Structure Integrity Assessment of a Windflow Power Plant's Axle

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Abstract: - A structure Integrity assessment was performed according to the FITNET* structure integrity procedure on axle with multiple cracks in the critical section. In order to determined the stress-strain condition of axle, numerical modeling was performed by using finite element methods. The results show that the range of the stress integrity factor for dynamic loading can exceed the fatigue stress intensity factor at threshold regions. Therefore, fatigue crack propagation by finding flaws is possible. Results also show, that the final collapse of an axle appears at a significant fatigue crack size. On the basis of these results, repairing by the welding of the critical area of an axle is recommended.

Key-Words: - Structure integrity assessment, windflow axle, crack's defects

1 Introduction

Nowadays a windflow power has plant become a significant source of electrical energy. It is an alternative to nuclear power, steam power or even hydro power plants. However, reliable production of electricity among others parameters depends on the axle of the windflow power plant. Mechanically, the axle is the most critical part of the plant and is loaded by bending (not torsion). This part consists of a mechanical beam, between the wind-rotors blades and the generator's housing. The axle is usually made of steel by a casting process. Changes in wall thicknesses and reduction of diameters can cause defects in materials as pores, flaws or remaining of slag. Therefore, for reliable use, it is necessary to perform structural integrity assessment of axle for flaws such as cracks. The aim of this paper was to find the maximum load carrying capacity for a windflow power plant's axle having a radial crack

2 Assessment procedure

During the inspection procedure, the presence of a crack in the windflow Power Plant's axle was detected in an area of geometrical change. The position and size of the detected crack in a critical section of the axle are shown in Figure 1. Since the quality assessment requires non existing cracks in a component, a new axle had to be cast. However, the main question was whether the presence of a crack was acceptable or not and if fatigue crack propagation is possible. In order to find the answer, pieces of cast steel were used for manufacturing tensile and fracture mechanic specimens.

The obtained tensile properties of cast steel are listed in Tab. 1. Fracture toughness values are obtained by CTOD testing according to standard ASTM E-1820 [1], and conservative values for three specimens are also listed in Tab. 1 as well.

Table 1 : Measured mechanical properties and fracture toughness of cast steel

Material	Cast steel
Yield stress $R_{p0,2}$	549 MPa
Ultimate tensile stress R_m	653 MPa
Young's modulus E	185,6 GPa
Poisson's ν	0,3
$CTOD_{0,2BL} = CTOD_{mat}$	0,275 mm
$J_{0,2BL} = J_{mat}$	185 N/mm

According to the FITNET procedure, it is allowed to assume worst crack geometry. This approach leads to conservative results. Therefore, the idealization of crack geometry is shown in Fig. 1.b, where a=20 mm is the cracks depth and 150° is radial surface crack's length. The wind-power plant's axle is loaded by bending as schematically shown in Fig. 2.

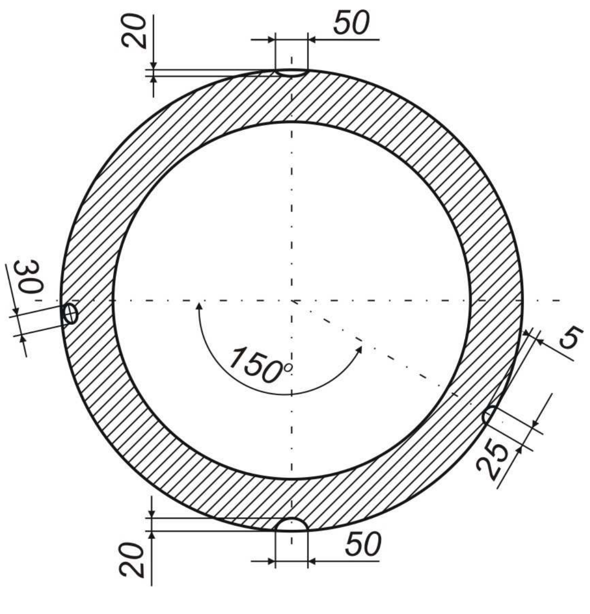

Figure 1.a) Critical section of axle with the position and sizes crack

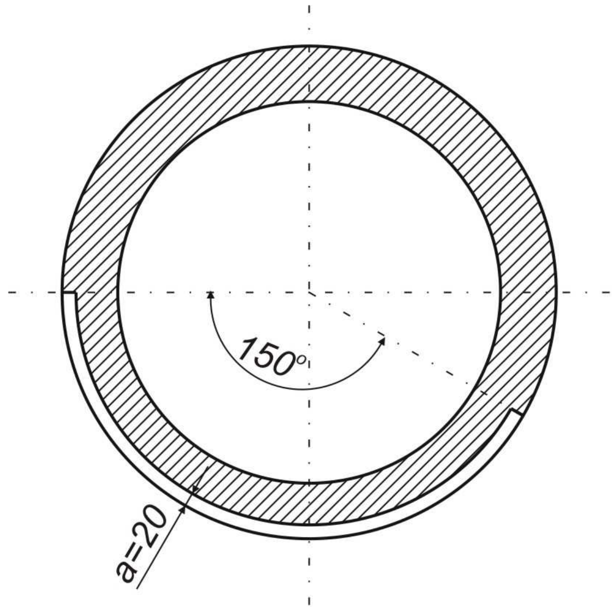

Figure 2.b) Idealized uniqe surface crack in the most critical region.

