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The Influence of Lubricant Conductivity on Bearing Currents in the Case of Rolling Bearing Greases

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Abstract: In the course of increasing electric mobility, the effect of electricity on parts of machines is more significant than before. Rolling bearings and their lubrication, as a part of electric motors, are subjected to harmful currents, which lead to damage in the bearing in the long term. In order to avoid such damage, the influence of the lubricant in the bearing is becoming increasingly important. The electrical behaviour of the system can be investigated by analysing the discharge currents and the breakdown voltage in rolling bearings with lubricants of different compositions. This paper presents a procedure for characterizing the breakdown voltage at the rolling bearing and the influence of conductivity of the lubricants on harmful electrical phenomena.

Keywords: EDM; breakdown voltage; bearing currents; electrical properties of greases

1. Introduction

Studies have shown [1–6] that the application of frequency inverters to control variable-speed inverter-fed electric motors and generators causes damage to the rolling bearings because in this case bearing voltages and bearing currents occur. In recent years, with developing electric mobility, this problem has become more important because of the increasing use of inverter-controlled electric motors in the automotive industry. Lubrication shows a crucial influence on the damage which is caused by bearing currents. Depending on the composition and the electrical and rheological properties of the lubricant, the occurring currents show different characteristics [7–11]. Currently, there are no standards or prescribed test methods for the characterization of the electrical lubricant properties, as the relative permittivity, specific electrical conductivity and breakdown field strength for rolling bearing lubrication [8]. There are standards for the investigation of the electrical lubricant properties only for transformer oils [12–14]. In this paper—based on the conference paper [15] of the 60th German Tribology Conference (GfT), and extending that—the investigation of rolling bearings subjected to test voltages is presented, where the focus is on the discharge currents, also called "electric discharge machining" currents (EDM currents), and their relation to the electrical properties of the lubricants (especially to the conductivity). For this purpose, lubricants with different rheological and electrical properties were experimentally tested in order to understand their influence on the bearing currents. In addition, this paper presents an evaluating scheme for the bearing currents and two methods for the investigation of the relationship between the lubricating film and the occurrence of the EDM-breakdowns.

2. Basics

2.1. Lubricant as Electrical Isolator

The operating conditions of a rolling bearing (rotational speed, axial- and radial load, temperature, etc.) and the lubricant properties define the lubrication condition in the bearing, which can be described with the lubricating film thickness parameter [16]. We differentiate three lubricating regimes as hydrodynamic lubrication, mixed lubrication and boundary lubrication. The lubrication film works as an electrical isolator between the conductive bodies, and it shows a capacitive behaviour [17,18]. As a result, the lubrication condition (i.e., lubrication film thickness) can be modelled with concentrated electrical components as capacity and resistance. The described relations are presented in Figure 1.

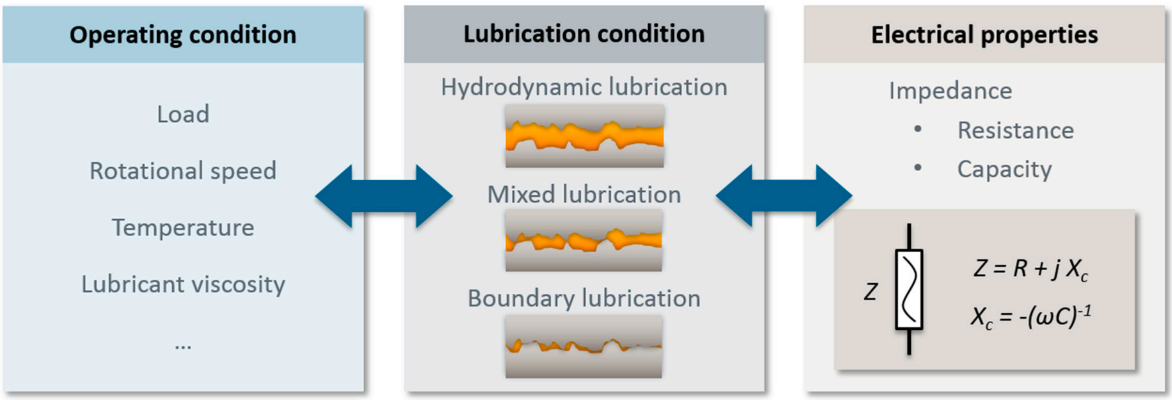

Figure 1. Relationship between the operating condition, the corresponding lubrication condition, and its electrical properties in rolling bearing.

The aforementioned resistance and capacity form a complex impedance value, which depends on the lubricant film thickness. The relation between the film thickness and the impedance value is explained in Figure 2. For the explanation, the impedance magnitude and phase angle are observed instead of the real and imaginary part of it. The phase angle varies between 0 and −90° because of the capacitive behaviour of the contact mentioned. With increasing film thickness, the impedance phase angle decreases and the impedance magnitude increases. Using this relation, important information can be gained regarding the lubrication condition and the lubricant properties with the help of impedance measurement.

