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ESTIMATION OF THE PIPELINES WORKING CAPACITY BASING ON THE RESULTS OF SEMIMODE TESTING

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Summary. *Analysis of the state of arts of estimation the pipelines operation capacity in Ukraine and other countries taking advantage of the technology of pipeline pigging and integrity management (PPIM and ILI technology) has been carried out. Basing on the results of semimodel testing, some aspects of estimation of defects of pipe metal are considered. The load-bearing capacity of a segment of a pipeline with elastic-plastic deformation, which had been detected during the inside-pipeline diagnostics of a long-time operating gas pipeline of the outer diameter 1220 mm has been experimentally investigated. The paper presents some particularities of experimental estimation of the pipeline segment strength in zones of local plastic deformation. The stress-strain state of locally plastically deformed segments of the pipeline has been determined using the semimodel testing. Basing on the investigations, recommendations for engineering practice are proposed.*

Key words: *pipeline, semimodel testing, diagnostics, elastic-plastic deformation, defects, fractured, strength.*

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Statement of the problem. In accordance with the standard requirements, the estimation of the working capacity of the main pipelines (MP) being in operation for more than 20 years, were carried out due to the results of the inside-pipeline diagnostics (IPD) [1]. Detection of the construction and operation defects of long-term operation MP, taking advantage of IPD, is the most reliable and effective method of estimation their structural health [2]. Sufficient advantage of IPD is the possibility of the total control of the pipeline along all its length. But during the process of IPD the number of non-fractured control methods is limited. For example, for the main gas-pipes (MG) it is, in fact, the magnetic method, for the oil-pipelines – the ultrasonic method correspondingly.

Because of the special location of the pig starting and reception units the minimum MP IPD area usually is equal to the distance between two compressor or pumping stations (80 – 170 km). Relatively small maintenance capacity of the pipeline enterprises, as well as the break down in the transporting of the product being impossible, it does not make possible to repair all defects detected by IPD. In such a case, in accordance with the current standards and methods [3 – 5], it is necessary to make ranking of the detected defects in the MP investigated area of the 80 – 170 km length and to establish the sequence of the repairing operations, depending on their further operation safety.

Analysis of the latest investigations and publications. The inside-pipeline crack detection of the gas and oil pipelines transporting system of Ukraine is carried out for the MP of the conventional pipes of diameter from 500 to 1400 mm, using the intellectual pigs of the company "Rosen Engineering GmbH", "Pipetronix", "Mostransgas", SPA "Spetsnaftogas", etc. [6, 7]. The requirements for the IPD of the MP linear part, using the complex of inside-pipeline means in the "Ukrtransgas", are presented in [8, 9]. The sequence of the MP IPD results analysis and management activity for the elimination of the detected defects are presented in the Provisions [10].

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The outcomes and problems of the MP diagnostics using the inside-pipeline pigs, as well as the providing pipelines integrity, taking advantage of the PPIM and ILI technologies (technology of pipeline pigging and integrity management), are analysed in the papers [11 – 13]. The problems of the MG diagnostics and non-fracture control during their long-term operation in Ukraine are presented in the paper [14]. The paper [15] is devoted to the investigation of the possibility of the diagnostics pigs to be used in the area of gas transition of the 1220 mm outer diameter pipeline. The mathematic modeling of deflection vibrations of the rectilinear area of the pipeline being under the movable diagnostics pig through the beam transition, caused by the weight of the pipes and forces initiated by the movable scrubbing or intellectual pig, is presented in the [16]. In the paper [7] the results of calculations of the land pipeline vibrations, the edge areas of which are mounted on the elastic base of the Vinkler type, taking into account the elastic interaction with the movable pig, are presented. The effect of the non-circular shape of the pipe on its stress state under the inside pressure loading is analysed in the paper [18]. The problem of safety during the long-term MP operation and conditions of providing the maximum safety are presented by the author in the [19]. Estimation of the residual strength of the pipelines with the dent-type defects is analysed in the paper [20]. The results of regularities investigation of the damage, deformation and fracture of specimens made of the 17G1S steel in the original and degradated states are presented in the monography [21]. The paper [22] is devoted to the determination of the stress-strain state of the elastically deformed MP areas according to the results of the inside-pipeline diagnostics taking advantage of the ILI technologies and numerical methods. From the analysis of investigations and publications, dealing with the working capacity of the long-term operating MP, it is clear, how complicated, complex and pressing this problem is, the further solving of which is needed nowadays by the structural health of the pipe-line transport.

The Objective of the article. To generalize the experience in the inside-pipeline diagnostics of the main pipelines both in Ukraine and foreign countries. To carry out the experimental investigations of estimation of the bearing capacity of the pipeline area under the elastic-plastic deformation, which was detected taking advantage of IPD. To improve the methods for determination of the defects ranking in the areas, detected during MP IPD.

