DIAGNOSTICS OF RESIDUAL TECHNOLOGICAL STRESS IN CIRCUMFERENTIAL WELDS IN PIPELINES

Andriy DRAGILYEV[1)], Stepan SAVULA[2)], Yuriy BANAKHEVYCH[2)], Vasyl OSADCHUK[3)], Andriy KYCHMA[3)]

1)Enterprise "Kraft – engineering",02002 Ukraine, Kyiv. M. Raskovoi str. 11. of. 1113., tel. +380(044)5173365, fax. +380(044)5599933, kraft@krafts.com.ua
[2)] Department UMG "Lvivtransgas",
[3)] National University "Lviv Politechnic" 79013 Ukraine, S. Bandery str. 35, tel. + 380 (322) 971639, fax. +380 (322) 971364, integrator@ukrpost.net

DIAGNOSTYKA SZCZĄTKOWYCH TECHNOLOGICZNYCH NAPRĘŻEŃ W KOŁOWYCH SPOINACH SPAWANYCH RUROCIĄGÓW

Streszczenie
W referacie opisano metodę oceny stanu naprężeń obok spoin spawanych rurociągów przy pomocy diagnostyki numeryczno - eksperymentalnej. Na podstawie analizy wyników przeprowadzonych badań sformułowano rekomendacje dla praktyki inżynieryjnej.

Słowa kluczowe: diagnostyka, naprężenia, spoiny spawane, rurociągi, matematyczny model.

Keywords: diagnostic, stress, circumferential welds, pipeline, mathematical model.

1. INTRODUCTION

Practical experience gained during pipelines exploitation shows that there are many factors of their reliability degradation. These are cyclic change of pressure, variation of temperature, and residual technological stress.

This paper develops a calculation-experimental method of residual technological stress determination in circumferential pipeline joints. It also presents a mathematical model and software for stress conditions diagnostics in welded circumferential joints of a cylindrical bobbin with preliminary workout of pipe edges. This model is based on calculation of invert problems of the shell theory with own deformations and uses experimental information received by a physical method.

The principles of calculation-experimental method of definition of the residual stresses in the welded shells are presented. This method is based on reverse problem solution of mechanics of deformable bodies with inherent stresses and using experimental information, obtained by nondestructive physical methods. 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 e_{ij}^{0}. Considering priory information about distribution of the deformations an idea of direct problem solution is introduced, and expressions for the stresses with unknown components of the field e_{ij}^{0} are written. In order to find the components, a functional is constructed. The functional minimization provides minimum theoretical calculated $\mathrm{I}_{\mathrm{k}}^{\mathrm{T}}$ significance of deviation of the characteristics of the fields of stresses from the experimental ones $\mathrm{I}_{\mathrm{k}}^{\mathrm{E}}$. After finding the fields e_{ij}^{0}, the residual stresses in an arbitrary point of the shell are calculated.

The proposed method takes into account heterogeneousness of stress distribution under instruments, which measure average values of physical characteristics and their influence on structurally phased changes in the region of the thermal impact on the device's precision.

The method can be described as follows. Components of the tensor of complete deformation e_{ij} are presented as the sum:

$$e_{ij} = e_{ij}^{e} + e_{ij}^{0}, \qquad (1)$$

where e_{ij}^{e} - components of the tensor of elastic deformations; e_{ij}^{0} - components of the tensor of conditional plastic eigen deformations. In addition to plastic deformations, the field e_{ij}^{0} accounts also to the deformations, caused by different structural transformations associated with the volume variations of a material. When the field e_{ij}^{0} is defined, components of the tensor of residual stresses are calculated for an arbitrary body point, in particular those, which could not be defined experimentally.

2. THE MATHEMATICAL MODEL OF CALCULATION-EXPERIMENTAL METHOD

The task on the determination of residual stresses in the closed cylindrical shell with circumferential joint is discussed. The model of a pipeline *2h* thick with bevel-butt weld joint and with gauge is show in Figure 1.

The material of a shell is considered to be homogeneous and isotropic. The position of an arbitrary point on a medium surface of a shell with radius R is defined by its coordinates z and β.

The field of the joint-localized eigen plastic circumferential deformations $e^0_{\beta\beta}$ and axis deformations $e^0_{\alpha\alpha}$ is approximated by functions:

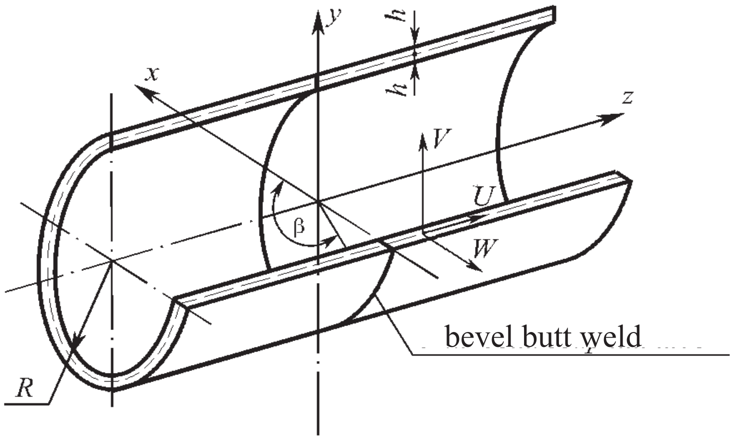

Figure 1. The scheme of bevel butt weld joint in the form of a closed circumferential cylindrical shell: U, V, W – the components of displacement vectors of the medium surface joint along the axis, in the direction of circle arc and in the direction of the normal to medium surface

