NON DESTRUCTIVE TESTING OF WELDED JOINTS

IMPROVEMENT OF RELIABILITY OF MAIN GAS PIPELINES BY USING REPEATED IN-PIPE FLAW DETECTION

D.P. VARLAMOV[1], **V.N. DEDESHKO**[1], **V.A. KANAJKIN**[2] and **O.I. STEKLOV**[2]
[1]Closed Joint Stock Company «Research and Production Association «Spetsmash», Moscow, RF
[2]Gubkin Russian State University of Oil and Gas, Moscow, RF

It is shown that the presence of a large number of abnormalities in welded joints is hazardous for safe operation of the system of main gas pipelines not only because of the probability of failure of the welded joints, but also because of formation of an additional factor, i.e. initiation and propagation of stress corrosion cracking defects in a zone of intersection of longitudinal and circumferential welds.

Keywords: *welded pipelines, integrity, in-pipe flaw detection, general and local corrosion, stress corrosion cracking, abnormal circumferential welded joints*

Stability of delivery of gas to consumers in the Russian Federation, countries of the Western and Eastern Europe, as well as of the Balkan Region is inseparably connected to the reliability and safety of operation of the unified system of gas pipelines of Company «Gazprom». The Russian gas industry exhibits a gradual growth of volumes of gas production, the forecast for 2020 being 670 bln m^3. However, the unified gas transportation system built as far back as under the Soviet Union underwent substantial changes because of disintegration of the Soviet Union. Today the multiline corridors of main gas pipelines pass through foreign countries, and inspection of their condition depends in many respects on foreign partners. On the average, service life of the entire system of main gas pipelines of the former Soviet Union has amounted to 30 years or more.

At present, both the Russian Federation and foreign countries have worked out the technology for maintaining integrity of main gas pipelines and putting them into repair on a timely basis to ensure their safe operation and increase productivity under the rated gas pressure. The key stages of the technology for maintaining integrity of main gas pipelines are as follows:

- subjecting pipelines to regular in-pipe flaw detection (IPFD) procedures with an interval of 3–5 years;
- estimation of hazard of detected defects and monitoring of their development;
- timely performance of repair-and-renewal operations on the defects that are hazardous for integrity of main gas pipelines.

Modern development of the market economy under conditions of severe competition imposes increasingly serious requirements to elaboration of the most advanced technologies, their consistency in the process of manufacture of materials and parts, and in provision of services. In this case, quality and reliability, as well as durability of the products play a decisive role in successful activities of not only individual enterprises, but also entire branches of economy of the country. Therefore, inspection of the condition of materials and quality of products becomes highly topical. The latest science and technology achievements and developments, i.e. thermal, optical, X-ray, different types of hard and soft radiation, ultrasound, eddy currents, magnetic fields and other methods of physical metals science, are used to provide continuous improvement of the procedures used to test pipes in main pipelines [1].

The pipes laid down with violation of design solutions, especially in mountain, irregular and swamp lands, as well as the pipes having relative residual welding stresses in heat-affected zones of the welds or in zones of complete bending of plate edges, are particularly hazardous for main pipelines, as zones of local stresses in metal are nearly the most important cause of initiation and propagation of defects of the type of stress corrosion cracking (SCC). In view that the exact location of SCC defects in underground gas pipelines can hardly be predicted even by using many known methods of physical metals science, while ultrasonic IPFD of gas pipelines is too costly, the efforts in the industry are aimed at development of magnetic IPFD.

Magnetic flaw detection equipment. Magnetic flaw detection equipment developed during the last 15 years by CJSC «RPA «Spetsneftegaz» for inspection of main oil and gas pipelines can be rated as