Analysis of the available material. During MP IPD it is needed to carry out a lot of preliminary work: to check the pig starting and reception units in particular, their reconstruction being performed, if necessary; to pig the pipes inner cavity using special scrubbing pigs, as well as to check the deviations of the pipeline geometric sizes from those standard ones, the deviation of the pipeline cross-sections from the circular shape in particular, and its minimum curvature radius. Sometimes during the pigging of the pipeline inner cavity the unexpected stoppage of the pipeline pigging tool can occur, caused by the sufficient cross-section deviation from the ideal shape. It results in two problems: firstly, in the stoppage area of the pigging tool the additional stresses and deformations are initiated, and, secondly, it is necessary to detect the pigging tool stoppage place in the pipeline. Very often the detection of the scrubbing pig stoppage place takes much more time, than the process of the pig drawing out from the pipeline. After that the control, using the intellectual (diagnostics) pig, is followed. Further the inspection by the intellectual (diagnostic) pig is performed. The diagnostic pig consists of the magnetic module with the sensors, the memory module provided with the software and the module of power supply. The pig moves due to the difference of pressure of the transported product and its location is recorded by the magnetic marker and GPS navigator. Depending on the pig kind, the following MP defects can be detected: the decrease of the pipe wall thickness (corroding pig); the crack-like defects (the EMAT-type pig); the elastically deformed areas, such as dents, corrugations, etc (geometric pig). Mathematic means make possible to analyse and to give out results of investigations as the mass data, graphs and diagrams.

The results of inspection, obtained by the intellectual pig, are presented as the decreased pipe initial wall thickness along its generant. The defect location in point A (Fig. 1) is found due to the retrieved sizes L_1 – the distance from the pig starting chamber to the nearest before the point A along the pig magnet marker movement M; L_2 – the distance from the marker M to the nearest before the point A circular weld seam along the pig movement; L_3 – the distance from the nearest circular weld seam along the pig movement to the cross-section, where the point A is located, as well as the location of the point A relatively the watch face. For the swift detection of the magnet marker location the multi-channel electro-magnetic search-measuring system has been developed and patented [22]. Having learnt the precise location of the magnet marker, the values L_2 and L_3 are found and the other parameters of the defects are determined while inspecting the pipeline in the pit.

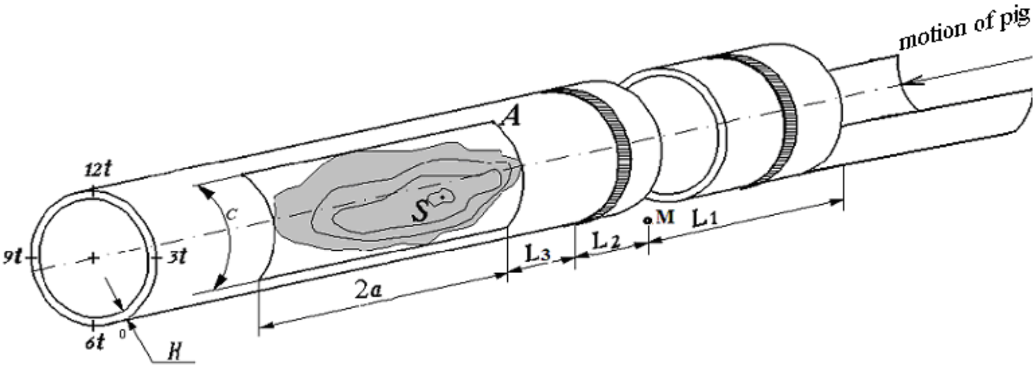

Figure 1. Detection of the pipeline metal defects at inside-pipeline diagnostics

The pipe metal losses are determined by the defect length 2*a* and width *c*, which are the projections correspondingly on the longitudinal axis of the pipe and its cylinder surface, as well as h_1 – the residual wall thickness and *b* – the greatest depth of the corroding damage in the point *S* (Fig. 2). Taking into account the great sizes of pipes, the diameters of which are in the range from 500 to 1400 mm, the spatial construction and the analysis of the mentioned above corroding damages is very labour-consuming procedure. One of the possible options of the corroding defect and its schematization is shown in Fig. 2.

In order to cut the labour expenses, basing on the objective-oriented principle, the software was developed, which makes possible to automize the spatial construction of the defected areas and to perform their schematization. This software is adapted with the software GEOSTAR, which is the component of the mathematic means using the method of the finite elements.

To obtain some statistic data on the available corroding defects, let us analyse the results of investigation of the main pipeline “Ivatsevychi – Dolyna III nytka” in the area from the compressor station “Kovel” to the compressor station “Sokal”. The inspection of the corroding defects of the mentioned pipeline was carried out taking advantage of the inside-pipeline flaw detection. Besides, the inspection of the mentioned above MG on the transitions across the water obstacles and marsh-ridden areas, as well as the places of corroding damages on the pit, has been carried out using the ultrasonic thickness gauge and special devices for the defects control. As the result of the carried out complex inspections of the corroding defects of the MG “Ivatsevychi – Dolyna III nytka” in the area CS “Kovel” – CS “Sokal” 203 damages have been revealed:

- the defects of the circular weld seam – 107 (which makes 52,7 %);
- the defects of the longitudinal weld seam – 4 (%);
- mechanical defects – 7 (3,5 %);
- corroding defects – 85 (41,8 %) (Fig. 3).

