Evaluation of the strong performance of the circular welded pipe connections with corrosion defects

UDC 622.692.4

© **O. S. Tarayevskyi**
Candidate of Technical Sciences
IFNTUNG

The paper shows the results of experimental studies and the analysis of the impact of long service life of the main gas pipelines, as well as of natural concentrators of stresses on the physical and mechanical p roperties of welded joints of steel 17G1S. A methodology was developed and patterns of gas pipeline welded joint material failure at static and low-frequency loads were established, as well as impact of stress concentrators during prolonged use. Some aspects of the mechanism of pipeline welded joint failure are considered.

Key words: corrosion, damage, pipes, welding joint, working pressure, hydraulics tests.

The problem of provision of high operational reliability of the header pipelines (HP) is of great value to the national economy of Ukraine, since their major part has been in operation for a long time and has exhausted its regulatory resources. Stable operation and high cost effectiveness of HP primarily depends on its technical condition. During the technical evaluation of the pipeline the reliable measurement of the stress-strain state (SSS) of its linear part as one of the main factors affecting the level of the structure operational reliability plays an important role. Otherwise the pipelines may be found in an emergency.

From the analysis of the causes of HP accidents it was established that their failures are associated with metal ruptures on the whole or on the metal rings in butt joints.

More than 50% structures are destroyed due to the corrosion damage, 37% accidents are caused by poor quality metal, its lack of ductility, impact strength, poor fusion lines, factory seams etc.

The detailed analysis of the causes of accidents in many cases helped to establish a direct link of the source of destruction origin with any, though hardly noticeable, defect of the metallurgical, manufacturing, construction and assembly or operational nature. This defect is the hub of stress on internal and external surfaces of the pipe. The factory defects are manifested in the form of defects of the pipe metal, non-metallic inclusions in the form of sulphide bands, shells, incomplete removal of residual local stresses of the welding seams, defects of mechanical damage of the inner surface of the pipe. During installation of pipelines and transportation of pipes to the destination point the mechanical damage in the form of dents, pockets, scratches, and defects in the transverse junction seams, including the lack of penetration etc.

To identify the impact of the working corrosion environment on the degree of strength and durability of steel pipes, it is necessary to characterize the corrosive environment. The interaction of the environment and the metal will depend on:

chemical composition and its individual components;

plastic and elastic deformation;

surface condition.

It is necessary to distinguish between three possible cases of the metal hydrogenation leakage:

hydrogenation of the metal with unstrained lattice;

hydrogenation of the metal with deformed lattice (cold metal deformation processes);

hydrogenation in the course of the metal deformation.

The structural condition of steel and its deformation significantly affect both the electrochemical corrosion processes and the diffusion processes, and the more unstable the phases are, the higher is its sensitivity to corrosion.

Improving the efficiency of GTS is an important issue that needs to be addressed. The process of designing and operation of such GTSs has some specific features. The imbalance in volumes of gas supply and its consumption leads to non-stationary gas flows, which in combination with a complex technological scheme of gas pipelines and rugged profile of the track makes it difficult to predict the operation modes and their management. The science-based definition of targets in terms of gas supply in non-stationary conditions it that you need to have reliable information on the daily, seasonal and other unevenness of gas consumption.

Table 1

Objects of tests and their main characteristics

Pipe No.	Dn×δ , mm steel make	Useful life before elimination, years	Cause of elimination by defect type	Dimensions of the maximum defect, mm	The maximum pressure (MPa), the nature of damage
1	1220 × 12 17 G 1 C	13	corrosion by VTD	1100 × 520 × 2,8	9.2, the state of fluidity
2	1220 × 14,5, 17 G 1 C	13	corrosion by VTD	3000 × 3,5	12.0, viscous
3	1220 × 12 17 G 1 C	17	accident KRN	general corrosion 800 × 0,5	9, 8, viscous
4	1220 × 12, 17 PSU	6	corrosion by VTD	general corrosion 800 × 4,4	11.0, viscous
5	1020 × 9, 17 G 1 C thermally reinforced	18	corrosion by VTD	peptic corrosion 900 × 4,4	8.0, viscous
6	1020 × 9, 17 G 1 C thermally reinforced	18	corrosion by VTD	peptic corrosion 300 × 3,0	10.5, viscous
7	1220 × 10,5; 17 G 2 SF, thermally reinforced	23	accident, structural defects in metal	cavity with depth up to 2.5	11, 3, viscous
8	1220 × 12,5, 17 GS	30	MG section which emerged in the swamp	corrugations, indentations 1220 × 800 × 109, ulcers up to 2.0	11.0, viscous

To date, there are two major emerging trends of forecasting:

• perspective (determination of uneven gas consumption in the design problems and development of gas supply systems);

• operational (construction and analysis of consumption graphs for mode control in real systems of gas transportation).

