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Electromechanical modeling by DEM for assessing internal ball bearing loading

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ABSTRACT

A numerical approach makes electrical measurements in a rotating ball bearing, in order to characterize the loading state of the bearing and to detect any defects. The ball bearing is modeled by discrete elements with a smoothed formulation of the local contact law. Contact forces are calculated using analogies with damped springs. Loads in accordance with the practice case are applied to the bearing. The electrical resistance of the contact is evaluated in an electromechanical model using Hertz's surfaces. The results show a link between the mechanical state of the bearing and the electrical measurement.

1. Introduction

Rolling bearings are commonly encountered components in domestic and industrial rotating machinery. There is a large number of bearings for all possible applications. Statistical studies show that industrial bearings are considered as critical mechanical components which represent between 40% and 50% of the malfunctions in rotating machinery. In order to ensure the industrial system's availability and the safety of goods and persons, the monitoring and diagnosis of bearing defects have to be considered with prime importance and the challenges in terms of productivity are non-negligible. Thus, defect detection in rolling component bearings has led to extensive research. Different experimental methods have been proposed for detection and diagnosis of bearing defects which may be broadly classified such as vibration and acoustic measurements, temperature measurements, defect signatures in the stator current motors, wear debris, and lubricant analysis. A review of vibration and acoustic measurement methods for the detection of defects in the rolling component of a bearing is presented in [1]. Vibration measurements are the most widely used. Knowledge of the state of bearing load is particularly important, but in practice, it is difficult to assess the bearing load accurately. The load distribution in machine elements is the first step in the analysis of their operating condition. From a numerical point of view, great care will be provided in the modeling of the bearing load and clearance [2,3]. The discrete element approach facilitates the modeling of the load. Simulations carried out for different radial loads are close to Harris's description [4]. An electrical measurement is proposed to assist in determining the load. Previous work has shown that the voltage–current characteristics of a static bearing describe a hysteresis. This effect is attributed to Branly's effect [5] which is also manifested in a metallic granular medium [6–8]. This unconventional approach attempts to measure the electrical resistance of the ball bearing in operation. The signature obtained includes indicators of the state of bearing load but also of the presence of possible defects, whether geometric or related to improper installation. Although in practice, the presence of an electrical current through the ball bearing is ordinarily harmful, the current densities required to perform a relevant experimental measurement are too low to cause damage [9,10]. Some authors [10] caution that the current flow leads to severe

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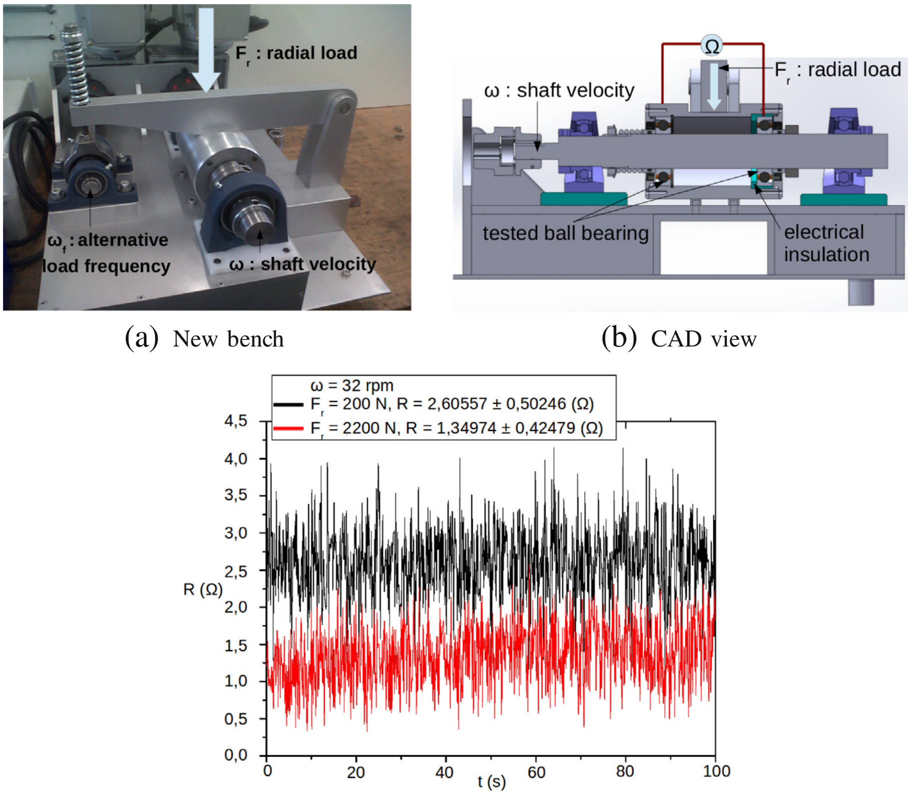
damages in the bearings and others [9] use the electrical current to create defects on surfaces. Muetze [11] gives current densities limits. Bearing current densities $J \leq 0.1$ A/mm^2 do not influence bearing life and bearing current densities $J \geq 0.7$ A/mm^2 may significantly reduce bearing life and a study of aging should be consider. Our measurements are performed at $I = 100$ mA and an estimation of maximal current densities on a contact gives $J_{max} \leq 0.04$ A/mm^2. An initial test bench was used to demonstrate the feasibility of the proposed method, in [12]. A new bench will soon allow electrical measurements that will be compared with the numerical results given in this paper.

Fig. 1-a is the new experimental device designed to study the electromechanical behavior of the ball bearing. The associated CAD view is shown in Fig. 1-b, where we can see the principle of electrical measurement. Fig. 1-c shows the sensitivity of the electrical measurement in response to mechanical loading, during run-up. This bench will enable proper loading of the ball bearing and it will also be possible to apply a variable load. From an experimental point of view, this technique could be advantageous at low velocity when the lubrication regime allows a steel–steel contact. In this velocity range (<100 rpm), the conventional analysis techniques are difficult to implement. Several simplifying hypothesis are introduced to represent this complex problem. Rings are assumed rigid with the exception of the local contact deformation given by the Hertz theory and the effect of the lubricant is mechanically and electrically ignored. The main objective of this paper is to understand how mechanical loading, based on the Harris's theory [4] affects the electrical response of the ball bearing, in dynamic mode. In Section 2, discrete modeling of a ball bearing is explained. The mechanical model is described and a loading protocol is proposed to properly load the bearing. Then, Section 3 is only interested in electromechanical coupling, a model of electrical conductance is introduced. A perfect metal/metal contact is assumed without lubricant effects. Mechanical and electrical numerical results are discussed in Section 4, for different loads of the ball bearing. The main goal of this study is to use an electrical measurement to distinguish the effects of different loads.

2. Discrete modeling of a ball bearing

The ball bearing could be seen as a multi-contact system. The rolling components and the cage are considered as discrete elements, represented by spheres. Each discrete element is subjected to mechanical forces. The Non-Smooth Contact Dynamics (NSCD) formulation was first used in previous work [12]. This approach has proved very restrictive when a realistic loading was considered. In this paper, we used the Smooth Discrete Element Method, developed by Cundall and Strack [13]. The spherical particles are rigid, a local contact deformation is considered and the interactions are governed by analogies with damped springs. The analogy with damped-



(a) New bench (b) CAD view

(c) Electrical measurement

Fig. 1. Experimental bench.