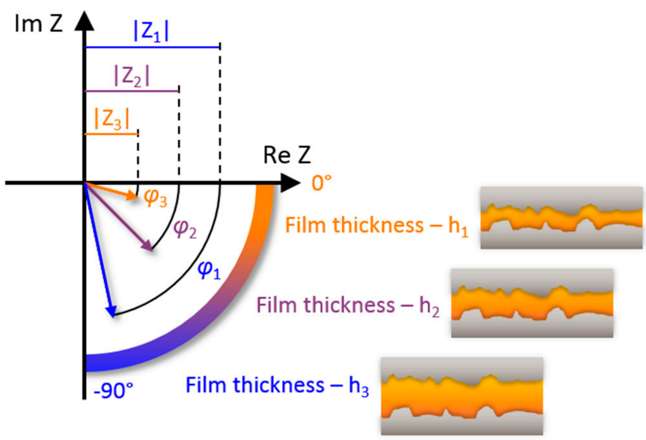

Figure 2. Relation between the lubrication film thickness and the complex impedance value.

2.2. Electric Discharge Machining (EDM) Breakdowns and EDM Currents

The bearing voltages and currents depend on the isolating capacity of the lubricating film between the conductive parts of the rolling bearing and on the system capacities in the electrical environment. With the help of oscillograph measurements, these voltages and the corresponding currents can be observed. The harmful EDM-currents and the categorisation of bearing voltages are presented corresponding to [15,19].

When the bearing voltage exceeds the isolating capacity of the lubricating film, an electric discharge occurs in the form of an arc between the rings and the rolling elements. The aforementioned isolating capacity of the lubricating film depends on the lubricating film thickness and the breakdown field strength of the lubricant [20,21]. This shows that the lubricant used in the bearing thus has a crucial influence on the occurrence of EDM currents. It is expected that the use of conductive lubricants will prevent voltage build-up across the lubricating film and thus prevent EDM breakdowns [8,22,23]. Figure 3a shows typical bearing currents and voltages during the application of a test voltage to a rolling bearing and the evaluation scheme of them, which was applied during the investigations. Three cases (cases A, B and C) are distinguished.

In Case A, the applied test voltage does not exceed the isolating property of the lubricating film. Due to this capacitive behaviour of the lubricating film, the voltage can build up completely and no EDM breakdowns occur. Only capacitive currents can be observed.

In case B, the applied voltage exceeds the isolating property of the lubricating film. Every time it occurs, the bearing voltage drops immediately and a peak in the bearing current signal can be seen. The probability of the EDM-breakdown increases with the reduction of the lubricating film (e.g., due to an increase in the temperature) or with increase of the applied voltage amplitude. Due to these changes, the breakdown field strength of the lubricating film is reached earlier.

In case C, no voltage can build up across the lubricating film, either due to the metallic contact between the asperities of the contact surfaces (i.e., due to the small lubricating film thickness) or due to such a high voltage amplitude at which the isolation of the lubricant has no influence anymore. Only voltage pulses and resistive (i.e., ohmic) currents can be observed. By using conductive lubricants, it is also expected that the resistive current will dominate during the operation of the rolling bearing and the voltage will not build up across the lubrication film [7,8,22,23].

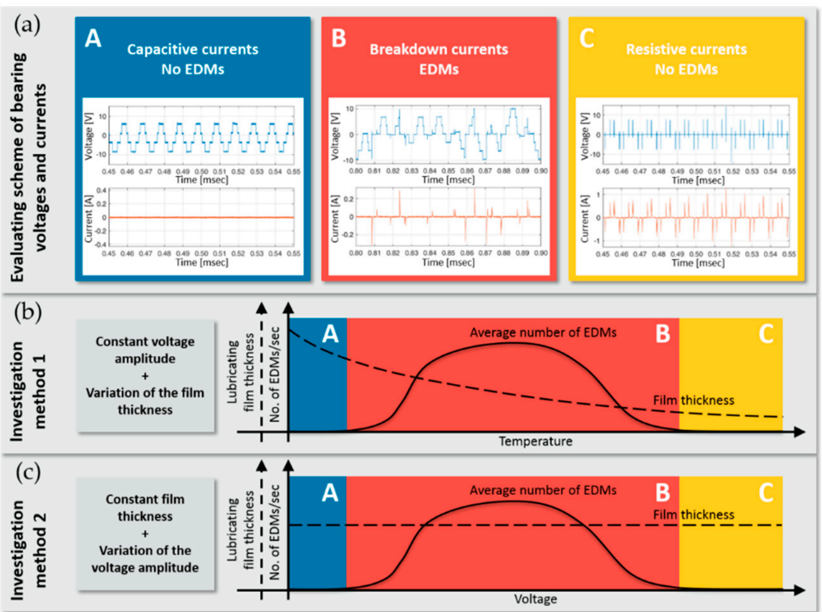

Figure 3. (**a**) Evaluating scheme of the bearing voltages and currents; (**b**) investigation method 1 of the bearing currents; (**c**) investigation method 2 of the bearing currents.