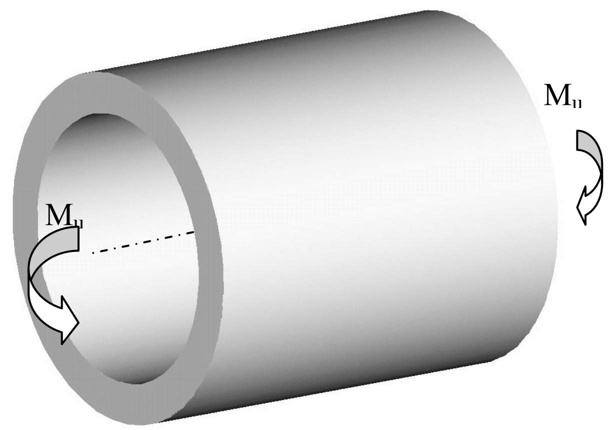

Figure 2 Manner of loading axle

Table 2: Geometry in critical section of the axle

Dimension	
Outside diameter $2R_0$	710.065 mm
Inside diameter $2R_i$	570.5 mm
thickness $T = R_0 - R_i$	70.25 mm
Crack depth a	20 mm
Surface Crack length 2c	150°

Stress intensity factor is calculted according to [2] Eq. (1)

$$K = \sigma \cdot \sqrt{\pi \cdot a} \cdot Y\left(\frac{a}{T}, \beta\right) \tag{1}$$

where $Y(a/T,\beta)$ is the stress intensity function, and σ is the principal opening load, obtained by finite element modelling. Distribution of crack opening stress along the axle is shown in Fig. 3, this loading corresponds to the highest loading matrix according to the design of the wind-power plant. Figure 3 shows that the highest stress appear in the area of sicovered cracks.

In structure integrity analysis the relavant stress is the crack's opening stress (mode I) σ_x as shown in Fig. 4. Fracture toughness of the material is determined using the fracture mechanics approach in terms of J integral or crack tip opening value CTOD=δ:

$$K_{mat} = \sqrt{\frac{J_{mat} \cdot E}{1-\nu^2}} = \sqrt{\frac{R_{p0,2} \cdot \delta_{mat} \cdot E}{1-\nu^2}} \tag{2}$$

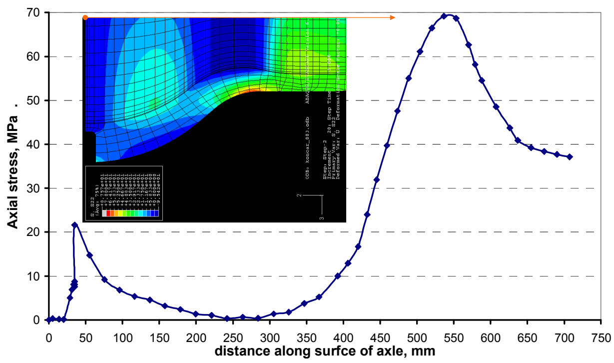

Figure 3 Crack's opening stress distribution on the surface of the axle in the longitudinal direction (load case 7.1c50: M_x=1581 kNm, M_y=402,5 kNm, M_z=308,3 kNm, M_{yz}=507,1 kNm, F_x=52,3 kN, F_y=-39 kNm, F_z=-289,8 kNm, F_{yz}=292,4 kNm)

The normalized load during the FITNET procedure is defined as

$$L_r = \frac{M_b}{M_Y} = \frac{\sigma_{ref}}{\sigma_Y} \tag{3}$$

M_y is limit bending moment at yielding the rest of the non-cracked ligament and σ_{ref} is the reference stress, taking into account the crack's size and loading manner.

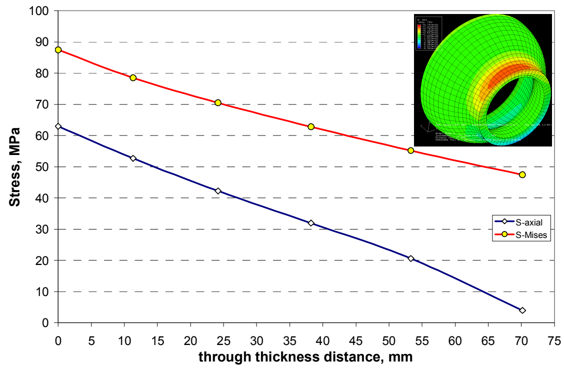

Figure 4 Distribution of opening stress σ_x and equivalent von Mises through the axles wall

