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Defects identification of the main gas pipelines

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Abstract

This paper describes a typical case of diagnosing and determining the causes of the formating of longitudinal cracks on the outer surface of the pipe, analyzes the current state of diagnosis of main gas pipelines. There is shown the importance of timely and correct response to diagnostic results. There is considered the experience in carrying out measures to optimize the repair processes of main gas pipelines by clearly establishing the timing of both evaluating the results of internal pipe diagnostics and the formating of repair plans, substantiating the criteria for choosing defects for repair and establishing a unified approach to the process, including technical documentation.

Keywords: *analysis of recommendations for the repair, in-line diagnostics, management system of gas pipeline integrity, optimization of defects repairs, replacement and strengthening of hazardous areas, technical diagnostics of gas pipelines, technical monitoring and non-destructive testing.*

Most of Ukraine's main gas pipelines operate over a calculated period, and the rationale for their continued safe operation is of strategic and economic importance [1]. To ensure reliable operation of the main gas pipelines (MGP) and according to annual diagnostic programs, PJSC "Ukrtransgaz" periodically monitors the technical condition of gas pipelines using instruments and technical means, and since 1996 – in-line diagnostics of main gas pipelines. The main task of diagnostics is to assess the actual technical condition of the gas pipeline and equipment installed in it with the subsequent repair of the identified defects in the gas pipeline body to ensure an operating life and reliable operation of the facility for at least 5 years [2, 3]. Untimely performance of diagnostic and repair works leads to an increase in the occurrence of failures and emergencies with unpredictable consequences [4, 5].

For the period 1996–2019 there were carried out more than 16 thousand km of corrosion inspection and 7.2 thousand km of inspection to identify longitudinal defects of gas mains in a single-thread measurement. It should be noted that to date, an in-pipe inspection of all main gas pipelines equipped with piston receiving/launching chambers has been carried out. Over the above time period, more than 31 thousand accidentally dangerous defects were identified and eliminated and a significant number of emergencies were prevented on the linear part of the main pipelines of the gas transmission system (GTS) of PJSC "Ukrtransgaz" [6]. The application of in-pipe inspection allowed to identify defects made during the production of pipes in factories that manufactured them, the so-called "manufacturing faults" (slag inclusions, delamination of the pipe metal, etc.), defects formed during the construction of pipelines by construction organizations (lack of penetration, pores, dents, cracks, displacements of pipe edges, etc.) due to improper organization of work and not too high qualification of performers, operational defects caused by imperfection of the insulation coating and errors in the maintenance organization of electrochemical means, high corrosivity of the medium, etc. [7].

An interesting and, by its nature, a unique case occurred in 2008 on the Urengoy–Pomary–Uzhgorod Du 1400 Ru gas pipeline of 7.400 MPa. According to the results of a piston pass in August 2007 to identify longitudinal defects in the section of the Ilintsi – Bar compressor station at 3871.81 km of the Urengoy – Pomary – Uzhgorod (UPU) gas pipeline (20,259.8 m from the launch chamber, according to ROSEN), there was detected a defect identified as metal loss – factory anomaly on a longitudinal weld with a depth of 11 % of the pipe wall thickness, 454 mm long, 14 mm wide. Figure 1 shows a fragment of the defect passport according to the technical report of the Rosen company [8], which performed an in-pipe inspection of the gas pipelines of PJSC "Ukrtransgaz" in 2007.