The analysis of the results of the inside-pipeline diagnostics shows, that about 23 % of the corroding damages can be presented as the semi-elliptic type of rotation. During the preliminary operations at the gas-transporting system “Ivatsevychi – Dolyna” near the CS “Birka” two areas of the pipeline were revealed, where the deflections of cross-sections from the ideal circular shape were sufficient enough. The investigations of these areas in the pits showed, that the pipeline broaching in the hill-side, being supported by the rock plate, has the dents of the semi-elliptic type of the 300 x 200 mm size and 65 mm depth (Fig. 4 a) and (Fig. 4 b).

The main concept while analysing the results of the MP IPD is the testing calculation of the detected defects in accordance with the standard [4]. The emergency recovering defects are the anomalies, the emergency repairing factor (ERF) of which is > 0,95; the dent depth equals or is greater than 3,5 % of $D_з$; the losses of the basic metal in the depth of 50 % or more; the anomaly of the circular weld seam is in the depth of > 50 % or the length along the circle, which equals or is more than $1/3\pi D_з$; the corrugations of the helix height, which is greater than the wall thickness [10].

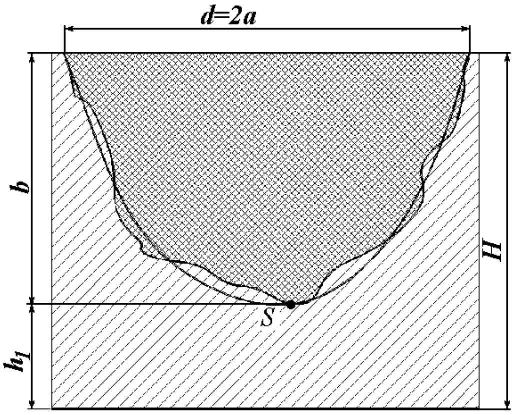

Figure 2. One of possible options of the corroding defect and its schematization

Figure 3. Corroding defects detected using the inside-pipeline diagnostics

For the swift determination of the detected defects ranking, the algorithm of the numerical modeling of the pipeline areas was proposed, which is based on the theory of the elastic-plastic deformation of the shells and modern algorithms of the non-linear mechanical problems discretisation using the method of finite elements. This approach to the analysis of stresses and deformation of the locally loaded pipe areas, taking into account their plastic deformation, can be applied during the preliminary operations of repairing.

Besides, the modeling of the stress-strain state of the damaged areas of the pipeline was carried out taking advantage of the software Solid Works Simulation. With this purpose the solid-body model of the inspected pipeline area was constructed, which was presented as the system of the shell finite elements of the shell, pipe type, etc.

The analysis of the calculation results showed, that the maximum similar stresses in the pipe metal in the dent place equal σ_E =460 MPa. This pipeline area of 1200 mm diameter is made of the 17G1S steel possessing such mechanical properties: yield limit – σ_T=390 MPa, ultimate strength – σ_B=580 MPa. The value of the pipe metal hardness, found experimentally, in the area in question is 1670 MPa due to the Brinnel scale. Using the dependence between the ultimate strength σ_B, the yield limit σ_T and the hardness value due to Brinnel HB [23], we will obtain σ_B=0,345 HB=0,345·1670=576,15 MPa and correspondingly, σ_T=0,367 HB – 240=0,367·1670 – 240=372,89 MPa.

a *b*

Figure 4. The plastic deformation areas of pipeline detected using the inside-pipeline diagnostics:
a – deformation of pipe body; b – deformation of metal in the areas of weld seams

Having compared the values of the mechanical properties of the pipe metal, obtained experimentally, with the maximum similar stresses in the dent place, calculated using the numerical method, it is seen, that σ_E=460 MPa and is greater than σ_T=390 MPa. Thus, similar maximum stresses exceed the yield limit. So, the area in question has been operating in the extreme conditions being sufficiently overloaded.

Investigations of the effect of the deformations of the pipe area on its bearing capacity were carried out on the test pressure reservoir, the general appearance of which is presented in Fig. 5. The sequence of mounting the pipe cylinder spherical bottoms and branch pipes are shown in Fig. 5. Geometric characteristics of the test reservoir components and the quality of steels they are made from, are presented on Table 1, and the main mechanical properties of their materials according to the certificates – on Table 2. The pressure reservoir is assembled from the dented segment 5, rings 2, 4, 6 and 7, cone-shaped adapter 3 and two spherical bottoms 1 and 8. The segment 5 with the area of local elastic deformations was detected during the inside-pipeline diagnostics of the MG "Ivatsevychi-Dolyna" being in operation. To fix the pipe fitting, in which water is supplied, a special branch pipe 9 was welded. For the air pickling a branch pipe with the air plug 10 was fixed (Fig. 5). The quality of the weld joints was controlled visually using *x*-ray and ultrasound flaw detection. The welding of the finished joint of the reservoir was performed at t°=3°C, experimental test at t°=29°C. The total dent square was $0{,}48\ m^2$. The maximum dent deflection was 65 mm, thus the relative dent depth was 65 / D_z =(65 / 1220) x 100%=5.33 %.

