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Crack growth prediction of mixer shaft

M. Růžička[a], K. Doubrava[a], M. Nesládek[a], J. Kuželka[a]

[a]*Department of Mechanics, Biomechanics and Mechatronics, Faulty of Mechanical Engineering, Czech Technical University in Prague; Technická 4, 166 07 Prague, Czech Republic*

1. Introduction

The subject of the assessment was a drive shaft of the horizontal chemical agitator mixer, which is used to produce polypropylene powder. The scheme of the equipment as well as the beam model of the assembly is depicted in Fig. 1 (left). The Zapex® gear coupling is mounted with the keyed joint connection on the agitator drive shaft. During operation, this joint proved to be a critical point of the structure and showed the appearance of fatigue cracks and insufficient service life. A detail of the shaft with a keyed joint and the area of an initiated crack from the keyway is shown in Fig. 1 (right) [2]. The goal of the analysis was to predict the crack rate of this damage under operating conditions and safe life of the shaft.

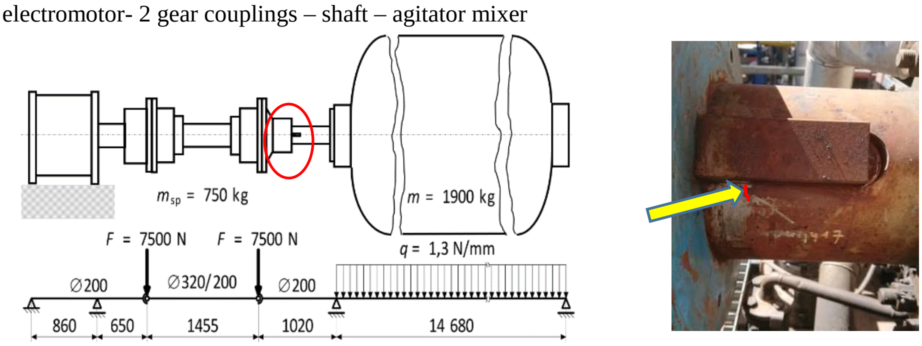

Fig. 1. The drive assembly of the mixer as well as the beam model of the assembly (left) and detail of the shaft with the keyed joint and the area of the initiated crack from the keyway (right)

2. Experimental analysis realized on the agitator mixer equipment

First, a strain-gauge analysis on the shaft was performed with the aim to obtain the nominal bending and shear strains and stresses, as well as the local strains near the found crack tip, see Fig. 2. These strain-gauge measurements were realized on four different power input levels. Mean strains and stress levels as well as amplitudes/ranges were averaged from measured time histories to evaluate the calibration lines between electric power input and nominal or local strains and stresses.

The correlation relationship between the long-time monitored electrical power input of the electromotor against the nominal normal bending stress and the shear stress on the agitator shaft is depicted in Fig. 3. It has been shown that these dependencies could be linearized and can be used to calculate bending and shear stresses for archived or currently acquired operational records power input of the electromotor.

Fig. 2. The scheme of the location of the installed strain gauges (left) and detail of the strain gauge rose at the crack tip (right)

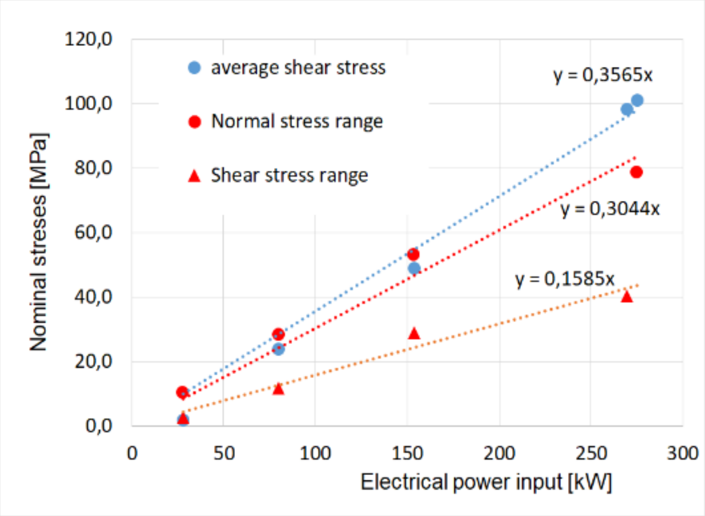

Fig. 3. Calibration lines: dependency between the electro motor power input and nominal normal bending and shear stresses on the shaft

3. Analytical and numerical analysis

Second, the FEM calculations on keyed joint connection model was performed to determine the stress concentration factors as well as crack length correction functions. These functions were subsequently used for an analytical calculations of stress intensity factors (SIF) *K* serving as a basis for the analytical crack growth models for a residual life prediction. Fig. 4 (right) shows the FE models of the keyed joint connection with selected crack length from the reconstructed geometry of the crack front in successive steps according to fractographic analysis. The SIF were calculated during cracks numerical propagation to determine the SIF correction functions $f_{K_i}\left(\frac{a}{d}\right) = \frac{K_i}{\sigma\sqrt{\pi a}}$ for the analytical predictions calculations. All three crack loading modes *I*, *II* and *III* were taken into account and correction functions were calculated from the relations

$$f_{K_i}\left(\frac{a}{d}\right) = \frac{K_i}{\sigma\sqrt{\pi a}}, \qquad i = I, II, III, \tag{1}$$

where a is the crack length, d is the shaft diameter and σ is nominal bending or shear stress.