During the inspection of this defect by the diagnostic laboratory of the UMG "Cherkassytransgaz", PJSC "Ukrtransgaz", using an Einstein-2 ultrasonic flaw

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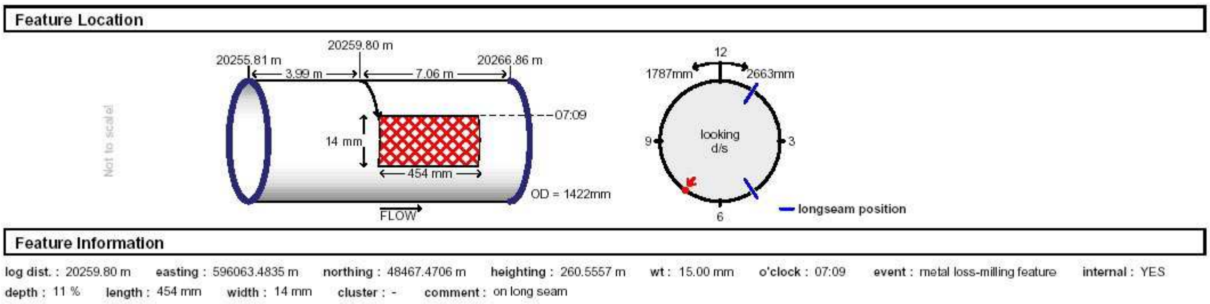


Figure 1 – The fragment of the defect passport according to the technical report provided by ROSEN

detector, there was found cracking of the main metal of the pipe body with a length of 3000 mm and a depth of 1.5 mm, shown in Figures 2 and 3.

Figure 2 – Longitudinal crack (frontally)

Figure 3 – Other cracks in the vicinity of the pipe seam

For an expert examination of a dangerous section of the UPU main gas pipeline in order to determine the cause of the formation of longitudinal cracks on the outer surface of the pipe, there were involved specialists from the Center for Certification and Quality Control of the Construction of Oil and Gas Complex Facilities, E. O. Paton Electric Welding Institute and SPC "Tekhdiagaz".

An expert survey has found that the route of the Urengoy–Pomary–Uzhgorod underground gas pipeline section crosses the area with swamps with a groundwater watershed at the level of the lower generating line of the gas pipeline. To prevent the ascent of the gas pipeline to the surface of the earth, there were used concrete UBOP-type weighters, mounted on both sides of the pipeline.

The following examinations were performed:

visual and optical inspection of the site in the vicinity of the seam zone of the longitudinal weld of the DN 1400 pipe with surface cracks;

non-destructive ultrasonic testing of the area in the vicinity of the seam zone of the longitudinal welded joint of the DN 1400 pipe in order to detect the depth of penetration of the crack into the pipeline metal;

non-destructive capillary inspection of a section in the vicinity of the seam zone of a longitudinal welded joint of DN 1400 pipe with the aim of more detailed identification of sections with cracks appearing on the surface of the pipeline metal;

electrometric measurements of the electrochemical protection system (ECP) of the gas pipeline in order to determine the protective and polarization potential;

quality control of the insulation coating;

assessment of the stress state of the metal of the gas pipe in this section;

the causes of cracking on the outer surface of the pipeline.

During the visual and optical inspection of the outer surface of the site in the vicinity of the seam zone of the longitudinal weld there were revealed:

a white coating on the metal surface in the section of the lower line of the gas pipeline, under a layer of insulation and primer;

after removing the white coating, stepped layering of the metal pipe surface (made by a metal device) on one side of the longitudinal welded joint, which is located along the entire length of the pipe at a distance of 7 mm from the welded joint and has a metal height difference of up to 0.6 mm, and longitudinal marks 0.5 m long on the other side of the welded joint;

a crack with a total length of up to 3000 mm (in the area of stepped surface layering), which is located along the welded joint and has an intermittent nature and the seepage on the pipe metal;

lack of corrosion pits or other manifestations of the corrosion process.

When conducting ultrasonic testing of a section in the vicinity of the seam zone of a longitudinal welded seam of a DN 1400 pipe, it was established that cracks in some places have a depth of up to 5 mm. The crack propagates in the direction of the longitudinal weld. The nature of the crack is intermittent, directed at an angle of 90° into the depth of the pipe metal, with a total length of up to 3000 mm.