Figure 1. Cleaning piston

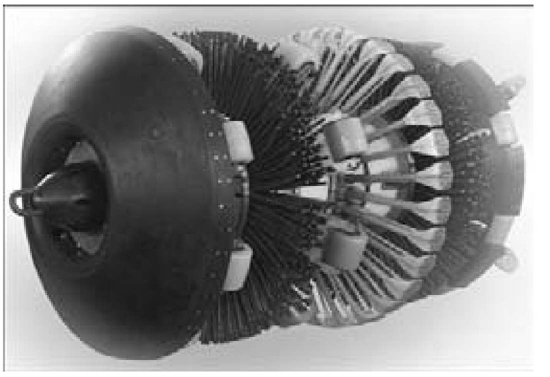

Figure 3. Electron multi-channel profile measurement gear

important achievements [2]. Development of domestic flaw detection gears allows comprehensive diagnostic examination of the conditions of pipelines and estimation of hazard of the detected damages in pipes. The IPFD system consists of several gears, each performing its function, where the starting sequence makes it possible to remove garbage and deposits from a pipe, determine the profile of pipes and possibility of passage of the flaw detection gears through the route, magnetise a pipeline and reveal the character and location of a damage at a high degree of precision. The system of gears for IPFD is shown in Figures 1–5.

The cleaning piston (Figure 1) designed for cleaning the internal cavity of a pipeline from garbage and deposits is equipped with calibration plates for initial determination of passability of a pipeline length.

The cleaning magnetic in-pipe one-section piston with a by-pass device (Figure 2) is intended for cleaning the internal cavity of a pipeline from ferromagnetic deposits and initial magnetisation. This is the first domestic in-pipe gear with a speed (by-pass) control device.

The electron multi-channel profile measurement gear (Figure 3) serves to reveal dents, crimps and out-of-roundness of a pipe, fix their sizes and locations on route of a gas pipeline, sense transverse welds, and initially detect corrosion defects.

The magnetic in-pipe two-section flaw detector for longitudinal magnetisation with a by-pass device (Figure 4), having the run speed regulation coefficient equal to 6, is meant to reveal defects of the type of metal losses on the internal and external surfaces of the pipe wall:

• general and pitting corrosion, transverse grooves, transverse cracks and abnormalities in transverse welds;

• defects of a mechanical origin, such as scores and scratches;

• defects of a metallurgical character — in-wall laminations and non-metallic inclusions.

The magnetic in-pipe two-section flaw detector for transverse magnetisation with a by-pass device (Figure 5) is designed for detection of SCC defects, transverse cracks, defects of the type of metal losses (general and pitting corrosion, longitudinal grooves), abnormalities in longitudinal welds, longitudinally oriented defects of a mechanical origin (scores, scratches), and defects of a metallurgical origin (in-wall laminations, non-metallic inclusions).

The flaw detector is equipped with an active by-pass having the run speed regulation coefficient equal to 6, which provides decrease in speed from 12 (speed of transportation of product via a pipe) to 2–3 m/s (optimal speed for magnetic flaw detection).

Analysis of unsoundness of welded joints, defects of general and local corrosion, and SCC defects in an extended multi-line system of main pipelines. This study presents analysis of unsoundness of an extended system of main gas pipelines with a diameter of 1420 mm conducted on a base of several sequential IPFDs by «Spetsneftegaz» by using a complete set of the equipment.

Analysis of unsoundness covered the scheme of propagation of such damages as general and local corrosion defects, SCC defects, abnormal circumferential welds, arrangement of the pipes laid down in sections,

Figure 2. Cleaning magnetic in-pipe one-section piston with by-pass device

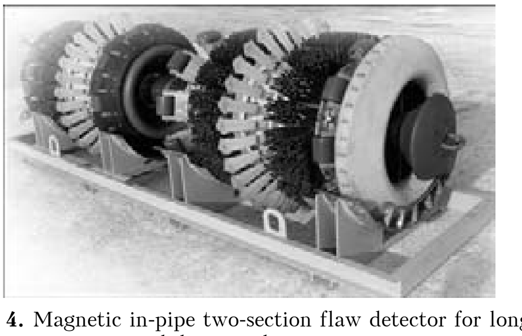

Figure 4. Magnetic in-pipe two-section flaw detector for longitudinal magnetisation with by-pass device

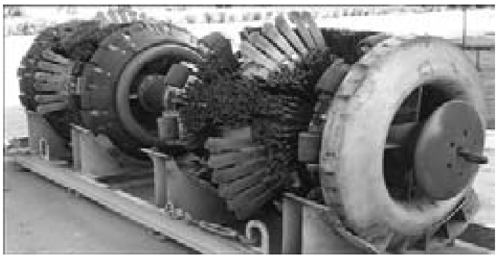

Figure 5. Magnetic in-pipe two-section flaw detector for transverse magnetisation with by-pass device

depending on the wall thickness and type of manufacture of the pipes over the major length of a region.