Figure 3b,c show two investigation methods to the bearing voltages, where the presented evaluating scheme can be implemented. In method 1 (Figure 3b), a constant voltage amplitude is chosen, and the occurrence of the EDM-breakdowns is evaluated next to the variation of the lubricating film thickness due to the variation of an operating parameter of the rolling bearing (e.g., with the variation of the temperature). With the decreasing film thickness, more EDM-breakdowns occur until a point where the resistive domain starts and after this point, only ohmic currents can be observed. In method 2 (Figure 3c), an operating condition is set, i.e., a constant lubricating film thickness and the applied bearing voltage amplitude is varied. At this method, the voltage domains of the presented cases of the evaluating scheme can be determined next to a chosen operating point of the bearing. Furthermore, the breakdown voltage of the lubricant can be determined by the generation of EDM-breakdowns at both of the investigation methods.

3. Investigated Greases

For the measurements, lubricating greases with different base oils and thickeners were investigated in order to examine the influence of insulating and conductive lubricating greases on the bearing voltages. The basic lubricant data of the greases can be found in Table 1. According to the datasheets of the lubricant manufacturers, two of the six investigated greases are electrically conductive (F5 and F6). As the greases are products from different manufacturers, the grease identifiers were made anonymous.

Table 1. The basic lubricant data of the investigated greases.

Test Grease	Temperature Range (°C)	Base Oil Viscosity at 40 °C (mm^2/s)	Base Oil Viscosity at 100 °C (mm^2/s)	Type of Base Oil	Type of Thickener	Electric Conductivity
F1	−40 to 200	130	20	Perfluorpolyether, Ester oil	Polytetra-fluorethylen, Polyurea	Not specified
F2	−30 to 160	165	18	Mineral oil, Synth. Hydrocarbon	Polyurea	Not specified
F3	−45 to 180	72	9.5	Ester oil	Polyurea	Not specified
F4	−50 to 260	190	34	Perfluorpolyether	Polytetra-fluorethylen, Polyurea	Not specified
F5	−40 to 180	90	9	Polyalphaolefin/Ester oil	Polyurea	Yes
F6	−35 to 140	82	12.5	Mineral oil, Synth. Hydrocarbon	Lithium	Yes

4. Test Bench and the Measurement Process

For the investigation of bearing currents and voltages, a test bench called "Gerät zur erweiterten Schmierstoffanalyse" (GESA) was developed at the Institute of Machine Elements, Gears, and Transmissions (MEGT) at the University of Kaiserslautern. It was a part of the research project FVA 650 II "Methodology for the practical characterization of electrical lubricant properties to improve the computational prediction of bearing currents" at the Research Association for Drive Technology (FVA). The electrical conditions of the rolling bearing are controlled with a special inverter, which was developed especially for this application (a more detailed description is given in [7,8]). With the help of this device, the measurement setup is able to reproduce the electrical conditions of the rolling bearing of inverter-fed electric motors. The special feature of these measurements is that the rotating speed (and the other mechanical conditions of the bearing, such as temperature and axial load) can be varied independently from the electrical conditions (as switching frequency and voltage amplitude among others). It makes possible a detailed investigation regarding the relationship between the mechanical and electrical conditions. The test rig and the measurement procedure are identical as they were applied in [19], their presentation also corresponds to it.

In this study vertically arranged deep groove ball thrust bearings (type 51208) were used with different test greases for the investigations. The bearing was driven by an electric motor, which was electrically isolated from the test cell. This test cell and its assembly can be seen in Figure 4.

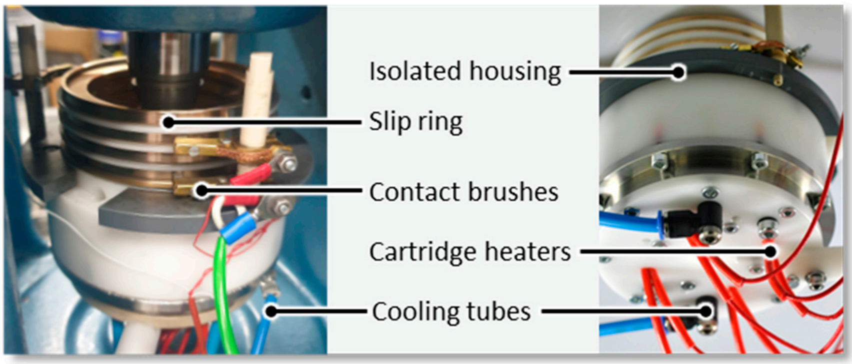

Figure 4. The assembly of the GESA test cell.