When conducting capillary inspection of a section in the vicinity of the seam zone of a longitudinal welded joint of a DN 1400 pipe (Fig. 4), it was found that a number of surface cracks with branched ends with a total length of up to 3000 mm are located on the surface of the gas pipeline metal at a distance of 7–15 mm from the longitudinal weld which tend to unite among themselves in the direction along the generatrix of the gas pipeline.

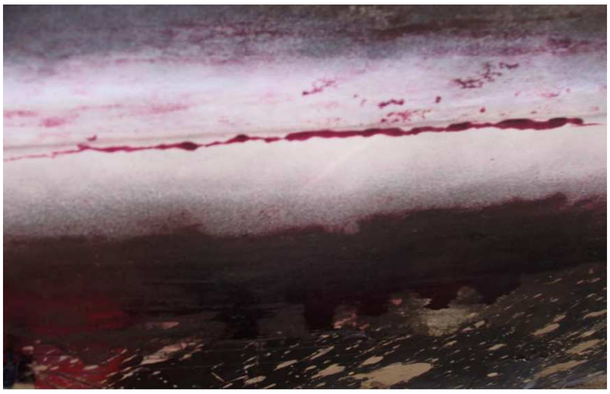


Figure 4 – General view of the surface after diagnosis by capillary control

When conducting electrometric measurements of the ECP parameters, it is found that the protective polarization potential of the gas pipeline is -1.25 V, the value of which is overestimated by 0.15 V, violates the requirements of regulatory documents [9], and can contribute to delamination of the insulating protective coating. When measuring the potential of a stationary electrode (a metal plate made of steel similar to steel of the pipeline) in the soil at a distance of 2.5 m from the gas pipeline and 0.05–0.10 m from the gas wall, there is found a difference of stationary potentials between them, the value of which is 0.1 V, which in turn indicates the presence of differences in electrolytic solutions in the soil, namely, the presence of an alkaline medium at the wall of the gas pipeline.

When determining the pH of the medium (soil and groundwater in the pit), it is found that the interaction of

soil and groundwater with chemicals leads to a neutral reaction of pH 7,

soil, selected between the gas pipeline and the concrete weight, with chemical reagents leads to an alkaline reaction pH 8.0–8.5;

the medium (near the surface of the concrete weight) with chemical reagents leads to an alkaline reaction pH 8.5.

The X-ray inspection of the state of the pipe metal confirms the results of previous studies and control, which are clearly visible in Fig. 5.

Figure 5 – Radiographic image of the defective place

Based on the results of the surveys, the following conclusions were made.

White corrosion (carbon film) on the surface of the gas pipeline metal under the insulation layer indicates the presence of a carbonate medium in the vicinity of the gas pipeline, which is formed as a result of the long-term effect of concrete weights on the soil environment. This is evidenced by the results of electrometric measurements and determination of the pH areas around the pipe soil medium.

The carbon film has protective properties against soil corrosion on the metal, as evidenced by the non-cored metal surface. But during operation, the metal of the gas pipeline is subject to cyclic loads, which contributes to the cracking of the carbonate film in the longitudinal direction and the emergence of crack-like local anode zones, which in their turn are the center of corrosion cracking.

The occurrence of a stepwise layering of the pipe metal surface and longitudinal lines in the vicinity of the seam zone of the longitudinal weld is due to the improper location of the pipe billet in the mandrel stand during the expansion at the manufacturer. During the operation of the gas pipeline, the local stepwise layering of the pipe surface is the center of the increased mechanical stresses of the metal at the annular intersection of the gas pipeline, the designations of which can go beyond the elastic zone of the metal, which is confirmed by stress state studies. The factors identified determine the possible causes of cracking on the outer surface of the pipeline.

A more detailed classification of crack formation can be performed having conducted destructive testing methods.

The potentially hazardous section of the UPU gas pipeline, which is located at 3871.81 km, was repaired by replacing the defective section with another one using materials that meet the requirements [10].