The data of estimation of unsoundness of 28 sections in the Western Siberia (two IPFDs were conducted with an interval of 4–5 years) on six parallel lines of the main gas pipeline were considered. It should be noted that a section extends to a distance from one compressor station (CS) to the other, the average length of one section being approximately 100 km [3].

General and local corrosion defects. Figure 6 shows zonality of propagation of general corrosion defects related to the explicit impact by relief and water cut. This can be seen at CS 9 and 10 — on all the lines, between CS 12 and 13 — on four lower lines at the end of the section, at CS 13 and 14 in the middle of the section — on four lower lines, and at the end of the section — on lines 1 and 2.

The total quantity of the general corrosion defects is high for the enterprise, and in many sections after the third IPFD the quantity of the defects substantially increased. No common regularity was fixed for propagation of the general corrosion defects over the section length, and the maxima were observed at the beginning, in the centre or at the end of a section on all parallel lines.

As established from the investigation results on the effect of the level of stresses and identification of a component of stresses that determines cracking and crack propagation path, corrosion cracks are caused by tensile components of stresses independently of the loading method. For all metals the time to cracking continuously decreases with growth of stresses. Increase of stresses caused by external loading, as well as of residual stresses leads to weakening and violation of continuity of protective films, growth of the concentration of elasto-plastic strains in microcracks and at the apex of a propagating crack, and to intensification of mechanical, corrosion and sorption processes related to the concentration of strains. Intensification of all related processes with increase in stresses results in acceleration of corrosion cracking.

Almost every section of all lines of gas pipelines in Western Siberia is subjected to SCC defects (Figure 7). The quantity of the SCC defects grows from inspection to inspection despite the efforts made to remove the earlier revealed defects. The new SCC defects are detected in sections where before they were absent, and they continue to be fixed in the sections where the SCC defects were already revealed and removed. Alarming is the fact of detection of the SCC defects in the third IPFD in second halves of the sections. The clear zonality of propagation of the SCC defects can be seen along the length of the sections

