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DESIGN-EXPERIMENTAL DIAGNOSTICS OF STRESS CONDITION IN THE GIRTH WELDED JOINTS ZONE OF PIPELINES BY MEANS OF ELECTROMAGNETIC METHOD

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Using the calculation-experimental method, based on the solution of inverse problems of the shell theory with internal stresses, and utilizing the experimental data obtained by electromagnetic method, the distribution of residual stresses near the circumferential weld in the main pipeline is defined and analyzed. In addition, the non-uniformity of their distribution under the electromagnetic transducer is considered. The averaged characteristics of the difference of principal stresses are defined experimentally with regard for the influence of the structural changes in the zone of thermal effect on the measuring device’s indices.

Corrosion resistance of basic metal and reliability of welded joints of trunk pipelines (TP) have essential influence on the period of their safe operation. At the same time while TP examining special attention is paid to installation welded joints as to one of the main reasons that causes damages. [1]. That is why for reliability increasing of pipeline transport the methodologies are being constantly improved on determining of the pipelines boundary conditions, the important component of which is methods development on pipes stress condition evaluation, namely technological residual stress in welded joints.

Below you can see mathematic model that is used for evaluation of stress condition in the zone of TP girth welded joint that is described in the works [2, 3], in frames of which a pipe is designed by girth cylinder casing with the thickness of $2h$ under an action of localized own plastic axially symmetric residual deformations caused by welding. At the same time it is admitted that welded girth joint is made under the same condition with respect to cutover (pass) that goes through its axle, perpendicular to basic pipe. Then on the summary basis of known in the literature design and experimental data, in case when zones of localized near joint girth $e^0_{\beta\beta}$ and axial $e^0_{\alpha\alpha}$ residual plastic deformations are different they can be approximated by the following expressions

$$e^0_{\beta\beta}(\alpha,\gamma) = -\mathbf{E}_1^* f_1(\gamma)\varphi_1(\alpha)S_1^0(\alpha),$$

$$e^0_{\alpha\alpha}(\alpha,\gamma) = -\mathbf{E}_2^* f_2(\gamma)\varphi_2(\alpha)S_2^0(\alpha), \tag{1}$$

where

$$f_i(\gamma)=1-m_i\left(1-\frac{\gamma}{h}\right)^2,\quad \varphi_i(\alpha)=1+s_i\frac{\alpha^2}{\alpha_i^2}-(3+2s_i)\frac{\alpha^4}{\alpha_i^4}+(2+s_i)\frac{\alpha^6}{\alpha_i^6},$$

$$S_i^0(\alpha)=1,\ |\alpha|\le\alpha_i;\ \ S_i^0(\alpha)=0,\ |\alpha|>\alpha_i;\ \ \alpha_i=z_i/R,\ i=1,2; \tag{2}$$

z_i – half-widths of plastic deformations zones; $\mathbf{E}_i^*, s_i, m_i$ – numerical parameters. Graphs of function $f_i(\gamma)$ and $\varphi_i(\alpha)$ for some parameters points s_i and m_i, that define welding modes, presented in the work [2].

Key equation for flexure defining (pipe movement along normal to its median surface) w in this case can be indicated in the following way

$$\left(\frac{d^4}{d\alpha^4}+4\lambda^4\right)w=-2R\,\mathbf{E}_1^*\left[2\lambda^4\left(1-\frac{4}{3}m_1\right)-\mu m_1\frac{R}{h}\frac{d^2}{d\alpha^2}\right]\varphi_1(\alpha)S_1^0(\alpha)+$$

$$+2\mathbf{E}_2^*m_2\frac{R^2}{h}\frac{d^2}{d\alpha^2}\varphi_2(\alpha)S_2^0(\alpha), \tag{3}$$

where $\lambda^2=3R^2(1-\mu^2)/(4h^2)$; μ– Puasson coefficient.

Having built the solution of equation (3) and having used formulas, presented in the work [4], correlation for determining flexure w, axial $\sigma_{\alpha\alpha}$ and hoop $\sigma_{\beta\beta}$ residual stress in welded joint can be shown as follows:

$$w(\alpha)=-\mathbf{E}_1^*R\lambda\left\{\frac{1}{2}\left(1-\frac{4}{3}m_1\right)F_{11}(\alpha)+\frac{1}{\sqrt{3(1-\mu^2)}}\left[\mu m_1F_{21}(\alpha)+k\,m_2F_{22}(\alpha)\right]\right\},$$

$$\sigma_{\alpha\alpha}(\alpha,\gamma)=\frac{E\,\mathbf{E}_1^*\lambda}{1-\mu^2}\frac{\gamma}{h}\left[-\frac{\sqrt{3(1-\mu^2)}}{2}\left(1-\frac{4}{3}m_1\right)F_{21}(\alpha)+\mu m_1F_{11}(\alpha)+k\,m_2F_{12}(\alpha)\right]+$$

$$+\frac{1}{1-\mu^2}\left(\frac{1}{3}-\frac{\gamma^2}{h^2}\right)\left[\mu m_1\varphi_1(\alpha)S_1^0(\alpha)+k\,m_2\varphi_2(\alpha)S_2^0(\alpha)\right],$$

$$\sigma_{\beta\beta}(\alpha,\gamma)=\frac{E}{R}w(\alpha)+\mu\,\alpha_{\alpha\alpha}(\alpha,\gamma)-E\,\mathrm{e}_{\beta\beta}^0(\alpha,\gamma), \tag{4}$$

