Lubrication of High Speed Ball-Bearings Using Polymer Additives

VIRGIL GEAMAN [1], **MIHAI ALIN POP**[1], **IRINEL RADOMIR** [1], **TIBOR BEDO**[1], **BOGDAN FLOREA** [2], **AUGUSTIN SEMENESCU** [2],
OANA ROXANA CHIVU[3]*, **MINODORA PASARE**[4], **MARIA ALINA GLIGOR**[5]

[1] Transilvania University of Brasov, 29 Eroilor Blvd., 500036, Brasov, Romania

[2] University Politehnica of Bucharest, Faculty of Material Science and Engineering, 313 Splaiul Independentei, 060021, Bucharest, Romania

[3] University Politehnica of Bucharest, Faculty of Engineering and Management of Technological Systems, 313 Splaiul Independentei, 060021, Bucharest, Romania

[4] Constantin Brancus University of Targu Jiu, Victoriei Str., 210007, Targu Jiu, Romania

[5] University Lucian Blaga of Sibiu, Faculty of Engineering, 10 Victoriei Blvd., 550024, Sibiu, Romania

The use of polymer additives for improving different characteristics of lubricants required in running of mechanical systems like polymer-thickened lubricants, have demonstrated highly efficiency as viscosity index improvers. The macromolecular coils dispersed into the oil contribute to the increase of the lubricant film thickness and reduce the risk of damage by scuffing of the contacting surfaces. The paper presents some experimental data for exploring new lubricants used for high speed ball bearings.

Keywords: lubrication, additives, polymer additive, polyethylene

Ball bearings are a type of rolling-element bearing that uses balls to maintain the separation between the moving parts of the bearing. The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads. Radial ball bearings can support moderate radial loads and moderate axial loads (parallel to the shaft). Ball bearings with shields or seals for protection can be lubricated to last for the operating life. Sometimes ball bearings are also called *deep groove ball bearings.*

High-speed ball bearings offer rotation speeds up to 500,000 rpm. There are ideal for low friction, low noise, and high-precision applications, like dental and medical equipment; aerospace equipment, servomotors, etc.

Whether bearings are made from standard stock or meet special requirements like: calibration capabilities, close tolerances and offer: low radial run-out, accuracy, rigidity, fast rotation, smooth operation, low noise, reduced heat. Some of these precision high speed ball bearings are shown in figure 1.

Fig. 1. Special high speed ball bearings designed for high-precision applications [11]

Polymers used as additives for the lubricant oils prolong the life of ball bearings and implicit for equipment by performing some important functions: viscosity improvers, dispersants, antiwear and extreme pressure agents, friction modifiers, pour-point depresants, oxidation and corrosion inhibitors, emulsifiers and demulsifiers, pour point depressants, foam inhibitors, etc. The additived lubricants in use are more resistant to oxidation, thermal degradation, microbial attack, and contamination. As polymer-in-lubricant dispersions, the polymer-thickened lubricants can be an efficient solution at lubricant transport, storage and processing. It was shown that polymers might contribute to improved performance by forming adsorbed or high-viscosity surface films with thicknesses in the range 40 to 150 nm, depending on polymer type, concentration and size.

The polymer properties and the processing concentration affect the lubricant performances. The macromolecular content depends on the chemical nature of the lubricants and additives and on the application; usually polymer concentration ranges from the order of tens of ppm too as much as 25%.

The chemical and mechanical action of lubricants additived with polymers is complex and not yet clearly understood. The purpose of this paper is to investigate the performances obtained in lubrication of concentrated contacts by using polyethylene as additives for the lubricant oil.

Polyolefins, and particularly polyethylene, have some particular properties [1, 2] that make them useful for some applications. Their characteristics depend on a great number of parameters, such as molecular structure, molecular weight and molecular weight distribution, morphology. Polyolefins can be used over a wide temperature range and they produce less hydrocarbon emissions than petroleum oils at similar viscosities, being also very resistant to oxidative and thermal degradation. By extending their range of application in the lubricants field, some important technical problems can be solved.

Experimental tests performed recently on ball bearings [3] showed that there is an optimum concentration of polymer dispersed into the oil which assures a maximum film thickness. This concentration was found in the dilute regime of concentration, where the rheological units are the individual particles formed by macromolecular coils dispersed into the oil.

Cann and Spikes [4] have shown that the lubricating films formed between contacts have two components. At very low speeds, the polymer forms an immobile film of thickness equivalent to two radii of gyration of the polymer molecules. This film thickness is independent of speed but is gradually squeezed from the contact when motion is halted. The film is likely to represent two monolayers of polymer, one of each surface and can be regarded as a boundary lubricating film. As the rotation speed is raised, a conventional elastohydrodynamic film is formed which is superimposed on the immobile film.