The voltages and currents flowing at the rolling bearing can be measured under controlled and reproducible conditions (rotating speed, axial load, and temperature). The undisturbed electrical conditions are ensured due to isolated housing, which can be cooled with the help of water-cooling or heated with cartridge heaters. As a result, the bearing temperature can be controlled between 10 and 100 °C. The measurement and the control of the current flow and temperature are realized by a self-developed slip ring. The test stand runs with a low-vibration level, which ensures the stable formation of the lubricating film in the rolling bearing. This is a requirement for characterizing the electrical properties of lubricants [10,24]. Furthermore, with the help of the measurement setup presented, the impedance (together with the capacity and resistance values) of the lubricated bearing can also be determined. In the case of each lubricant, the same measurement process was applied (similarly to [19]). The whole process and its phases can be seen in Figure 5. The first phase is 16 h long without applying voltage, and it serves as pre-conditioning of the lubricant and the bearing. The rotating speed and the axial load are constant. In phase 2, the previously presented "investigation method 2" is used (Figure 3c). Accordingly, the operating conditions are constant (rotating speed, axial load, steady-state temperature) and test voltage is applied to the bearing, which is varied from 1 to 60 V (peak-to-peak voltage amplitude) with a fixed switching frequency of 10 kHz. Phases 3 and 4 follow the "investigation method 1" presented in Figure 3b. Correspondingly, in these cases, the applied voltage amplitude is fixed (phase 3 with 5 V; phase 4 with 20 V) and the lubricating film thickness is varied with the variation of temperature (10–100 °C) at constant rotating speed and axial load. The applied test conditions of each phase are summarised in Table 2.

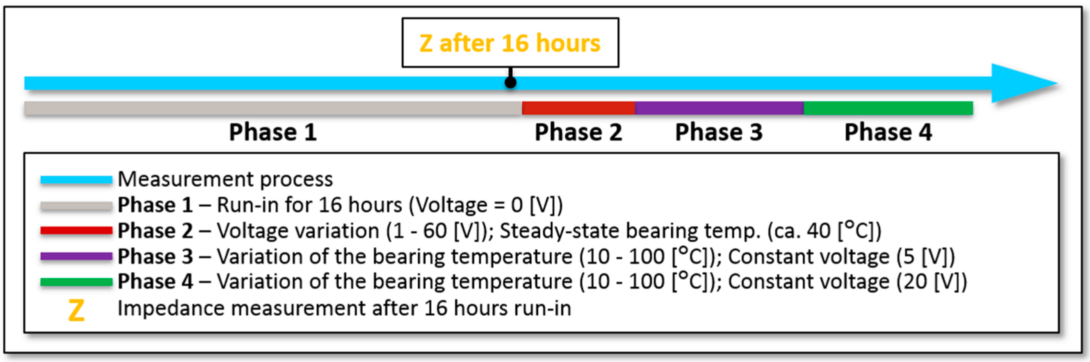

Figure 5. The measurement process for the investigated lubricants.

Table 2. The test conditions of the individual phases of the measurement process.

Phases	Rotational Speed (min^{-1})	Axial Load (N)	Applied Voltage (V)	Switching Frequency (kHz)	Bearing Temp. (°C)	Bearing Type
Phase 1	1000	240	-	-	Steady-state	51208
Phase 2		200	1–60	10	Steady-state	
Phase 3		200	5	10	10–100	
Phase 4		200	20	10	10–100	

5. Results

In this section, the results are presented in accordance with the applied measurement process and the containing phases. In addition, the following subsections contain the evaluation and interpretation of the measurement results.

5.1. Results of the Preliminary Investigations

The precise electrical properties of the greases are not available in the case of product greases. Therefore, in the preliminary stage of the investigations, the specific conductivity of the lubricants was measured in a cylinder capacitor, which can be seen in Figure 6 as a function of the temperature.

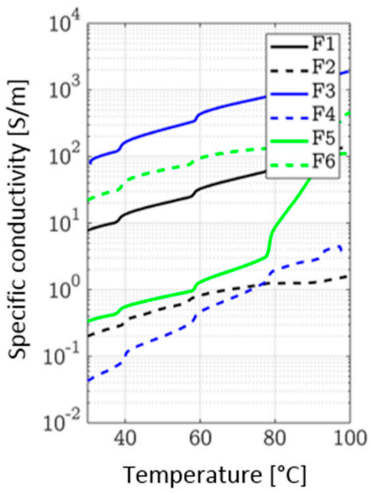

Figure 6. Measured specific conductivity of the test greases at switching frequency of 20 Hz, temperature from 30 to 100 °C and at a pressure of 1 bar in a cylinder capacitor.

A cylinder capacitor was used to determine the specific conductivity of each lubricant at a frequency of 20 kHz as a function of the lubricant temperature between 30 and 100 °C. The results show that the conductivity of all lubricants increases with the increasing temperature (i.e., with the decreasing viscosity). According to the manufacturer's specifications, the two conductive greases (F5 and F6) are expected to have the highest specific conductivities. However, the measurements show that grease F3—with the lowest base oil viscosity (at 40 °C)—has the highest specific conductivity over the entire temperature range. Whereas grease F4—with the highest base oil viscosity (at 40 °C)—has the lowest conductivity. The conditions occurring in the cylinder capacitor only partially correspond to those occurring in the rolling contact. An essential difference in the conditions in the rolling contact is the distance between the electrodes. While the electrode distance in the cylinder capacitor is 1 mm, smaller distances occur in the lubrication gap of a rolling bearing. This could explain why lubricants F5 and F6 do not have the highest specific conductivity. Potential conductive additives in the greases are too small to show its effect in a cylinder capacitor, the isolated-based oil encapsulates them. In the case of smaller distances, as it occurs in rolling bearings, the dissolved additives can lead to the conductivity of the grease. Therefore, for rolling bearing lubricants, the measurement of the specific conductivity in a cylinder capacitor is only recommended if it is known how the conductivity in the lubricant was reached.

