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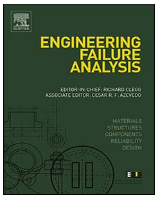

A numerical investigation of the plastic deformation at the spall edge for a roller bearing

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ABSTRACT

A clear understanding of dynamic contact characteristics in roller bearings (RBs) is a primary task for vibration analysis of the machineries, especially in the presence of spall failures. This work presents a new dynamic modelling method for a RB with a spall on the races to predict the time-varying plastic deformation at the spall edge. An improved two-degree-of-freedom dynamic model is used to calculate vibrations of the RB. Effects of the spall length, spall edge radius, external radial load, and rotor speed on the dynamic impact force between the spall edge and roller, maximum contact stress at the spall edge, total contact deformation between the spall edge and roller, plastic deformation at the spall edge, and spall edge propagation rate are analyzed. The proposed method is validated by a finite element (FE) method. The numerical results illustrate that the spall edge shape, external radial load, and rotor speed have a significant influence on the dynamic impact force, maximum contact stress, total contact deformation, plastic deformation, and spall edge propagation rate. This paper provides a greater understanding of the effects of the spall sizes and the spall edge shape on the contact characteristics and the vibrations for the RBs.

1. Introduction

As one of the key components, roller bearings (RBs) are widely used in various industrial machineries, such as aerospace, wind turbine, railway, and vehicle, which play a valuable capacity in the system performances. A clear understanding of contact characteristics in the RB is a primary task for vibration analysis of the machineries and industrial maintenance purpose, especially in the presence of spall failures [1]. The reason is that vibration performances of the machineries are strongly influenced by the spall failures.

Several works have been reported on formulating vibrations of rolling element bearings (REBs) with the spall failures. For instance, Ost and Baets [1], Tandon and Choudhury [2], Kiral and Karagulle [3], Sassi et al. [4], and Behzad et al. [5] studied the vibrations of the REBs due to the spall failures based on the force excitation models. Sopanen and Mikola [6], Cao and Xiao [7], Patel et al. [8], Nakhaeinejad and Bryant [9], Rafsanjani et al. [10], Liu et al. [11,12], Niu et al. [13], Wang et al. [14], Ahmadi et al. [15], and Khanam et al. [16] predicted the vibrations of the REBs due to the spall failures using the force excitation models based on the additional displacement excitation models and the Hertzian contact theory. The above works defined the spall edge shape as a sharp one, which cannot accurately formulate spall edge propagations. Those models cannot accurately describe the influence of the spall edge shape on the vibrations of REBs too.

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Nomenclatures

b	semiwidth of the contact surface, mm
b_{ud}	ultimate semiwidth, mm
c	bearing damping coefficient, N s/m
D_{r}	roller diameter, mm
D_{m}	pitch diameter, mm
E	elastic modulus, Pa
F_{ci}	total dynamic impact force between the roller and the edge, N
F_{rf}	restoring force between the race and the roller, N
F_{sf}	static force, N
F_{df}	dynamic force, N
F_x and F_y	external force components applying on the inner race, N
g	gravitational acceleration, m/s^2
H_{sd}	additional displacement due to the spall, mm
K	contact stiffness factor, N/m
k_{ss}	ratio of the shear stress to the maximum contact stress
L_{sp}	spall length, mm
l_{e}	equivalent contact length for the roller, mm
m	rotor mass, kg
N_{ci}	impact times
n_{s}	rotor speed, r/min
Q	external force, N
Q_{ud}	ultimate external force for the ultimate elastic deformation, N
$Q_{\max}$	maximum force applied on the roller, N
R_1 and R_2	radii of the contact bodies, mm
R_{e}	spall edge radius, mm
x and y	inner race displacements, m
$\dot{x}$ and $\dot{y}$	inner race velocities, m/s
$\ddot{x}$ and $\ddot{y}$	inner race accelerations, m/s^2
θ_i	angular displacement for ith roller, rad
ε	load distribution factor
ν	Possion's ratio
ζ	equivalent elastic modulus factor, 1/Pa
γ	radial clearance, μm
χ	impacting material coefficient
ξ_i	loading zone factor
ψ_i	angular position of the ith roller, rad
σ_{ud}	Von Mises yield stress, Pa
σ_{s}	yield strength for the bearing material, Pa
δ_{et}	total contact deformation at the spall edge, mm
δ_{ep}	plastic contact deformation at the spall edge, mm
δ_{ud}	ultimate elastic contact deformation at the spall edge, mm
δ_{tep}	total plastic contact deformation at the spall edge, mm
$\Sigma\rho$	curvature sum for the contact bodies, 1/mm
ΔV	impact velocity, m/s
Superscript	
i	ith impact

In fact, for a healthy roller bearing, the contact of cylindrical rollers with races produces a narrow rectangular footprint of finite length, which deviates from the idealized Hertzian theory of an infinite line contact [17]; for a defective roller bearing, the periodic impact between the spall edge and the roller will produce stress concentration points. When the concentrated stress at the spall edge is increased beyond the von Misses yield criterion, as shown in Fig. 1, the plastic deformation at the spall edge will be produced and can led to the spall edge propagation process. As shown in Fig. 1(a), L, B and H denote the spall length, width, and depth. The spall edge shape can be assumed to be a cylindrical one [18] as shown in Fig. 1, the spall edges at different propagation stages can be formulated as the cylindrical surfaces with different radii, such as $R_{\mathrm{e}1}$ and $R_{\mathrm{e}2}$.

Some works have been conducted on studying the spall propagation process for the REBs. Some of them studied the spall propagation rate, the contact stress between the spall edge and the rolling element, and the plastic deformations at the spall edges by using static contact force models. For instance, Lundburg and Palmgren [19], Kotzalas and Harris [20], Xu and Sadeghi [21], Hoeprich [22], and Li et al. [23] presented experimental and simulation studies for predicting the spall initial and propagation. Branch et al. [18,24], Rosada et al. [25], Arakere et al. [26], and Forster et al. [27] used finite element (FE) and experimental methods to study the spall edge propagation in ball bearings. The above works were only focused on the static force models for the spalls in REBs. Therefore, they cannot accurately formulate the dynamic force produced by the spalls. Some of them studied effects of spall edge shapes on the vibrations of the REBs. For example, Liu and Shao [28], Khanam et al. [29] and Kogan et al. [30] used

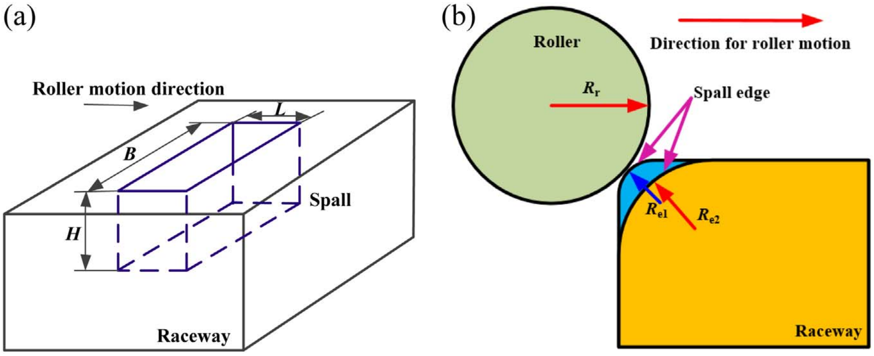

Fig. 1. (a) Spall sizes and (b) dynamic impacts at the spall edge for a RB.

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