It is believed that industrial gas consumers consume gas evenly throughout the day. This statement is not always true, as the number of gas consumed as fuel in industry depends on many factors, such as uneven receipt of raw materials, process requirements to the quality of products etc. Therefore, for the industrial gas consumers there is also the daily non-uniformity of gas consumption, which may differ significantly from the non-uniformity of gas consumption by households, which is mainly determined by lifestyle and the related nature of power consumption. The buffer consumers can use different fuels (including the natural gas), and their use in the region leads to smoothing of uneven gas consumption.

The fluctuations of operating pressure in GTS pipelines during the day depend on the nature of the consumption of a particular region, which has a number of gas consumers. The number and nature of gas consumption by them during the days determine the fluctuations of consumption in the gas transportation system, which in turn causes pressure fluctuations. The nature of gas consumption by consumers is subdivided into three groups, i.e. industrial gas consumers, households and buffer consumers. However, this subdivision is quite arbitrary.

For efficient supervisory control the record of fluctuations in gas consumption during the day is of primary importance. For such studies it is important to establish the cause of the non-stationary processes, which in most cases determines the nature of its flow. All causes of occurrence of the non-stationary processes can be subdivided into permanent and pulsed.

In addition, a sharp increase or reduction of gas intake by the consumers leads to instability of its flow in the pipeline, and unsteady processes resulting from changes in the density of gas can last for hours or even days. The similar consequences are brought about by the increase or reduction of the gas swap, the sudden switching on or off of the compressor stations, opening or closing of valves etc. Therefore, the overall process of pressure monitoring in the pipeline is characterized by the range of frequencies.

Problem Status

The underground gas mains, despite the comprehensive protection against corrosion, including the passive protection with anti-corrosion coatings and active electric chemical protection, yet are often exposed to various degrees of corrosive damage. However, to date the regularities of strength behavior of the corrosion defects are not studies in full.

Thus, the existing regulatory requirements for safe and failure-free operation of gas mains quite clearly regulate the immediate removal of substandard corrosion damage. Among other things, the development of corrosion defect in underground pipes is latent in nature and usually occurs suddenly in the form of emergency failures of varying complexity. In this situation, the methods allowing to estimate the rate of exhaustion of the strength resource of the gas pipe leading to the development of corrosion defects remain incomplete. On the other side, the modern ways of intra-pipe defectoscopy with direct measurement within one-cycle inspection help to identify the vast majority of corrosion defects. Meanwhile we see the picture of plurality of corrosion damage, the removal of which requires scientific justification of temporary priorities, since the instant elimination of defects, as required by the applicable regulations, is not possible for technical reasons.

To clarify these gaps in research and industrial stand, the large-scale hydraulic tests of corrosion damaged pipe found defective in the operated gas pipelines was performed.

The following classification group analyzes the results of tests of eight facilities (Table 1) prone to corrosion damage with the depth of more than 10% of the wall thickness.

It should be noted that the corrosion defects are found only on the outer surface of the pipe in the sites of through or closed injuries of insulation coating. Obviously, the corrosion thinning of the pipe wall cause the local increase of the stress-strain state and weakening of the pipe. Intuitively, this can be illustrated by comparing the deformation of defect-free and defective areas during tests of the pipe seams 12 and 13. The measurement results are presented in table. 2.