5.2. Results of Phase 1

In the case of every lubricant investigated, the presented measurement process was carried out with a new thrust ball bearing. Therefore, it was necessary to start the investigations with a run-in period. Otherwise, the initial roughness peaks of the contacting surfaces may come into contact during the subsequent phases and the measurement of a stable lubrication condition would not be possible. Phase 1 serves this purpose, and the run-in is performed with constant rotational speed and axial load without applied voltage at the bearing. The impedance and phase angle measurements were carried out after the preconditioning and the results are shown in Figure 7. The measurements are performed at a speed of 1000 min^{-1}, a load of 200 N and at the steady-state temperature of the bearings.

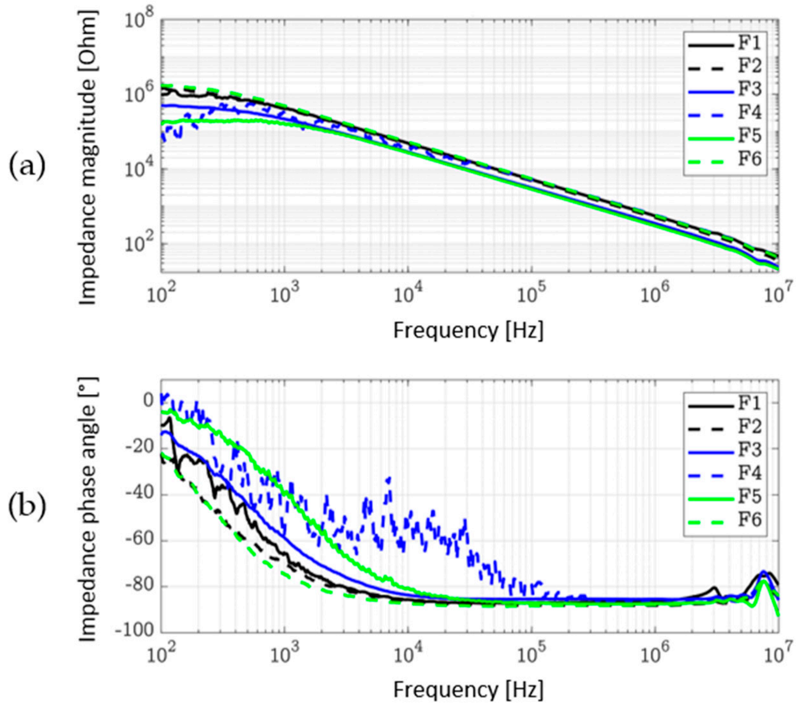

Figure 7. Measurement results of (**a**) the bearing impedance magnitude, and (**b**) the impedance phase angle after 16 h preconditioning at steady-state temperature, a rotational speed of 1000 min^{-1}, and a load of 200 N.

For the conductive lubricants (grease F5 and F6), a lower impedance magnitude can be expected over a wide frequency spectrum in comparison with the other greases. In addition, the measured phase angle should remain at about 0° for the conductive greases. The measurements show that the impedance magnitude and the phase angle have a similar course for all examined greases. As the frequency increases, the impedance magnitude decreases and the phase angle shifts in the direction of −90°. Only grease F4 shows a significant difference in the resulting values, which can be explained with its high base oil viscosity values (Table 1). This high viscosity leads to high friction in the lubricant between the contacting surfaces. This effect can be seen on the steady-state temperature of the grease F4, which is approximately 15 °C warmer than the steady-state temperature of the other greases (Table 3). Presumably, the bearing operates with a smaller lubricating film thickness with this grease, as shown by the impedance phase angle in Figure 7b. The fluctuations of the measurement signal of grease F4 also refer to this phenomenon.

In general, the results of the impedance measurement show that there are no significant differences between the isolating and conductive greases in the case of the investigated operation condition (steady-state temperature, 1000 min^{-1} rotational speed, 200 N axial load). The capacitive behaviour of the lubricant film can be measured also with isolating greases, and this film may be broken through due to electric charges.

Table 3. Steady-state temperatures of the test greases.

