THE VARIATION OF THE STRESSES IN THE AREA OF DIAMETER CHANGE IN GAS PIPELINES

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Abstract: The paper presents an analysis of the variation of stresses at a gas pipeline in a geometric discontinuity zone of the diameter. The analysis was performed by assimilating the pipe area with variable diameter with an axially symmetric structure loaded with internal pressure. Stresses were determined using the method of moments, theory for axially symmetrical structures. The analysis was performed according to a set of parameters that define the geometry of a joining between a conical frustum and a cylinder and the loading mode with internal pressure. Efforts and stresses were determined in the meridian direction and in the circumferential direction adjacent coatings combining the two axially symmetries.

Keywords: stress, gas pipeline, axially symmetric shell

1. INTRODUCTION

On the path of gas pipelines are areas where there must be installed various devices necessary for proper operation. In some cases, the installation requires the adjustment of the pipe diameter.

Thus, there are inserted pipe segments with a pipe diameter different from that of the pipeline from that path. In Figure 1 there are presented a case in which the main pipe diameter needs to be modified. The transition from the normal diameter of the pipe to the modified one is made using a conical frustum shaped pipe section.

Fig. 1. Pipe with a variable diameter.

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Geometric discontinuity of the pipe diameter will be created in the joining area of the crossing section. The discontinuity part of the pipe diameter will produce a variation of stresses in the area.

The literature has analyzed several variants for loading. Thus in [1] is analyzed the stresses in axisymmetric shells using membrane theory. A similar approach is presented in [2] where the stresses are analyzed by analytical membrane theory and CAM finite element program. The paper [3] analyzes the stresses and deformations using nonlinear equations solved by the method of integration with multisegment method. Paper 4 presents an experimental analysis of the behavior to the external pressure of a cone cylinder junction.

This paper reviews the stresses variation caused by internal pressure in the connection area of a cone with a cylindrical shell.

2. HYPOTHESIS AND RELATIONS OF CALCULATION

The study of efforts and stresses was conducted for the joining area between the pipe and the crossing section, Figure 2 a, b.

The analysis was performed by assimilating the assembly between the pipe and crossing section with two axisymmetric shells, one conical and one cylindrical, with constant wall thickness and loaded with internal pressure.

At the study of axisymmetric shells, it was determined that moving in the normal direction to the shell, can be defined through two kinds of functions, one that grows quickly and one that pays the same way in a small relative length [5].

This property can be used for the study of deformation and stresses in a shell rather long, in the vicinity of a border contour of a corresponding independent mounting on the contour of the second border [6].

For determining the efforts on the junction contour between the shells 1 and 2, the two shells are separated and efforts corresponding to the moment theory are applied on the junction contour, Figure 3a.
In order to obtain simpler balance relationships, the simple basic system shown in Figure 3 is used. In this case, the forces on the common border of the two shells are equal, independent of the value of the angles \( \alpha_{01} \) and \( \alpha_{02} \). The forces \( F_0 \) and \( P_0 \) are determined from the equilibrium condition of the forces projected on the symmetry axis direction.

\[
F_0 = N_{a2} \sin \alpha_{a2} + T_{a2} \cos \alpha_{a2}
\]
\[
P_0 = T_e \sin \alpha_{a2} - N_{a2} \cos \alpha_{a2}
\]

(1)

If the variable \( \alpha_{02} \) is changed and a new variable \( s \), is determined with the relationships:

\[
s = R_e \tan(\alpha - \alpha_{02}) \equiv R_e (\alpha - \alpha_{02})
\]

(2)

where: \( R_e \) is the radius of the shell’s meridian arc; \( s \) is the meridian arc’s length.

We obtain the relations:

\[
M_\alpha = M_0 \cdot e^{-k_s} \left[ \cos(k \cdot s) + \sin(k \cdot s) \right] + \left( P_0 + F_0 \cdot \cot \alpha_0 \right) \cdot \frac{\sin \alpha_0}{k} \cdot e^{-k_s} \sin(k \cdot s);
\]

\[
M_\theta = \mu \cdot M_\alpha;
\]

\[
T_\alpha = -2k \cdot M_0 \cdot e^{-k_s} \sin(k \cdot s) + \left( P_0 + F_0 \cdot \cot \alpha_0 \right) \cdot \sin \alpha_0 \cdot e^{-k_s} \left[ \cos(k \cdot s) + \sin(k \cdot s) \right];
\]

\[
N_\alpha = \frac{F_0}{\sin \alpha_0} + 2 \cdot k \cdot M_0 \cdot \cot \alpha_0 \cdot e^{-k_s} \sin(k \cdot s) -
\]

\[\left( P_0 + F_0 \cdot \cot \alpha_0 \right) \cdot \cos \alpha_0 \cdot e^{-k_s} \left[ \cos(k \cdot s) - \sin(k \cdot s) \right];\]

