SELF-LUBRICATING BEARINGS OF POLYMER MATERIALS – APPLICATION AND PERFORMANCES

A. MARINKOVIC [1], M. STANKOVIC [1], T LAZOVIC [1], LJ. MILOVIC [2]

1 INTRODUCTION

Sliding bearings are applied when it comes to special design or functional constraints. For example design constraint such is dimension of the sleeve diameter could impose usage of sliding bearings. If sleeve diameter is less than 15 mm or greater than 300 mm, there are usually mounted sliding bearings. Sliding bearings are usually applied at high shaft speeds or in case when low level of vibration and noise is requested. Most of machine and equipment manufacturers are trying to eliminate or at least to reduce lubrication systems in aim to settle production costs down without sacrificing machine performances. According to numerous analyses and investigations, more than 50% of bearing failures are lubrication related. In a study (MIT, USA) it was estimated approximately $240 billion is lost annually due to downtime and repairs to equipment damaged by poor or inadequate lubrication [1].

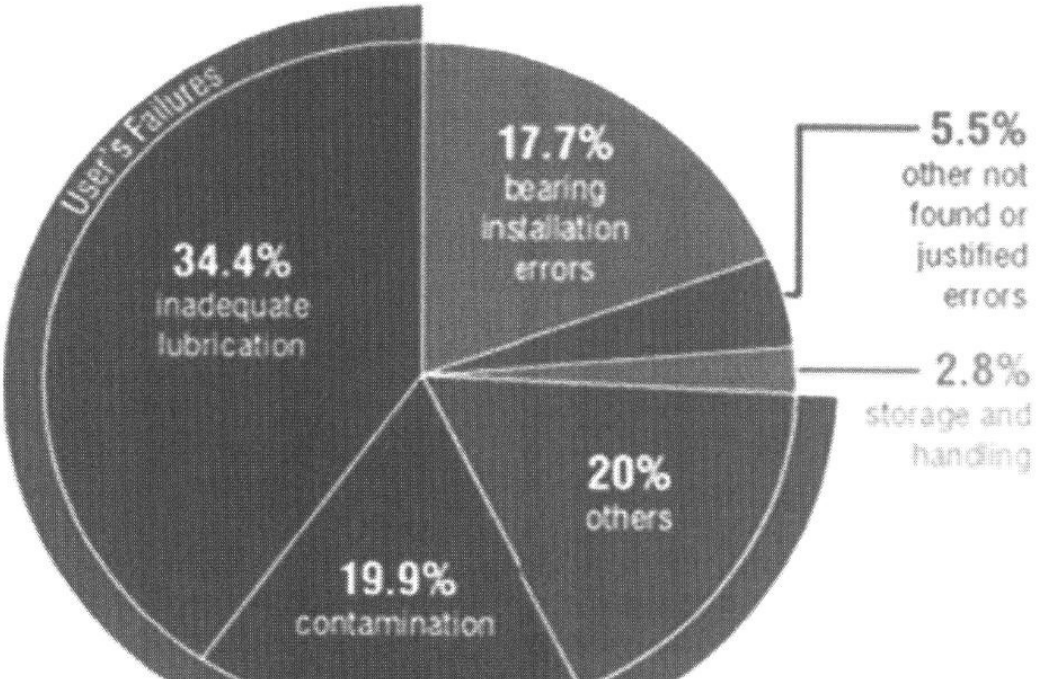

Figure 1: Lubrication related bearing failures

1 University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade 35; amarinkovic@mas.bg.ac.rs

2 University of Belgrade, Faculty of Technology and Metallurgy, Karnegijeva 4, 11120 Belgrade

By eliminating lubrication from machinery, equipment manufacturers can minimize the costs and risks associated with maintenance for the end user. Because of lubrication problems and costs, which are dominant during the working life, a possible solution is to apply some of self-lubricating sliding bearings. This kind of bearing has been applied in a wide range of machine types, used in every day's situations. This fact can be easily understood if several advantages of this type of bearings compared to standard sliding and rolling bearings are considered. Generally, their production is pretty simple, which makes the price lower, for simple mounting they could be made in segments, and in operating they produce less noise and vibrations. Regarding the fact that they do not need any additional lubrication during the operation process, those bearings are very convenient for maintenance and they have long operating life. There are two different types of self-lubricating sliding bearings:

- Sliding bearings that contain lubricant, either in special storage or in their own material structure, for example porous metal bearings,
- Sliding bearings that work without oil or grease.