Plastic collapse at the base of the FITNET procedure is obtain

$$L_r^{max} = \frac{1}{2} \cdot \left[\frac{R_{p0,2} + R_m}{R_{p0,2}}\right] \tag{4}$$

In the FITNET procedure the failure assessment curve-FAC is defined for materials with continues hardening:

$$f(L_r) = \left[1 + \frac{1}{2} L_r^2\right]^{-\frac{1}{2}} \cdot \left[0,3 + 0,7 \cdot e^{-\mu \cdot L_r^6}\right] \quad for \quad 0 \le L_r \le 1 \tag{5}$$

$$\text{where } \mu = \min\begin{cases} 0,001 \cdot \dfrac{E}{R_{p0,2}} \\ 0,6 \end{cases} \tag{6}$$

$$\text{and } f(L_r) = f(L_r = 1) \cdot L_r^{\frac{N-1}{2 \cdot N}} \quad for \quad 1 \le L_r \le L_r^{max} \tag{7}$$

strain hardening exponent N is given by the empirical term:

$$N = 0,3 \cdot \left(1 + \frac{R_{p0,2}}{R_m}\right) \tag{8}$$

where $R_{p0,2}$ and R_m are yield stress and ultimate tensile stress, respectively (see Tab. 1).

Table 3 Reduction of maximum bending stress at constant crack depth $a = 20\ mm$

Surface length	Surface angle	Maximum bending stress
l (mm)	β (°)	σ_x, N/mm^2
5	0,8°	583
40	6,45°	557
120	19,36°	530
200	32,27°	507
400	64,54°	470
600	96°	450
935	150°	440

Each intersection point in the failure assessment diagram-FAD between FAC and loading curve represents the potential danger of a fracture, as shown in Fig. 3. Normalized load contains one value at each intersection point. Therefore, the corresponding value of the applied bending moment M_b is known, if the limit bending moment M_Y is calculted.

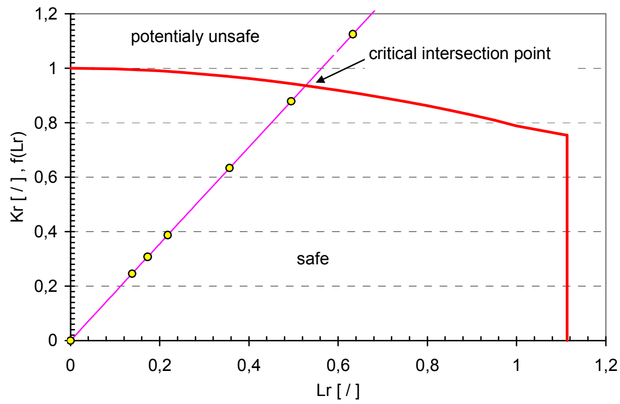

Figure 5 FAD plot for axle with crack $a = 20\ mm$ and surface crack length β=150°

Figure 6 shows the variations in maximum loading capacity coresponding to different surface radial crack length for two-crack depths a = 30 mm and a = 40 mm. In order to estimate rest loading capability it is possible to repeat the same procedure for a few crack sizes. Limit bending moment is determined for each crack's length. Table 3 shows values for maximum carrying capactiy regarding different crack lengths.

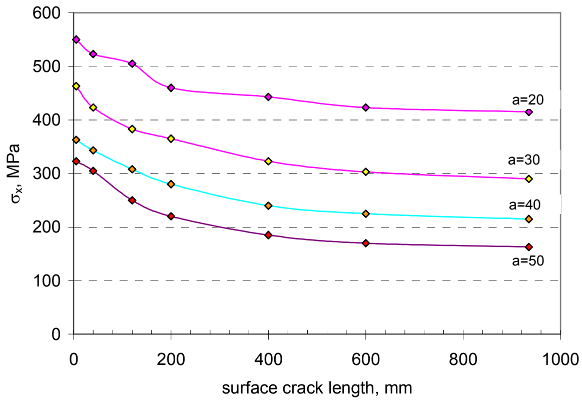

Figure 6 Reduction of maximum carry capacity in regard to crack depth and surface lengths

3 Conclusion

The obtained results show that in the case of overloading, the brittle fracturing of an axle is possible if crack propagates to critical crack length. FEM analysis shows that maximum load appears on an axle according to a combination of bending and tensile loading. The loading code for wind power plants is used during structural integrity assessment. The results of this analysis help to judgment about acceptance or refusal axle regarding to the windflaw. According to the FITNET structure integrity procedure, structural integrity assessment has to be performed for an axle with multiple cracks in critical sections. The results show that the range of the stress integrity factor for dynamic loading can exceed the fatigue stress intensity factor at threshold regions. Therefore fatigue crack propagation after finding flaws is possible. The results also show, that the final collapse of an axle appears at a significant fatigue crack size. On the basis of these results repair by welding at a critical area of an axle is recommended.

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