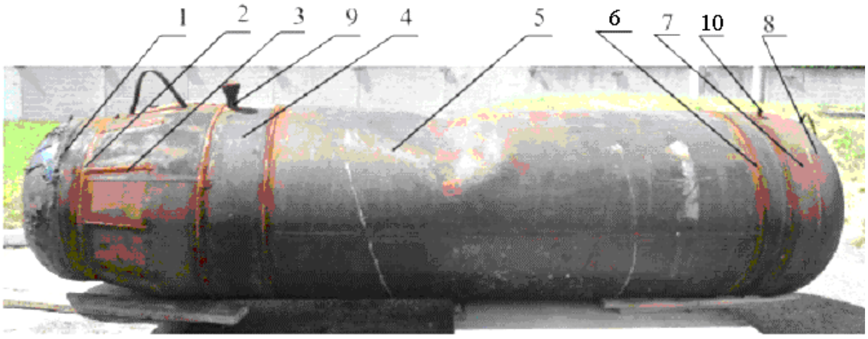

Figure 5. General appearance of a pressure test reservoir: 1 – semi-spherical bottom; 2 – transitional ring; 3 – cone-shaped adaptor; 4 – transitional ring; 5 – pipe segment; 6 – ring; 7 – transitional ring; 8 – semi-spherical bottom; 9 – branch pipe; 10 – branch pipe with plug

Geometric characteristics and the steels quality of the reservoir bottoms and pipe segments, as well as the main mechanical characteristics of their material are presented on Table 1 and Table 2.

Table 1

Geometric characteristics and steels quality of constituent parts of reservoir

No	Outer diameter D_z, mm	Length of pipe segment l, mm	Thickness of wall δ, mm	Shape	Steel quality
1	1020	200	22	Semi-spherical bottom	09G2S
2	1020	250	18	Transitional ring	17G1S
3	1020/1220	700	16	Cone-shaped adaptor	17G1S
4	1220	400	14	Transitional ring	17G1S
5	1220	2430	12	Pipe segment	17G1S
6	1220	300	16	Transitional ring	17G1S
7	1220	250	18	Transitional ring	17G1S
8	1220	250	22	Semi-spherical bottom	09G2S

Table 2

Main mechanical characteristics of materials of semi-spherical bottoms and pipe segments

No Constituent part of reservoir	Steel quality	Ultimate strength, MPa	Yield limit, MPa	Strain, %	Impact strength of main metal KCV, J/sm^2	Impact strength of weld joints KCV, J/sm^2	Fraction of plastic component in DWTT, %
1;8	09G2S	520	340	22	61	29,0	81
3;6	17G1S	570	400	24	58	51	89
5	17G1S	580	390	25	47	42	87
2;4;7	17G1S	575	360	23,5	48	39	83

The test pressure reservoir in question is a thin-wall axle symmetric shall, in which the main stresses σ_{κ} and σ_m are available. The third main stress is directed normally to the reservoir surface, the maximum value of which equals the pressure force P in the reservoir. In the thin-wall reservoirs the ring σ_{κ} and axis σ_m stresses are sufficiently greater than the inside pressure P, here the ring pressures σ_{κ} being in two times greater than those the axle ones σ_m.

As the gas pressure force in the pipelines is sufficiently less than the ring and axis pressures in the pipe body, we consider the shell material to be in the plane stresses state.

Constituent elements of 17G1S steel (in terms of mass) according to certificate are presented on Table 3.

Table 3

Constituent elements of 17G1S steel (in terms of mass) according to certificates

No of pipe segment	No of certificate	C	Mn	Si	S	P	Al	C_{eqv}	Mo	V	Nb	Ti	Cu	Ni	Cr
I	2116	0,18	1,37	0,5	0,025	0,02	0,008	0,46	0,001	0,004	0,029	0,015	0,01	0,02	0,02
II	9Y2901	0,09	1,5	0,25	0,003	0,017	0,029	0,43	0,001	0,004		0,013	0,01	0,02	0,02

Estimation of the bearing capacity of the test reservoir. The test pressure reservoir was subjected to the hydraulic testing by the static pressure. The creation of the additional pressure, created by water, was formed by the plunger pump of the blowing pump unit A-30, mounted on the car "Kraz" undercarriage. The pressure of the reservoir was measured by the manometer MO. The blowing pump unit was able to create the additional pressure in the reservoir to 30 MPa. The pressure P in the reservoir being increased step-by-step with the ΔP=1 MPa step, the change of the dent depth was controlled (Fig. 6). After that the weld joints were controlled visually. The parameters of the stress state were recorded too using the measuring device "MESTR-411" and the segment metal hardness – by the wearable electronic hardness tester "ТЕМП-3". The measurement were taken a number of times and their average values were found.