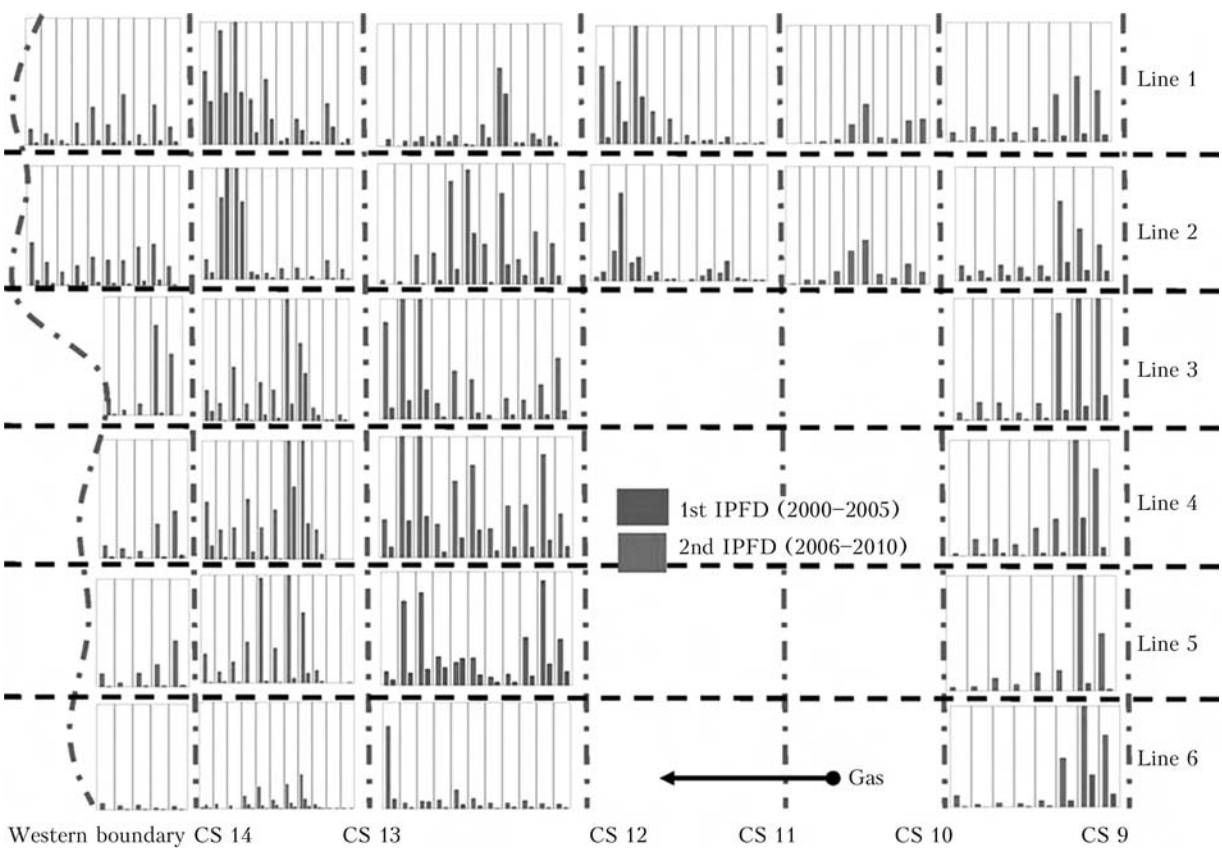

Figure 6. General and local corrosion defects of pipelines in Western Siberia: scale $0Y$ in all diagrams consists of 0–800 defects; scale $0X$ — length of the sections divided by 10 km

