DETERMINATION OF CONTACT PRESSURE OF REINFORCING SLEEVE IN REPAIR OF PIPELINES WITH SURFACE DEFECTS

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An important step of maintaining the operability of main land pipelines is periodical technical diagnostics and, if required, repair operations in the sections with detected inadmissible defects. One of the promising methods to restore the load-carrying capacity of the wall with typical defects (in particular, thinning of main pipeline wall as a result of local corrosion loss of metal) is mounting reinforcing structures of the type of welded bands and leak-tight sleeves. This enables redistribution of stresses from service load between pipe walls and repair structure so that the detected defect was admissible in the working conditions. In order to do it, it is necessary to guarantee sufficient efficiency of repair, in particular, ensure the required contact pressure in the area of surface interaction of the pipe and reinforcing structures. For this purpose, a numerical-experimental procedure has been developed for assessment of the value of contact pressure at mechanical interference of the repair structure (mounting in the defective section of the main pipeline), and methods of numerical assessment of the nature of load redistribution in «pipeline–repair structure» contact pair were proposed, which allow analyzing the influence of repair parameters on the degree of restoration of load-carrying capacity of a pipeline with specific defect. In addition, a test sample of mechanical deformometer was developed, with a design adapted to measurement of circumferential displacements in the wall of reinforcing structure at its mounting on the pipeline. Preliminary laboratory investigations confirmed the effectiveness of the proposed procedure that allows recommending it for application at repair of operating main pipelines. 11 Ref., 1 Table, 5 Figures.

Keywords: *pipeline, thinning defect, repair, reinforcing welded structure, contact pressure, circumferential deformations, mechanical deformometer*

Maintaining the operability of main pipeline systems is an important and urgent task for Ukrainian economy. Periodical technical diagnostics of pipeline condition is performed to ensure their safe service, in particular, to detect service defects and assess the admissibility of the defective section condition. In the case of inadmissible shortening of safe residual operating life of the main pipelines (MP) with the known extent of damage, required repair operations are performed to restore the load-carrying capacity of the pipeline in the area of detected defects. At present methods of MP repair without taking them out of service are becoming ever wider applied, that allows avoiding product transportation during repair-reconditioning operations, reducing labour consumption and adverse influence on the environment [1–3]. In particular, various techniques of reinforcement of pipeline defective sections by reinforcing welded structures (RWS) of the type of bands and leak-tight sleeves are widely applied in Ukraine. This allows redistribution of stresses induced by operating pressure in MP between pipe walls and RWS and lowering the stress level in the defect area, bringing it into an admissible state.

According to normative-technical documentation [4, 5], before RWS mounting and welding, it is necessary to lower the pressure in the pipeline from working pressure P to the level of $P_{rep} = 0.7P$, as well as ensure tight contact between the surfaces of the pipe and RWS due to creation of contact pressure (interference) ΔP_{in}, which forms at structure assembly and at increase of inner pressure up to working pressure after repair (Figure 1). Value of contact pressure essentially influences lowering of stresses in the pipe wall with surface defects and largely determines reinforcement effectiveness and structure operability after repair, so that determination and monitoring of development of contact interaction of MP and RWS is an important task. Currently available design procedures for ΔP_{in} determination are rather cumbersome and require a number of difficult-to-determine values that limits their application in repair practice [6]. This work presents numerical-experimental procedure developed by the authors for monitoring the value of contact pressure at MP repair by its reinforcement by welded sleeves (bands).

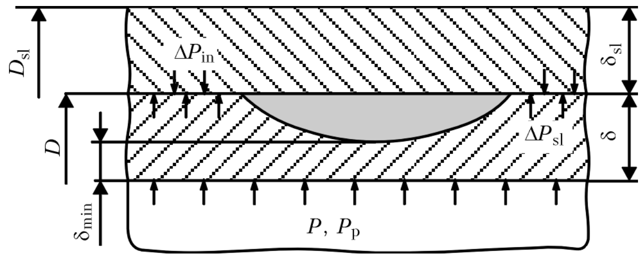

Figure 1. Schematic of redistribution of inner pressure after reinforcement of pipe defective section by a sleeve: D, D_{sl} — outer diameters of pipe and reinforcing structure, respectively; δ, δ_{sl} — wall thicknesses of pipe and reinforcing structure, respectively; δ_{min} — minimum residual wall thickness in the defect location; P_p, ΔP_{sl} — parts of pressure P taken up by walls of pipe and reinforcing structure; ΔP_{in} — contact pressure on reinforcing structure on pipe

In the approximation of uniform distribution of contact between the surfaces of «pipeline–reinforcing structure» contact pair working pressure in MP after mounting the repair structure can be presented by the following dependence:

$$P = P_p + \Delta P_{sl} + \Delta P_{in}, \quad (1)$$

where P_p, ΔP_{sl} is the part of working load taken up by the pipeline and repair structure, respectively.