The fracture of the test reservoir was detected, when the inside pressure reached 10,0 MPa (Fig. 7). The dent area in the pipe segment (5) almost reached its original (non-deformed) place (Fig. 8). The decrease of the maximum dents deflection under different pressures in the test reservoir is presented on Table 4.

Figure 6. Monitoring of the dentdepth during the reservoir test

Figure 7. Segment of fractured test reservoir

Figure 8. Appearance and shape of pressure reservoir after testing

The biaxial stress state under the elastic and plastic deformation of the test pressure reservoir pipes, that is, the state of the deformed area of the pipe with a dent, and the process of the reverse deformation of the segment wall under the internal pressure were investigated experimentally. During semimodel tests the investigated reservoir was damaged on the weld joint cross-sections, the total stress concentrator of which were the cross-section of the ring seam of the 1220 mm outer diameter and one of the longitudinal seams of the cone-shaped adapter of 1200 mm × 1200 mm outer diameter (Fig. 7).

Table 4

Reduction of maximal depth of dent for different pressures in the test reservoir

P, MPa	0	4,0	9,0	0
Δ, mm	65	32	15	8

That is why while ranking the detected by the MP inside-pipeline diagnostics areas in the zone of the weld joints, the types and sizes of defects, coefficients of the weld joints reduction and non-relaxed residual stresses must be taken into account. The pressure reservoir tests showed, that the dent area under the internal pressure remained its bearing capacity at σ_K =498,33 MPa. It testifies, that the areas with the elasto-plastic deformation, the micro and macro cracks being not available, are of higher bearing capacity, than those mentioned above weld joints. Here the calculated ring stresses in the non-deformed area of the pipe segment 5 equaled σ_K =498,33 MPa. For the pipe segment material 5 (steel 17G1S) according to the industrial certificate for pipes, the yield limit equals σ_T = 390 MPa and the ultimate strength – σ_B=580 MPa.

Conclusions. 1.To reduce the time for the detection of MP defects location using the intellectual pigs inspection it is necessary to use GPS technologies and preliminary mounted and fixed electro-magnetic markers, here, it is worth the distance between two neighbouring markers being not more than 1000 mm.

2. Semimode testings of the pressure reservoir of outer diameter 1220 mm and the wall thickness 12 mm showed, that the pipe area with the relative dent depth of 5,33 % was not damaged at the pressure 10 MPa. According to the standard regulations [10], the admissible relative dent depth must not exceed 3,5 %. Thus, for this area of the pipe made of steel the 17G1S the relative dent depth is by 30 % larger than the maximum value admissible in the standard regulations [10]. It proves the fact, that for the given situation the admissible values presented in [10] are of the safety margin.

3. The carried out investigations testified, that the dent area of the pipe made of the steel 17G1S, being in operation since 1979, remained its bearing capacity and can transport gas at pressure 5,5 MPa. It is worth being taken into account during ranking of the detected defects and scheduling the sequence of the repairing-maintenance operations.

References

1. SOU 60.3-30019801-006.2004. Standart orhanizatsii Ukrainy: Haluzeva systema diahnostychnoho obsluhovuvania obladnania mahistralnykh hazoprovodiv ta AHNKS. – K.: DK „Ukrtranshaz”, 2004. 178 p. [In Ukrainian].
2. Banakhevych Yu.V., Banakhevych R.Yu. Dosvid identyfikatsii vyiavlenykh defektiv vnutrishnotrubnoiu diahnostykoiu v DK „Ukrtranshaz”, Tekhnicheskaia diagnostika i nerazrushayushchiy control, no. 2, 2013, pp. 40 – 46 [In Ukrainian].
3. SOU 60.3-30019801-067.2009. Standart orhanizatsii Ukrainy: Mahistralni hazoprovody. Otsinka faktychnoho tekhnichnoho stanu potentsiino nebezpechnykh dilnyts. Metody i metodyky. – K.: DK „Ukrtranshaz”, 2009. 188 p. [In Ukrainian].