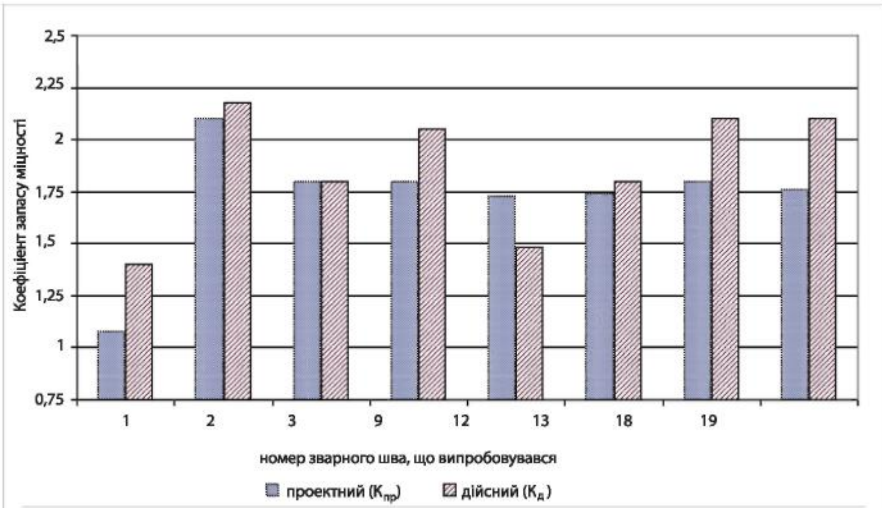

Fig. 1. Comparison of designed and actual reserve ratios

Table 2

Results of tube deformation in the transverse direction from action of the internal pressure

Tensimeter installation site	Increase of tensimeter indications with changing pressure, MPa						The average deformation subject to pressure change by 1 MPa	
	0 ÷ 1	1 ÷ 2 2 ÷ 3 3 ÷ 4			4 ÷ 5	5 ÷ 6	Tensimeter graduation	Relative%x10^2
Welded pipe seam 12								
Vast corrosion zone with the depth up to 4.4 mm	-1	32	29	28	22	24	27	6.75
Short defect with the depth up to 4 mm	13	14	13	13	10	12	12, 5	3.13
Vast corrosion zone with the depth up to 4.1 mm	56	27	20	17	15	15	18, 8	4.70
Short defect with the depth up to 5.2 mm	16	14	6	8	8	11	10.5	2.63

Short defect with the depth up to 4.5 mm	34	20	16	17	13	12	14.4	3.60
Long defect with the depth up to 3.5 mm	19	12	9	10	7	9	9.4	2.35
Welded pipe seam 13								
Vast corrosion zone with the depth up to 1 mm	53	17	18	14	13	10	14.4	3.60
Vast corrosion zone with the depth up to 3 mm	80	29	26	18	17	13	20.6	5.15
Vast corrosion zone with the depth up to 2.5mm	63	28	22	16	5	22	18.6	4.65
Undamaged pipe	10	9	14	11	10	10	10.7	2.68

From Table 2 we can see that the actual deformation of the pipe in the undamaged area is comparable to the calculated value determined according to the generalized Hooke's law for plane stressed state, i.e. the obtained results, excluding the clearly abnormal indications of some tensimeters observed at the first stage of the load, should reflect the ongoing processes clearly enough.

Then, returning to the obtained results, we can state that tensimeters 2, 4 and 6, usually installed in the area of non-extensional defects, fixed the deformation comparable to the deformation of the undamaged pipe, i.e. such defects did not cause a marked strength reduction.

Still, the areas of the major corrosion defects (tensimeters 1, 3, 8 and 9) have been subject to deformation to a much greater extent than with defect-free pipe, i.e. these areas had higher stress. As the subsequent load showed, the break of seam 12 happened in the area of installation of tensimeter 1, where the greatest deformation was fixed that exceeded the undamaged zone deformation 2.52 times. As for pipe 13, in the course of tests it was subjected to artificial defects, which became the center of destruction.

In addition to the above, the real integral estimate of availability and value of weakening of the defective pipe still can be determined only after its destruction, as it was done in the final stages of testing of pipe seams 2, 3, 9, 13, 18 and 19.

The test and calculation results of the considered pipe seams are presented in Table 3.

Hence we see that the five tested joints (1, 2, 9, 12 and 13) have the corrosion defects which, pursuant to the applicable statutory documents, are classified as inadmissible.

The presence of such damages required the repairs to eliminate them or reduce the operating pressure down to safe values (by 4.3 to 30% of the designed pressure).