The resulting range value of the stress intensity factor taking into account all three crack loading modes was determined according the relation

$$\Delta K_{eff} = \sqrt{\Delta K_I{}^2 + \Delta K_{II}{}^2 + \Delta K_{III}{}^2/(1-\nu)}\,. \tag{2}$$

Fig. 4. The fractographic reconstruction of the crack front in different damage time and FEM model geometry for selected crack lines for calculation of the SIF and geometric correction functions [2]

Finally, the residual fatigue life analysis was done according to the Paris-Erdogan, Klesnil-Lukáš and NASGRO crack growth models [3]. The type of model depends on the form of the function g in the crack growth equation

$$v = \frac{da}{dN} = g\left(\Delta K_{eff}\right). \tag{3}$$

Material parameters of these models were investigated for the used material (36NiCrMo16 steel) experimentally on the small specimens [1]. For crack propagation studies, the NASGRO model according the next equation (4) with the following experimentally determined parameters was finally chosen, see Table 1

$$v = v = C\left(\Delta K_{eff}\right)^{n} \frac{\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^{p}}{\left(1-\frac{K_{max}}{K_{c}}\right)^{q}}\,. \tag{4}$$

Table 1. NASGRO model equation parameters

C	n	p	q	ΔK_{th}	K_0	ΔK_c
	-	-	-	MPa√m	MPa√m	MPa√m
1.90E-11	2.7	0.85	0.5	8.94	4.62	110

Fig. 5 (top) shows the time history of the electrical power input of the machine for which a fatigue crack growth of the initiated crack was simulated. Predictions of further crack growth were subsequently calculated for repeated typical three-months operational loading until the limited crack length before formation of a quasi-brittle fracture in the whole shaft cross-section. The crack length curve in Fig. 5 shows the predicted growing of the primary detected crack (12 mm in the length) and a limited service life for further operation of the agitator mixer.

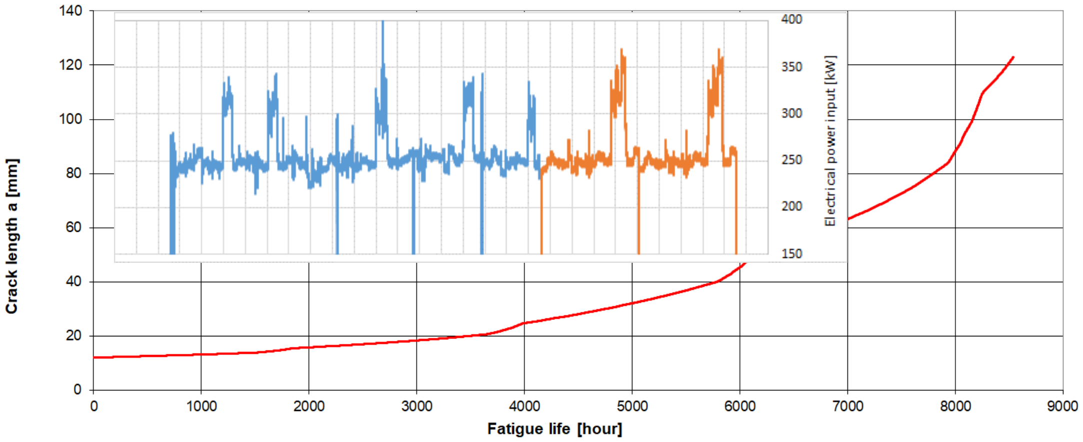

Fig. 5. The time history of the electrical power input of the machine (top) and predicted crack length growth curve according the NASGRO model (bottom)

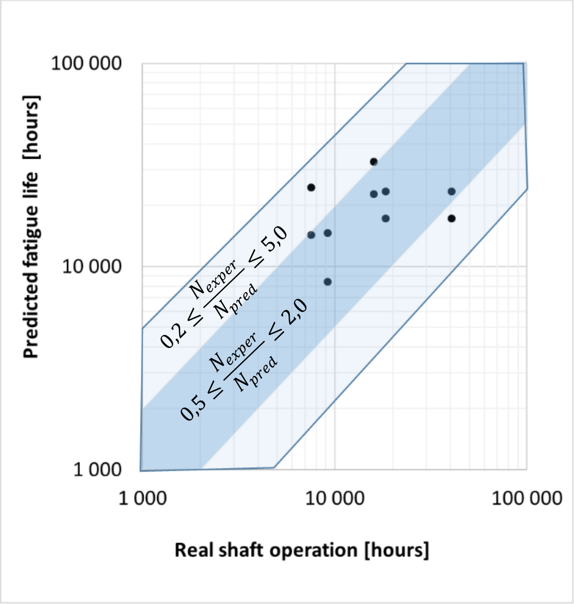

Fig. 6. Calibration of the power input and nominal stresses on the shaft (left) and FEM model geometry of the FE crack lines models for calculation of the SIF and geometric correction function (right) [2]

4. Conclusion

Based on the findings presented above, the following conclusions can be drawn:

- The fatigue life of this type of joint under the given operating loadings is insufficient.
- Operation leads to the formation and propagation of fatigue cracks and there is a risk of operational failure.
- When a short fatigue crack is found, its further growth can be predicted.
- For further safe life designs, a fatigue life factor of $k = 5$ should be recommended.
- It would be appropriate to reconstruct the given type of keyway connection.

References

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