First group are sliding bearing with special material structure, such as porous metal bearings, those were intensely investigated at the end of last century and their advantages were presented in numerous papers and literature [2], [3]. This paper is focused on the second group of bearings produced on polymer basis which is optimized with fiber reinforcement and solid lubricants. They are an ideal solution for machinery that requires clean and oil-free operation.

2 MATERIALS AND ADVANTAGES OF PLASTIC BEARINGS

There are several typical groups of materials for plastic bearings, taking into account their physical-mechanical performances [4]:

- Thermoplastic materials,
- Phenol and Epoxy plastic materials,
- Elastomers,
- Multilayer plastic materials.

Thermoplastics and thermoplastic materials are polymers that turn to liquid when heated and turn solid when cooled. They can be repeatedly remelted and remoulded, allowing parts and scraps to be reprocessed. In most cases they are also very recyclable. Some thermoplastics contain filler materials such as powders or fibres to provide improved strength and/or stiffness. Products in thermoplastics could also contain solid lubricant fillers such as graphite or molybdenum disulfide; metal powders or inorganic fillers with ceramics and silicates aimed to improve their mechanical and tribological performances.

Polyethylene (PE), Fluoroplastics (such as PTFE), Polyamide (PA) and Polyoxy-methylene (as POM) are common materials from thermoplastics group and in general, those are being used in sliding bearing manufacturing with characteristics important for typical sliding bearing applications. If somebody needs plastic bearing for extreme high load, Homopolymers or Copolymers (POM) with highest strength are recommended. If bearing exploitation occurs in high environmental temperature conditions, Polytetrafluoroethylene (PTFE) is useful with maximal working temperature around 200 °C. From tribology point of view, materials such PTFE is, has the lowest friction coefficient value (between 0,02 and 0,06 in dry conditions). If we need good wear resistance of the bearing, materials as Polyamide (PA) and POM plastic materials are recommended. Other plastic materials except above explained group of Thermoplastics are not so common in use, but we could apply them in some special cases. Multilayer plastic materials are useful in combination with some metal as a matrix, with different coatings or solid lubricants (known as composites). Because of current great plastic bearing expansion in a wide range of different applications, many companies are exploring and try to come on the market with their products.

If we are taking into account proper lubrication delivery as a critical factor for the operation of ball bearings and most require continued maintenance for re-lubrication, this is a starting reason for thinking about their replacement with plastic bearings. There are also additional parts required to protect ball bearings from contaminants. According to several institutes' research, the leading cause of bearing failure is due to contamination of the lubrication by moisture and solid particles. If as little as 0.002 percent water gets mixed into the lubrication system, it increases the probability of failure by 48 %. Just six percent water can reduce the bearing lifetime by 83 %. Ball bearings require seals to keep oil in and unwanted water and liquids out, as well as wipers / scrapers to keep dust and debris out. Seals are to last sufficiently long yet do not perform well in dirty and dusty environments and can also increase friction in the application. In some applications where dust and debris are prevalent during operation, seals and wipers may require frequent replacement.

3 PLASTIC BEARING APPLICATIONS

Regarding their advantages, plastic bearings are a good solution for many applications in machinery that require clean and oil-free operation. They also perform well in dirty environments since there is no oil to attract dust and dirt, like in the agricultural industry. Some manufactures create individual planting row units using walking gauge wheels to deliver a consistent planting depth (Figure 2). Oil impregnated bronze bearings were used to facilitate this movement till requiring replacement few times a season because of high wear due to the very abrasive conditions. By replacing all of dozens bronze with corresponding plastic bearings, lifetime of machine was increased several times, with higher reliability and reduced cost [5].

Packaging equipment manufacturers for handling a wide range of products had been using lot of metal linear ball bearings. The machines are capable of reaching up hundreds of cycles, respectable loads, while operating at high speeds, where metal bearings scored the shafts and leaked grease on some of the machines. Replacement with linear plain plastic bearings the linear bushings have surpassed millions of cycle mark on some of the company's packaging machines with little to no noticeable wear (Figure 2).

Figure 2: Plastic bearings application in agriculture and packing machines

Shipbuilding and hydraulic turbine building have accumulated much experience with the use of sliding bearings made of UGET carbon plastic [6]. These include friction units of a driving rudder set of ships of different types and design (supports for rudders and rudder machines) with regard to stabilizers, interceptors, drives for actuators of Kingston valve type, and scupper screens, as well as mast elevating extending devices and mechanisms (Figure 3). Sliding bearings have been previously made of bronze, and shafts have been made of a corrosion resistant material having rather low antifriction characteristics, corrosion resistant steel or titanium alloys. Therefore, in the absence of a reliable oil lubrication system there is a danger of seizure of metallic bearings, which may result in the failure of the whole mechanism. UGET carbon plastic containing poly functional epoxy resin and tissue of low module carbon fibre was developed. Bearings made of UGET carbon plastic are successfully used with shafts made of bronze and steels of different hardness and structure.

