lubricants

Commentary

Behavior of Lubricated Bearings in Electric Circuits

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Citation: Kirchner, E.; Bartz, M.; Becker-Dombrowsky, F. Behavior of Lubricated Bearings in Electric Circuits. *Lubricants* **2024**, *12*, 89. https://doi.org/10.3390/lubricants12030089

Received: 14 February 2024
Revised: 5 March 2024
Accepted: 9 March 2024
Published: 11 March 2024

In recent years, electrical damage phenomena in rolling and plain bearings have become increasingly important due to the growing electrification of individual mobility and renewable energy technologies. Being a major root cause, the electrically induced bearing failure has been intensively analyzed in fundamental and application-oriented research. Even though being of general importance for, e.g., electric mobility, much of the research work is published in German; this special issue shall provide a comprehensive overview in the topic of the behavior of lubricated bearings in electric circuits. The models available in the literature by Furtmann [1,2] and Gemeinder [3] for describing the electrical impedance behavior of rolling element bearings were developed for the analysis of electrically induced bearing damage [4]. The current impedance models of rolling element bearings assume operation in the elasto-hydrodynamic range according to Prashad [5] and describe the individual rolling contacts under full lubrication as plate capacitors that are electrically connected via the components of the rolling element bearing. The rolling contact between the rolling element and the bearing raceway develops a Hertzian contact surface, which represents the surface of the plate capacitor. The models of Furtmann [1,2] and Gemeinder [3] are based on the consideration of the loaded rolling elements only; Schirra extends the approach by including the load-free rolling element contacts for sensory purposes [6,7]. For journal bearings, due to the absence of rolling elements and the rather plain bearing surfaces, more sophisticated models, such as the cylinder capacitor, can be used to achieve a good agreement between model predictions and test rig measurements, e.g., for the lubricating film thickness or other operation conditions [8–11]. However, such methods cannot be used for insulating coatings, such as those found in tilting pad bearings with, e.g., PEEK thrust pads forming an extra capacitor arranged in series with the lubrication film. For plain bearings, this is a recent field of research and current research, e.g., by Stottrop et al., uses combined methods with inductive measurement methods here [12]. In addition to measuring the thickness of the lubricating film, there is also a trend towards sensor-integrated bearing types [13].

In addition, the ongoing discussions on the digitalization of industrial processes in general combined with a strong trend towards health monitoring and predictive maintenance have led to a trend to use operation-condition-dependent electrical properties of rolling element bearings and hydrodynamic journal bearings as highly integrated sensors. The lubricated bearing becomes an active element in the electric circuit. In industrial practice, the early detection of damage in rolling element bearings is based on the observation of structure-borne noise levels, oil contaminants, and component temperature [14–16], whereby the warning times before a failure are comparatively short. Initial damage to the raceways in the form of a geometric deviation relative to the new condition must be present in order to be able to detect the damage via the change in the vibration signature. In many cases, the evaluation of the structure-borne sound signature via an order analysis provides direct information about the location of the initial damage [14,17,18]. An earlier identification of incipient damage by in situ measurement methods directly on the bearing is not sufficiently usable at the moment, and the use of artificial intelligence methods always requires a change in the operating behavior of the machine in order to be able to detect incipient damage [19]. The usage of machine-learning methods is state of the art, but it also widens the scope of the current research to optimize the response time between damage occurrence and damage detection [20–22]. The challenge is that a high amount of well-structured data in a high quality is necessary to train the algorithms [23]. Another challenge with most techniques is that the sensors, attached or integrated [24], require additional installation space [25–27]. While it is quite uncomplicated for certain operating parameters to integrate sensors in as neutral a way as possible, e.g., for temperature measurement [28], it is more difficult for load distribution and damage detection [18,29,30]. One way of detecting damage as early as possible would be to use the electrical impedance of the bearing, which is a major advantage in terms of the desired resilient system behavior if an adaptive control system can be used to respond to the onset of damage [31]. Another possibility is offered by printed sensors, such as those used by [32–35], but these are not yet for widespread use in bearings. Initial work on the integration of thin sensors in bearings can be found, for example, in Konopka et al. [36–38].

Hence, the electrical behavior of both rolling and plain bearings is a hot topic in machine element research [30], as well as in electric machine development. Recent challenges are, for example, current passages which can damage rolling bearings; the load-dependent behavior of rotor bearings in electric machines that influences the performance and reliability of the overall system; and challenges which arise, e.g., when coatings and components are used that affect the electrical conductivity. However, the electrical characteristic of bearings, such as the load-dependent electrical behavior, the use of insulating and conductive coatings, or the integration of further components, make these bearings attractive as sensory elements to accelerate digitization processes. Finally, damage patterns resulting from electric effects need to be explained, quantified, and predicted for all kinds of lubricated bearings including the lubricant itself.