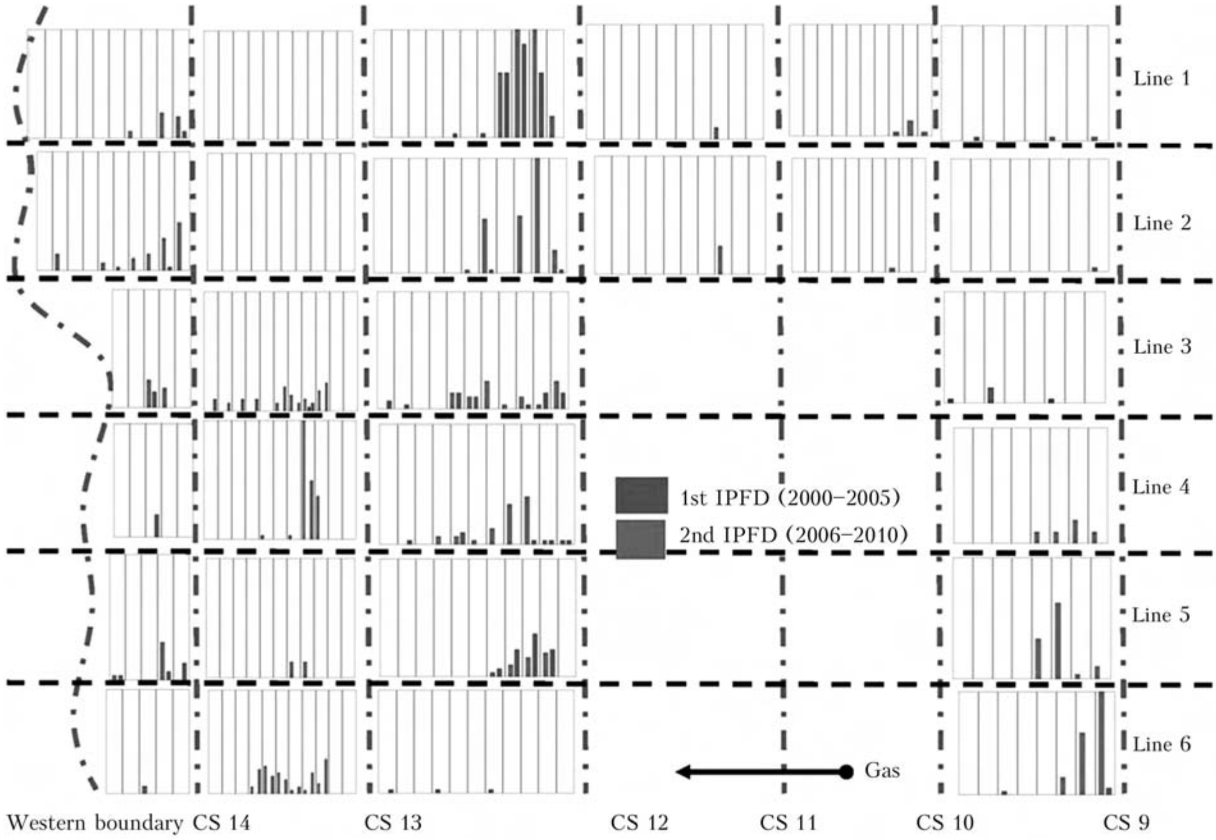

Figure 7. SCC defects of pipelines in Western Siberia: scale $0Y$ in all diagrams consists of 0–30 defects; scale $0X$ — length of the sections divided by 10 km

(there are much more SCC defects in the first half of the sections). The quantity of the SCC defects is substantially different in the same zones on parallel lines of gas pipelines, this being another evidence of a considerable effect of the wall thickness and type of the pipes laid down in the sections.

Abnormal circumferential welded joints. Specific features determining causes, character, kinetics and mechanism of corrosion fractures of the welded joints are attributable mainly to the thermal-deformation effect of the welding process, which causes unfavourable changes in properties of metal and its stressed state, this aggravating the negative impact of the environment.

Analysis of causes and mechanisms of failures of the welded joints on pipelines shows that fracture begins, as a rule, from the plane surface defects located mostly in the root layers of the welds. In all the cases, to ensure reliable and safe operation of a pipeline it is necessary to prevent development of a defect before it transforms into a through crack. Plane defects, i.e. cracks, lacks of penetration and undercuts, are most dangerous. One of the most common defects in butt welding of pipes is lack of penetration in the weld root. Often this defect combines with edge displacement. In the field welds it is difficult to technologically avoid formation of lacks of penetration and edge displacements [4].

Figure 8 shows abnormalities in the welded joints detected from the results of IPFD in the Central Region and in the Western Siberia. The Central Region was taken for comparison as a region with the best natural-climatic conditions for operation of main gas pipelines. It should be emphasised that the type of abnormality of a circumferential weld is established from the results of IPFD and requires a more precise definition using the external diagnostic equipment. A limited capability of the magnetic method used for IPFD, having a sufficient degree of reliability in identification of the type of abnormality, is shown in the first column of the diagram in Figure 8.

Unexpected corrosion-mechanical fractures of the welded joints and structures to form cracks of the avalanche type, caused by the combined impact of the environment and stresses under static (corrosion cracking), repeated static and cyclic loadings, are very hazardous.

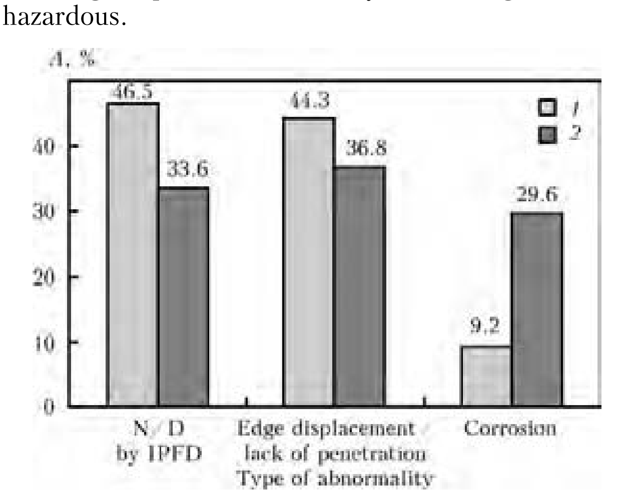

Figure 8. Types of abnormalities A in joints revealed in third IPED in the Central Region (*1*) and Western Siberia (*2*)