Table 3

The results of tests and calculation of the welded pipe seams with corrosion damage

Parameter			Number of the tested pipe welding seam							
			1	2	3	9	12	13	18	19
Diameter and nominal thickness of the pipe wall, mm			1220 × 12, 0	1220 × 14,5	1220 × 12,0	1220 × 12,0	1020 × 9,0	1020 × 9,0	1220 × 10,5	1220 × 12,0
Steel make			17G1S	17G1S	17G1S	17G1SU	17G1S	17G1S	17G2SF	17GS
Statutory mechanical characteristics, MPa	Tensile strength, σ_{in}		520	520	520	520	600	600	550	520
Corrosion defect	Yield point, σ_t		360	360	360	360	420	420	380	350
	Short (s) Long (l)		l	l	l	l	l	l	s	l
	Maximum defect depth	mm	2.8	3.5	0.5	4.4	4.4	3.0	2.5	2
		%	23.3	24, 1	4.2	36.7	48.9	33.3	23.8	16.0
Allowed defect depth,%			21.2	21.7	21.2	21, 2	28, 1	August 2, 1	70.0	22.2
Pressure of the welded seam rupture, MPa			9.2	12 0	9.8	11 0	8.0	10.5	11, 3	11 0

Coefficient of the designed strength reserve, K^{T}_{av}	1.8	2, 15	1.8	1, 8	1.71	1.71	1, 8	1.8
Coefficient of the designed reserve outside the yield point, K_d	1.05	1.26	1.05	1, 05	1.0	1.0	1.05	1.05
The actual rate of strength reserve, K_{pr}	1.48	2.22	1.81	2.04	1.48	1.94	2.09	2.04
Index of strength reliability K_d / K_{Ave}	1, 41	1.03	1,006	1.13	0.87	1.13	1.16	1.13
Permissible operating pressure	5, 17,	5.15	5.4	4.27	3.78	4.94	5.4	5.4
Permissible operating pressure	4.14	4.22	5, 17,	3.42	2.76	3.6	4, 11	4.54

Having assessed the damage, the defects in the welded pipe 18 can be classified as requiring repair. Meanwhile the level of operating pressure reduction at all tested facilities (in case of failure of repair) becomes even more significant (by 4.3 to 27.1%) compared to the original version.

At the same time the comparison of the actual K_d and designed K_{av} of the strength reserve ratios and their ratio K_d/K_{Ave}, the graphic images of which are given in Fig. 1 and 2, shows that only in one case (welded pipe seam 12) the required pipe reliability is not provided.

According to [5, 6], if it is impossible to carry out the repair works here, it is necessary to reduce the operating pressure to 3.78 MPa, which is 70% of the designed pressure.

Incidentally, the results of hydraulic test of this welded seam show that the designed reserve factor is ensured by the operating pressure, equal to p = 8/1, 71 = 4.68 MPa (86.7% of the designed pressure), i.e. by 23.8% more than its value.

For other welded pipe seams, save for facility 1, wherein the tube has been led to the metal fluidity only, the actual strength reserve vs. the designed one is 0.6 to 16% (see Fig. 2), i.e. the actually required pipe reliability is provided even in the case when the applicable regulations require the repair or technological measures to reduce the operating pressure (welded seams 2, 9 and 13).