4. DSTU–NBV.2.3–21:2008. Vyznachennia zalyshkovoi mitsnosti mahistralnykh truboprovodiv z defektamy. – Kyiv: Minrehionbud Ukrainy, 2008. 88 p. [In Ukrainian].
5. ASME B31G. American Society of Mechanical Engineers. Manual for determining the remaining strength of corroded pipelines. New York. 1991.
6. Savula S.F., Banakhevych Yu.V., Oliinyk I.Ya., Bakaiev O.Ya. Rezultaty vnutrishnotrubnoi diahnostyky MH (Komarno-derzhkordon Ukrainy-Respublika Polshcha). Informatsiinyi ohliad DK Ukrtranshaz. Vol. 42, no. 6, 2006, pp. 17 – 19 [In Ukrainian].
7. Soloviov O.B. Provedennia vnutritrubnoi diahnostyky prykordonnykh dilnyts mahistralnykh hazoprovodiv Sumskoho LVUMH MH „Kyivtranshaz". Pidvyshchennia nadiinosti ta efektyvnosti roboty liniinoi chastyny mahistralnykh hazoprovodiv hazotransportnoi systemy DK „Ukrtranshaz". Kyiv: DK „Ukrtranshaz", NVTS „Tekhdiahaz", 2012, pp. 86 – 92 [In Ukrainian].
8. STP 320.30019801.052-2002. Standart pidpryiemstva: Mahistralni hazoprovody. Propuskannia vnutrishnotrubnykh zasobiv na dilnytsi hazoprovodu. K.: DK „Ukrtranshaz", 2009. 40 p. [In Ukrainian].
9. STP 320.30019801.066-2002. Standart pidpryiemstva: Mahistralni hazoprovody. Vnutrishnotrubne obstezhennia liniinoi chastyny. K.: DK „Ukrtranshaz", 2010. 21 p. [In Ukrainian].
10. Polozhennia pro analiz vnutrishnotrubnoi diahnostyky mahistralnykh hazoprovodiv DK „Ukrtranshaz" ta orhanizatsiiu vykonannia remontnykh robit z usunennia defektiv. DK „Ukrtranshaz". Kyiv, 2009. 31 p.
11. Nonemaker J., Steinvoorte T., Subramanian R. Planting the Flags. // Pipelines international. Issue 34. 2017. Pp. 18 – 20.
12. O'Brian J., Moran S., Kirkwood M. Impact of crack profiles on pipeline integrity: advancing assessments with new ILI capabilities system // Pipelines international. Issue 32. 2017. Pp. 22 – 25.
13. Barbian A., Beller M., Thielager N., Willems H. A new in-line inspection tool for the quantitave wall-thickness measurement of gas pipelines: first results.// International conference "Pipeline Technology 2009". (October, 11 – 14, 2009, Ostend, Belgium). 2009. Pp. 305 – 306.
14. Dubovoi Ye.V., Okhrimchuk S.O. Problemy provedennia diahnostyky i neruinivnoho kontroliu mahistralnykh hazoprovodiv v protsesi ekspluatatsii. Pidvyshchennia nadiinosti ta efektyvnosti roboty liniinoi chastyny mahistralnykh hazoprovodiv hazotransportnoi systemy DK „Ukrtranshaz". Kyiv: DK „Ukrtranshaz", NVTS „Tekhdiahaz". 2012. Pp. 14 – 18. [In Ukrainian].
15. Lokhman I.V., Banakhevych Yu.V., Drohomyretskyi M.M. ta in. Vyznachennia mozhlyvosti i umov propusku diahnostychnykh porshniv na diliantsi vantovoho perekhodu. Truboprovidnyi transport. Spets. vyp. „Aktualni problemy tekhnichnoho diahnostuvannia truboprovodiv i tekhnolohichnoho obladnannia na nykh". 2008, pp. 38 – 43 [In Ukrainian].
16. Tesliuk V.M., Kharchenko L.Ye. Matymatychne modeliuvannia zhynnykh kolyvan priamoliniinoi dilianky truboprovodu pid diieiu rukhomoho diahnostychnoho porshnia. Modeliuvannia ta informatsiini tekhnolohii: Zbirnyk naukovykh prats. Vyp. 69. Kyiv: Instytut problem modeliuvannia v enerhetytsi im. H.Ye. Pukhova NAN Ukrainy. 2013, pp. 126 – 135 [In Ukrainian].
17. Kharchenko L. Fluctuation of multi-section aboveground pipeline region under the influence of moving diagnostic piston / Lidiya Kharchenko, Yevhen Kharchenko// Vibration in Physical Systems. V. 26. Poznan: Poznan University of technology, 2014. Pp.105 – 112.
18. Oryniak I.V., Lokhman I.V. Nekruhlist formy truby ta ii vplyv na napruzhenyi stan pry navantazhenni vnutrishnim tyskom. Pidvyshchennia nadiinosti ta efektyvnosti roboty liniinoi chastyny mahistralnykh hazoprovodiv hazotransportnoi systemy: zbirnyk dopovidei (Yaremche, 2012) DK „Ukrtranshaz". 2012, pp. 3 – 13 [In Ukrainian].
19. Enrique Acuna C. Minimising threats and maximising safety: an integrity management system // Pipelines international. Issue 34. 2017. Pp. 38 – 40.
20. Oryniak I.V., Shlapak L.S. Otsenka predelnogo davleniia truby s vmiatinoy. Problemy prochnosti. 2001, no. 5, pp. 101 – 110 [In Russian].
21. Marushchak P.O., Bishchak R.T., Danyliuk I.M. Trishchynostiikist materialiv i konstruktsii: tryvaloekspluatovani mahistralni hazoprovody. Ternopil: "ZAZAPRINT". 2016, 184 p. [In Ukrainian].
22. Alexander Chris, Evaluating damage to on – and offshore pipelines using data acquired using ILI. // Journal of pipeline engineering. Vol. 8, №1 First Quarter. 2009, pp. 35 – 46.
23. Savula S.F., Banakhevych Yu.V., Drahiliev A.V., Kychma A.O. Opyt primeneniia elektromagnitnogo markirovaniia pri provedenii vnutritrubnoy diagnostiki gazoprovodov v UMG „Lvovtransgaz". Materialy XIII Mezhdunarodnoy delovoy vstrechi „Diagnostika 2003" „Malta". 2003. Tom 3. Chast 1. Pp. 70 – 74 [In Ukrainian].
24. SOU 60.3-30019801-007:2004. Standart orhanizatsii Ukrainy: Mahistralni hazoprovody. Neruinivnyi control pry kapitalnomu remonti. K.: DK „Ukrtranshaz", 2004. 54 p. [In Ukrainian].

