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MONITORING METHODS OF TECHNICAL STATE OF OIL AND GAS PIPELINES

1. INTRODUCTION

For the present, pipeline transport is widely used for transportation of the gas, liquid, and loose materials on great distance due to productivity and profitableness. Oil and gas pipeline system is one of the biggest transport systems all over the world.

Pipeline transports is an object of high attention. During operations of the transnational pipe transportation system, a number of hardships arise; most of them are common to the oil and gas industries of Russia, Ukraine, Poland, Germany and other countries. Therefore, it is beneficial to exchange information concerning the latest technologies. Comprehensive inspection of cross-country pipelines enables us to evaluate their condition, prompt reparations and carrying out preventive operations.

Besides the constructive peculiarties, the outer influence, that is environment in which the pipelines are situated, have crucial role in the strength of the pipeline system. The pipelines work under the static and repeat static loading, are used in different climatic zones, hydrogeological conditions and are in the constant interactions with surrounding environment which has great importance for the safety of the transport system [1].

2. THEORETICAL BACKGROUND

For the evaluation of the stress state of the pipeline systems, we propose combinated methods of structural geology, neotectonics, and the methods of the mechanics of deformed

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solid [2]. Geological methods are used for the determination of the direction of the principal stress axis (including paleostress one) in the crust. For the evaluation of the boundary condition state of the pipelines, the finite element modeling is used.

The methods proposed make it posible to determine geodynamic activity abyssal tectonic structures and their effect on a pipeline [3, 4]. On the basis of these methods, potentially dangerous intervals of pipeline can be found. Disigning new pipelines, it is necessary to avoid pipeline location in tectonic places. It is desirable to carry out periodical or continuous monitoring for potentially dangerous intervals of the existing pipelines in geodynamically active zones. For this purpose, "intellectual inserts" or foil rosette-type strain gauges [5] as well as an electromagnetic sensor of transformer type can be used. The practice of operating pipelines shows the most dangerous are the places near welding beads in wich there are residual stresses [6].

The task of the determination of residual stresses in the closed cylindrical shell with circumferential joint is discussed. The material of a shell is considered to be homogeneous and isotropic.

The principles of calculation-experimental method of stressed state determination in welding pipeline joints are presented. This method is based on a solution of the reverse problem of mechanics of deformable bodies with natural stresses and using experimental information obtained by nondestructive physical methods, such as electromagnetic, ultrasonic, interferometry holography and others [7].

The initial equations are the ones of the shells theory which takes into consideration availability of the conditional plastic deformations described by the tensor field. Components of the tensor of complete deformation eij are presented as the sum [8]

$$e_{ij} = e_{ij}^{e} + e_{ij}^{0} \tag{1}$$

where:

e_{ij}^{e} – components of the tensor of elastic deformations,

e_{ij}^{0} – components of the tensor of conditional plastic natural deformations.

In addition to plastic deformations, the field also accounts for the deformations caused by different structural transformations associated with the volume variations of the material.

For a circular cylindric shell $2h$ thick under the influence of axes-symmetric residual technologic deformation, the principal eguation of flexure of pipe is made up.

Applying generalized function apparatus the solution of the principal eguation as well as formulae for determining circular $\sigma_{\beta\beta}$ and axial $\sigma_{\alpha\alpha}$ stresses in a pipe are obtained.

Normal axial $\sigma_{\alpha\alpha}$ and circular $\sigma_{\beta\beta}$ of residual stresses in of arbitrary point pipeline, which are caused by residual strain which are cansed by welding are determinated by the formulae

$$\sigma_{\alpha\alpha}(\alpha,\gamma) = \frac{3\gamma}{2h^3} M_1(\alpha) + \frac{E}{1-\mu^2}\left(\frac{1}{3} - \frac{\gamma^2}{h^2}\right)\left[\sum_{K=0}^{n_1} a_{K1}^{(2)} \alpha^k + \mu \sum_{K=0}^{n_2} a_{K2}^{(2)} \alpha^k\right] S^0(\alpha)$$

$$\sigma_{\beta\beta}(\alpha,\beta)=\frac{1}{2h}N_2(\alpha)+\frac{3\gamma}{2h^3}M_2(\alpha)+\frac{E}{1-\mu^2}\left(\frac{1}{3}-\frac{\gamma^2}{h^2}\right)\cdot \tag{2}$$

$$\cdot\left[\sum_{K=0}^{n}a_{K2}^{(2)}\alpha^k+\mu\sum_{K=0}^{n_1}a_{K1}^{(2)}\alpha^k\right]S^0(\alpha)$$

where:

