Vibration signatures of defective bearings and defect size estimation methods

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Abstract

Rolling element bearings are widely used in rotary machinery, often with extremely demanding performance criteria. The failure of bearings is the most common reason for machine breakdowns. Machine failures can be catastrophic, resulting in costly downtime and sometimes in human casualties. The implementation of condition monitoring systems, which use data from various sources to determine the state of bearings, is commonly used to predict bearing failure. Hence, a considerable amount of attention has been devoted to bearing failure modes, fault detection, fault development and life expectations of bearings. The focus of this research is on the fault detection and defect size estimations of ball and cylindrical rolling element bearings with outer race defects.

In classic bearing vibration condition monitoring methods, the trend of vibration amplitudes is often used to determine when a bearing should be replaced. As a defect on the surface of a bearing raceway enlarges, the changes in the size and shape of the defect due to successive passes of the rolling elements can result in a fluctuation of the averaged measured values of the vibration amplitude. As an alternative to studying measures of vibration severity in order to determine the size of the defect indirectly, the actual geometric arc length of a bearing defect can be determined from the vibration signal and used to decide when to replace the bearing. The research in this project provides an insight into both the stiffness behaviour of a defective bearing assembly, with ball and cylindrical rolling elements, and the characteristics of the vibration signature in defective bearings in order to identify the vibration features associated with the entry and exit events of bearing defect. The ultimate aim of this research is to develop methods to accurately estimate the size of a defect on the outer raceway of a bearing, which are not dependent on the

magnitude of the vibration response, but instead use these features for tracking defect size in bearings.

In the research conducted here, the vibration excitation of a bearing associated with line-spall defects is studied both experimentally and analytically. An improved nonlinear dynamic model of the contact forces and vibration responses generated in defective rolling element bearings is proposed to study the vibration characteristics in defective bearings. It is demonstrated that previous models are not able to predict these events accurately without making significant assumptions about the path of rolling elements in the defect zone. Similar to the results of the analytical modelling, the experimental results show that there are discrepancies in previous theories describing the path of the rolling elements in the defect zone that have led to poor results in simulating the vibration response and the existing defect size estimation methods. The parametric study presented here shows that the relative angular extents between the entry and exit events on the vibration results decrease with increasing load. Significant speed dependency of these angular extents is shown by simulation and experimental measurements of defective bearings as the operational speed increases. The sources of inaccuracy in the previously proposed defect size estimation algorithms are identified and explained. A complete defect size estimation algorithm is proposed that is more accurate and less biased by shaft speed when compared with existing methods.

A method is presented for calculating and analysing the quasi-static load distribution and varying stiffness of a bearing assembly with a raceway defect of varying load, depth, length, and surface roughness. It has been found that as the shaft and rollers in a defective bearing rotate, it causes the stiffness of the bearing assembly to vary, which cause parametric vibration excitations of the bearing assembly. It is shown that when the defect

size is greater than one angular roller spacing, signal aliasing occurs and the vibration signature is similar to when the defect size is less than one angular roller spacing. Using the results from simulations and experimental testing, signal processing techniques are developed to distinguish defect sizes that are less than or greater than one angular roller spacing.

The results of this study provide an improved hypothesis for the path of a rolling element as it travels through a defect and its relationship to the vibration signature in a bearing.

Contents

Declaration

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Nomenclature

c	linear contact damping
c_s	damping of the support, subscript "s" defines the component 'Support'
cl	bearing clearance
D_b	roller diameter. Subscript "b" is used for 'Ball'
D_p	nominal pitch diameter. Subscript "p" means "Pitch"
F	contact forces
g	acceleration of gravity
K	load-deflection factors
k	nonlinear contact stiffness
k_s	stiffness of the support. Subscript "s" is used for 'Support'
m_b	mass of the rolling elements, subscript "b" is used for 'Ball'
m_i	mass of the inner ring plus the shaft, subscript "i" is used for "Inner"
m_o	mass of the outer ring plus the support structure. Subscript "o" is used for "Outer"
m_r	equivalent mass associated with the high frequency bearing resonance. Subscript "r" is used for "resonance"
N_b	number of rolling elements
Q	radial contact force
T	total kinetic energy
t_i	time to impact
V	total potential energy
W	static load

Symbols

ϕ	angular position
α_i	angle of impact
ω_s	run speed of the shaft
ω_c	run speed of the cage
δ	contact deformations
δ_max	maximum contact deformations
γ	defect shape function

Subscripts

in	denotes the inner raceway
j	denotes the j^{th} rolling element
out	denotes the outer raceway
r	denotes the r^{th} row of the bearing