To facilitate different types of motion for medicine purpose machines (detection equipment); robot could use linear guide system and plastic self lubricating plain bearings. The linear guides facilitate translational motion of the positioning module, which provides gross positioning for the robot's needle driver. The needle driver is a vital part of the system, as it enables the rotation and translational movement, where advantages of plastic bearings are requested. The bearings enable the robot's motor to rotate the needle using the mechanism by way of a timing belt. This rotating needle would reduce tissue damage while enhance targeting accuracy. Many plain bearings were used to create a revolute joint, also known as a "pin joint" or "hinge joint", to provide single-axis rotation and contribute to proper and reliable work of such detection machines.

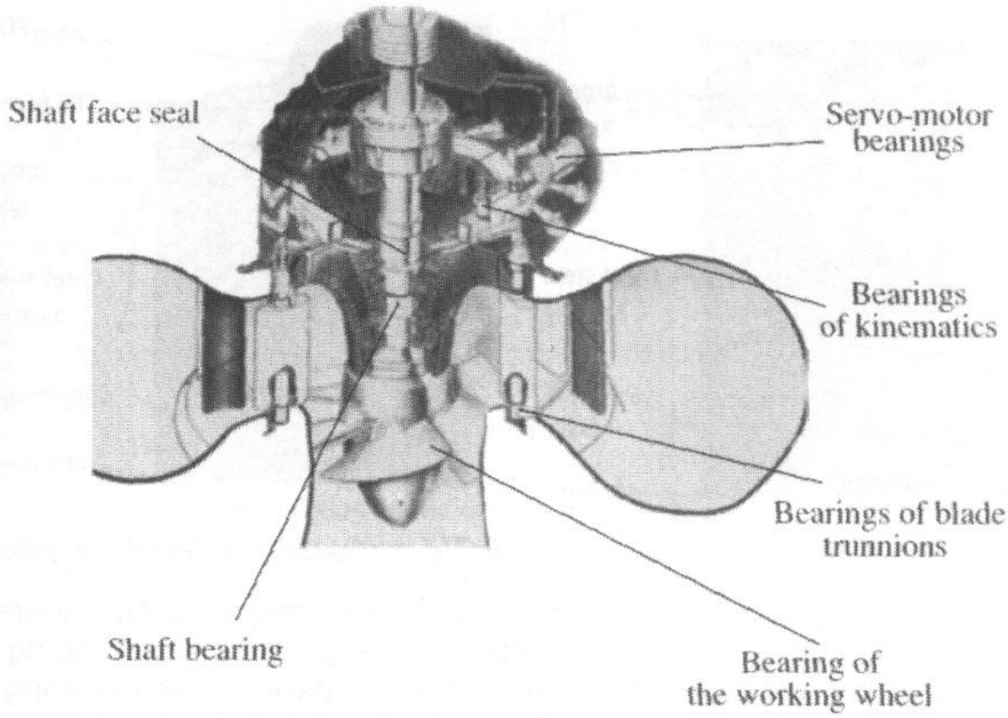

Figure 3: Sliding friction unit of a hydraulic turbine

4 INVESTIGATION OF TRIBOLOGICAL PROPERTIES

4.1 Materials and samples for testing

Sliding bearings tested in those investigations are made of composite materials with polymer matrix and belong to the group of self-lubricating bearings operating without oil or grease. There is a filler added to the base material which purpose is to reduce the coefficient of friction of the base material and therefore to eliminate the need for additional lubrication. Application of these bearings take place if lubrication isn't efficient due to very high or very low temperatures, operation in vacuum or chemically active environment; lubrication could spoil the product (e.g. food Industry); or when lubrication is not possible or too difficult due to design reasons (e.g. household appliance). Here are presented some initial results of examination of two types of polymer layer composite bearings.

First observed was PTFE-based composite bearing, with wall structure shown in Figure 4. This type of dry sliding bearing is designed to operate without lubricant and it is particularly suitable for high loads and medium speed. Its operating temperature is up to 250 °C and best using sliding velocity is up to 2 m/s. Another observed is POM composite sliding bearing with cross section also shown in Figure 4, specially designed to operate with boundary lubrication. This kind of bearing requires only a trace of lubricant to operate satisfactorily for long periods, so they are considered as pre-lubricated bearings. The sliding surface has a highly effective grease retention system, as "lubricant reservoirs". This POM Composite consists of three bonded layers: copper plated steel backing strip and a sintered porous tin bronze matrix covered with an acetyl (POM) resin.

