Periodic breathing in transverse annular cracks in real rotating machinery

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Long Abstract

Introduction

Transverse annular (or circumferential) cracks have a rather unusual shape and are, luckily, not very common in rotating machines, albeit they can be caused by the generation of multiple initiation points. This case is analyzed in the paper, in which a transverse annular crack is triggered by equally spaced initiation points over the whole circumferential surface of the shaft cross-section located at the first high pressure stage of the steam turbine (see Figure 1).

Figure 1. Initiation points in the dovetail slots of 1st high pressure stage and crack close-up.

A remarkable and detrimental characteristic of transverse annular cracks is the weakness of the usual symptoms of crack presence in a rotating shaft. Actually, in this case, crack breathing causes unusual changes in the area moments of inertia of the damaged cross-section. On the contrary, the thermal transients to which the turbine is subject during the load rises, performed at the end of the run-ups from a cold state, highlighted the sensitivity of the synchronous vibrations to the shaft temperature.
Therefore, the fault symptoms caused by this crack are different from those induced by usual shaft transverse cracks [1]. The breathing mechanism of this annular crack, caused by gravity [2], is analysed by means of a mathematical model to study the influence of the crack opening and closing on the harmonic content of the turbine vibration. The good fitting between simulated results and experimental data endorses the reliability of the mathematical model introduced in this paper.

1. Crack geometry

Figure 2 shows a complete front view of the cracked section of the shaft. A thin slice of the shaft was cut from the two halves, on the same side of the crack. The above mentioned specimens were used to perform fractographic and metallographic investigations whose results are summarised in [3].

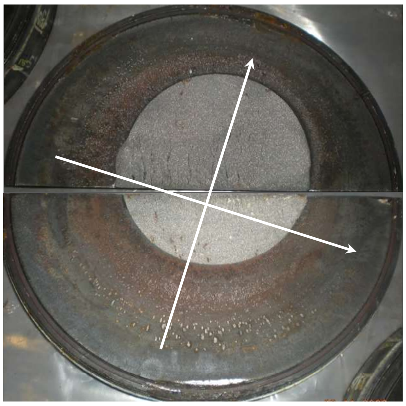

Figure 2. Front view of the complete cracked section of the shaft.

A preliminary finite element model (FE) of the turbine shaft has been generated, composed of beam finite elements whose geometrical and mechanical characteristics allow the flexural and torsional stiffness of the shaft as well as its inertia properties to be simulated.

This model has been used to evaluate the bending moments and shear forces acting at the cross-sections close to the crack, caused by the rotor weight. Afterwards, in order to reduce the computational time taken by the study of the crack breathing mechanism, a further more accurate three dimensional, 3D, finite element model of only a short part of the shaft has been generated using the Commercial Code ABAQUS (Figure 3).

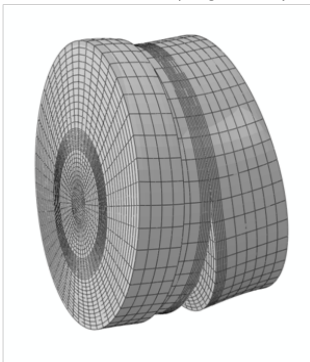

Figure 3. Detail of the 3D finite element model of a short part of the shaft that contains the cracked section.

Then, the periodic changes in the local flexural stiffness of the shaft have been considered in the simplified finite element model of the turbine rotor. This model has been used to simulate the periodic changes in the static deflection of the shaft, caused by gravity, over a full revolution. The experimental data have been successfully compared to the numerical results of this study.

References

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[2] Papadopulos C.A., Some comments on the calculation of the local flexibility of cracked shafts, Journal of Sound and Vibration, 278 (4-5) (2004) 1205-1211.

[3] Barella S., Bellongini M., Boniardi M., Cincera S., Failure Analysis of a Steam Turbine Rotor, Engineering Failure Analysis, 18 (2011) 1511-1519.