Work [7] gives graphic dependencies, which characterize the degree of stress redistribution after MP repair by reinforcement at ideal fit of RWS to the pipeline. For this case part of pressure P, which will be taken up by RWS wall, can be described by the dependence

$$\Delta P_{sl} = (P - P_{rep})\chi_1, \quad (2)$$

where $\chi_1 = \left(1 + \frac{(0.5D_{sl})^2\,\delta}{(0.5D)^2\delta_{sl}}\right)^{-1}$.

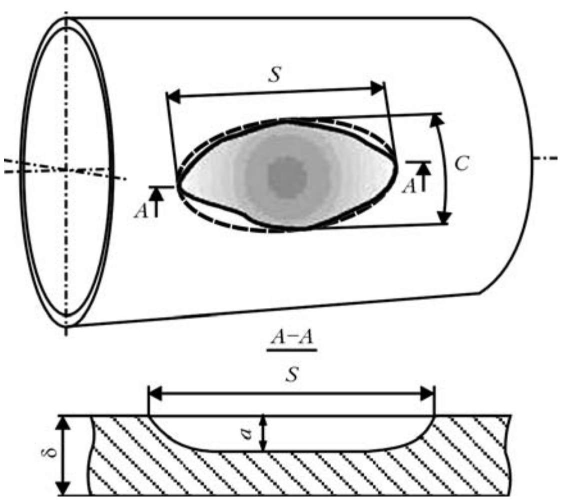

Figure 2. Schematic of thinning of pipe wall of the type of local corrosion metal loss: S — length; C — width; a — depth of defect

Formula (2) does not allow for contact pressure ($\Delta P_{in} = 0$) created during RWS mounting, welding of longitudinal welds and pressure increase up to working pressure. If at pressure in the pipeline $[P]$, pipe wall defects become admissible, then to ensure long-term operating reliability of pipeline section with the mounted repair structure the following condition should be satisfied:

$$P_p \le [P]. \quad (3)$$

Respectively, from (1)–(3) it follows that

$$P - (P - P_{rep})\chi_1 - \Delta P_{in} \le [P]. \quad (4)$$

Hence, pressure in the pipeline P_{rep}, at which RWS should be mounted, is as follows:

$$P_{rep} \le \frac{[P] - P(1 - \chi_1) + \Delta P_{in}}{\chi_1} \text{ at } \Delta P_{in} > 0. \quad (5)$$

Thus, criterion for selection of the required contact pressure value follows from (5)

$$\Delta P_{in} \ge P - [P] - \chi_1(P - P_{rep}). \quad (6)$$

Determination of maximum pressure $[P]$, at which the detected defects are admissible, is based on the requirements of the respective specified norms and standards, depending on operating conditions of a specific MP section and nature of damage [8, 9]. In particular, a typical MP defect is thinning of its wall of the type of local corrosion at metal loss (Figure 2). Admissibility of the state of MP defective section is assessed by numerical evaluation of reference stresses in the area of geometrical anomaly. Accordingly, allowing for additional influence of the characteristic force impact of the repair structure allows reducing the problem of restoration of pipe load-carrying capacity to selection of the balance of load redistribution between the walls of the pipeline and RWS. Substantiation of required ΔP_{in} value requires knowledge of admissible linear defects (Figure 3), which allow making a conclusion about admissibility of detected defects under the conditions of contact unloading [10].