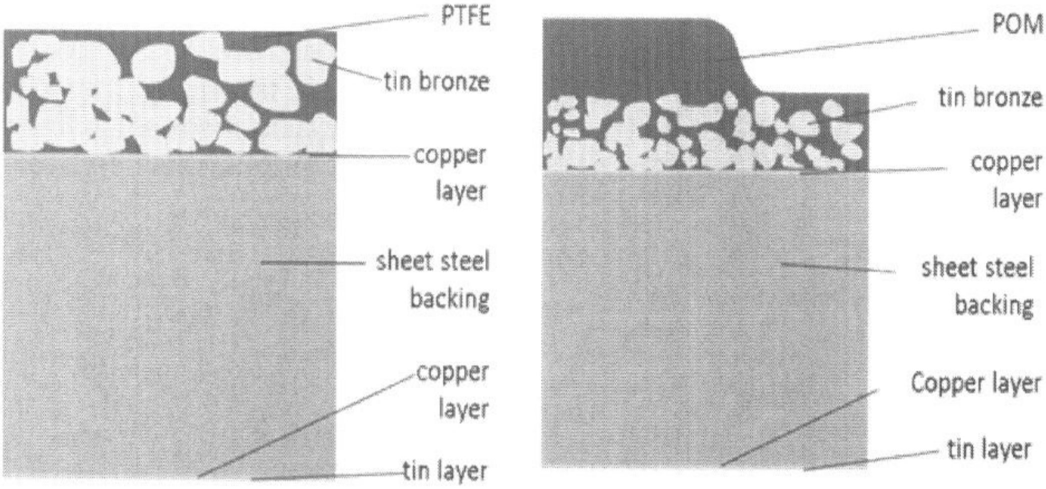

Figure 4: Cross section of PTFE / POM composite material samples

Experiments are carried out at Mechanical Engineering Faculty, Laboratory of Machine Design Department. For the experiments is used own testing rig named as USL 5-30, composed on USL1 idea [7] in cooperation with bearing manufacturer. Examined selected samples for testing have dimensions of ∅20 / ∅23 × 20 mm, as a common size for some of their typical applications. In combination with shafts made of steel 16MnCr5 (Hardness: 60 HRC), loose fit in shaft-bearing interface was defined by ∅20 H7/f7, where an operating clearance in testing belongs to range 20-62 µm. Using this test rig system for experiments it was convenient to apply a portable DAQ system acquisition with full bridge strain (torque moment) and temperature measurement [8].

4.2 Experimental results and discussion

For mentioned composite materials (PTFE and POM layer), the temperature and friction factor trend was obtained due to a time under the following parameters: radial load of 92 N and 995 min^{-1} as rotational velocity. This working regime for experiments is selected by using results of polymer materials studies [9]. Bearing manufacturer catalogues were also assisted as a background and guide in proper testing regime selection. According to typical bearing applications and operating performances, authors focused on higher velocity and lower load. Obtained results of operating temperature measurement and friction coefficient are shown for PTFE (Figure 5a) and POM composite materials (Figure 5b). The shown results are selected from several samples those are tested in same operating conditions and represent typical bearing performances those could be polynomial represented. Conducted bearing tests show that temperature and also coefficient of friction values become a constant till hour of work. Experiments show that bearings with PTFE layer reach higher temperature values than samples in POM composite, which could be explained by a bit lubricant amount applied from start and kept in small depots on the surface during the operating. Observed parameters for both composite materials take predicted values for relative low bearing load and high sliding velocity, according to manufacturer catalogues [10].