The following measures have been developed for further safe operation of gas mains:

constant monitor of the state of the gas pipe tube at locations of concrete weights in gas pipeline sections of DN 1400 pipes (beam crossings, marshland, water accumulation, etc.);

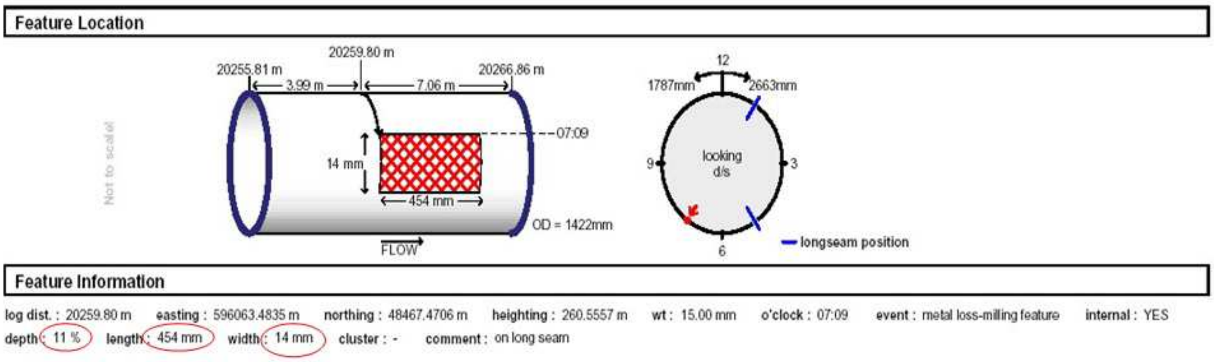
diagnostics in order to detect surface cracks (replace defective pipes with standard ones in accordance with the requirements of [10]) in places with the simultaneous action of several unfavorable factors;

re-insulation of sections of the gas pipeline with identified surface cracks in accordance with the requirements of [9];

replacement of the concrete weight with similar ones made of another material, or anchor;

taking into account cases of mismatch of defects with gas turbine engines located at longitudinal seams of gas pipelines sections (within 30 km from the compressor station), special attention should be paid to the actual dimensions of their priority examination and identification.

It should be noted that after the incident in PJSC "Ukrtransgaz", significant work was carried out in several areas aimed at preventing similar cases in the



No	Description of the deffect	Parameters
	Defects of primary repair	
5	External, internal metal loss, or their combination (corrosion, manufacturing defect, construction defect)	1. Depth equal to or more than 50% 2. Longitudinally located defects with a depth of **≥ 10 %** and placed along a longitudinal seam (± 200 mm) with a ratio of length to width **L/W≥30** with a defect width of **≤2h** (h is the gas main wall thickness) 3. Transversely oriented defects with a depth of ≥10% are placed along an annular seam (± 200 mm) with a ratio of width to length (W/L) ≥30 with a defect length of ≤2h (where h is the gas main wall thickness)

Figure 6 – Criteria for assessing defects typed as metal loss

future. This work is aimed at improving the overall quality of in-pipe inspection (more stringent requirements, the formation of a working group made of representatives of the Company and the company executing the in-pipe inspection of the gas pipelines, etc.), expanding the scope of examinations using other diagnostic methods. And also, the work on the application of diagnostic examination results has been raised to a higher level. Specialists of the PJSC "Ukrtransgaz" (including the branch of the Scientific and Technical Center "Tekhdiagaz") have developed the Regulation [11]. This document is aimed at optimizing the repair process of gas mains by clearly setting deadlines for evaluating the results of technical documentation as well as creating repair plans, defining criteria for selecting defects for repair, establishing a unified approach to the process, including documentation planning and reporting, executive documentation, etc. The document was developed taking into account the existing experience of organizing work of the Company branches and is a component of a “live” and effective system for ensuring reliable operation of the gas transport system based on in-pipe inspection – from planning and implementation of in-pipe inspection to analysis of the results and adequate response to them [12, 13].

