Greased Rolling Bearings Deterioration in the Presence of the Electrical Field

MIHAIL CATALIN TIRON[1], STEFAN GRIGORAS[1]*, FLAVIAN FARCAS[1], AURICA FARCAS[2]

[1] "Gh. Asachi" Technical University, 61-63 Mangeron Blvd., 700050, Iasi, Romania

[2] "Petru Poni" Macromolecular Chemistry Research Insitute, 41A, Al. Grigore Ghica Voda, 700487, Iasi, Romania

Lubrication aspects, in extreme operating conditions, highlights important problems concerning bearings design or greases behaviour management for given operating conditions. The researches that were done in the last period were focused on greases service life and behaviour versus rolling bearings operating conditions but, it must be emphasized, that some particular aspects such as the presence of the electrical fields were less studied. Some results in this specific area were previously forwarded by Prashad who highlighted issues such as greases resistivity modifications with time, particular bearings and lubricating greases damaging mechanisms. Aspects concerning temperature influence on grease resistivity, correlations between greases structural, physical and chemical deterioration and bearings specific failures, in the presence of the electrical field, are questions that must be answered. These problems are very important because electrical rotating machines support bearings reliability is strongly dependant on greases service life and performances. The paper presents some correlations between the electrical field characteristics and electrical motors rotors support rolling bearings greases deterioration based on lubricant's SEM and raceways microscopical analyses. Starting from these results it can be concluded that rolling bearings deterioration under the influence of the electrical field is a complex phenomenon with effects, both, on lubricating greases and bearings rolling contact surfaces. From this point, a greases deterioration model, in the presence of the electrical field, will be proposed.

Keywords: lubricating greases, electrical field, deterioration

The last years tendencies in rolling bearings lubrication research field focused on greases behaviour can be highlighted. This is, mainly, due to the simplicity of the grease lubrication systems (no cooling or recirculation circuits are needed) and, also, because of creating new possibilities in miniaturising the rolling bearings assemblies. The more intense presence of greases on world's lubricants market and the higher demands concerning the machines or devices performances determined new researches on greases quality and behaviour improvement. It is already known that, when normal functioning conditions occur, rolling bearings service lives are given by manufacturer's or Lundberg-Palmgren calculus equations but if particular situations are present, such as those governed by severe operating parameters, their reliability is strongly dependant on lubricating greases behaviour. In this context, remarkable results were obtained in lubricating greases rheology [1-4] and service life [5-9] (taking into account bearings operating parameters influence such as speed, load, temperature, lubricant amount, contaminants) researching areas. It can be highlighted that all achieved results have limited applicability, being available just for the tested lubricants and for a narrow functioning conditions interval.

The last decade interest on environment protection had as consequence an increased demand for the ecological power sources such as the electrical rotating machines. In particular, their mechanical parts are functioning in an "electrical medium" that has a specific influence on shafts support rolling bearings greases properties and behaviour. The researches that were ran by Prashad [10-12], until now, touched aspects like bearings operating parameters influence on their impedance and on lubricating film's withstand voltage, greases resistivity variation with time and some deterioration mechanisms for lubricating greases and rotors support bearings were proposed. In this context, in order to diminish the electrical wear, lubricants nylon 12 powder additives are considered [13] and in [14] rotor's hybrid support rolling bearings solution is forwarded.

Having in view the above presented information, it can be concluded that there are questions waiting for answers, among them, the following being significant: operating temperatures influence on lubricating film's withstand voltage and on greases electrical properties (resistivity, ρ, and dielectric constant, ε), a deeper study of greases and rolling bearings deterioration correlations, forwarding a lubricant's deterioration model considering bearings "electrical load". As a first step of these researches, the present paper has as main aim to identify dependences between the applied potential drops characteristics and rolling bearings/greases deterioration that could offer important information in elaborating a lubricant's damaging model in this specific functioning conditions (with grease replacement interval recommendations) avoiding expensive solutions such as hybrid rolling bearings.