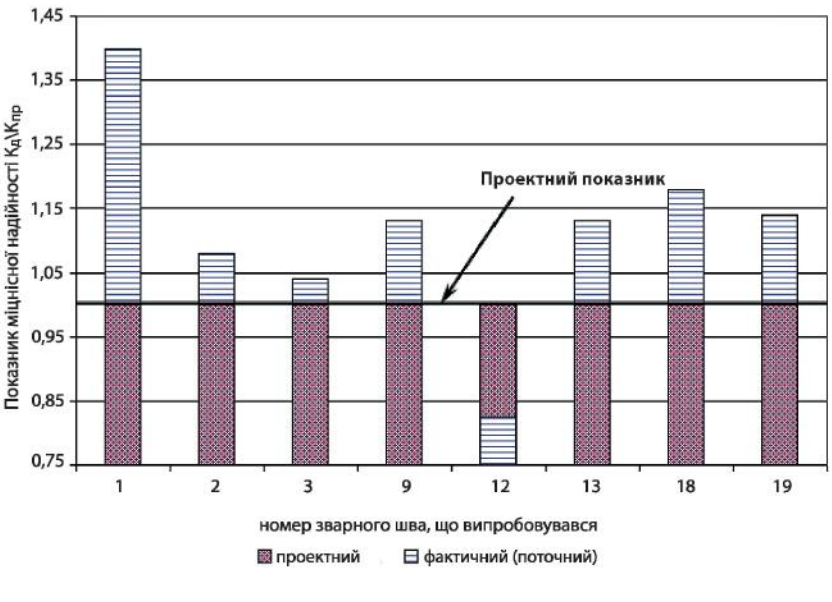

Fig. 2. Indicators of strength reliability for the tested welded pipe seams

Conclusion

So, as a result of hydraulic testing of welded pipe seams with inside pressure it was found that subject to availability of the corrosion damage in excess of the regulatory value, the current level of strength resource of gas pipes turns out to be ambiguous: it may remain sufficient to secure the further operation (welded pipe seams 9, 13, 18 and 19), be critical or equal (welded pipe seams 2 and 3) not defined for evaluation (welded pipe seam 1) or actually dangerous (welded pipe seam 12). Each of these states requires individual control of the operational reliability level of the gas transportation facility. In the first case, is an integral monitoring, in the second it is regular maintenance, in the third it is designing of detailed studies, and in the fourth it is urgent repairs etc. This control should be based on the system of criteria priorities for assessment of the current efficiency of gas pipes prone to corrosion.

The tests show that the calculation of allowable stresses arising inside the gas pipe and resulting from uneven gas consumption in irrigating environments should be carried out in view of $p_{кс}$ coefficient, which will allow increasing them, and thus increasing the throughput capacity of the mains by increasing the pressure. The presented method allows making the right and reasonable choice of the magnitude of allowable stresses and the required number of loading cycles in the course of operation of the working environment. The fatigue processes in steel are probabilistic in nature. This, together with non-destructive control methods and the use of risk analysis within the framework of the existing security concept ("implement and correct"), allows to maintain the pipeline in the working condition. However, indisputable is the fact that in these operating conditions (I underline the joint action of variable loads and environment) and during the long-term operation the pipe material accumulates the defects that eventually lead to their destruction. The specific hazards is posed by remote places (it is impossible to eliminate the risk in due time) or difficult operating conditions (e.g., the pipeline found itself in the shear zone). Here it is necessary to apply a new concept of risk analysis, i.e. "anticipate and prevent."

References

1. **Karpenko G.V.** Steel strength in corrosion environment/G.V. Karpenko. - M.: Mashgiz, 1963. - 188 p.

2. **Pokhmurskyi V.I.** Corrosion mechanical destruction of welded structures/V.I. Pokhmurskyi, R.K. Melekhov. - K.: Scientific opinion, 1990. - 347 p.

3. **Pokhmurskyi V.I.** Corrosion fatigue of metals/V.I. Pokhmurskyi. - M.: Metallurgy, 1985. - 207 p.

4. **Kryzhanivskyi E.I.** Influence of hydrogenation on corrosion and mechanical properties of welded seams of pipelines/E.I. Kryzhanivsky, O.S. Tarayevskyi, D. Y. Petrina // Exploration and development of oil and gas deposits. - 2005. – No. 1 (14). - p. 25 - 29.

5. **Kryzhanivskyi E.I.** Influence of uneven gas consumption on the pipe stressful condition/E.I. Kryzhanivskyi, O.S. Tarayevskyi // Exploration and development of oil and gas deposits. - 2004. – No. 3 (12). - p. 31 - 34.

6. **Tsyrulnyk O.T.** Sensitivity of the welded junction of steel 17G1S of the mains to hydrogen embrittlement / O.T. Tsyrulnyk, E.I. Kryzhanivskyi, O.S. Tarayevsky [et al.]. // Physical and chemical mechanics of materials. - 2004. – No. 6. - p. 111 - 114.

Article Author

Tarayevskyi Oleg Stepanovych

Candidate of Technical Sciences, assistant professor of oil and gas transportation and storage department of Ivano-Frankivsk National Technical University of Oil and Gas. Scientific research interests: provision of trouble-free operation of pipelines in difficult conditions.