Test Greases	F1	F2	F3	F4	F5 *	F6 *
Steady-state temperature (°C)	40	42	41	55	40	38

* conductive greases

5.3. Results of Phase 2

The system, consisting of rolling bearing and grease, behaves capacitive for all investigated lubricants (see Section 5.2). It can be assumed that the lubricating film has an isolating effect in the rolling contact and will break through when a high-frequency voltage is applied so that the voltage amplitude exceeds the isolating property of the lubricant. Therefore, in phase 2 of the investigations, a test voltage was applied to this system with peak-to-peak voltage amplitude from 1 to 60 V, while the operating conditions were not changed (i.e., the lubricating film thickness was constant). This corresponds to the "investigation method 2" (Figure 3c). The further measurement conditions can be found in Table 2. The aim of the investigation was to determine the voltage ranges of the lubricant film in which capacitive, EDM and resistive currents occur and to observe the influence of the conductivity of the lubricants on the harmful EDM domain. For this purpose, the applied test voltage was gradually increased (1–10 V with 0.1 V steps; 10–60 V with 5 V steps). Figure 8 shows the measurement results of phase 2.

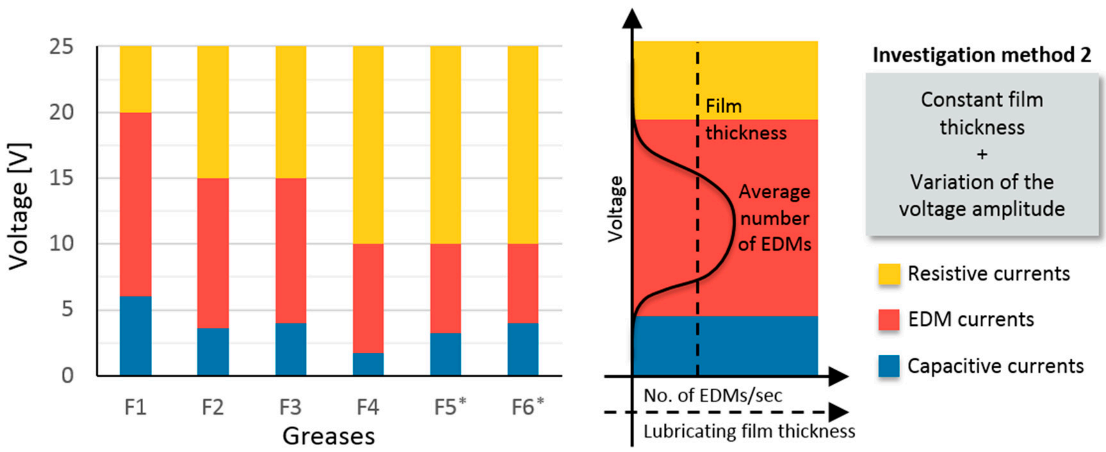

Figure 8. Measurement results of phase 2 with voltage variation (1–60 V). Determination of the capacitive, electric discharge machining (EDM) and resistive current ranges at steady-state temperature, a rotational speed of 1000 min^{-1}, an axial load of 200 N and an inverter switching frequency of 10 kHz (* conductive greases).

In the case of low test voltage amplitudes, there is a complete build-up of voltage across the lubricating film (i.e., capacitive currents can be measured) for all tested greases. This means that an isolating lubrication film can build up for all of the investigated lubricants (whether conductive or not). With increasing test voltage amplitude, EDM-currents occur with all lubricants. In this domain, the occurrence of the EDM breakdowns will increase with the increasing test voltage and after a maximum point, it will decrease and finally, the resistive domain will be reached. Here, the voltage cannot build up across the lubricating film and only ohmic currents flow. Based on the measurement results, a significant difference can be observed between the conductive and isolating greases. Greases F5 and F6 show shorter EDM domain—it starts at ca. 4 V and it finishes at 10 V—relative to the other greases. As already mentioned, the rolling bearing with grease F4 has a higher steady-state temperature. Due to the resulting lower lubricating film thickness, the results for F4 can only be compared with the other greases to a limited extent in this phase.

Conclusions from phase 2:

- Capacitive, EDM and resistive currents occur with all of the investigated greases.
- With conductive grease, ohmic currents already occur at a lower applied voltage and the EDM-domain can be shortened.

5.4. Results of Phase 3 and Phase 4

In phase 2 the "investigation method 2" (Figure 3c) was applied, where the lubricating film thickness was constant, and the applied voltage amplitude was varied. In phases 3 and 4, the measurements were carried out in accordance with the "investigation method 1" (Figure 3c). In this case, the bearing currents are investigated as the function of the temperature (i.e., the lubricating film thickness). Higher temperature (i.e., lower lubricant viscosity) leads to lower lubricating film thickness in the rolling bearing (the other operating parameters such as rotating speed and axial load are constant). The bearing is cooled down first to 10 °C then gradually heated up to 100 °C. During the entire heating, bearing voltages and bearing currents are measured and recorded in regular temperature steps at every 1 °C. Based on the evaluated data, the temperature ranges in which capacitive-, EDM and resistive currents occur can be determined. In addition, the number of the detected EDM breakdowns per second, and the voltage amplitude of them can be also determined. In phase 3, the investigations were performed with an applied voltage amplitude of 5 V and in phase 4 with an applied voltage amplitude of 20 V. Figure 9. shows the occurrence of the EDMs as the function of the bearing temperature at the applied test voltages.