\[
N_\theta = p \cdot R_\theta - \frac{R_\theta \cdot F_0}{R_\alpha \sin \alpha_0} + 2 \cdot k^2 \cdot M_0 \cdot e^{-k_s} \left[ \cos(k \cdot s) - \sin(k \cdot s) \right] +
\]

\[2 \cdot k \cdot R_\theta \cdot \sin \alpha_0 \cdot \left( P_0 + F_0 \cdot \cot \alpha_0 \right) \cdot \cos \alpha_0 \cdot e^{-k_s} \cdot \cos(k \cdot s);
\]

\[k = \frac{\sqrt{3 \cdot (1 - \mu^2)} }{\sqrt{R \cdot \rho \cdot h}}; \quad F_0 = \frac{p \cdot \left( r_b^2 - r_a^2 \right) }{2 \cdot r_a}.
\]

(8)

Value magnitudes \( M_0 \) and \( P_0 \) is determined from the system of equations:

\[
2 \cdot M_0 \cdot (k \cdot z + \alpha \cdot k \cdot z) + P_0 \cdot \left( \sin \theta_0 \cdot z - \alpha \sin \theta_0 \right) = -2 \cdot D_2 \cdot k \cdot z \cdot \left( \phi_2 \cdot \phi_3 \right) -
\]

\[-F_0 \left( \cos \theta_0 \cdot z - \alpha \cdot \cos \theta_0 \right);
\]

(9)
\[ 2M_0 \left[ \left( \frac{1}{R_0} \right)_2 - \alpha \cdot \left( \frac{1}{R_0} \right)_1 \right] + 2P_0 \cdot r \left[ \left( \frac{1}{k \cdot R_0^2} \right)_2 - \alpha \cdot \left( \frac{1}{k \cdot R_0^2} \right)_1 \right] = \]
\[ = - \left( \frac{p}{k^2 \cdot R_0} \right)_2 + \alpha \cdot \left( \frac{p}{k^2 \cdot R_0} \right)_1 + \frac{F_0}{r} \left[ \left( \frac{R_0 + \mu}{R_a} \right) \right]_2 - \alpha \cdot \left( \frac{R_0 + \mu}{R_a} \right) \left[ \left( \cos \theta_0 \right)_2 + \alpha \cdot \left( \cos \theta_0 \right)_1 \right] \]
\[ \text{(10)} \]

where:
- \( \alpha = \left( \frac{E \cdot h^2}{R_0} \right)_2 \left( \frac{E \cdot h^2}{R_0} \right)_1 \); \( r = \left( R \cos \theta_0 \right)_2 = \left( R \cos \theta_0 \right)_1 \); \( D = \frac{E \cdot h^3}{12(1 - \mu^2)} \);
- \( E \) is the modulus of elasticity of the material; \( \mu \) is the Poisson’s ratio.

For shell 1, it is done in a similar manner, if the shell rotates by 180° about an axis perpendicular to the symmetry axis “xx”. In this case, the angle between the symmetry axis and the normal to the meridian curve in the considered point will be the additional angle, which will produce a change of sign in the \( \cos \) and \( \cot \) functions.

When comparing the efforts that act on the junction contour for the rotated shell 1 with the efforts acting on shell 2, Figure 4, we notice a change of sign only for the force \( P_0 \). For shell 1 we obtain similar relations with (9) and (10) by changing the sign properly.

Figure 5 presents the variation of the moment diagram \( M_0 \), along the meridian, for values of angle \( \beta = 10^\circ \), \( \beta = 20^\circ \), \( \beta = 30^\circ \) for \( r_a = 150 \text{ mm} \), \( r_a = 200 \text{ mm} \), and \( h_1 = h_2 = 8 \text{ mm} \).
Figure 5. Variation of moment $M_{\alpha}$ along the meridian.

Figure 6 presents the diagram of variation of the moment $M_{\alpha}$ depending on the meridian angle $\beta$, for $r_a=150$ mm, $h_1 = h_2 = 8$ mm, for $s=0$ mm, $s=20$ mm and $s = 40$ mm.

Figure 6. Variation of moment $M_{\alpha}$ depending on the angle of inclination of the cone.
Figure 7 present the variation of forces $N_a$ and $N_b$ and Figure 8 summarizes the normal stress variation diagrams for $\sigma_a$, $\sigma_b$ and the angle value $\beta = 10^\circ$, $\beta = 20^\circ$, $\beta = 30^\circ$ and for $r_a = 150\ mm$, $r_b = 200\ mm$, $h_1 = h_2 = 8\ mm$.

3. CONCLUSIONS

The bending moment $M_a$ is maximal on the common border between the conical and cylindrical shells. At a distance of less than $0.2r_a$ from the common border of the two shells, the bending moment is zero.
The angle of the conical shell influences the level of efforts on the common border of the two shells, following an approximately linear law.

Since the effect of the bending moment is much larger than that of the axial force, normal stresses on the inner surface of the cone are similar to the variation of the bending moment.

REFERENCES