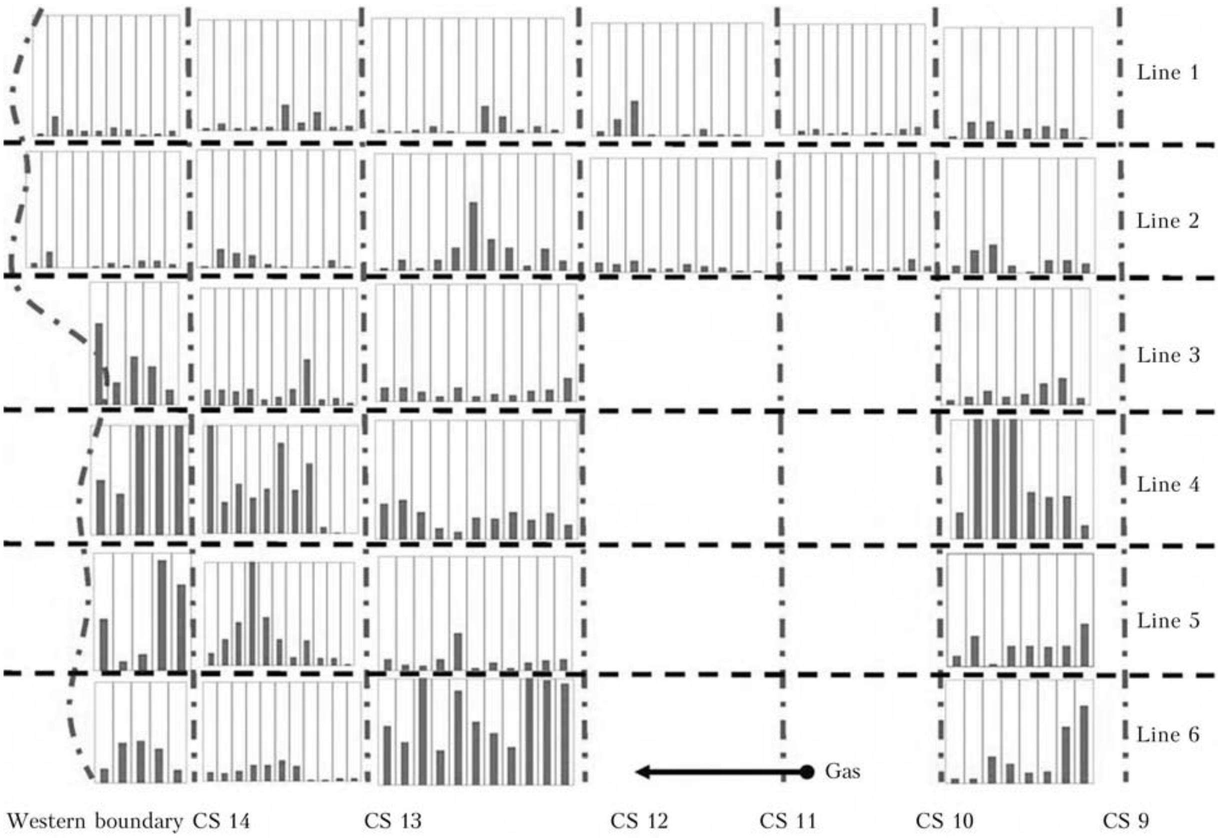

Figure 9. Abnormal circumferential welds on pipelines in Western Siberia: scale $0Y$ in all diagrams consists of 0–100 defects; scale $0X$ — length of the sections divided by 10 km