Omitting other topics of the Regulation [11], we can focus on the part that defines the criteria for choosing defects for repair, distributing them in order of execution of the additional examination and/or repair, which are given in Table 1.

The purpose of this part of the Regulation [11] is to provide engineers with instruments to perform an analysis of the results of the in-pipe diagnostics. It was formed on the basis of the conditions for providing an operational primary analysis of the results; accordingly, there were defined clear criteria for choosing defects with their parameters. Usually this approach is somewhat conservative, but it solves the problem. For a more detailed analysis, specialized calculations should be carried out according to current regulatory documents. All present defect parameters for repair are determined based on:

the analysis of existing regulatory documents;

existing operating experience (repair, additional flaw detection control, accidents).

So, to assess the quality and volume of work performed, we give an example by the number of normative documents analyzed to choose criteria for evaluating dents (Table 2).

A number of defect selection parameters for inspection/repair are determined on the basis of existing operating experience and are sometimes quite conservative, but in the face of too high a price error, in particular at export gas pipelines of Ukraine, is a justifiable measure. Everyone knows the problems of the limited capabilities of in-pipe inspection tools regarding the detection of stress-corrosion cracking. There is a sad experience of accidents, additional flaw detection control, where defects discovered in fact differed from the characteristics indicated in the in-pipe inspection report. As an example, we recall, again, a defect in the Urengoy–Pomary–Uzhgorod gas trunkline 3871.81 km (see Fig. 2, 3) when, contrary to the information of the IPI report, stress-corrosion cracking was actually revealed. In order to prevent the possible ignoring of such defects, we introduced such a criterion as: "external metal losses are longitudinally oriented with a depth of ≥ 10 % and are placed along a longitudinal weld (± 200 mm) with a length to width ratio of ≥ 30 with a defect width of ≤ 2h (h – pipeline wall thickness)." Figure 6 shows the establishing such a criterion for assessing defects on DN1400 pipes.

Table 1 – Criteria for choosing defects for repair after obtaining the results of the in-pipe repair

Description	Parameters
Primary Repair Defects	
Anomalies, which are categorized according to [13]	«Critical» or «considerable»
Anomalies for which the repair coefficient is ERF	≥ 0.95
Anomalies for which the conditional coefficient according to [14] is as follows	≤ 1.05
Geometry defect (anomaly of internal diameter – a dent)	Depth equal to or more than 3.5 % of D_{in}
External, internal metal loss, or their combination (corrosion, factory anomaly, construction defect)	Depth equal to or more than 50 % Longitudinally oriented with a depth of ≥ 10 % and placed along a longitudinal seam (± 200 mm) with a length to width ratio (L/W) ≥ 30 with a defect width of ≤ 2h (h is the gas main wall thickness) Transversely oriented with a depth of ≥ 10 % and placed along an annular seam (± 200 mm) with a width to length ratio (W/L) ≥ 30 with a defect length of ≤2h (h is the gas main wall thickness)
Annular seam anomaly	Depth ≥ 50 % or circle length equal to or more than $1/3\pi D_{in}$
Anomaly of a longitudinal seam	The length along the seam axis is equal to or more than $2\sqrt{D_{in}h}$
Corrugations	Wave height more than wall thickness
Crack in the pipe body or in the weld	All defects
Stratification at an angle in the near-seam area, stratification with access to the surface, stratification with protuberance	All defects
Defects to be repaired and located in potentially hazardous areas of the gas mains[1]	All defects
Defects to be repaired (previous inspection)	
Anomalies, according to [13] are categorized as	«Moderate»
Geometry defect (anomaly of the inner diameter) adjacent to the weld (100 mm) or located on the weld	All defects
External, internal metal loss, or their combination (corrosion, manufacturing defect, construction defect)	Depth equal to or more than 30 % The number of defects with a depth of ≥ 20 % in one section is more than 10 The number of defects with a depth of ≥10 % placed along a longitudinal seam (± 200 mm) in one section is more than 5 Longitudinally located defects with a depth of ≥ 10 % with a ratio of length to width L/W ≥ 10 with a defect width of ≤ 2h (h is the gas main wall thickness) Transversely oriented defects with a depth of ≥ 10 % are placed along an annular seam (± 100 mm) with a ratio of width to length (W/L) ≥ 10 with a defect length of ≤ 2h (h is the gas main wall thickness) Defects ≥ 10 % deep in the longitudinal weld zone (± 200 mm) in areas within 30 km of the compressor station
Stratification in the near-seam section (100 mm)	All defects
Annular seam anomaly	The total length of a circle equal to or more than $1/6\pi D_{in}$, metal loss with a depth of more than or equal to 30 %
Anomaly of the longitudinal (spiral) seam	One defect along the seam axis of more than 10 mm