Georges et al. [5] have demonstrated that quite low molecular weight polymers form immobile films at

BASE OIL	
Parameter	*value*
density (g/cm³)	0.870
kinematic viscosity (m²/s) at 20°C	167.58
at 100°C	15.26
viscosity index (IV)	88
pour point (°C)	-20
POLYETHYLENE	
Parameter	*value*
average molecular weight (g/mol)	118000
methyl groups per 1000 C atoms	44
density (g/cm³)	0.917
melting point (°C)	112
melt flow index (g/10min)	2.7
cristallinity (%)	46

Table 1
PHYSICAL PROPERTIES OF BASE OIL AND POLYETHYLENE

Geometry	*value*
outside diameter (mm)	32
bore diameter (mm)	15
width (mm)	9
ball diameter (mm)	5
number of balls	20

Table 2
DIMENSIONS OF BALL BEARING TESTED

immediately adjacent surfaces. The layers have a thickness approximately equals to diameter of polymer coils [6], implying the presence of a monomolecular film adsorbed on the solid surface.

Experimental part

For experiments were tested oils with a paraffinic structure and also with a content of low amount of iso-paraffins, cycloparafins and aromatics. Low-density polyethylene (PE) was used as additive for the lubricant oil. The polymer has an average molecular weight of 118 000 g/mol and a branched structure (table 1).

The intrinsic viscosity ([h], dL/g) of dilute solution of polyethylene in the lubricant oil was determined by using an Ubbelohde suspended level viscometer. Calculation of intrinsic viscosity was made by simultaneous extrapolation of η_{sp}/c vs. c and $ln(\eta)/c$ vs. c plots to infinite dilution so that both plots gave the same intercept.

-c - is concentration in [g/dL];

-η_p - is the specific viscosity, $\eta_{sp} = [(\eta_{suspension} - \eta_{oil})/\eta_{oil}]$.

The low-voltage electrical resistance method was used to estimate the degree of contact taking place between the rollers and the raceways.

The bearing insulating resistance was measured in stabilised thermal regime for different bulk lubricant temperatures. Corresponding to each bulk lubricant temperature, when the bearing electrical resistance was monitored, the average film thickness at the raceway contacts was computed. The calibration curve representing an electrical resistance - minimum film thickness relationship was obtained by applying the last mean square method on the semi empirical dependence: $R_b^{exp\,erimental} = f\left(h_{av}^{theoretical}\right)$. For the film thickness measurements, the electrical circuit is connected between the driving shaft and the bearing housing of tapered rolling bearing. In this system there are three zones where the lubricant film is formed: between outer ring and balls, between inner ring and balls, and also between ball-holders and balls. Using the calibration curves for each lubricant system, the minimum film thickness versus bearing speed at different temperatures and polymer concentrations was plotted.

Results adn discussions

The intrinsic viscosity [h] is related to the hydrodynamic radius R_H by the following relation [7]:

$$R_H^3 = 0.0955 \cdot [\eta] \frac{M_w}{N_A} \qquad (1)$$

where:

- N_A is the Avogadro number;

-M_w/N_A is the weight of one polymer chain.

According to these data, the monomolecular film adsorbed on the solid surface has about 25 - 27 nm thick.

The theoretical radius of gyration is given by:

$$R_G = a \cdot \sqrt{\frac{N}{6}} \qquad (2)$$

where:

-a is the length of the monomer;

-N is the number of monomers.

For the studied system, the radius of gyration was calculated as being 7.48 nm.

The ratio hydrodynamic radius to gyration radius R_H/R_g is considered as a criterion for the solvent quality [8]. According to the literature, it has a value close to one for a q-solvent and more (1.7 - 2.5) for a good solvent; here it is found to be 1.78 – 2.1. It is concluded that the base oil is a good solvent for polyethylene.

The dissolved polymer adopts a progressively more open molecular conformation in solution as temperature is raised, so that it makes a larger contribution to the overall viscosity of the system at high than at low temperatures. This behavior determines an improving of the film forming properties when such dilute solutions of polyethylene are used as lubricants. The thickness of polymer layer adsorbed on the solid surfaces corresponds to about a coil diameter of the polymer (2·R_H). The boundary of the flow appears at the top of layer thickness L, showing that the small molecules of solvent are removed from the polymer layer or immobilised into the macromolecular coils [6]. The layer structure is controlled by the polymer adsorption and the solvent quality [6, 9].