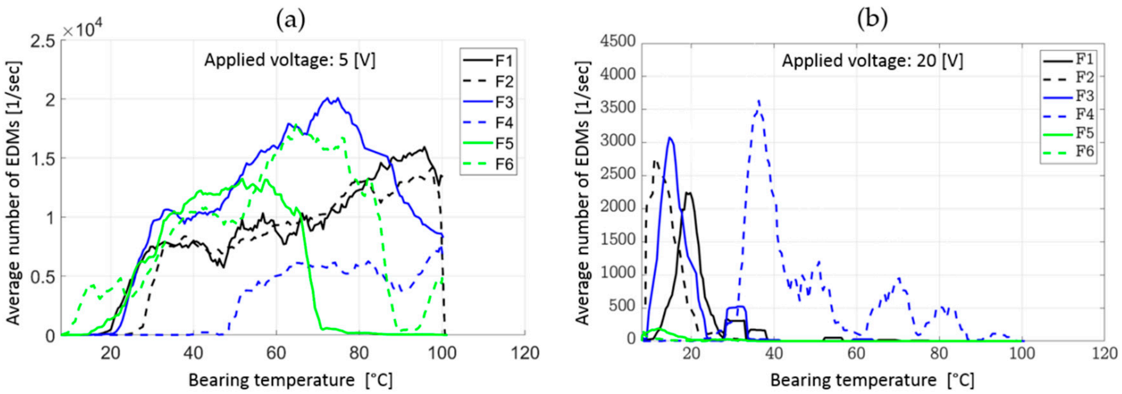

Figure 9. The average EDM breakdown number per second as a function of bearing temperature at a speed of 1000 min^{-1}, a load of 200 N and an inverter switching frequency of 10 kHz from phase 3 and 4 of the GESA investigations; (**a**) measurement results at an applied voltage of 5 V; (**b**) measurement results at an applied voltage of 20 V.

For an applied test voltage of 5 V the evaluation shows that EDM-breakdowns can be occur for all investigated lubricants. The EDM-currents were detected over a wide temperature range. In the case of greases F1, F2, F3, F5 and F6, the lubricating film can already break down at low temperatures. At grease F4—with the highest base oil viscosity—EDM-currents do not occur until a temperature of approx. 50 °C is reached. When considering the isolating greases (F1, F2, F3 and F4), it is observable that the lubricating film can break down up to a bearing temperature of 100 °C. For the conductive grease F5, ohmic currents occur predominantly from a temperature of approximately 70 °C. The number of EDM currents drops sharply. The conductive grease F6 also behaves similarly. The number of EDM currents drops sharply from a temperature of approximately 90 °C and ohmic currents predominate. The base oil viscosities of greases F3, F5 and F6 are similar at 40 and 100 °C (see Table 1). However, they show different tendencies in Figure 9a. This means that the aforementioned difference probably does not relate to the viscosity but to the composition of the lubricant and its conductivity.

With an applied voltage of 20 V (Figure 9b) there are clear differences compared to the measurements with 5 V. First of all, the number of EDM breakdowns for all greases is significantly lower compared to the measurements with an applied voltage of 5 V. For isolating greases, EDM currents occur increasingly at low bearing temperatures, where the lubricating film is higher. In addition, the temperature range in which EDM-breakdowns occur is smaller. As the temperature rises, ohmic currents flow in the majority of cases. There is no voltage build-up across the lubricating film. EDM currents could only be detected at higher temperatures with grease F4. This is due to the mentioned high base oil viscosity of the grease. With the conductive lubricants F5 and F6, EDM currents could only be detected at low bearing temperatures between 10 and 20 °C. In the case of these greases, no or only sporadic voltage builds up, so that predominantly resistive currents are detected. There are clear differences between the conductive and the remaining greases.

In addition to the number of EDMs and the temperature range in which bearing currents occur, it is also important to consider the level of voltage at which the EDM currents occur. Therefore, Figure 10a,b show the maximum and mean EDM breakdown voltage occurring at an applied test voltage of 5 V and 20 V for all investigated lubricants.