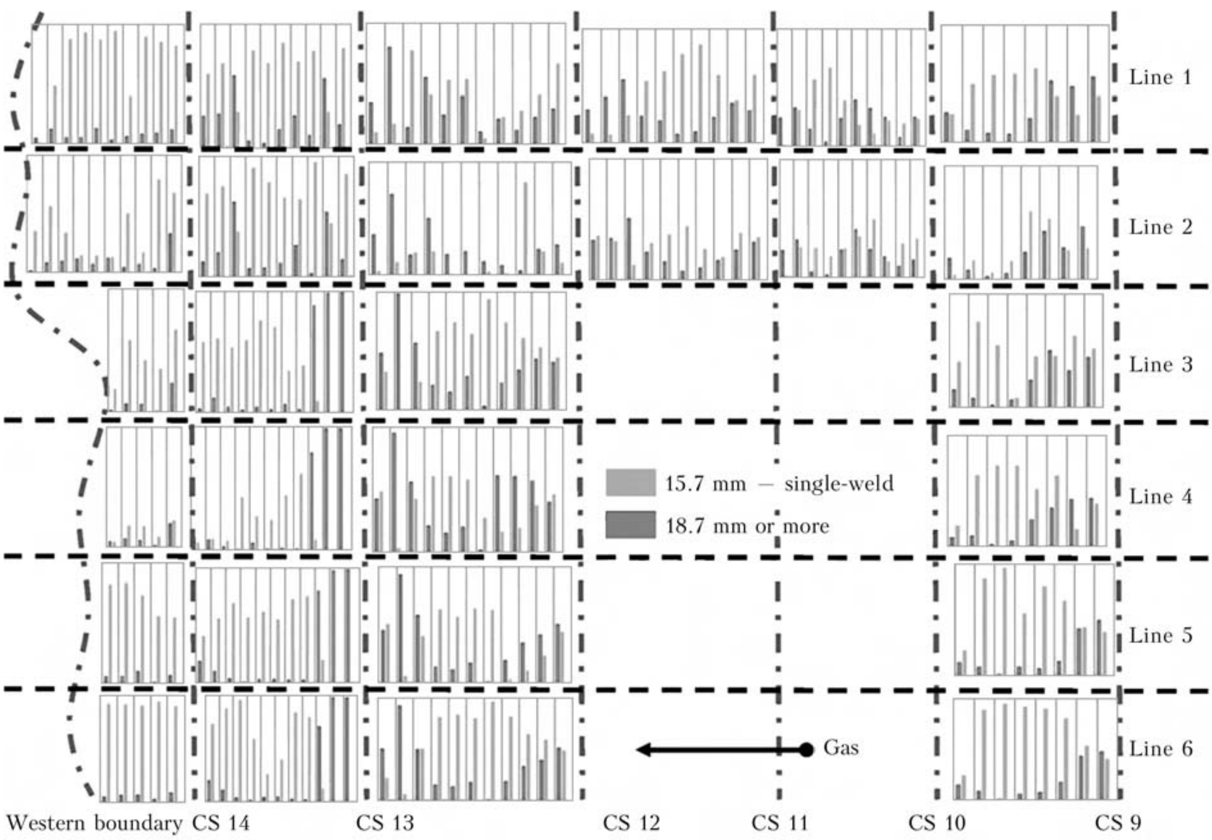

Figure 10. Distribution of pipes in sections depending on wall thickness and type of manufacture of pipes in Western Siberia: scale $0Y$ in all diagrams consists of 0–900 pipes; scale $0X$ — length of the sections divided by 10 km

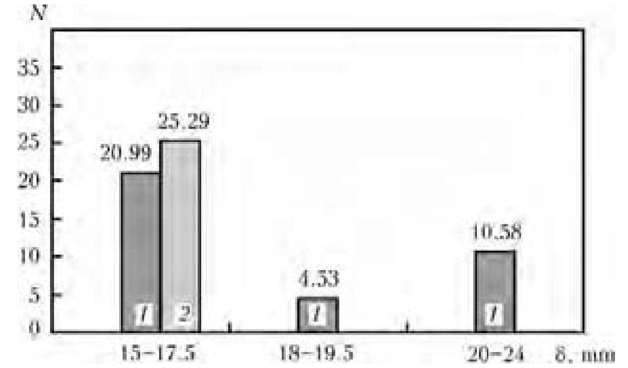

Figure 11. Specific quantity of SCC defects depending on wall thickness δ and type of manufacture of single-weld (*1*) and spiral-welded (*2*) pipes 1420 mm in diameter: *N* — quantity of pipes with SCC defects per 100,000 pipes