[1] potentially hazardous sections of the GM should include sections according to clause V.1.11 [15] + aboveground sections of GMs, intersections with roads and railways, intersections with gas mains

Continue Table 1

Description	Parameters
Corrugations	Wave height over 0.5 of the wall thickness
Line Scratch, Scuff	Depth ≥ 10 %
Inadmissible structural elements, connecting parts that do not meet the requirements of SD	All defects
Anomaly of an annular seam – discontinuity of a planar type	Defect ≥30 % deep
Anomaly of the longitudinal (spiral) seam	Defect ≥30 % deep

Table 2 – Requirements of regulatory documents for the assessment of the danger of dents by their geometric parameters

Country (Organization) / Normative document (standard)	Position (half perimeter)	Dent on the pipe body	Seam dent
Canada Canadian Standards Association CSA Z662-03 [16]	Upper section	to 6 % D_{in}	to 2 % D_{in} for D > 300 mm or to 6 mm
	Lower section	—//—	—//—
Great Britain AEA OTR 2001/038 [17]	Upper section	to 6 % D_{in}	is not allowed
	Lower section	—//—	—//—
The USA ASME B31.8 [18]	Upper section	to 6 % D_{in} or deformation < 6 %	to 2 % D_{in} or deformation < 4 % for a viscous seam
	Lower section	—//—	—//—
The USA API 1160[19]	Upper section	to 2 % D_{in} for D > 300 mm	is not allowed
	Lower section	до 6 % Dз	calculation/inspection to 6 month
The EU/USA PDAM[2] [20]	Upper section	1) to 7 % D_{in} 2) to 10 % D_{in} in case of pinching	is not provided for
	Lower section	to 10 % D_{in} in case of pinching	is not allowed
The USA DOT GasRule (Part 192) [21]	Upper section	1) to 6 % D_{in} (1 year to respond) 2) more than 6 % D_{in} and allowable level of deformation (monitoring)	1) to 2 % D_{in} (1 year to respond) 2) more than 2 % D_{in} and allowable level of deformation (monitoring)
	Lower section	1) more than 6 % D_{in} (monitoring)	1) to 2 % D_{in} (1 year to respond) 2) more than 2 % D_{in} and allowable level of deformation (monitoring)
Great Britain BGC/PS/P11[22]	Upper section	to 12 % D_{in}	is not allowed
	Lower section	—//—	—//—
Norway DNV-RP-F101[23]	Upper section	to 12 % D_{in}	is not allowed
	Lower section	—//—	—//—
The USA PHMSA DOT Liquidrule (Part 195)[24]	Upper section	1) to 6 % D_{in} (immediate respond) 2) to 3 % D_{in} (60 days to respond) 3) to 2 % D_{in} (180 days to respond)	to 2 % D_{in} (180 days to respond)
	Lower section	to 6 % D_{in}	to 2 % D_{in} (>180 days to respond)

[2] Pipeline Defect Assessment Manual is an international project supported by 30 global oil and gas companies, such as Advantica Technologies, BP, CSM, DNV, EMC, Gaz de France, MOL, Petrobras, Promigas, SNAM Rete Gas, Shell Global Solutions, Statoil, Toho Gas and Total.