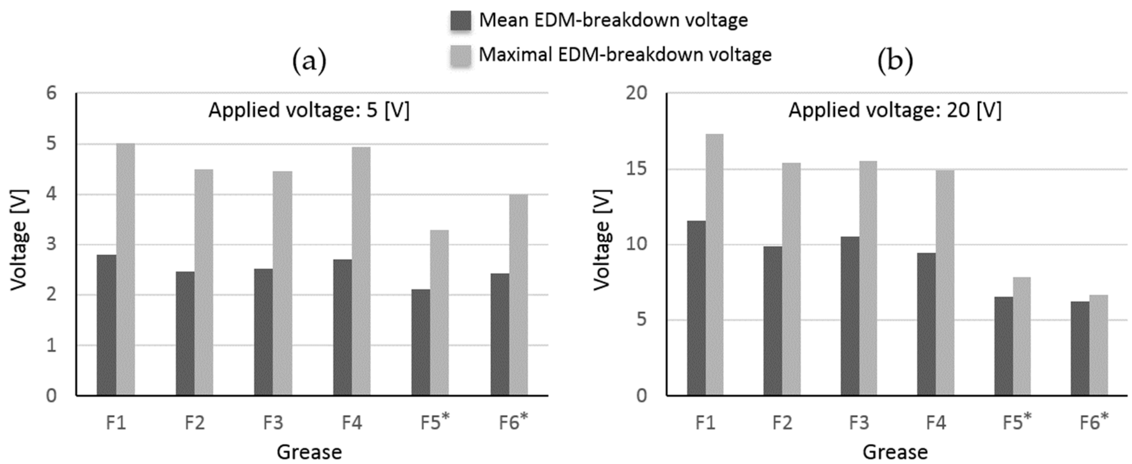

Figure 10. The maximum and mean EDM breakdown voltage occurring at an applied test voltage amplitude for all investigated lubricants; (**a**) results at an applied test voltage of 5 V; (**b**) results at an applied test voltage of 20 V (* conductive greases).

The presented values were determined as the mean and the maximal value of the EDM voltage measurements. The presented values were determined as the mean and the maximal value of the EDM voltage measurements. In phase 3 of the investigation, the differences in the EDM voltages between conductive and non-conductive greases are low. The mean EDM voltages for all greases are between 2 V and 2.5 V. The maximum EDM breakdown voltages of the conductive greases are slightly lower than this value of the other greases. In phase 4, where higher test voltage amplitude was applied, the influence of the conductive greases is more recognisable on the bearing currents. The measurements with greases F5 and F6 show significantly lower mean and maximal EDM voltages than the other test greases.

Conclusions from phase 3 and 4:

- In the case of low applied voltage amplitude (5 V), the influence of conductive lubricants is low. The mean and maximum EDM voltage of conductive lubricants is lower compared to insulating lubricants, but the differences are not significant.
- When a high test voltage (20 V) is applied, the capacitive currents are prevented in the temperature domain investigated using conductive lubricants. Predominantly ohmic currents flow.

6. Summary and Outlook

In this paper, investigation methods and their results were presented regarding the influence of lubricant conductivity on the bearing currents. The focus was on the occurrence of EDM currents and the different electrical conditions in the rolling bearing. It is known that bearing currents and the associated bearing and lubricant damage depend on the lubricant film thickness and the amplitude of the high-frequency voltage applied to the bearing [8]. Furthermore, depending on the composition and the electrical and rheological properties of the lubricant, different electrical effects can be observed in the bearing. In order to understand the influence of lubricant conductivity on the harmful bearing currents (i.e., on the EDM breakdowns), two investigation methods were presented. In investigation method 1 (Figure 3b), the lubricating film thickness is varied and the applied voltage amplitude is constant. In contrast, during the investigation method 2 (Figure 3c), the lubricating film thickness is constant and the applied voltage amplitude is varied. The measurements were carried out on a thrust ball bearing test rig "GESA", which was developed at the MEGT institute at the University of Kaiserslautern.

The measurement results in the cylinder capacitor show different characteristics than the measurement results in Sections 5.3 and 5.4 regarding the difference between the conductive and the other greases. Consequently, the cylinder capacitor can be used to a limited extent in the case of rolling bearing lubricants, as the distance between the capacitor electrodes is bigger than the lubricating film thickness in rolling bearing contacts [15,19]. Although it was expected that the conductive lubricants result in lower bearing impedance, the measurements show no significant differences in the impedance values between the greases at a steady-state temperature. When applying a high-frequency voltage to the bearing, in the case of lower voltage amplitude a complete voltage can build up across the lubricating film for all tested greases. Under certain conditions (low voltage or high lubricating-film thickness) an isolating lubricating film can be formed in the bearing for all greases investigated. As a result, EDM-breakdown occurs when the isolating lubricant film thickness is reduced or the applied voltage is increased. This was also observed with the conductive greases F5 and F6. Compared to the result of phase 3, the measurements in phase 4 with an applied test voltage of 20 V show a significant difference between the conductive and the other greases. In the case of greases F5 and F6, the conductive currents can be prevented already at a higher lubricating film thickness (i.e., lower bearing temperature) and the domain of EDM currents also shortened. Mostly resistive (ohmic) currents flow in the investigated temperature range.

The investigations showed that the conductivity of the lubricant greases has a significant influence (especially in the case of higher applied voltages) on the bearing currents. With the application of conductive lubricants, the occurrence of resistive currents is higher, but the difference between the damage caused by EDM and resistive currents is not entirely known. Therefore, long-term measurements with conductive greases are recommended in order to investigate the long-term effect of them on the rolling bearing. In addition, the investigated greases are product greases for which the exact composition is only partially known. The analysis of sample greases—in which it is known how the conductivity in the lubricant is achieved—allows a better evaluation of the investigations. It is also recommended to compare greases with similar rheological properties (e.g., similar base-oil viscosity). This results in comparable lubricating film thicknesses for the lubricants at fixed operating points of the investigations.

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