$$e^0_{\beta\beta}(\alpha,\gamma) = -\varepsilon_1^* f_1(\gamma)\ \varphi\ (\alpha)\ S^0(\alpha), \quad (2)$$

$$e^0_{\alpha\alpha}(\alpha,\gamma) = -\varepsilon_2^* f_2(\gamma)\ \varphi\ (\alpha)\ S^0(\alpha), \quad (3)$$

Where

$$\varphi_i(\alpha) = 1 + s_i\frac{\alpha^2}{\alpha_0^2} - (3+2s_i)\frac{\alpha^4}{\alpha_0^4} + (2+s_i)\frac{\alpha^6}{\alpha_0^6}$$

$$f_i(\gamma) = 1 - m_i\left(1-\frac{\gamma}{h}\right)^2 \quad i = 1,2,... \quad (4)$$

$S^0(\alpha) = 1, \quad |\alpha| \le \alpha_0; S^0(\alpha) = 0, \quad |\alpha| > \alpha_0;$

$\alpha_0 = z_0 / R$ (z_0 – half width of zone plastic deformation);

ε_i^*, s_i, m_i – constant parameters ($\varepsilon_i^* > 0$, $0 \le m_i \le 0.25$).

The plot of function $\varphi(a)$ for some value of parameter s, which describes different welding conditions, is showed in Figure 2. For an arbitrary value of the parameter s, function φ and its derivatives are equal to zero on the border $\alpha = \pm\alpha_0$. Function $f(\gamma)$ characterizes the heterogeneity of distribution of residual deformations e^0_{ij} along the gauge of the pipe.

In accordance with the correlations (1)-(4) [4] the key equation, which defines the displacement deflection of the pipe W (normal to the medium surface of the pipe), is presented as follows:

$$\left(\frac{d^4}{d\alpha^4} + 4\lambda^4\right)W = -R\varepsilon_1^*\left[\ 2\lambda^4\left(1-\frac{4}{3}m_1\right) - \frac{R}{h}\left(\mu m_1 + \frac{\varepsilon_2^*}{\varepsilon_1^*}m_2\right)\frac{d^2}{d\alpha^2}\ \right]\varphi(\alpha)S^0(\alpha). \quad (5)$$

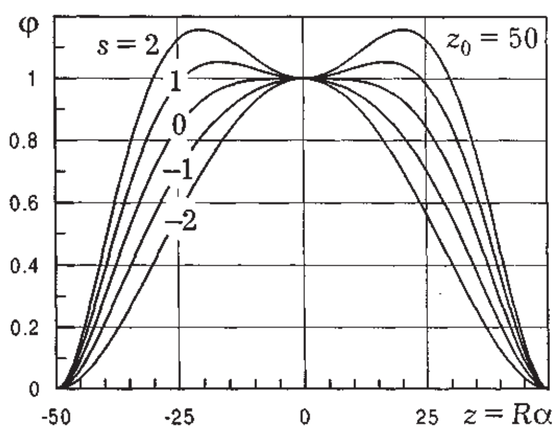

Figure 2. The function describing the pattern of plastic deformations

Where $\lambda = 3R^2\left(1-\mu^2\right)/\left(4h^2\right)$, μ – the Poisson coefficient.

The deflection of the pipe W is derived from the equation (5) at the basis of the apparatus of generalized functions. Due to the apparatus the expression for deflection of the pipe W is obtained. The expression includes the unknown values ε_0^{*2}, α_0, m_i and s. The result is derived with the account of experimental information concerning the averaged characteristics of the differences of the principal stresses. The information is obtained at the basis of the electromagnetic method, due to the MESTR-411 device application. For these purposes the functional is built. The functional minimization ensures minimal derivations of the theoretically revealed differences between principal stresses σ_*^T and experimental values σ_*^E. The task of the field definition is solved as the inverted task of shell theory with residual stresses, which is conditionally correct. A functional is formulated to reveal the plastic deformation field parameters ε_i^*, α_0, m_i, s. Due to the functional minimization the area and amplitude of plastic deformations are (5)

3. DETERMINATION RESIDUAL STRESSES IN A PIPELINE

Using the proposed calculation-experimental method, the residual stresses in neighborhood of the circumferential joint of the pipeline Ø 1220 × 15.2 mm, material – steel 17Г1С, E=2.1*10^5 MPa, $\mu = 0.3$, $\sigma_T = 380$ MPa, is determined.

