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THE DURABILITY CALCULATION FOR AERIAL TRANSPORTATION PIPELINES SUBJECTED TO COMPLEX LOADS

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Abstract: *This paper presents a rigorous analysis of the complex state of loads endured by the aerial transportation pipes, taking in consideration the pipe own weight effect, the weight of the transported fluid, the effect generated by the fluid pressure, the effect of the thermal stresses caused by temperature variation and the wind influence. Although the model that describes the interaction of all four effect is complicated, this paper presents a fully explication the effect of all four loads on the pipe durability. The calculation has been done using the NASGRO 5.01 software.*
Key words: *crack propagation, durability, variable loadsList 4-*

1. INTRODUCTION

The transportation system that use pipeline to carry the materials, especially the aerial pipes, are very complicated mechanical structures which requires high security measures during exploitation.

Hence, at its design, the designers must take in consideration all the factors that affect the normal functionality of the aerial transportation pipelines. During the designs stage, an important parameter is estimation of the pipeline durability. The durability is mainly affected by the constructive characteristics, by the construction materials, by the loading conditions and by atmospheric conditions.

In the paper are presented the most important forces that affect a transportation pipe, taking in consideration the pipe own weight, the difference in temperature between the inner and outer pipe surface and the effect caused by the wind action.

2. DIFFERENT TYPES OF LOADS

The aerial transportation pipes with thick walls, used to carry fluids or gases, can be loaded with different forces function to the exploitation condition, by the holding mode and so on.

a.Stresses caused by pipe bending due to the own weight effect

The normal stress, perpendicular on the transversal section of the pipe, it is given by the following equation:

$$\sigma_x = \frac{M_{i\max}}{W} \tag{1}$$

in which W is the strength modulus of the transversal section of the pipe.

The bending momentum, $M_{i\max}$, it is calculated as effect of the pipe weight cumulated with the weight of the transported fluid. The bending momentum depends on the pipe holding system.

b.Stresses caused by the inner pipe pressure

It is well known that if the pipe is loaded with internal pressure, in any given point from the pipe wall, the stress components are computed with the following equations:

$$\sigma_{rp} = p\frac{R_1^2}{R_2^2 - R_1^2}\left(1 - \frac{R_2^2}{r^2}\right) \tag{2}$$

$$\sigma_{\theta p} = p\frac{R_1^2}{R_2^2 - R_1^2}\left(1 + \frac{R_2^2}{r^2}\right) \tag{3}$$

for which: R_1 and R_2 are the inner and the outer pipe radius; r is the radius from the pipe axis to a certain point from the transversal section of the pipe; σ_{rp} and $\sigma_{\theta p}$ are the normal stresses on the radial direction, respective on the circumferential direction.

The stresses σ_{rp} and $\sigma_{\theta p}$ have tensile effect and can vary from zero to some maximal values function to the pressure values, which can vary during the pipe exploitation.

The stress components corresponding to the circumferential area, $\sigma_{\theta p}$, can play an important role in fatigue crack propagation, on the pipe longitudinal direction.

c.Thermal stresses

In a certain point from the transversal section of the pipe the following stresses are observed (Mocanu, 1992):

$$\sigma_{rt} = \beta \cdot t\left(r - \frac{R_2^3 - R_1^3}{R_2^2 - R_1^2} + \frac{R_1^2 R_2^2}{R_1 + R_2}\cdot\frac{1}{r^2}\right) \tag{4}$$

$$\sigma_{\theta t} = \beta \cdot t\left(2r - \frac{R_2^3 - R_1^3}{R_2^2 - R_1^2} - \frac{R_1^2 R_2^2}{R_1 + R_2}\cdot\frac{1}{r^2}\right) \tag{5}$$

$$\sigma_{xt} = \beta \cdot t\left(3r - 2\frac{R_2^3 - R_1^3}{R_2^2 - R_1^2}\right) \tag{6}$$

for which:

- $\beta = \dfrac{E\alpha_0}{3(1-\mu)(R_2 - R_1)}$;
- E – elastic modulus for longitudinal direction; μ - Poisson coefficient; α_0 thermal extension coefficient.

It can be shown that if the temperature difference $(t = t_2 - t_1)$ between inner and outer surface of the pipe its stay in 20 – 30 domain, the stress values for σ_{rt}, $\sigma_{\theta t}$ and σ_{xt} can be added together.

This type of thermal difference can be generated by temperature modification from day to night, in this way the pipe endure a variable load.

The constituent stress $\sigma_{\theta t}$ promote the crack propagation on longitudinal direction and the constituent stress σ_{xt} promote the crack propagation on circumferential direction.

d.Stresses caused by the wind action

It is known that a pipe facing an air flow having the speed v, it is loaded with variable force (Augustin, 1973):

$$F_p(t) = \frac{1}{2}\rho \cdot v^2 \cdot c_K \cdot d \cdot \cos\omega t \; [N/m] \quad (7)$$

In equation (7), ρ is the air density, v is the air speed, d is the external pipe diameter, $\omega = \frac{2\pi \cdot S \cdot v}{d}$ is the pulsation of the periodically force F_p, c_k is an bearing unitary coefficient with values between $0,45 \div 1$. For $R_e \approx (10^4 \div 10^5)$, the bearing unitary coefficient is $c_k \approx 1$, $S = \frac{f \cdot d}{v}$ is the Strouhal number, *f* is the separation frequency of the swirls.

