspection enables to detect and identify all dangerous and potentially dangerous pipeline defects including SCC.

The technologies and equipment ensure all the required operations, including inner pipe-surface cleaning, caliper logging, defect detection by MFL and TFI tools, and defect measurement.

Intelligent pigs of new generation are equipped with bypass devices able to regulate velocities of pigs’ movement and provide ILI without changing gas flow regimes. The tools have been certified as complying with the internationally accepted standards.

The complex ILI services also include technical conditions evaluation, life-resource prediction, and recommendations for repairs.

High reliability of ILI results is confirmed by systematic correlation of inspection results and defect parameter measurements during excavations of pipeline defect zones.

On the whole magnetic ILI tools have inspected more than 100 thousand km of JSC Gazprom trunk gas pipelines in Russia.

ILI tools have surveyed more than 6 thousand km of trunk gas pipelines in Iran, Argentina, India and other countries.

2. DIAGNOSTICS RESULTS

Corrosion defects such as general corrosion, pitting corrosion and SCC make up a larger part of the detected defects. Comprehensive statistic analysis of ILI data has been conducted. Specifications of one-dimensional and three-dimensional statistic distributions of depth, length and circumferential width of detected corrosion metal loss defects were obtained.

It is proved that distribution of three-dimensional random variable of metal loss corrosion defects is of multimodal character. It points to the fact of existence of several different mechanisms that form and develop metal loss stress corrosion defects.
When defect depth is less than the 20% of pipe wall thickness, four types of defects with their own specific sizes can be identified: compact defects (corrosion stains); defects developed predominantly in longitudinal and transverse directions; vast general corrosion defects (Fig. 1). Deeper defects are mainly represented by corrosion pits (pitting corrosion).

Fig. 1. Statistic distribution of parameters of corrosion metal-loss defects of trunk gas pipelines

The information about most possible combinations of the above defect types is important for a subsequent choice of repair technology parameters.

Rated assessments show that the majority of metal loss corrosion defects don’t reduce the pipeline strength. However, such defects are potentially dangerous if timely measures on replacement of insulation are not taken in the zones where corrosion damages start developing.

Metal loss corrosion defects reducing the pipe strength, currently account for 3 - 4%, while 0.3 - 0.4% of the above mentioned detected defects are destined for urgent repairs, according to the most conservative assessment (Fig. 2).
SCC defects are predominantly located in the lower part of pipeline perimeter, being concentrated along longitudinal weld seams. SCC damages are considerably more dangerous, than general corrosion defects. About 30% of detected SCC defects are dangerous ones, with other defects being potentially dangerous.

Potential danger of SCC defects is also rooted in the velocities of SCC growth, which are relatively higher as compared to the general corrosion defect growth velocities. Practice of repeated surveys of gas pipeline SCC damages has shown that SCC growth velocities reach 1.5 mm per year. The deeper are such cracks, the quicker is their growth velocity (Fig 3).

Calculations have shown that with due regard for threshold sensitivity of ILI tools on a 15% level, cracks can reach critical parameters (50% of pipe wall thickness) in 2-3 years after in-line inspections, depending on pipe wall thickness. These data are very important for making decisions on periods of ILI of pipelines with SCC defects.

In view of the relatively high SCC growth velocity, a higher threshold sensitivity of ILI tools is rather important for detecting and identifying SCC at early stages of formation and development. That is made possible by applying the EMA technology. Fig. 4 gives one such example of a crack 0.5 – 1.0 mm deep and 5.0 –15 mm long that was detected and identified at an early stage of its formation and development.
Due to the creation of modern ILI technology and a range of ILI tools of every standard size with controlled velocity of movement, we have, since 2004, been able to provide comprehensive in-line inspection of JSC Gazprom trunk gas pipelines and detect such severe defects as metal loss and stress corrosion cracks without changing gas flow regimes. That has made it possible to apply a gas pipeline system operation strategy as per the technical conditions of the pipeline, and formulate future plans and technologies of local repairs, reconstruction and re-insulation of pipeline sections in accordance with their ILI results.

A flexible repair strategy is applied to all combinations of defects. It is based on the prediction assessments meeting the “fitness for operation” and “design strength” criteria. The repair strategy based on “fitness for operation” criterion is aimed at emergency-free operation of a gas pipeline section within a certain given period of time, and envisages repairs of “inadmissible” and strength-reducing defects. The repair strategy meeting the “design strength” criterion is aimed at maintaining pipeline strength parameters on a higher (design) level.

Models have been developed to optimize periods and scopes of repairs after in-line inspections as well as periodicity of follow-up inspections.
The ILI data have of late become basic to formulating reconditioning schedules and re-insulation and reconstruction programs for sections of JSC Gazprom trunk gas pipelines. Up to now, the timely implementation of such plans has made possible a 50% reduction in the number of failures of the trunk gas pipelines.

Over the last years, the tendency towards a reduction in the number of stress corrosion-related failures of trunk gas pipelines has become stable due to an increase in the scopes of ILI to detect SCC. Today, the number of such failures has been reduced 2.5 – 3 times (Fig. 5).

![Annual and Sum-Total Scopes of Stress-Corrosion](image)

![Incidence of Pipeline Failures Caused by Stress Corrosion](image)

Fig. 5. Dynamics of surveys of stress corrosion damages and of trunk gas pipelines failures

### 3. REPAIRS WITH COMPOSITE SLEEVES

As to local repair of defects that insignificantly reduce the pipeline strength, technologies of repair sleeves usage are broadly applied.

A model has been developed for deformation and rupture of a pipe with a metal loss corrosion defect repaired with a composite sleeve. The model describes joint deformation of the pipe and repair
sleeve with due regard for metal elastic-plastic properties, tensile strength and elasticity modulus of the sleeve material.

Comprehensive calculations of strength have proved that efficiency of repairs depends on sizes of defects and specifications of repair sleeves.

The restraining impact of a repair sleeve on the development of circumferential deformation in a damaged zone increases with the growth of repair sleeve strength and elasticity modulus. As investigations have shown, repair of vast zones of metal loss defects is the most efficient. Repair efficiency decreases with the reduction of defect sizes. In case of local pitting corrosion defects, such repair practically does not increase the pipe strength. Also inefficient is repairing longitudinal and transverse grooves and crack-like defects using composite repair sleeves. When repairing vast 200-600 mm wide defects, the best effect is reached by using “stiff” repair sleeves with a high elasticity modulus (Fig. 6).

Fig. 6 Influence of composite repair sleeves elasticity modulus on restoration of load-carrying capacity in repaired corroded pipes

Also reasonable is the use of “stiff” repair sleeves when applying a combined technology of local stress corrosion defect repairs. The method consists of cutting out damaged metal zones 200 to 600 mm wide and then installing the repair sleeves.

4. CONCLUSION

Thus the creation and large-scale introduction of the technologies and comprehensive systems of trunk gas pipeline ILI, as well as the enormous databank of ILI data make it really possible to start operating the gas pipelines depending on their “technical conditions”.

ILI results have become a reliable basis of providing safety and efficiency of JSC Gazprom trunk gas pipelines operation. With the growth of ILI scopes, in spite of pipelines ageing, success has been achieved in stabilizing the incidence of emergencies in general and then reducing it 50% over a recent period. The stress corrosion-related incidence of failures reduced 2.5 – 3 times.
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