Improved Crack Closure Line Position: An Improved Model for Crack Breathing Phenomenon

R. Ramezanpour, M. Ghayour and S. Ziaei-Rad

Department of Mechanical Engineering, Isfahan University of Technology 84156-83111 Isfahan, Iran

(Received 3 October 2012; accepted 15 November 2013)

The dynamic behaviour of a cracked Jeffcott rotor is investigated in this paper. The crack is located at the midpoint of the rotor. It is known that when the static deflection dominates the vibration of the rotating shaft, the crack opens and closes according to the shaft rotation. This phenomenon is known as crack breathing. There are several models for classifying crack breathing phenomena, such as the switching crack model, harmonic approach model, and response-dependent breathing crack model. In order to model the breathing of the crack in the response-dependent breathing crack model, the concept of a crack closure line position (CCLP) is proposed and used by some researchers. The main scope of this work is to present an improved crack closure line position (ICCLP). By using several contour plots over the crack's surface, it is shown that the imaginary line that separates the open and closed parts of a breathing crack should not be considered perpendicular to the crack tip. It is also shown that the improved model positively agrees with those proposed in the literature. The effects of ICCLP on the coefficients of the local flexibility matrix are investigated.

NOMENCLATURE

Symb.	Unit	Description
I	m^4	area moment of inertia for the cross section
k_{ij}	N/m, N/rad	cross-coupled stiffness
dp	m	disk diameter
e	m	eccentricity
$[k]_g$		global stiffness matrix
φ	rad	initial phase angle
$[c]_l$		local flexibility matrix of the cracked shaft
m	kg	mass of the disk
ν		Poisson ratio
R, d	m	radius and diameter of the shaft, respectively
α	rad	rotor center displacement in rotational direction
l	m	shaft length
k_x	N/m	stiffness in x direction
k_y	N/m	stiffness in y direction
k_u	N/m	stiffness in longitudinal direction
k_T	N/rad	stiffness in torsional direction
W	Nm	strain energy due to crack
U	Nm	strain energy of uncracked shaft
t	s	time in seconds
$[C_s]$		total flexibility matrix of the uncracked shaft
$[K]_l$		local stiffness matrix
η_0	m	location of elemental strip along η' direction
$[H]$		transformation matrix
h	m	height of the element strip
J_p	m^2	polar moment of inertia for the cross section
q_1	N	longitudinal force (internal reaction)
c	Ns/m	transversal damping coefficient
E	N/m^2	modulus of elasticity
q_4, q_5	Nm	bending moments (internal reactions)
c_T	Ns/rad	torsional damping coefficient
γ	m	crack depth
Ω	rpm	revolutionary speed
c_u	Ns/m	longitudinal damping coefficient
$M(t)$	Nm	external torsional excitation
G	N/m^2	modulus of rigidity
ω_T	rpm	torsional excitation frequency
A	m^2	cross sectional area of the crack
x, y	m	transversal displacements of center of disk
u	m	longitudinal displacement of center of disk
α	rad	torsional displacement of center of disk
F_z	N	longitudinal force (external load)
T	Nm	torsional moment
J	kgm^2	mass moment of inertia of the disk
K_{I}^i	$N/m\sqrt{m}$	opening mode of the crack due to internal load "i"
K_{III}^j	$N/m\sqrt{m}$	tearing mode of the crack due to internal load "j"
K_{I}	$N/m\sqrt{m}$	total opening mode of the crack
K_{III}	$N/m\sqrt{m}$	total tearing mode of the crack
F_1, F_2, F_{III}		influential functions

1. INTRODUCTION

Many investigations have been conducted concerning the overall behaviour of cracked shafts in past decades. In general, a crack in rotating shafts may be classified in three different ways: opened crack, closed crack, and breathing crack. In other words, if a cracked shaft rotates under external loading, then the crack opens and closes regularly per revolution, which could be said to breathe. This phenomenon is produced