For wind speed between 20 and 40 m/s, the separation frequency of the swirls is $(40 \div 83) Hz$. For this frequency over the pipe is generated a dynamical force that takes values between $25 \div 105\, N/m$.

The force $F_p(t)$ is perpendicularly to the pipe and is having the same direction as the air flow. The force $F_p(t)$ generates in the pipe a bending stress that is variable function to the air flow conditions. The resulted normal stress is computer with equation (1). The moment M_i is calculated as effect of the dynamical force $F_p(t)$, supposing that is uniform distributed on the pipe length (Birkoff, 1953).

In conclusion, the forces that affect a transportation pipe are: the pipe own weight, the internal pressure, the temperature difference between inner and outer surface and the air flow effect.

There are two more interesting case studies: the effect of the wind (air flow); the effect of the internal pressure cumulated with the thermal effect.

The action of the air flow must be analyzed separately because this load can affect the pipe during tens of hours, wile the effect of other loads can be insignificant.

The effect of the internal pressure and the thermal effect can be studied simultaneously, both of them being variable and periodically.

3. NUMERICAL SIMULATION AND RESULTS

For the numerical simulation it is considered a pipe with outer diameter of $D = 400mm$ and two different thickness of the pipe wall, 10 and 18 *mm*. The numerical simulation has been done using the NASGRO 5.01 software (NASGRO 5.01, 2007).

The pipe is made from low carbon steel having the following characteristics: strength stress: $\sigma_r = 310.3 N/mm^2$ and yield stress: $\sigma_c = 172.4 N/mm^2$

The initial dimensions of the elliptical shape crack (fig. 1) are: the small semi axis $a = 0.508mm$; the large semi axis $c = 2.54mm$.

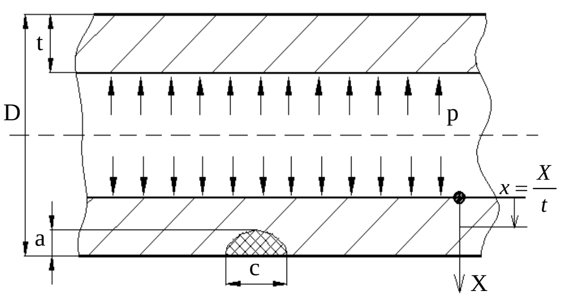

Fig. 1. The initial crack shape

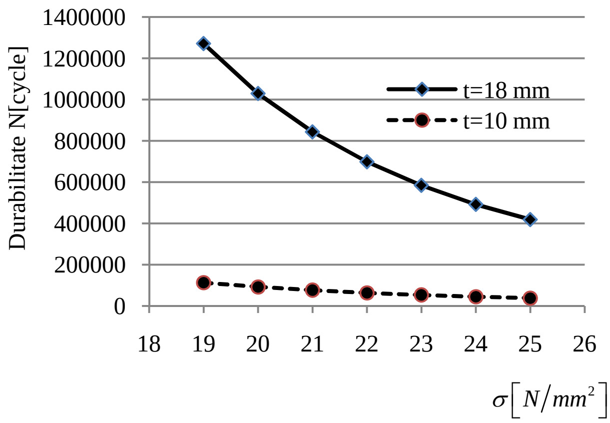

Fig. 2. The pipe durability function to the stress

Cases that has been studied:

a.If the pipe is loaded simultaneously with internal pressure and with thermal stress (different temperature between inner and outer pipe surfaces), summing of the $\sigma_{\theta p}$ stress and the $\sigma_{\theta t}$ stress has the effect of no crack propagation.

b.If the pipe is loaded only by the cyclical variation of the $\sigma_{\theta p}$ stress, the pipe durability it is function to the different values of the $\sigma_{\theta p}$ stress (corresponding to internal pressure *p*) and to the different values of the wall thickness. The results are illustrated in figure 2.

4. CONCLUSION

The theoretical study and the simulation that have been cared out conduct us to the following conclusions:

-Combination of the fourth loading forces it is complicated their interaction affect directly the durability estimation in case of the aerial transportation pipes.

-The thermal stresses caused by the temperature difference between inner and outer pipe temperature do not affect to much the pipe durability (Pintilie & Albut, 2009). The explanation for this phenomenon is that the temperature difference generates in the wall thickness tensile stresses and compression stresses.

-The durability of the pipe is manly affected by the load generated by the internal pressure, as is shown in figure 2. This effect it is more pronounced if the pipe wall is thicker.

-The effect of the wind can be very important if its speed is between 20 and 30 m/s (Pintilie & Albut, 2009).

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