As an example of application of the above methodology, given below are the results of calculation of repair characteristics of a pipe wall with surface thinning of an ellipsoidal shape of the following geometrical dimensions, mm: S = = 600, C = 550, a = 3.5 (Figure 4). The pipe is made from low-alloyed steel X60 (yield point σ_y = 420 MPa, admissible stresses $[\sigma]$ = 286 MPa, D = 1020 mm, δ = 10 mm), and operates at P = = 5.5 MPa. One can see from the diagram (see Figure 3) that this defect is admissible in the case, when inner pressure is equal to $[P] \approx$

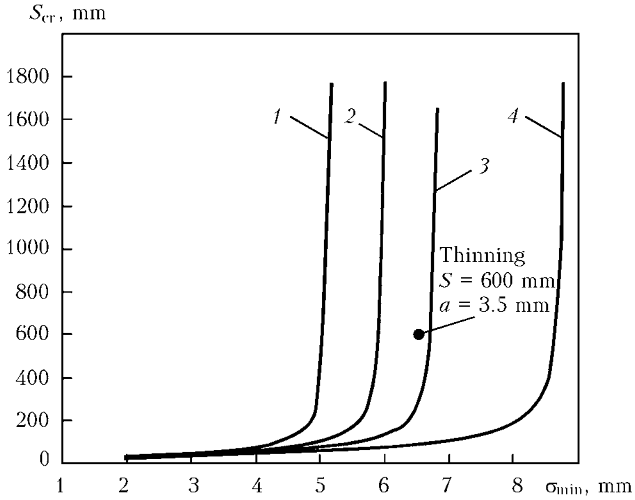

Figure 3. Diagram of admissible linear dimensions of pipe wall thinning S_{cr} depending on minimum thickness of pipe wall δ_{min} for pipeline of 1020 × 10 mm size from X60 steel with maximum service load P = 5.5 MPa at different inner pressures: *1* — 0.6P; *2* — 0.7P; *3* — 0.8P; 4 — P

≈ 0.77P. The Table gives the results of calculation of minimum required ΔP_{in}, depending on RWS wall thickness δ_{sl}, made according to (6).

Calculation results lead to the conclusion that to satisfy condition (3) it is possible to vary sleeve wall thickness δ_{sl} and contact pressure ΔP_{in}. Correct determination of ΔP_{in}, particularly for the case of $P_{rep} \to P$, is the most significant for ensuring the operability of a section repaired using the sleeve. Interference at mounting RWS on pipeline defective section can be controlled using the method of experimental measurement of circumferential displacements of RWS wall, due to elastic deformation at mechanical interference. In this case, ΔP_{in} calculation in RWS wall is performed by determination of Δl — variation of length l of the selected basic section of the structure, as a result of interference, compared to unloaded state and subsequent calculation by the formula

$$\Delta P_{in} = \frac{\Delta l}{l} E \frac{2\delta_{sl}}{D + 2\delta_{sl}}, \qquad (7)$$

where E is the steel modulus of elasticity.

In order to follow Δl variation under field conditions at repair-reconditioning operations on an operating pipeline, the currently operating strain gauges and deformometers [11] were used as a basis to develop a new modification of a mechanical deformometer with base $l \approx 100$ mm, the appearance and schematic of which are given in Figure 5. The instrument allows measurement of circumferential deformations on cylindrical surfaces of 380 mm and greater diameter by the results of direct measurement of reciprocal motion of a pair of depressions, made on the sleeve surface by punching.

Measurement principle consists in transferring the displacements in the structure from contact points through reinforcing lever *1* with 1:5 arm ratio to clock-type indicator *2*. Transverse rack *4* with two assemblies for magnetic pressing

Results of calculation of required ΔP_{in} at repair of pipeline of 1020 × 10 mm size from X60 steel with wall thinning of S = = 600 mm, C = 550 mm, a = 3.5 mm

P, MPa	$[P]$	P_{rep}	δ, mm	δ_{sl}, mm	ΔP_{in}
5.5	~0.77P	0.7P	10	10	0.083P
				15	0.054P
				20	0.035P

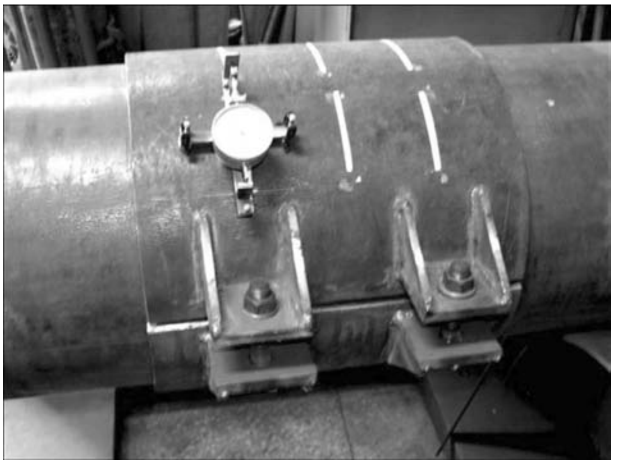

Figure 4. Experimental facility with mechanical deformometer for contact pressure determination