Список використаної літератури

1. СОУ 60.3-30019801-006.2004. Стандарт організації України: Галузева система діагностичного обслуговування обладнання магістральних газопроводів та АГНКС.– К. : ДК «Укртрансгаз», 2004. – 178 с.
2. Банахевич, Ю.В. Досвід ідентифікації виявлених дефектів внутрішньотрубною діагностикою в ДК «Укртрансгаз» [Текст] / Ю.В. Банахевич, Р.Ю. Банахевич // Техническая диагностика и неразрушающий контроль. – № 2. – 2013. – С. 40 – 46.
3. СОУ 60.3-30019801-067:2009. Стандарт організації України: Магістральні газопроводи. Оцінка фактичного технічного стану потенційно небезпечних дільниць. Методи і методики. – К. : ДК «Укртрансгаз», 2009. – 188 с.
4. ДСТУ–НБВ.2.3–21:2008. Визначення залишкової міцності магістральних трубопроводів з дефектами. – Київ: Мінрегіонбуд України, 2008. – 88 с.
5. ASME B31G. American Society of Mechanical Engineers. – Manual for determining the remaining strength of corroded pipelines. – New York. – 1991.
6. Результати внутрішньотрубної діагностики МГ (Комарно-держкордон України – Республіка Польща) [Текст] / С.Ф. Савула, Ю.В. Банахевич, І.Я. Олійник, О.Я. Бакаєв // Інформаційний огляд ДК Укртрансгаз, 2006. – № 6 (42). – С. 17 – 19.
7. Соловйов, О.Б. Проведення внутрішньотрубної діагностики прикордонних дільниць магістральних газопроводів Сумського ЛВУМГ МГ "Київтрансгаз" [Текст] / О.Б. Соловйов // Підвищення надійності та ефективності роботи лінійної частини магістральних газопроводів газотранспортної системи ДК «Укртрансгаз». – Київ: ДК «Укртрансгаз», НВЦ «Техдіагаз», 2012. – С. 86 – 92.
8. СТП 320.30019801.052-2002. Стандарт підприємства: Магістральні газопроводи. Пропускання внутрішньотрубних засобів на дільниці газопроводу. – К. : ДК «Укртрансгаз». – 2009. – 40 с.
9. СТП 320.30019801.066-2002. Стандарт підприємства: Магістральні газопроводи. Внутрішньотрубне обстеження лінійної частини. – К. : ДК «Укртрансгаз». – 2010. – 21 с.
10. Положення про аналіз внутрішньотрубної діагностики магістральних газопроводів ДК “Укртрансгаз” та організацію виконання ремонтних робіт з усунення дефектів. – ДК “Укртрансгаз”. – Київ, 2009. – 31 с.
11. Nonemaker, J. Planting the Flags [Text] / J. Nonemaker, T. Steinvoorte, R. Subramanian // Pipelines international. – Issue 34. – 2017. – P. 18 – 20.
12. O’Brian, J Impact of crack profiles on pipeline integrity: advancing assessments with new ILI capabilities system [Text] / J. O’Brian, S. Moran, M. Kirkwood // Pipelines international. – Issue 32. – 2017. – P. 22 – 25.
13. A new in-line inspection tool for the quantitave wall-thickness measurement of gas pipelines: first results. [Text] / A. Barbian, M. Beller, N. Thielager, H. Willems // International conference “Pipeline Technology 2009”. (October, 11 – 14, 2009, Ostend, Belgium). – 2009. – P. 305 – 306.
14. Дубовой, Є.В. Проблеми проведення діагностики й неруйнівного контролю магістральних газопроводів в процесі експлуатації [Текст] / Є.В. Дубовой, С.О. Охрімчук // Підвищення надійності та ефективності роботи лінійної частини магістральних газопроводів газотранспортної системи ДК «Укртрансгаз». – Київ : ДК «Укртрансгаз», НВЦ «Техдіагаз», 2012. – С. 14 – 18.
15. Визначення можливості і умов пропуску діагностичних поршнів на ділянці вантового переходу [Текст] / І.В. Лохман, Ю.В. Банахевич, М.М. Дрогомирецький та ін. // Трубопровідний транспорт. Спец. вип. “Актуальні проблеми технічного діагностування трубопроводів і технологічного обладнання на них”. – 2008. – С. 38 – 43.
16. Теслюк, В.М. Математичне моделювання згинних коливань прямолінійної ділянки трубопроводу під дією рухомого діагностичного поршня [Текст] / В.М. Теслюк, Л.Є. Харченко // Моделювання та інформаційні технології: Збірник наукових праць. – Вип. 69. – Київ : Інститут проблем моделювання в енергетиці ім. Г.Є. Пухова НАН України, 2013. – С. 126 – 135.
17. Kharchenko, L. Fluctuation of multi-section aboveground pipeline region under the influence of moving diagnostic piston [Text] / Lidiya Kharchenko, Yevhen Kharchenko// Vibration in Physical Systems. – V. 26. – Poznan: Poznan University of technology, 2014. – P. 105 – 112.
18. Ориняк, І.В. Некруглість форми труби та її вплив на напружений стан при навантаженні внутрішнім тиском [Текст] / І.В. Ориняк, І.В. Лохман // Підвищення надійності та ефективності роботи лінійної частини магістральних газопроводів газотранспортної системи: збірник доповідей (Яремче, 2012) / ДК “Укртрансгаз”. – 2012. – С. 3 – 13.
19. Enrique Acuna, C. Minimising threats and maximising safety: an integrity management system [Text] / Enrique Acuna, C. // Pipelines international. – Issue 34. – 2017. – P. 38 – 40.
20. Ориняк, І.В. Оценка предельного давления трубы с вмятиной [Текст] / І.В. Ориняк, Л.С. Шлапак // Проблемы прочности. – 2001. – № 5. – С. 101 – 110.

