PROBABILISTIC RELIABILITY ANALYSIS OF STEAMLINE WITH DEFECT IN WELDED JOINT

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This paper provides a reliability analysis of one of the most critical power plant component - welded steamline, taking into account their exposure to the statis 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 experimantal data should be statistically worked out, using certain probabilistic level α (1,2):

$$P(y-\sigma_{y/x}t_{\alpha,k} < a_y < y+\sigma_{y/x}t_{\alpha,k}) = \alpha \qquad (1)$$

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

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where $\bar{x}$ and $\bar{y}$ denote the mean values of x and y, r - correlation coefficient, σ_x and σ_y - mean quadratic deviation values of x and y and $t_{\alpha,k}$ - Student's coefficient.

As an example steamline (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).

Steamline 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 $N=5\cdot10^4$.

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

$$R_{zs} = 400 - 16.5\cdot T \tag{2}$$

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

$$T = \frac{1}{\pi}\left(\frac{K}{\sigma}\right)^2 = \frac{a}{Q}\left[1 + 0.12\left(1-\frac{a}{l}\right)\right]^2\left(\frac{2s}{\pi a}\,\mathrm{tg}\,\frac{\pi a}{2s}\right) \tag{3}$$

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

The corresponding value of stress intensity factor is:

$$K_u = \sigma_{max}\sqrt{\pi\cdot T_0} = 3.87\ \mathrm{MPa}\sqrt{m} \tag{4}$$

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 (σ_d) is determined by the marked area, β_n.

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

$$T_d = T_n - Z_{0.95}\,\sigma_x/\sqrt{n} = 16.5 \tag{5}$$

where $Z_{0.95}$ = 1.96 is the argument value for the 95% statistical reliability, σ_x = 4.76, n = 20, as defined in (3), under the probability β_n that residual strength will not be less than σ_d.

Required number of cycles to initiate the crack from the defect poor root penetration type is given by (3):

$$N_i = 95.6 - 15.7 \cdot K_u$$

i.e., with 95% statistical reliability:

$$N_i = 95.6 - 15.7 \cdot K_u - \sigma_{y/x} \sqrt{\frac{1}{n} + \frac{(x - x)^2}{(n - 1)\sigma_x^2}}\, t_{\alpha,k} = 29,400$$

where $\sigma_x = 2.62$, $n = 31$ and $\sigma_{y/x} = 21.3$, (3). Number of cycles needed for the fatigue crack growth from T_0 to T_k is:

$$N_r = N - N_i = 50,000 - 29,400 = 20,600$$

Having in mind the Paris law, one can write:

$$N_f = \int_{T_o}^{T_k} \frac{dT}{C(\Delta K)^m} = \left. \frac{2 \cdot 10^6 (K^*)^m}{(m-2)\sigma_{max}^m T^{(m-2)/2}} \right|_{T_o}^{T_k}$$

where $\frac{dT}{dN} = 10^{-6}\left(\frac{K}{8.6}\right)^{3.5}$, $m = 3.4$, $K^* = 8.5$, (3), giving T_k = 17.5 mm for the final value of general crack size parameter.

Therefore, the appropriate argument value Z_k is

$$Z_k = \frac{T_n - T_k}{\sigma_x}\sqrt{n} = 1.033$$

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% statictical 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.

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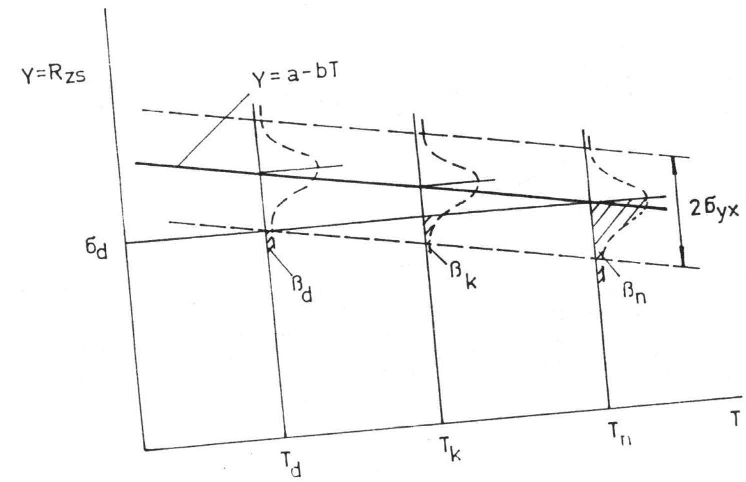

Figure 1 Probabilistic diagram of weldment strength dependency on the general parameter of defect size