Here

$$F_{ij}(\alpha)=\int_{-\alpha_j}^{\alpha_j}\varphi_j(\zeta)\exp\left[-\lambda|\zeta-\alpha|\right]\left[\cos\lambda(\zeta-\alpha)+(-1)^{i-1}\sin\lambda|\zeta-\alpha|)\right]d\zeta,$$

$i=1,2$ $\qquad$ $k=\mathbf{E}_2^*/\mathbf{E}_1^*$, E – Jung module.

Arbitrary numerical parameters $\mathbf{E}_i^*, k, \alpha_i, m_i, s_i$ are included in the expressions (4) that characterize fields of residual deformations e_{jj}^0 $(j = \alpha, \beta)$. For definite welded joints these parameters are determined by means of experimental information on residual stresses characteristics in pipelines, which can be received by non-destructive methods, namely by electromagnetic and ultrasonic ones [5].

If to use electromagnetic method the average difference of main stresses σ_+^E on the electromagnetic transformer contact surface of the measuring gauge and pipe is received, ultrasonic method allows determining average difference of basic stresses σ_0^E by the pipe metal volume that is situated under piezoelectric transformer.

Then for determining parameters $\mathbf{E}_1^*, k, \alpha_i, m_i, s_i$ functional is being built

$$g(\mathbf{E}_1^*, k, \alpha_i, m_i, s_i) = \sum_{n=1}^{n_1} p_n \left[\sigma_+^T(\mathbf{E}_1^*, k, \alpha_i, m_i, s_i; \alpha_n) - \sigma_+^E(\alpha_n) \right]^2 +$$

$$+ \sum_{m=1}^{n_2} q_m \left[\sigma_0^T(\mathbf{E}_1^*, k, \alpha_i, m_i, s_i; \alpha_m) - \sigma_0^E(\alpha_m) \right]^2, \qquad (5)$$

that characterizes discrepancy between experimentally determined parameters of stress condition σ_+^E and σ_0^E in the pipe cutover $\alpha = \alpha_n$ and similar values σ_+^T and σ_0^T, which are received theoretically by using formulas (4). Here p_n, q_m are some weight pluralities; n_1, n_2 – quantity of hoop pipe cutovers, in which measurements are fulfilled.

Now minimizing functional (5), we can find such values of parameters $\mathbf{E}_1^*, k, \alpha_i, m_i, s_i$, which provide the smallest discrepancy between experimentally determined and similar theoretically calculated characteristics of stresses fields. After these parameters are found by formula (4) the residual stresses are calculated in the arbitrary point of welded pipe joint.

Having used proposed method the residual stresses are determined near girth joint of «B.Volytsa-Dolyna» gas pipeline through the Stryy river (Ø1420×22,5 mm; material – steel X–70; E=2,1·10^5 MPa; μ=0,3). Experimental information is received by means of electromagnetic method, which is presently widely used during stress condition evaluation of gas-main pipelines under operation circumstances. For measuring conducting gauge «MESTR–411» is used with electromagnetic transformer of transformation type, which construction is patented in Ukraine [6]. Measuring results of this gauge are indicated in digital form by way of three digits with sign specifying (+, –).

It is known that while using physical methods, namely electromagnetic one measuring results are influenced by deformation of metal grain in the direction of plate-texture rolling and in the zone of thermal impact near welded joint, they are influenced also by structural metal changes. In order to consider this influence it is necessary to determine initial data of the gauge for the steel grade, of which pipe is made.

Texture influence on the initial gauge data is determined on the pipeline in unloaded condition on a definite distance from welded joint or on standardized sample for this material. For consideration of the structural transformations influence in the welded joint zone on the magnetic metal properties the samples are cut with welded joint and basic metal zone (Fig.1) out of a metal of reserve pipes or out of a pipe during repair, then the residual technological stress is released by heat treatment and initial gauge data are determined in the zone of thermal influence.

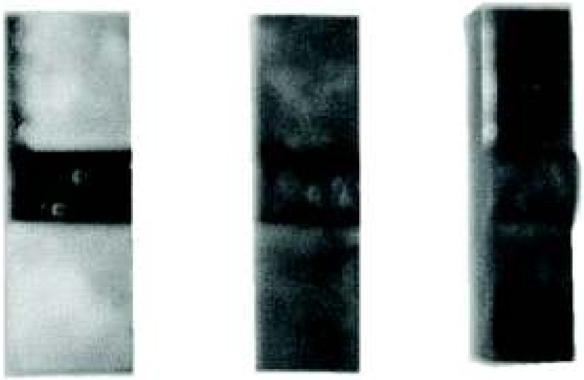

Fig. 1 Samples with welded joint and basic metal zone

On the basis of starting (initial) gauge data of MESTR–411 and corresponding data in a loaded condition by having used calibrated coefficient and methodology for determining difference of basic stresses [7], the value $\sigma_+^E(\alpha_n)$ has been defined in cases when electromagnetic transformer center was located in different pipe cutovers $\alpha = \alpha_n$.