Greased rolling bearings-electrical field correlations

<u>The rolling bearings and the electrical field</u>

In the electrical rotating machines daily operation potential drops between rotors shaft's ends, support rolling bearings and their housing were observed sufficient conditions for the existence of an electrical current through them being created. Among the causes of this phenomenon are asymmetries and mounting errors, electrostatic effects, mechanical unbalances, air gap fields, a magnetized shaft or other machine parts. The asymmetries between machine parts are followed by the appearance of a net flux linking the shaft the bearings and

* email: stgrig@mec.tuiasi.ro

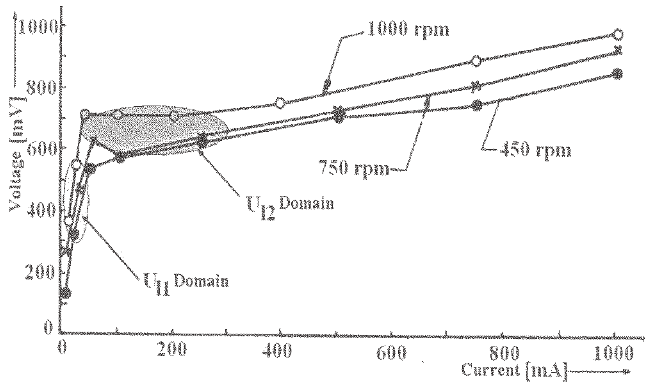

Fig. 1. Bearing's voltage vs. current. Threshold voltages domains

their housing. At a threshold voltage value, that depends on lubricant's resistivity, on bearings design and operating parameters, an electrical breakdown occurs within the rolling contacts lubricating film causing an arching effect or a silent discharge through the lubricant. The current value is mainly dependant on the voltage amplitude and on bearing's impedance [10]. All this assembly of complex factors is leading to rolling bearings failure because of specific faults, like corrugations or corrosion, due to greases lubrication properties loss (the lubricant becomes corrosive) or to the arching effects within the lubricating film [14].

Lubricating film threshold voltages

When a rolling bearing is subjected to the influence of an electrical field a certain value of the electrical current can be observed only when the applied potential drop reaches a withstand value. There are two values to be mentioned. The first one, U_{l1}, obtained increasing the applied voltage from zero to a maximum value with no momentary current flow, is called the first threshold voltage. The second one, U_{l2}, is reached when for any light increase of the potential drop high currents flow can be measured within the bearing as shown in figure 1 [10].

The bearing's threshold voltages are dependant on lubricating film thickness and operating speed (they are increasing with the film thickness and speed) and, also, they are connected to lubricants electrical properties and bearings design. No significant dependence on bearings load were observed [10].

Rolling bearings impedance

Lubricants electrical resistivity has a decisive influence on rolling bearings impedance. By this point of view two kind of greases were identified: low resistivity ($\rho \approx 10^5$ Ωm) and high resistivity ones ($\rho \approx 10^9$ Ωm). If low resistivity greases are used silent discharges within the lubricating film occurs and the greases electrochemical decomposition is present having as result corrosive products that affect bearings metallic surfaces. On the opposite, when high resistivity greases are considered, electrostatic energy is accumulated and due to the arching effects bearings raceways/rolling bodies are deteriorated [10].

In [15], taking into account the resistive and capacitive behaviour of the lubricating greases, a roller bearing impedance model is proposed. At this stage it can be highlighted the operating parameters influences on rolling bearings impedance, the most significant ones being films thickness and the operating speed [10].

Rolling bearings deterioration mechanisms

When rolling bearings are passed by electrical currents two specific damaging types were identified [10-12]:

-when low resistivity greases are used, silent discharges within the bearing occur and the electrochemical decomposition of the grease has as immediate result new corrosive components like LiOH and Li_2CO_3; the latter ones affect the raceways quality, corrugations begin to appear and the rolling bearing fails due to lubricants contamination and because of the permanent deformations in the loaded zone;

-in case of high resistivity greases, electrostatic energy is accumulated until the threshold limit is reached; at critical voltage values the arching effect determines bearing's damaging by mass transfer and high local temperatures.

Lubricating greases in the electrical fields

When subjected to potential drops lubricant greases have particular behaviour. Depending on applied voltages and exposure time their resistivity is always increasing with time. It was experimentally established that resistivity increases are more intense for higher current values. In the same time, if the potential drop is stopped there were observed the greases resistivity recovering tendencies (resistivity values decreases close to the initial point of the experiment) [16]. Taking into account the above information it could be affirmed that, for future researches, an interesting influence factor on greases electrical properties could be the rolling bearings operating temperature.

Experimental part

For tests a mineral oil and LiCa stearate soap based grease was selected (3 NLGI consistency grade, 164-165^{0}C dropping point). This type of lubricant was preferred because the mixed soaps based greases are cheaper than the other ones and they have almost the same lubricating properties as the Li soap based lubricants.

For the service tests, a specialized test rig, as presented in figure 2, was designed. All important operating conditions were monitorized and controlled: applied potential drop (from 0 to 3 V), operating speed (from 0 to 3500 rpm), bearings radial load, functioning temperature (from 20 to 150^{0}C). The general testing conditions were as follows: radial load F_R = 750 N (1/20 of 6206 radial rolling bearing dynamic capacity rating); rotating speed n = 3500 rpm; functioning temperature T = 90^{0}C; 33% of bearings free volume lubricant amount.

