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Experimental study of the impact of grease particle contaminants on wear and fatigue life of ball bearings

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ABSTRACT

Ball bearings' rating life is reduced when they are installed, operated and maintained under harsh environmental conditions as they suffer from excessive wear due to debris contaminants in the lubricant. This life reduction is taken into account when calculating the modified rating life but the impact of contaminant's variables such as size, hardness and concentration level are not determined in detail. In this work, greases contaminated with particles of different sizes and hardness (steel and corundum) are tested to shed new light in the way these parameters and wear's progress are related. A test rig is utilized and the most recent methods on vibration analysis regarding bearings' condition and estimated residual life are assessed and evaluated. At the end of the tests, optical inspections using a stereoscope verify the vibration analyses results. It can be concluded that wear is more severe when harder particles are used, but regarding their size, it seems that wear progresses in a different manner depending on particle's hardness and brittleness as soft ductile particles are rolled over and hard brittle particles are crushed down.

1. Introduction and theory overview

Rolling element bearings are critical components of many modern engines and machinery. When bearings have been chosen correctly, handled, installed and maintained properly, their service life can be well predicted from their basic rating life L_{10} as it is calculated by their manufacturer. Usually the operating conditions are different from the ideal conditions on which the L_{10} life is based. In order to take into account these different operating conditions, the international standard ISO 281:2007 has moved towards a system approach of the bearing and has introduced the modified rating life L_{nm} which is based on the L_{10} life, the reliability modification factor a_1 and the modification factor α_{ISO} which is a function of lubricating conditions, lubricant contamination, operating temperature and fitting stresses.

If no sudden failure occurs, bearings degrade and finally fail because of normal wear and fatigue phenomena which are unavoidable. Usually, bearings are replaced after a certain time which has been predefined according to the load they actual carry, the operating time and their estimated basic rating life L_{10} or modified rating life L_{nm}. In order to have a better resource management, maintenance strategies are shifting from preventive maintenance techniques to condition-based techniques.

Many diagnostic tools are used in order to estimate the current condition of a bearing and/or to monitor its condition in real time. Vibration signal analysis is a largely used and effective tool for the diagnosis of the current condition of a bearing,

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[1] http://www.mech.ntua.gr.

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Nomenclature

c	constant (related with the shear stress)
C_u	fatigue load limit, N
D	ball or roller diameter, mm
d	pitch diameter, mm
d_i	inner raceway diameter, mm
d_o	outer raceway diameter, mm
e	constant (Weibull slope)
e_c	contamination factor
f	shaft rotation frequency, Hz
f_{bpfi}	ball pass frequency inner raceway, Hz
f_{bpfo}	ball pass frequency outer raceway, Hz
f_c	cage/central rotation frequency, Hz
f_r	ball rotation frequency, Hz
g	acceleration of gravity, 9.81 m/s^2
h	constant (related with the depth of the maximum stress)
K	kurtosis
L_{10}	basic rating life, 10^6 rev
L_n	basic rating life (with a probability n), 10^6 rev
L_{nm}	modified rating life, 10^6 rev
p	exponent on basic rating life
P	dynamic equivalent load, N
Q	actual load, N
Q_c	basic dynamic load, N
S	skewness
Z	number of rolling elements
α	contact angle, °
α_1	life modification factor for reliability
α_{ISO}	life modification factor, based on a systems approach
κ	viscosity ratio of the lubricant
μ	mean
σ	standard deviation

as vibrations are indicative for an abnormal performance. Although vibration analysis has been widely used in order to identify a potential single fault, this type of analysis has not been used in identifying or measuring the wear of a bearing.

In this paper we experimentally evaluate vibration signal analysis methods for bearings under various lubricant contamination conditions which cause accelerated wear. A set of eight experiments has been conducted, using two different kinds of contaminants (Al_2O_3 and steel) with four different particle sizes. The vibration analysis is performed in the time and in the frequency domain in order to evaluate the accuracy of each indicator under these operating conditions. At the end of the experiments the vibration analyses findings are verified with optical inspections of the bearings.

1.1. Basic rating life of rolling element bearings

During their operating life, bearings are carrying loads which cause variable stresses to the contact surfaces. These Hertzian contact stresses are the main cause of fatigue, determining the useful operating life. This service life of rolling element bearings can be estimated based on the Weibull distribution and its application on bearings. Based on Weibull's theory Palmgren and Lundberg [1] proposed that for a given probability n, the service life of bearing can be calculated from the equation below:

$$L_n = \left(\frac{Q_c}{Q}\right)^p \tag{1}$$

where L_n is the basic rating life (with a probability n); Q_c is the basic dynamic load (the load where the bearing is expected to last for more than one million of cycles); Q is the actual load and p is the constant which is a function of constants c, e, h, regarding maximum shear stress exponents, Weibull slope and the type of the bearing.

Several functions which correlate the constants c, e, h, have been proposed by researchers [2,3] based on different assumptions of the importance and the influence of each one. Regardless of the adopted theory, constant p has been experimentally approximated to the values 3 for ball bearings and 10/3 for roller bearings. Usually, the basic rating life L_{10} is used, expressing the expected life with 90% reliability. In addition, the basic dynamic radial C_r or axial C_a load is used in conjunction with the dynamic equivalent radial P_r or axial P_a load.