This Special Issue presents a current synopsis of both industrial and academic research results addressing the behavior of lubricated bearings in the electric circuit both from a (passive) damage-oriented perspective as well as from an (active) sensorial point of view. The requirements on the accuracy of a phenomenological math model increase drastically when moving from the passive to the active behavior. We are delighted that this Special Issue brings together seven articles covering the entire spectrum mentioned above.

To begin this Special Issue, the earliest paper contained in this issue provides an important and necessary overview of the state-of-the-art research regarding electrical bearing currents. Schneider et al. [39] pave the scene discussing firstly rolling element bearings suffering current-induced bearing damage in electrical drive systems, and they describe the mechanisms leading to known electrical damage patterns. They consider the harmful current passage in the machine element as a phenomenon on the system level taking into account the whole drive system consisting of the machine elements, the electric motor, and the connected power electronics. This publication provides an overview of the state-of-the-art research regarding electrical bearing currents.

Graf et al. [40] investigate the influence of parasitic currents using a thrust bearing lubricated with mineral oil. In particular, the influence of an additional electrical load and the lubricant, which is chemically analyzed to detect changes in the lubricant, are investigated. These investigations are compared with the raceway damages that occur, and a comparison with mechanical reference tests is carried out. These investigations are motivated by the increased occurrence of parasitic currents in electric motors and are therefore highly relevant for e-mobility, in particular.

In addition to the analysis of the influence of the electrical load and the lubricant on parasitic currents, it is important to know the lubricant film conditions, as these have an important influence on the current passage due to the lubricant film height. This is precisely the task addressed by Maruyama et al. [41], who present a lubrication condition monitoring method for the line contact of a thrust needle roller bearing using the electrical impedance method. At first, Maruyama et al. show the theoretical feasibility of determining the oil film thickness and the breakdown ratio when an AC voltage is applied to a line contact. The theoretical findings are then investigated experimentally, revealing deviations between the theoretical assumptions and the applied results. A final discussion shows that the developed method can be suitable to determine the lubricant film conditions in EHD line contacts, and the recent challenges are pointed out.

Zaiat et al. [42] show that the surface topology has an important influence on current passages by investigating the influence of pittings in the EHL rolling contact on the electrical capacitance. To investigate this, a multi-physical numerical calculation is extended by the pitting geometry, which changes the electric properties. The changes in the electric properties are measured using the electric capacitance of the contact and put into perspective with regard to the EHL contacts geometry. The results show that with the same pitting structures, even small deviations in the pitting geometry result in larger deviations in the capacitance, which means that pittings have an important influence on current passages.

The lubricant film height has an important influence on the current passage. Nevertheless, this is difficult to measure. However, since it is also difficult to measure the load distribution and the strain, which can be used to draw conclusions about the lubricant film height, for example, Bartz et al. [43] presents a way of using printed sensors to measure the strain in small installation spaces, such as in rolling bearings. This technique is also applicable for condition monitoring and predictive maintenance. Using the example of a cylindrical rolling bearing, Bartz et al. show the main advantages of this method, based on experimental investigations that are compared with an FE simulation.

The article by Safdarzadeh et al. [44] provides a very application-oriented investigation of the factors influencing the bearing currents, in particular the effect of variable DC bearing current amplitude, bearing current polarity, mechanical force, rotation speed, bearing temperature, and number of the balls on the fluting in an axial ball bearing. The results show in great detail the effects of increasing or decreasing an influencing variable on the electrical DC bearing currents and the interdependencies between them.

The above-mentioned papers show the many perspectives of the ongoing research in the topic of this Special Issue and indicate which research is currently required to improve future applications, e.g., in the important field of the mobility transformation with alternative drives or sustainable energy generation, such as wind power, in order to ensure safe operating conditions.

In the end, Puchtler et al. [45] investigate the influence of axial and radial loads as well as the impact of rotational speed to the occurrence of electrical bearing damage. Several new bearings are tested under varying operational conditions. They are electrically loaded by a realistic voltage signal with alternating amplitudes to trigger harmful bearing currents. The authors provide insights into the damaging process and its behavior, which is especially interesting for different applications fields like the electric individual mobility or wind energy.

Finally, the Guest Editors would like to thank all the authors for their great contributions, as well as all the reviewers and the staff at MDPI *Lubricants* for their valuable support and professional assistance.

Author Contributions: Conceptualization, E.K. and M.B.; writing—original draft preparation, E.K., M.B. and F.B.-D.; writing—review and editing, E.K. and M.B.; project administration, F.B.-D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

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