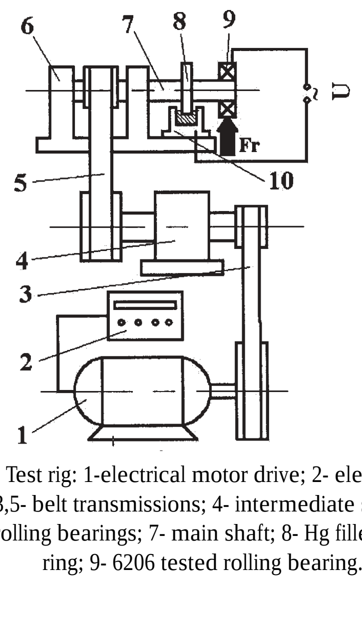

Fig. 2. Test rig: 1-electrical motor drive; 2- electronic speed converter; 3,5- belt transmissions; 4- intermediate support bearing; 6- support rolling bearings; 7- main shaft; 8- Hg filled bath; 10-steel ring; 9- 6206 tested rolling bearing.

Table 1
ROLLING BEARINGS "ELECTRICAL LOAD"

Applied voltage, U [mV]	Bearings internal current, I [mA]
U_{l1}= 287-300	70
U_{l2}= 568-600	500
U= 1100	750

Table 2
SERVICE LIFE TEST RESULTS AND WEIBULL DISTRIBUTION PARAMETERS

		Lot 1	Lot 2	Lot 3
Current I [mA]		70	500	750
Experimental service life [10^6 rotations]	1.	8,885	5,145	1,955
	2.	10,133	6,008	2,240
	3.	10,403	6,325	2,986
	4.	11,743	7,606	3,251
	5.	11,804	8,297	3,746
	6.	12,552	8,887	3,803
	7.	12,617	9,582	4,007
	8.	13,675	10,025	4,441
	9.	14,421	10,124	5,139
	10	15,710	10,983	5,918
Weibul distribution parameters				
Slope parameter (β)		6,85	5,315	3,632
Scale parameter (a)		13,037	9,039	4,184
L_{10} service life[10^6 rot.]		9,386	5,919	2,252
L_{50} service life [10^6 rot.]		12,358	8,437	3,783

The "electrical load" was established corresponding to three potential drops values, table 1. Corresponding to these values three lots consisting of ten sealed ball bearings each were tested.

During the service life experiments the running temperature control and data acquisition were performed using the control&measuring chain, as shown in figure 3, based on LabView 6.1 environment and Bruel&Kjaer equipment. The moment of greases deterioration was established based on bearings global radial vibration and it was considered that the lubricant is damaged when bearings radial acceleration is greater than its initial value with about 30%.

Results and discussions

The greased rolling bearings service life tests results are presented in table 2 and it can be observed that experimental data is respecting the Weibull distribution. As first remark, it can be affirmed that lubricants and bearings service lives have significant decreases when bearings internal current increases. The differences between the three tested lots were highlighted based on greases SEMs analyses and on bearings raceways damaging degree evaluation.

Greases SEMs analyses

During the initial, intermediate and final tests stages grease samples were collected. The fresh grease sample image, as shown in figure 4, confirms the LiCa soap composition. It can be observed the Ca crystals that are dispersed in the Li soap mesh with small, medium and large size fibres. Sample structure is uniform and it is characteristic for a fresh lubricant.

The first intermediate sample, corresponding to I=70 mA and U_{l1} applied voltage, shows that lubricants deterioration began. The oil-soap separation initiation, the first Li soap conglomerates and Ca crystals fragmentation can be observed (figure 5). When the "electrical load" was increased (I= 500 mA and U_{l2} applied voltage), at the intermediate stage of the test, the lubricants Li soap structure is almost destroyed, fragmented Ca crystals can

