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FATIGUE CRACK GROWTH PREDICTION FOR PIPES WITH KNOWN INITIAL CRACK

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ABSTRACT
The inspection of various structures often detects a fatigue cracks developed during long service life. These fatigue cracks significantly reduce remaining fatigue life and fatigue strength. Influence of the initial fatigue cracks size in pipes on the remaining fatigue life is considered in this paper. A computer simulation of fatigue crack growth was used in this analysis. Obtained results could be very useful to determine optimal inspection intervals.
Keywords: prediction of fatigue crack propagation, steel pipes, assessment of remainig fatigue life

1. INTRODUCTION
Fatigue is one of the most frequent form of the failures of the structural details, machine elements, pressure vessels and piping systems. According to ref. [1,2,3] 50 -90 percent of all mechanical failures are fatigue failures. This study focuses on the assessment of fatigue damage in a piping system. The fracture mechanics approach was utilized, average material properties were assumed.

2. ANALYSIS OF CRACK PROPAGATION
2.1. Crack propagation model
The crack propagation lives were calculated with the Paris equation [4]:

$$\frac{da}{dN} = C(\Delta K)^m \tag{1}$$

where

da/dN = crack growth rate,
ΔK = range of stress intensity factor,
C and m = material constants.

2.2. Stress intensity factor
The stress intensity factor was calculated by using Raju and Newman solution [5] for internal surface longitudinal cracks in pipes (Fig.1) Eq.(2):

$$K_I = \frac{pR}{t}\sqrt{\pi\frac{a}{Q}}F_i\left(\frac{a}{c},\frac{a}{t},\frac{t}{R},\phi\right) \tag{2}$$

where:

$$Q = 1 + 1.464\left(\frac{a}{c}\right)^{1.65} \tag{3}$$

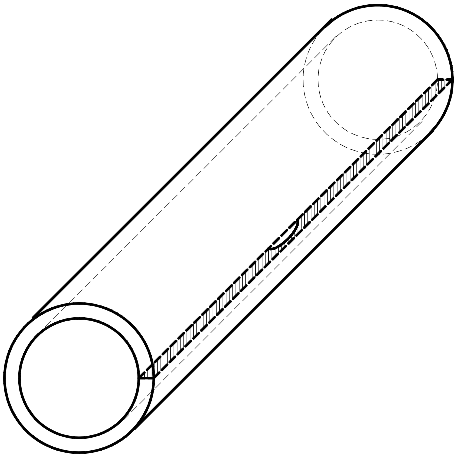

Figure 1. Pipe with longitudinal internal surface crack

$$F_i = \frac{t}{R}\left(\frac{R_0^2}{R_0^2 - R^2}\right)\left[2G_0 - 2\left(\frac{a}{R}\right)G_1 + 3\left(\frac{a}{R}\right)^2 G_2 - 4\left(\frac{a}{R}\right)^3 G_3\right] \tag{4}$$

where a = depth of surface crack, $2c$ = surface crack length, t = cylinder wall thickness, the shape factor for an elliptical crack, Q is the square of the complete elliptic integral of the second kind and is approximated by Eq.(3), p = internal pressure in cylinder, R , R_0 = inner and outer radii of cylinder. Influence coefficient for jth stress distribution on crack surface, G_j , was obtained from the appropriate finite element solution and given in tables [5] for the particular velues of t/R , a/c , a/t, . G_j values for anoter a/t values was determined in this work by using regresion analysis:

$$\begin{aligned}
G_0 &= 0.90933 + 0.64333\left(\frac{a}{t}\right)\\
G_1 &= 0.60133 + 0.27\left(\frac{a}{t}\right)\\
G_2 &= 0.48133 + 0.15667\left(\frac{a}{t}\right)\\
G_3 &= 0.409 + 0.11667\left(\frac{a}{t}\right)
\end{aligned} \tag{5}$$

3. PREDICTION OF THE REMAINING FATIGUE LIFE

Average material properties, for steel, were assumed: m = 3, C = $4.9\cdot 10^{-12}$, with ΔK in units of $\mathrm{MPa}\sqrt{\mathrm{m}}$ and da/dN in units of m/cycle, threshold stress intensity factor ΔK_{th} = 2 MPa√m . Geometrical parameters are: t/R = 0.25, t =10 mm, R = 40 mm, R_0 =50 mm, a/c =0.4. The remaing fatigue life (crack propagation life) N_p is obtained from the equation:

$$N_p = \int_{a_i}^{a_f} \frac{da}{C(\Delta K)^m} \tag{6}$$

The equation (6) was solved by 32-point Gaussian quadrature method [6]. These calculations were performed by using the computer program based on this procedure. Numerical integration was performed for several values of *Δp* and a_i . Calculated values *a* vs *N* are shown in Fig. 2.