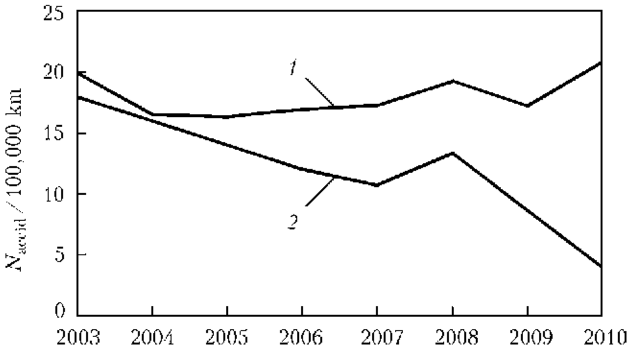

Figure 12. Effect of growth of the scopes of IPFD on decrease in failure rate: *1* — scope of flaw detection, thou km; *2* — failure rate, quantity of accidents a year per 100,000 km

In the Central Region and Western Siberia apoproximately half of all abnormal joints are of a serious danger for operation of gas pipelines (lacks of penetration or edge displacements). The presence of such a large number of edge displacements and lacks of penetration in the Central Region is related, first of all, to the quality of construction, rather than to the natural-climatic conditions, this being indicative of a low level of corrosion in the joints (9.3 % in the Central region, and 29.6 % in the Western Siberia).

Many abnormal circumferential welds were fixed in the Western Siberia (Figure 9). This is associated with severe natural-climatic conditions exerting a considerable effect on the quality of construction and service conditions of gas pipelines.

Characteristics of pipes laid down in the main gas pipeline system. The sensitivity to technological and service effects, the types of failures of main gas pipelines and the importance of ageing are different for different generations of steels welded, which are meant for the oil and gas industry, such as low-carbon, low-alloy, and low-alloy steels with microadditions of active carbide-forming elements. The effect of corrosive environments, fluctuations of temperatures, working loads and stresses change with time the structure and properties of the metal used, compared to its initial characteristics.

The factor of dependence of the amount of SCC defects in a section and pipes laid down in it (wall thickness and type of manufacture of a pipe) is most pronounced in the Western Siberia (Figure 10). For example, almost no SCC defects were fixed in a section of CS 12 and 13 on the sixth line by any IPFD, whereas they were present in large quantities in the rest of the sections. The indirect dependence of the stressed state on a complex relief of land (presence of thin-walled pipes surrounded by a large quantity of thick-walled ones) and amount of SCC defects was also seen.

According to the data of statistical analysis conducted on 5 mln pipes with over 6000 SCC defects revealed in them (Figure 11), the thin-walled pipes (15.0–17.5 mm) were proved to be 2–3 times more sensitive to the SCC defects than the pipes with a wall thickness of more than 18 mm.

Among the thin-walled pipes, the single-weld pipes had more SCC defects than the double-weld pipes [5]. As approximately 1/3 of all the pipes laid down in the extended multi-line system of main gas pipelines with a diameter of 1420 mm are the thin-walled double-weld pipes, IPFD is the only efficient method for prevention of emergency fractures.

IPFD performed annually on 18,000–20,000 km of large-diameter gas pipelines belonging to «Gazprom» made it possible to substantially improve their reliability and safety, and ensure the failure-free transportation of gas to consumers in Russia and abroad. According to the IPFD data, this was provided due to a 5 times decrease in the failure rate achieved in the last 10 years by applying selective repair and re-insulation of hazardous sections of gas pipelines (Figure 12).

CONCLUSIONS

1. To ensure safe operation of the system of main gas pipelines, it is necessary to continuously implement a set of the measures meant to timely reveal and remove defects from a linear part of the pipelines by using multiple IPFDs, and conduct comprehensive analysis of the state of the pipes and prediction of the amount of defects for the next 3–5 years.

2. A large number of abnormalities of the welded joints is hazardous for safe operation of the main gas pipeline system not only because of the probability of fracture of a welded joint, but also because of formation of an additional factor consisting in initiation and propagation of SCC defects in the zone of intersection of longitudinal and circumferential welds.

3. IPFD is the most efficient method for prevention of emergency fractures of pipes in the extended multi-line system of main gas pipelines.

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