21. Марущак, П.О. Тріщиностійкість матеріалів і конструкцій: тривалоексплуатовані магістральні газопроводи [Текст] / П.О. Марущак, Р.Т. Біщак, І.М. Данилюк. – Тернопіль: "ZAZAPRINT", 2016. – 184 с.
22. Chris, Alexander. Evaluating damage to on – and offshore pipelines using data acquired using ILI. [Text] / Chris Alexander // Journal of pipeline engineering. – Vol.8, №1 First Quarter. – 2009. – P. 35 – 46.
23. Опыт применения электромагнитного маркирования при проведении внутритрубной диагностике газопроводов в УМГ «Львовтрансгаз» [Текст] / С.Ф. Савула, Ю.В. Банахевич, А.В. Драгилев, А.О. Кычма // Материалы XIII Международной деловой встречи "Диагностика – 2003" Мальта. – 2003. Том 3. – Часть 1. – С. 70 – 74.
24. СОУ 60.3-30019801-007:2004. Стандарт організації України: Магістральні газопроводи. Неруйнівний контроль при капітальному ремонті. – К. : ДК «Укртрансгаз», 2004. – 54 с.

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ОЦІНЮВАННЯ РОБОТОЗДАТНОСТІ МАГІСТРАЛЬНИХ ТРУБОПРОВОДІВ ЗА РЕЗУЛЬТАТАМИ ВНУТРІШНЬОТРУБНОЇ ДІАГНОСТИКИ

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Резюме. *Проаналізовано сучасний стан внутрішньотрубної діагностики магістральних трубопроводів як в Україні, так і в країнах близького та далекого зарубіжжя з використанням PPIM та ILI технологій. Проведено експериментальні дослідження оцінювання несівної здатності ділянки трубопроводу з пружно-пластичним деформуванням, яка була виявлена під час проведення внутрішньотрубного діагностування тривало експлуатованого магістрального газопроводу з зовнішнім діаметром 1220 мм. Для визначення ранжування виявлених різнотипних дефектів, запропоновано підхід числового моделювання трубопровідних ділянок, який базується на основі теорії пружно-пластичного деформування оболонок і сучасних алгоритмів дискретизації нелінійних задач механіки методом скінченних елементів. Проведено моделювання напружено-деформованого стану пошкоджених ділянок трубопроводу за допомогою програми Solid Works Simulation. Дослідження впливу локальних пластичних деформацій ділянки труби на її несівну здатність проводили на випробувальному напірному резервуарі, який піддавали гідравлічному випробуванню статичним тиском. Східчасто збільшуючи тиск P у резервуарі з кроком ΔP=1 MPa, конролювали зміну глибини вм'ятини, проводили візуальний контроль зварних швів. Фіксували також параметри напруженого стану за допомогою вимірювального приладу «MESTR-411» і твердість металу котушок переносним електронним твердоміром «ТЕМП-3». При цьому вимірювання проводили кілька разів і визначали їх усереднені значення. Експериментально досліджено двовісний напружений стан в умовах пружного і пластичного деформування труб випробувального напірного резервуару, а саме, стан деформованої стінки труби з вм'ятиною і процес зворотного деформування стінки котушки під дією внутрішнього тиску. Руйнування випробувального резервуару відбулося при досягненні тиску 10,0 MPa. Сформульовано рекомендації для інженерної практики.*

Ключові слова: *магістральні трубопроводи, внутрішньотрубна діагностика, пружне і пластичне деформування, дефекти, руйнування, міцність.*

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