N_2 – circular force,
M_1, M_2 – axial and circular bending moments,
$\alpha = z/R$ – stretch coordinate, where z is distance from axis of welding joint,
R – middle radius of pipe,
γ – coordinate lengthwise external of normal to median layer,
h – half-thickness of pipe,
E – modulus of elasticity,
μ – Poisson's ratio,
$\varphi_{ki}(\alpha)$ = α^k,
$S_0^0(\alpha)$ = 1, if $|\alpha| \leq \alpha_0$,
$S_0(\alpha)$ = 0, if $|\alpha| \geq \alpha_0$, where $\alpha_0 = x_0/R$,
x_0 – halt-width of zone of plastic deformations,
$\alpha_{kj}^{(\upsilon)}, \alpha_0$ – unknown parameters, which are determined with the help of the functional

$$g(a_{kj}^{(v)},\alpha_0)=\sum_{n=1}^{n_1}p_n[\sigma^T+(\alpha_n,a_{kj}^{(v)},\alpha_0)-\sigma^E(\alpha_n)]^2 \tag{3}$$

where:

σ_+^T, σ_0^T – averaged differences of the principal stresses over the contact area between the sensor and the outer surface of the pipe that are theoretically expressed and determined experimentally according to electromagnetic methods,
α_n – coordinate of the sensor centers,
n_1 – number of hoop pipeline intersections, for which the measurements are performed,
p_n – weight coefficients.

Then the minimization of functional (3) is performed. This provides minimal deviation of the theoretically calculated σ_+^T from experimental values σ_+^E and determines unknown parameters $\alpha_{kj}^{(\upsilon)}$, α_0. When $\alpha_{kj}^{(\upsilon)}$, α_0 are known, circular and axial stresses can be calculated for every part of the pipeline.

3. RESULTS AND DISCUSSION

Using the proposed calculation-experimental method, the residual stresses in neighborhood of the circumferential joint of the pipeline ∅ 1220 × 15.2 mm, material – steel 17Γ1C, $E = 2.1 \cdot 10^5$ MPa, $\mu = 0.3$, $\sigma_T = 380$ MPa, is determined. Experimantal measuring is done with “MESTR-411” device.

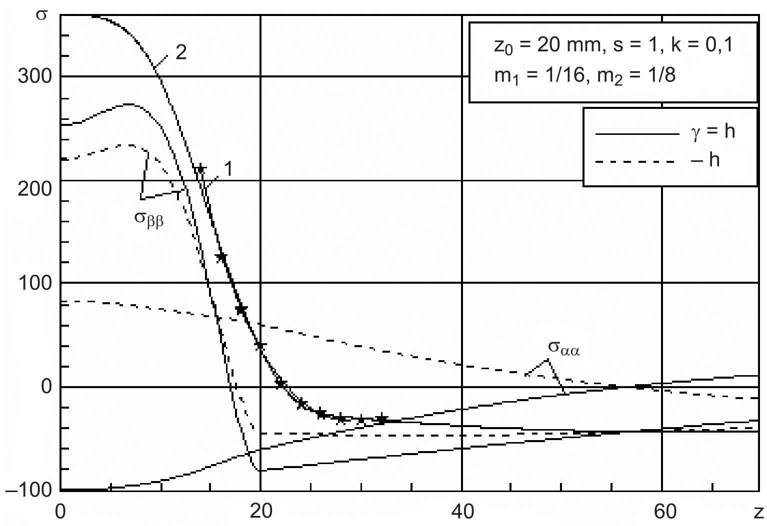

Fig. 1. Distribution of residual stress in circumferential welding pipeline joints

Figure 1 shows correlation between the distance from the axis of the welding joint and circular $\sigma_{\beta\beta}$ and axial $\sigma_{\alpha\alpha}$ technological stresses on inner and outer surfaces of the pipeline. Experimental data (curve 1) is approximated by a polynomial function (curve 2).

The carried-out analysis showed that the following hold for the discussed welded joint:

- Circular residual stresses on internal and external pipe surfaces near the joint are tensile and take the greatest values on the internal surface of the pipe; and from a certain distance from the joint axis they become compressive stress.
- The axial residual stresses are compressive on the external surface and tensile on the internal surface; at a certain distance from the axis they change their signs.
- Obtained experimentally the value σ_+^E on the external pipe surface may essentially exceed the level of extremal residual stresses.

One of the indeces of oparational reliability of pipeline is coefficient of safety margin n_p. According to the standard [9], the parameter n_p is determined by the expression

$$n_p = \frac{\sigma_{cal}}{\sigma_w} \tag{4}$$

where:

σ_{cal} – calculated stress, which can take one of the following values: $\sigma_{0.2}$ conditional yield strength, or σ_B strenght limit;

σ_w – maximum total stress.

Determining the safety margin of a pipeline, it is necessary to take into account non-relaxed residual stress near circumferential welding bead using the formula

$$n_p = \frac{\sigma_{cal}}{\sigma^p \pm \sigma^{res}} \tag{5}$$

where:

σ^p – stress from gauge pressure,

σ^{res} – non-relaxed residual stress, which are determined according to formulae (2).

The change of total srtess coused by defects, in weld joints must be addittionally taken into account by means of stress concentration factors.

For the example considered, numerical calculations have show, that taking into account the technological stresse essentially changes values of the coefficient of safety margin for a pipeline. In the zone of tensile residual stresses, this coefficient decrease to 40% per cent; and in compressiwe residual stresses zone, it can be increased within the range 10–18%.

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