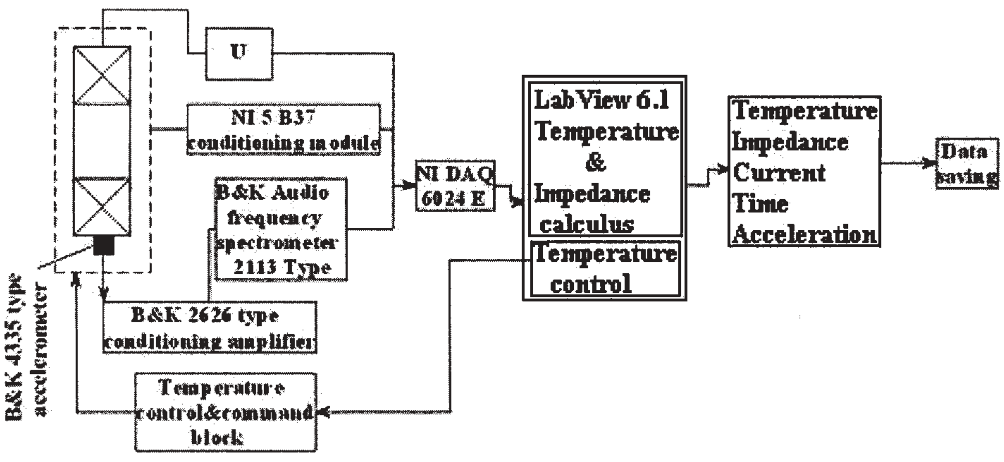

Fig. 3: Control & measuring chain

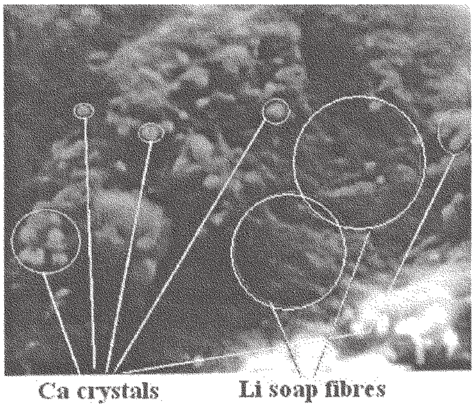

Fig. 4: Fresh grease sample (x 15000)

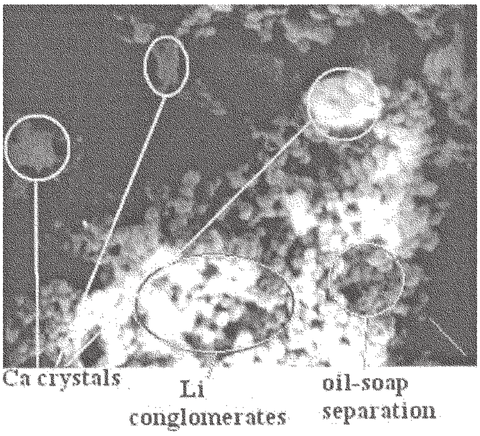

Fig. 5. Intermediate grease sample (x 7500)

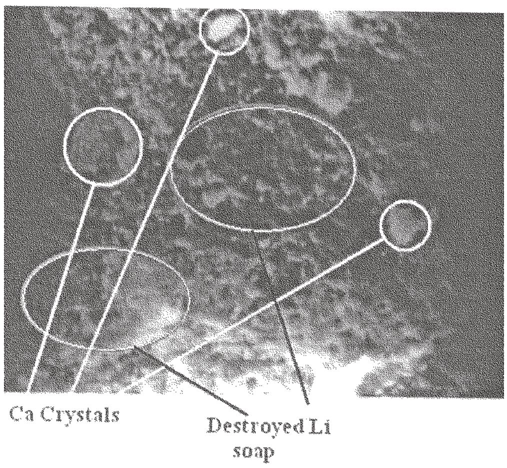

Fig. 6. Intermediate grease sample (x 9000)

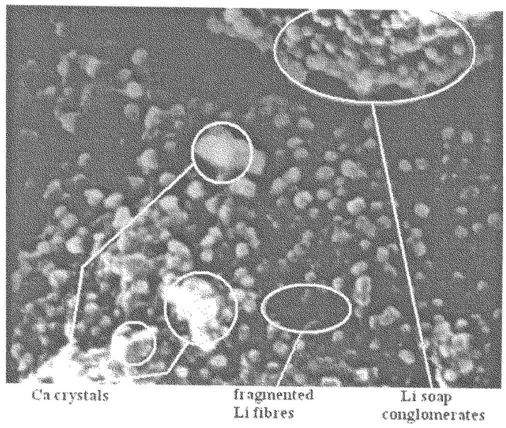

Fig. 7. Damaged grease sample (x 7300)

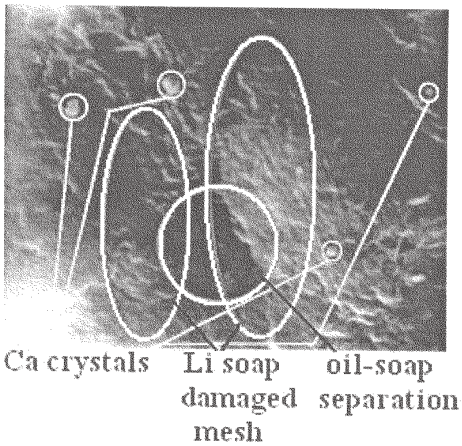

Fig. 8. Damaged grease sample (x 9100)