If to approximate contact surface between gauge transmitter and pipe by hoop radius R_0, then the expression for analogous theoretical value $\sigma_+^T(\alpha_n)$ can be written in the following way

$$\sigma_+^T(\alpha_n; \mathbf{E}_1^*, k, \alpha_i, m_i, s_i) = E\,\mathbf{E}_1^*\, J_+^T(\alpha_n; k, \alpha_i, m_i, s_i), \qquad (6)$$

where

$$J_+^T = \frac{2}{\pi r_0^2} \int_{\alpha_n - r_0}^{\alpha_n + r_0} \left[\hat{\sigma}_{\beta\beta}^+(\alpha) - \hat{\sigma}_{\alpha\alpha}^+(\alpha)\right] \sqrt{r_0^2 - (\alpha - \alpha_n)^2}\, d\alpha,$$

$\hat{\sigma}_{jj}^+(\alpha) = \sigma_{jj}(\alpha, +h) \big/ (E\,\mathbf{E}_1^*)$; $j = \alpha, \beta$; $r_0 = R_0 / R$; α_n – coordinates of hoop centers along the pipe during measurements.

Measurement is conducted in the cutovers along pipe axle on four equally remote on pipe surface longitudinal lines (pipeline pressure during measurement was 4 MPa). Experimental data were averaged on each cutover and after their processing values of $\sigma_+^E(\alpha_n)$ were calculated, depicted as stars in the Fig. Then these values were substituted in a functional and by means of its minimization the following values of unknown parameters were received: $\mathbf{E}_1^* = 4 \cdot 10^{-4}$; $k = 1{,}5$; $z_1 = 22{,}5$ ($\alpha_1 = 0{,}032$); $z_2 = 12$ ($\alpha_2 = 0{,}017$); $m_1 = 0{,}08$; $m_2 = 0{,}15$; $s_1 = 4$; $s_2 = 5$.

Graph of function approximation (7) is depicted as *1* curve in the Fig. 2

Found values of these parameters are substituted in formulas (4) and hoop $\sigma_{\beta\beta}$ and axle $\sigma_{\alpha\alpha}$ stresses are calculated on the pipe surfaces, their graphs are depicted in Fig. 2. Graph of σ_{+}^{T} is depicted as *1* curve in the Fig.

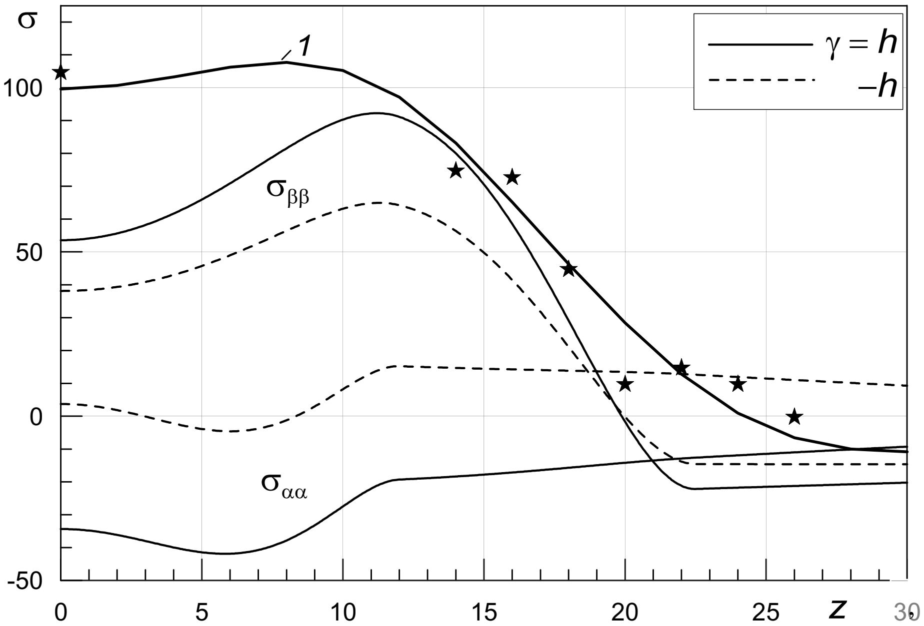

Fig. 2 Stresses dependence on the pipe surface from distance to the axle of pipeline welded joint

Analysis of the presented graphs shows that hoop residual stresses for the examined girth multi-layer welded joint are stretching near joint and with removal from joint axle they become compressed. Axle stresses with removal from joint axle are stretching on inner surface and compressed on external surface. Received experimentally averaged value of main stresses difference σ_{+}^{E} on pipe external surface can sufficiently exceed level of maximal residual stresses.

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