The inner and outer contact resistances can be considered approximately equal. This assumption is based on the variation of the computed λ parameter for both inner and outer roller contacts as a function of the bearing rotational speed (λ = h_{min}/σ, σ is the composite surface roughness). The variation of Lambda parameter as a function of ball bearing speed is presented in figure 2. The tests were made for the typical ball bearings very used in construction of lawn mower equipment with geometry given in table 2.
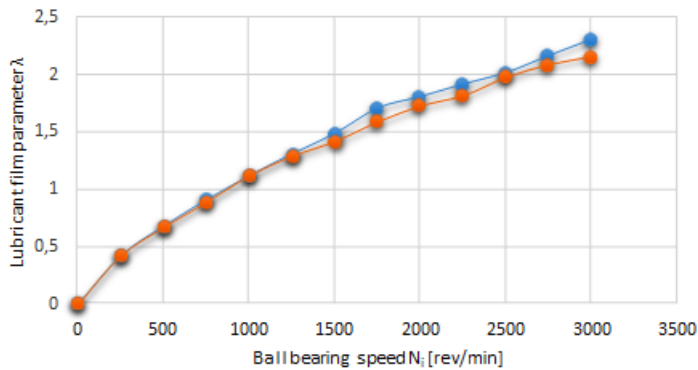
Fig. 2. The variation of Lambda parameter (λ) from the raceways versus rotational speed; (λ_i – yellow line - lubricant film parameter for inner ring contact; λ_o - blue line - lubricant film parameter for outer ring contact)

The basic relation for the electrical resistance of a lubricated contact is given by:

$$R = \frac{\rho \cdot h}{A} ; \qquad (3)$$

where:

-ρ - is the electric resistivity of the lubricant;

-h - is the average lubricant film thickness at the contact interface;

-a - is the effective Hertzian contact area.

We can estimate that in the tapered ball studied, the Hertzian contact area in rib - ball contacts is approximately 1:24 of Hertzian contact area in ball raceway. As a consequence, the ratio between electrical resistance of the rib - ball end and ball - raceway contact, respectively, is approximately 24:1. If the film thickness at the rib - ball end is twice that of the film thickness in the raceway contact, the ratio R_0/R_{rib} is approximately 0.022 and we consider that this value can be neglected reporting to the unity.

Conclusions

The engine oils can contain a certain proportion of dissolved polymeric material. Under high temperature engine conditions, the polymer-thickened lubricants act as viscosity index improvers. The additived lubricant oil becomes able to form reasonably thick hydrodynamic and elastohydrodynamic films.

The macromolecular coils dispersed into the oil contribute to the increase of the lubricant film thickness and reduce the risk of damage by scuffing of the contacting surfaces.

Usually, ball bearings which are working in unprotected environments, like grass cutting, have shields or seals for protection and are lubricated for the whole operating life.

References

1. ADAMS J.L., FOSTER G.N., RASTOGI S.R., VOGEL R.H. and Wasserman S.H., Polymer Pre-prints, **39** (1) 1998, 190 - 191.

2. VASILE C. AND SEYMOUR R.B. Eds., Handbook of Polyolefins. Synthesis and Properties, Marcel Dekker Inc., New York, 1993.

3. BERCEA M., BERCEA I., POHONTU M. AND OLARU N.D., Proceedings of 11-th International Colloquium on Tribology, T.A. Esslingen, 13 - 15 January 1998, vol. 1, 601 - 615.

4. CANN P.M. AND SPIKES H.A., Tribology Transactions, **37**, 1994, 580 - 586.

5. DOBROTA, D., TITU, M. A., DOBRIA, F., PETRESCU, V., The Analysis of Homogeneity of the Chemical Composition in Castings Made of Aluminum Alloy, Rev. Chim. (Bucharest), **67**, no. 3, 2016, p.520

6. CICIC, D-T., RONTESCU, C., AMZA, C. Gh., CHIVU, O., The Combined Effect of Chemical Elements on the Propertiesof a Layer Deposited by Welding, Rev. Chim. (Bucharest), **66**, no. 9, 2015, p.1299

7. CHIVU, O., RONTESCU,C., CICIC, D. T., Research On The Quality Of Heterogeneous Welded Joints Between Copper And Stainless, Rev. Chim.(Bucharest), **66**, no.11, 2015, p.1752

8. O. CHIVU; C. RONTESCU; D. T. CICIC; G. BALAN; (2016),The Effects Of Reconditioning By Welding Of Crankshafts In Automotive Industry; Metalurgija; ISI; **Vol.55**, Br./No 1, Str./P 1-144, Zagreb, Sijecanj-Ozujak/ January-March 2016, ISSN 0543-5846; 55-58

9. JACOBSON, B.O., Rheology and Elastohydrodynamic Lubrication, SKF Engineering and Research Centre B.V., Nieuwegein (The Netherlands) 1991 - **Chap. 18**, Non-Newtonian Fluid Model, p. 289.

10. PRASHAD, H., Wear, **131**, 1989, 1 - 14.

11. *** http://www.ibsco.com/precision-ball-bearings.php