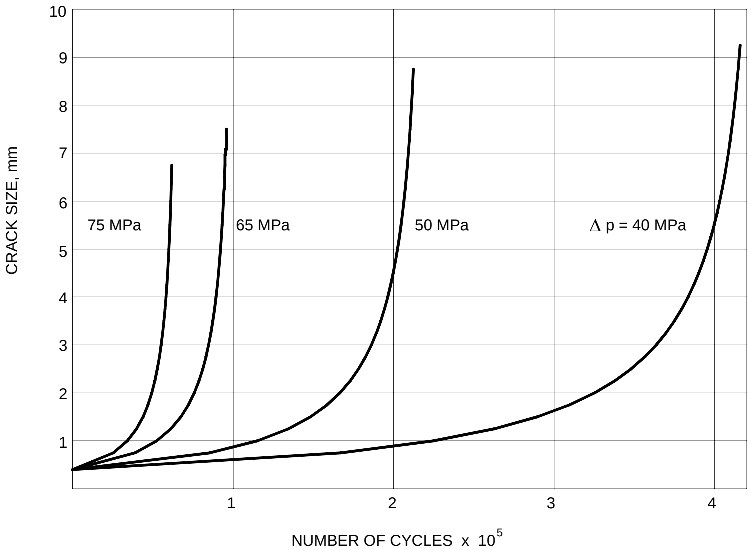

Figure 2. Determined a – N curves for various values of pressure ranges

Based on known initial crack size, the remainig fatigue crack propagation life was obtained and shown in Figure 3.

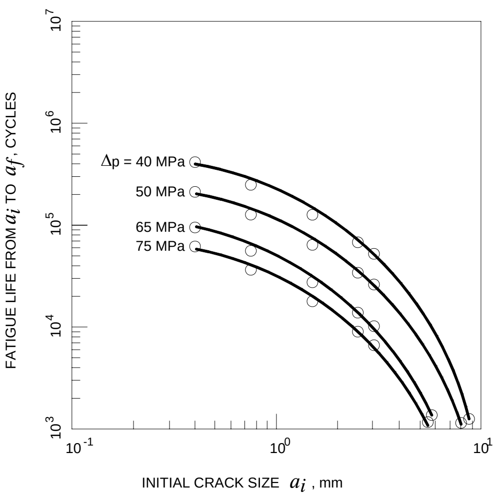

Figure 3. Predicted remaining fatigue lives for known initial crack

Dependance of safe internal pressure range of specific size of detected initial crack so that the fatigue crack stops its growth (*$\Delta K < \Delta K_{th}$*) is shown in Fig.4.

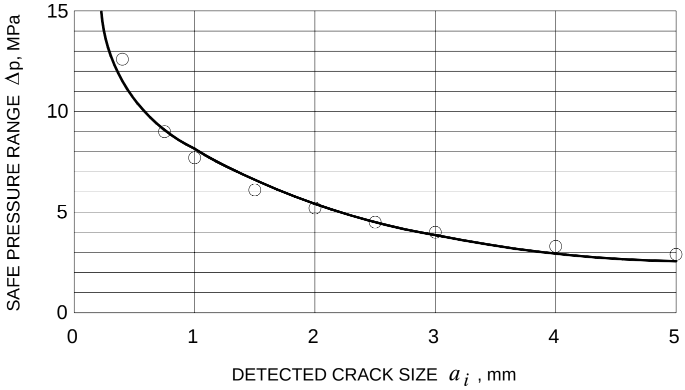

Figure 4. Safe pressure range for non-propagatig crack

4. CONCLUSIONS

Most of old structures subjected to cyclic loading containes a small fatigue crack developed during long service life. It seems reasonable, at least in some cases, to perform periodical ultrasonic or radiografic inspections in order to detect potential fatigue crack. To assure safe and reliable service life but also for an optimized maintenance strategy, it is necessary to have a precise estimation of lifetime consumption of critical components. Than one can predict remainig fatigue life i.e. time until final failure and choose the best moment of time to perform the repair.

5. REFERENCES

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