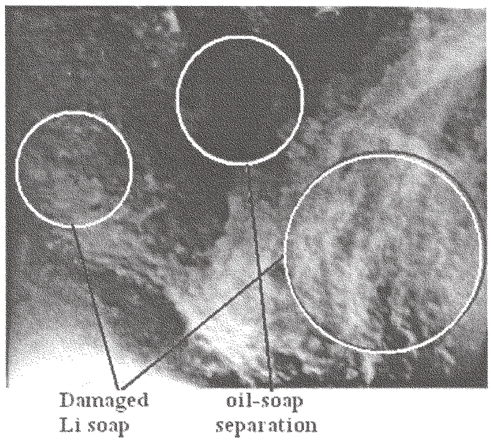

Fig. 9. Damaged grease sample (x 9000)

be identified and, also, structures tixotrophic behaviour was present (fig. 6).

Corresponding to the first set of the bearings "electrical load" damaged grease samples were taken (fig. 7). Lubricants initial structure is completely destroyed, Li soap conglomerates are present and small Ca crystals are rarely observed. Lubricants tixotrophy is also present based on Li small fibres that are trying to recover soaps initial structure. For the second set of "electrical load" values the image of the damaged grease sample is presented in figure 8. Again, Li soap conglomerates, small Ca crystals and the soap-oil separation can be identified. Even at this deterioration stage the lubricant still has tixotrophic behaviour.

For the third set of the "electrical load" values, because of the rapid increase of bearings vibration level, no intermediate samples were collected. As seen in figure 9 the Li soap structure is totally damaged, the Ca crystals are very small size and oil-soap separation phenomenon is present.

Rolling bearings raceways analysis

Corresponding to the different "electrical loads" two types of failures were detected. The first one is when small or medium bearings internal currents occur. In this situation corrugations and corrosion spots can be localized and bearings deterioration by electrical pitting is initiated (figs. 10-11). The second kind of fail is when high currents are present. In this case, due to electrical arching effect, holes in soaps structure were created and, in these areas, the thickener was not able to retain in its structure the base oil. The immediate consequence was the appearance of an "electrical starvation" phenomenon and the initiation of bearings seizure blue slip bands.

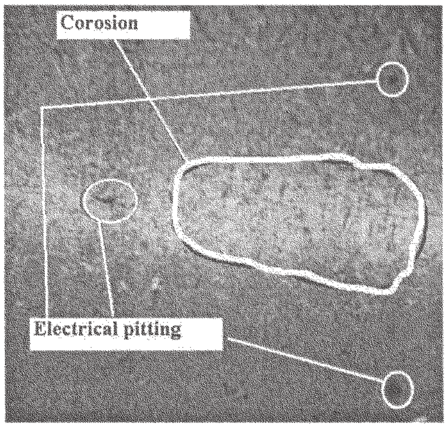

Fig.10. Raceway specific faults (x 400)

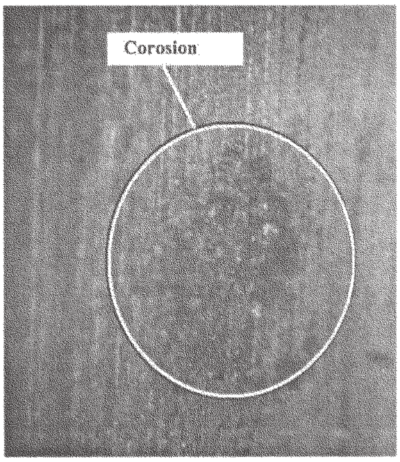

Fig. 11:. Raceway specific faults (x 400)

Conclusions

The greased rolling bearing deterioration under the influence of the electrical field is a complex phenomenon and it is due to lubricant greases quick deterioration.

Even at low bearings applied potential drops lubricant greases damaging is a consequence of their electrochemical decomposition and major structural changes.

Depending on rolling bearings "electrical load" their deterioration is due to the appearance of corrugation/ corrosion spots or because of the "electrical starvation" phenomenon.

Lubricant greases samples and bearings raceways analysis confirmed the phenomenon complexity and a better understanding of lubricants behaviour in these conditions will be accomplished considering the chemical deterioration criterion.

Lubricant greases damaging mechanisms complete elucidation in correlation with service life tests will permit to forward a lubricants deterioration model in the presence of the electrical fields based on which recommendations for the bearings grease replacement intervals to be formulated.

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