This paper provides a reliability analysis of one of the most critical power plant component - welded steamline, taking into account their exposure to the static pressure, low-cycle fatigue and creep damage.

INTRODUCTION

Most of the power plant users run their equipment at high professional level, but they rarely pay enough attention to the weldments unless a failure occurs. It is typical that only then a serious monitoring of weldments behavior starts. Therefore, it is the aim of this paper to provide a reliability analysis of one of the most critical power plant component - welded steamline, having in mind their exposure to the static pressure, low-cycle fatigue and creep damage.

ESTIMATION OF OPERATION CAPACITY REDUCTION

In order to make a probabilistic reliability analysis of welded steamline containing a defect in welded joint, the experimental data should be statistically worked out, using certain probabilistic level $\alpha$ (1,2):

$$P\left(y - \frac{\sigma_y}{\nu} a_k x_k < y < y + \frac{\sigma_y}{\nu} a_k x_k \right) = \alpha$$

(1)

$$y = a + bx = \bar{y} + r \frac{\sigma_y}{\sigma_x} (x - \bar{x}) ; \quad \sigma_{y/k} = \sigma_y (1 - r^2) \frac{n - 1}{n - 2}$$

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where \( \bar{x} \) and \( \bar{y} \) denote the mean values of \( x \) and \( y \), \( r \) - correlation coefficient, \( \sigma_x \) and \( \sigma_y \) - mean quadratic deviation values of \( x \) and \( y \) and \( t_{n,k} \) - Student's coefficient.

As an example streamline (inner diameter 219 mm, wall thickness 24 mm) with weld bridge seam - poor penetration in weldment root in the form of crack-like defect (\( a_0 = 2 \) mm deep, \( 2l_0 = 5 \) mm long).

Streamline was made of 14 MoV 63 steel and loaded as follows: pressure 14 MPa, temperature 520°C, stress amplitude 98 MPa. Allowed design stress at 520°C for this steel is 93 MPa. Designed number of start-ups and shut-downs is \( N = 5 \times 10^5 \).

Weldment strength dependence on a defect size (represented by a general parameter \( T \)) for the static loading has been found experimentally (3):

\[
R_{xx} = 400 - 16.5 \cdot T
\]  

(2)

where \( T \) can be expressed as follows (for both static and cyclic loads):

\[
T = \frac{1}{K} \left( \frac{K}{\sigma} \right)^2 = \frac{a}{Q} \left[ 1 + 0.12 \left( 1 - \frac{a}{T} \right) \right] \left( \frac{2s}{ma} \tan \frac{ma}{2s} \right)
\]  

(3)

where \( a \) denotes defect depth (mm), \( j \) - defect length (mm), \( Q \) - defect shape coefficient and \( s \) - weldment thickness. For given data, \( a_0 = 2 \) mm, \( 2l_0 = 5 \) mm, one gets \( T_0 = 1.03 \) mm.

The corresponding value of stress intensity factor is:

\[
K_u = \sigma_{max} \sqrt{\pi T_0} = 3.87 \text{ MPa}\sqrt{\text{m}}
\]  

(4)

Figure 1 shows probabilistic dependence of weldment strength on a general crack size parameter \( T \). Crossing of the regression line and allowed design stress defines the upper limit of general crack size parameter \( T_n \). Thereby, probability of residual strength being equal or greater than the allowed stress (\( \sigma_z \)) is determined by the marked area, \( 
\beta
\).

Therefore, \( T_n \) can be calculated as follows: \( T_n = (a - \sigma_z)/\sigma = 18.6 \) mm. Now, the admissible value of a general crack size parameter, \( T_n \), can be obtained for the 95% statistical reliability:

\[
T_n = T - Z_{0.95} \sigma / \sqrt{n} = 18.5
\]  

(5)

where \( Z_{0.95} = 1.96 \) is the argument value for the 95% statistical reliability, \( \sigma = 4.76 \), \( n = 20 \), as defined in (3), under the probability \( \beta_n \) that residual strength will not be less than \( \sigma_z \).
Required number of cycles to initiate the crack from the defect
poor root penetration type is given by (3):

\[ N_1 = 95.6 - 15.7K_u \]

i.e., with 95\% statistical reliability:

\[ N_1 = 95.6 - 15.7K_u - \sigma_y/\sigma_x \left[ \frac{1}{n} + \frac{(x - x)^2}{(n-1)\sigma_x^2} \right] \alpha \kappa = 29,400 \]

where \( \sigma_y = 2.62, n = 31 \) and \( \sigma_y/\sigma_x = 21.3 \), (3). Number of cycles needed for the fatigue crack growth from \( T_0 \) to \( T_1 \) is:

\[ N_r = N - N_1 = 50,000 - 29,400 = 20,600 \]

Having in mind the Paris law, one can write:

\[ N_r = \int_{T_0}^{T_1} \frac{dT}{C(T)^m} = \frac{2 \times 10^6 (K_u)^n}{(n-2)\sigma_y \alpha \kappa T^{n-2} / \sigma_x} \]

where \( \frac{dT}{dN} = 10^{-4} (K_u)^n \), \( n = 3.4, K_u = 8.5 \), (3), giving \( T_1 = 17.5 \) mm for the final value of general crack size parameter.

Therefore, the appropriate argument value \( Z_k \) is

\[ Z_k = \frac{T_1 - T_0}{\sigma_x} = 1.033 \]

giving the probability for steamline failure

\[ Y_k = 1 - P_k = 14.4\% \]

where \( P_k = 85.6\% \) is obtained directly from \( Z_k \).

CONCLUSIONS

It has been shown, with 95\% statistical confidence, that due to
defect of poor root penetration type in weldment, (2 mm deep and 5
mm long) steamline operation capacity is reduced for 14.4\% after
50,000 load cycles, out of which 29,400 cycles were needed for the
crack initiation.
REFERENCES


Figure 1 Probabilistic diagram of weldment strength dependency on the general parameter of defect size

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