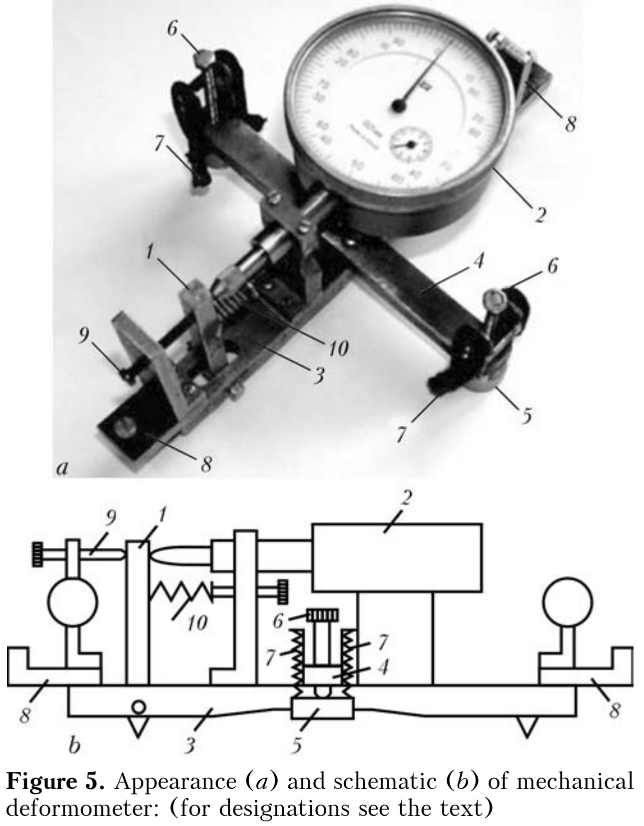

Figure 5. Appearance (*a*) and schematic (*b*) of mechanical deformometer: (for designations see the text)

of the deformometer to RWS is fastened in the middle part of base *3* for a stable fastening of deformometer to cylindrical surface. Each assembly located at rack end faces, consists of yoke *5* with caulked-in magnet, governing screw *6* and springs *7*, balancing pressing-down. In the case of insufficient pressing of the instrument to the metal, links *8* are provided on the band lower half for deformometer fastening. The links allow, by placing circumferential safety straps on them, avoiding accidental disconnection and falling down of the instrument. Holding assembly (screw *9* with spring *10*) is provided for fastening of the rod and lever (instrument mounting and transportation).

To ensure complete control of uniform clamping of the pipe, several deformometers can be used, which are mounted in the characteristic points of the repair structure.

Preliminary laboratory testing of the deformometer in a special facility (see Figure 5) consisting of a pipe section from steel 09G2S of 377 × × 11 mm size, 1000 mm length and 400 mm long band with 11 mm wall thickness, confirmed sufficient accuracy (approximately 1 μm) and effectiveness of the developed deformometer that allows recommending it for application in repair-restoration work in operating MP.

Conclusions

1. Numerical-experimental procedure was developed to assess the contact pressure between pipeline walls and RWS in terms of effectiveness of restoration of load-carrying capacity of pipeline wall with typical service defects. Numerical algorithm was proposed for assessment of load redistribution at contract interaction of structural elements and influence of reinforcement on admissibility of pipeline operation. The case of a typical thinning defect of the type of metal loss is used to show the essential influence of the value of RWS mechanical interference at its mounting on repair effectiveness.

2. Pilot sample of mechanical deformometer was developed with its design adapted to measurement of circumferential displacements in the wall of the reinforcing structure at its mounting on the pipeline. Proceeding from the results of laboratory tests, it was established that the accuracy of measurement of displacements in the wall of the reinforcing structure using this deformometer (approximately 1 μm) is sufficient for assessment of the magnitude of mechanical interference and confirmation of the effectiveness of repair of defective sections of the pipeline.

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