The measurements at the basis of the MESTR-411 device were provided in 20 sections on 3 lines along the generatrix of a pipeline; the results were averaged. For obtained experimental data near the joint and at the distance 250 mm from its axes (the pipeline pressure was equal to 3.5 MPa), the corresponding values $\sigma_+^E(z)$ were calculated. The values are presented by stars in Figure 3. The results of calculations are approximated by a polynomial function. The diagram of the function is presented on Figure 3 (curve 1).

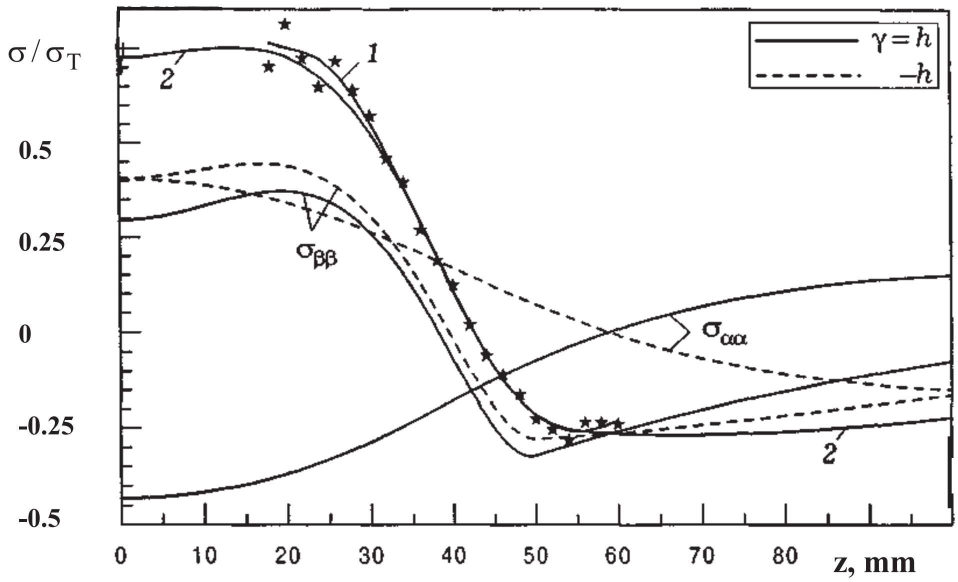

Figure 3. Stresses distribution near the joint on pipe surfaces

Carried-out analysis showed that the following holds for the discussed welded joint:

- Circumferential residual stresses on internal and external pipe surfaces near the joint are extensive and gain the greatest values on the internal surface of the pipe; at the distance from the joint axis they are transformed into the compressive stress;
- The axis residual stresses are contracting on the external surface and extensive on the internal surface; at the distance from the axis they invert signs;
- Given experimental value σ_+^E on the external pipe surface may greatly exceed the level of extreme residual stresses.

REFERENCES

[1] Banachewich J., Koval R., Kychma A. Nondestructive stress monitoring of gas pipelines. Zeszyty problemowe Badania nieniszczące, Numer 7 październik 2002 r materiały 31 Krajowej Konferencji Badan Nieniszczących 31 KKBN Szczyrk 22-24 X 2002. - Warszawa . - 2002. - S.253 - 257.

[2] Zubik J.L., Kychma A.O., Kowal R.I., Banachewicz Y.W.: Monitorowanie stanu technicznego gazociągów przesyłowych na terenie Ukrainy. Materiały XI międzynarodowej konfe-rencji naukowo-technicznej "Nowe metody I technologie w geologii naftowej, wiertnictwie, eksploatacji otworowej i gazownictwie", – AGH Kraków, - 2000. - S. 275 - 277.

[3] Jones B., Huuskonen E., i Erdbrink K. Ocena integralności spoin obwodowych na podstawie wyników inspekcji wewnętrznej gazociągu w odniesieniu do możliwości podniesienia ciśnienia eksploatacyjnego w stosunku do jego wartości projektowej. Materiały II Krajowa Konferencja Techniczna "Zarządzanie ryzykiem w eksploatacji rurociągów", – Płock, - 1999. - S. 165 - 175.

[4] Osadchuk V., Bolshakow M., Palash V. Nondestructive method determination of residual stress in weld shells. Mashinoznavstvo (Ukraine). 1997. №1. S. 5 – 9.

Andriy DRAGILYEV Ms.-Eng., Director Enterprice "Kraft - Engineering", specializes in field exploitation of pipeli-nes. Author of 11 scientific papers

Stepan Savula Ms.-Eng., Technical Director State Enterprice "Lvivtransgas", specializes in field exploitation of pipelines. Author of 27 scientific paper

Yuriy BANAKHEVYCH Dr.-Eng., Chief of Department State Enterprice "Lvivtransgas", specializes in field exploitation of pipelines. Author of more of 40 scientific papers.

Vasyl OSADCHUK Dr.-Hab., Professor, Director of Chair Welding Engineering National University "Lviv polytechnic", specializes in field of Mechanics deformation solid body. Author of 3 monographs and of more 200 scientific papers.

Andriy Kychma, Dr.-Eng., Associate Professor, Chair of Machine Elements National University "Lviv poly-technic", specializes in field technical diagnostics of pipelines. Author of more than 100 scientific papers.