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Efficiency analysis of vibration based crack diagnostics in rotating shafts

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ABSTRACT

The vibration based damage detection has practically no alternative as applied to the rotating shafts of steam turbines during operation. A lot of vibration method of damage detection are developed till present time. But the efficiency of all these methods is very dependent on the type of structure, way of its deformation and on the type of damage. At a moment practical engineers have no instrument to make right choice of most appropriate method of damage detection for some or other structure.

The comparative estimation of efficiency of different vibration diagnostics methods to detect damage of sub-critical size is complex and time-consuming process. So there was developed quite simple method of selection of most efficient vibration method of damage detection for a certain structure with a certain type of crack and at a certain type of deformation. This method is based on the determination of relative change of shaft's compliance caused by a crack with the use of linear fracture mechanics. As an example there was performed the comparative sensitivity analysis of several vibration methods of damage detection to the presence of longitudinal and transverse crack in a shaft at bending and torsional vibration.

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1. Introduction

The fact that crack or local defect affects the dynamic response of a structural member is known long ago [1]. A lot of vibration based method of damage detection were developed till present time. The most widely used among them are the change of natural frequencies, mode shapes or modal damping, and non-linear effects, etc. [2–6].

In such a way, practical engineers often face the problem of making right choice for most appropriate method among the variety of damage detection methods as applied for definite structure. Unfortunately, this problem cannot be solved easily because the efficiency of vibration damage detection is very dependent on the type of structure, way of its deformation and on the type of damage.

The assessment of possibility of vibration diagnostics to detect damage of sub-critical size is complex and time-consuming process. Currently it is carried out either theoretically using quite complex models or experimentally. Both ways are not appropriate for engineering applications.

Abbreviations: SIF, stress intensity factor; HPC, high pressure cylinder; MPC, middle pressure cylinder; LPC, low pressure cylinder.

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Nomenclature

a	crack depth
A_1	amplitude of first harmonic
A_2	amplitude of second harmonic
b	width of the crack front
c	half width of the crack front
D	diameter of the shaft
d	diameter of the hole in the shaft
E	Young's modulus
f	natural frequency of the intact shaft
f_c	natural frequency of the cracked shaft
F	area of shaft's cross-section
F_I	approximation function for the mode *I* crack
F_{II}	approximation function for the mode *II* crack
F_{III}	approximation function for the mode *III* crack
G	shear modulus
I	axial moment of inertia
I_p	polar moment of inertia
K_I	mode *I* stress intensity factor
K_{II}	mode *II* stress intensity factor
K_{III}	mode *III* stress intensity factor
L	length of the shaft
L_c	crack location
m	mass of the shaft
M	bending moment
M_{tr}	torsional moment
q	length of the longitudinal crack
W	axial section modulus
W_p	polar moment of cross-section resistance
δ	compliance of shaft
δ_o	change of compliance of the cross-section with crack
$\gamma = a/D$	relative depth of the transverse crack
$\lambda = 2a/(D-d)$	relative depth of the longitudinal crack
v	Poisson's ratio
ρ	density of a material
ψ	damping ratio

So the idea of the study was to develop a relatively simple method of comparative assessment of the sensitivity of different vibration damage detection methods based on the determination of relative compliance of cracked section with the use of linear fracture mechanics. The method was demonstrated as applied to the cracked shaft at bending and torsion vibration.

The appropriate modelling of the influence of crack on the stiffness (compliance) of mechanical systems is of paramount importance in the problem of vibration damage detection.

The most simple modelling of cracks in terms of local reduction of stiffness was performed by slots of different shapes (rectangular, square or triangular) [7–9]. Crack was modelled also by reducing the moment of inertia of cracked section [10] or the elastic modulus of the material [11]. The influence of crack on the compliance of a beam was simulated by the extra pair of bending moments [12,13] or by two pairs of self-equilibrating forces [14]. The most complex model of crack took into account stress distribution in the vicinity of crack [15].

However, during several last decades the widely used way to determine the compliance of cracked section was based on the fracture mechanics approach using the Castigliano's theorem and the relations between the strain energy release rate and the Stress Intensity Factor (SIF) [16,17]. Fracture mechanics makes it possible to perform quite simple and at the same time highly accurate modelling of crack itself and of its impact on vibration characteristics of structures. Such a model of crack does not change the mass of structure, much more accurate predicts the change of natural frequencies and mode shapes, especially in case of fatigue cracks. Besides it can reveal the non-linearity of vibration of structures with the so called closing crack (crack which periodically opens and closes during vibrations).

The vibration based damage detection has practically no alternative as applied to the rotating shafts of steam turbines during operation because it is not possible to provide immediate excess to the object of diagnostics which is covered by the protective shell.

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