Continue Table 2

Ukraine/Ministry of Fuel and Energy of Ukraine [25]	Upper section	to 3.5 % D_{in}	to 1 % D_{in}
	Lower section	—//—	—//—
The Russian Federation / VNIIGAZ [26]	Upper section	to 6 % D_{in}	to 3 % D_{in}
	Lower section	—//—	—//—
The Russian Federation / Gazprom [27]	Upper section	to 3 % D_{in}	to 2 % D_{in}
	Lower section	—//—	—//—

The described evaluation criteria (sequence of inspection/repair) of defects are an integral part of a comprehensive assessment of the technical condition of the pipeline with the definition of recommendations on the volume of selective repair or overhaul according to the results of the assessment:

the data of diagnostic examinations of pipeline metal;

results of a study of the actual physical and mechanical characteristics of steels [28, 29];

results of comprehensive surveys of anticorrosion protection and corrosion state of gas mains facilities;

actual situation in the terrain, etc. [30].

In general, the described procedure can be characterized as a component of the pipeline integrity management system [31].

The activities of any enterprise in the end should ensure profit, for which it is necessary to use resources as efficiently as possible. One of the ways to optimize costs is to introduce an effective and flexible system where the expenses on diagnostic, repair, emergency and recovery measures are interconnected and agreed on the basis of a detailed analysis (including risks) [32].

Today, it is conditionally possible to distinguish two methodologies in Ukraine for ensuring reliable operation of pipelines:

1) regulatory, in which the periodicity, volumes and means of diagnostic control and repair methods are clearly defined by the standards. Moreover, there is often a link not to the real technical condition, but to the operation life of the main gas pipelines. This approach contradicts common engineering sense, when further actions (repair, diagnostics) should depend on the actual condition of the pipe, monitoring the condition, statistics of damage, etc., and not on the regulations;

2) a universal or so-called pipeline integrity management system – where the solutions are interconnected and agreed on the basis of a detailed analysis (including risks).

The actual numbering of methodologies generally indicates the sequence of development of the integrity system for the main gas pipelines of the PJSC "Ukrtransgaz" – up to now, it can be said, to a certain extent, that there is a system, clearly regulated by the requirements of existing regulatory documents and the requirements of supervisory authorities, which determines the volume, periodicity of diagnostics and repair methods. However, it is more logical to prevent emergencies by means of a deliberate systematic approach to ensure the reliability of the gas transmission system with a certain level of risk. Adopting the progressive world experience, the PJSC "Ukrtransgaz" implements a system for managing the integrity of pipelines, based on the existing geographical information system for certification and technical monitoring of gas pipelines and an analytical software and hardware complex, which is being developed. Given the significant importance, the volume and progressiveness of this issue, we believe that it is advisable to separately disclose the above topics in general and regarding software and analytical complex in particular.

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Ідентифікація дефектів на магістральних газопроводах

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Описано характерний випадок діагностування та визначення причин утворення поздовжніх тріщин на зовнішній поверхні труби, проаналізовано сучасний стан діагностики магістральних газопроводів. Показано важливість вчасного та правильного реагування на результати діагностики. Розглянуто досвід у проведенні заходів з оптимізації процесів ремонту магістральних газопроводів шляхом чіткого встановлення строків оцінки результатів внутрішньотрубної діагностики та формування планів з ремонту, обґрунтування критеріїв вибору дефектів для ремонту і встановлення єдиного підходу до процесу, в тому числі і до технічної документації.

Ключові слова: *аналіз рекомендацій з ремонту, заміни та зміцнення небезпечних ділянок, внутрішньотрубна діагностика, оптимізація процесів ремонту дефектів, система управління цілісністю газопроводів, технічна діагностика магістральних газопроводів, технічний моніторинг та неруйнівний контроль.*