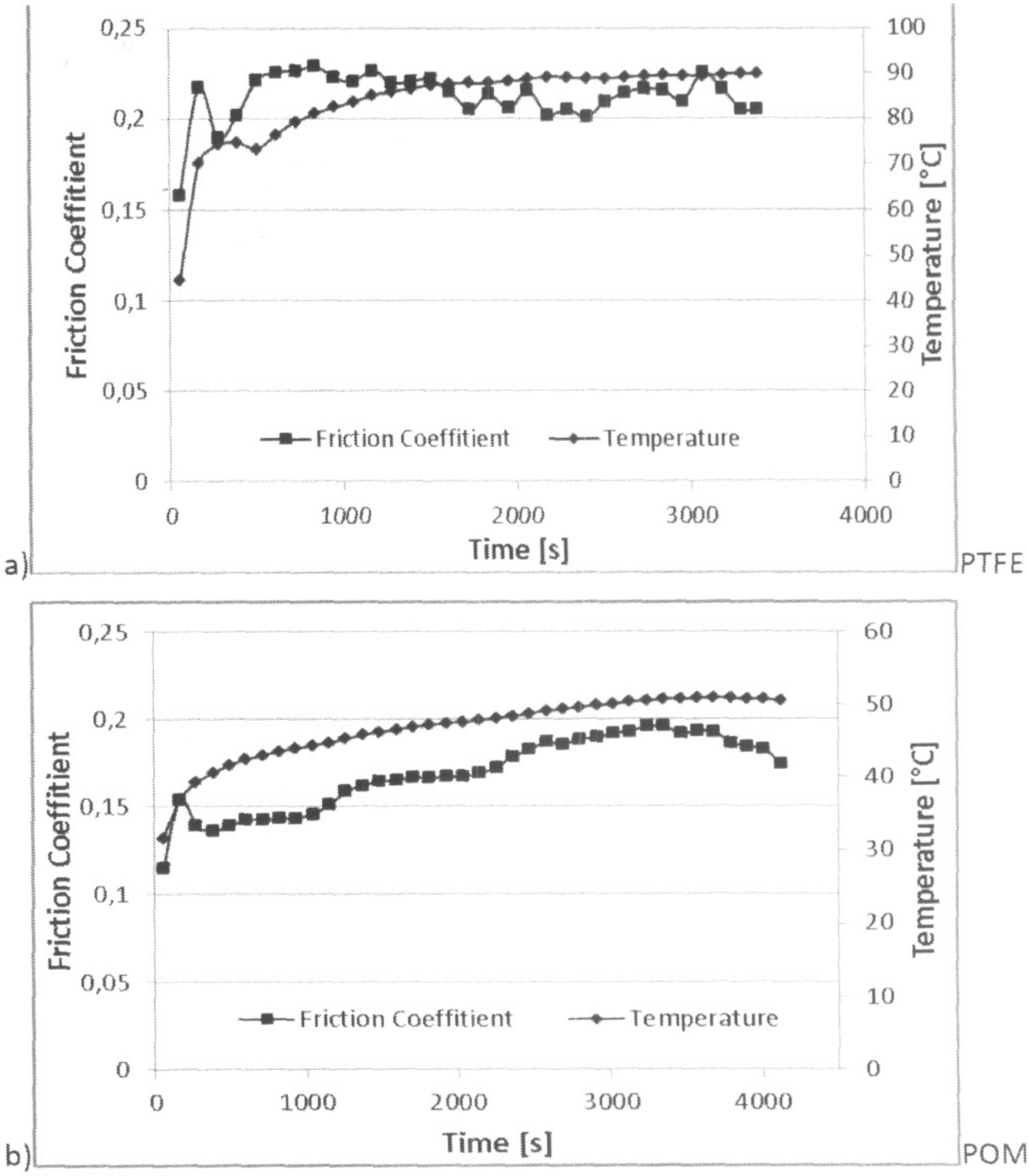

Figure 5: Bearing temperature and friction coefficient due to a working time for a) PTFE and b) POM composite materials

5 CONCLUSION

Determination of wear rate as a significant tribology parameter requests lot of experiments aimed to make some worthy conclusion. Taking into account that up to date investigations are still in progress, authors in this moment could just offer an observation concerning wear rate comparison between PTFE and POM materials. Results of experiments under above mentioned operating conditions show that samples with PTFE layer lost about 0,1 % of mass for a few hours of testing, while POM samples maintain their weight. It could be explained following the fact that POM bearings with depots retain lubricant and thus less wear in exploitation. It used to be said that presented results represents only a single regime investigation, where similar tests performing are in progress for other working regimes typical for this kind of bearings. Results of further investigations will be presented in next conferences and published in corresponding Journals.

6 ACKNOWLEDGEMENT

This work has been performed within the projects TR-35021 and TR-35011. These projects are supported by the Republic of Serbia, Ministry of Education, Science and Technological Development, which financial help is gratefully acknowledged.

7 LITERATURE

[1] Mat Mowry: The Thrue Cost of Bearing Lubrication. igus White Paper, igus®inc.USA, 2012.

[2] Cheng J.A., Lawley A., Smith W.E., Robertson J.M.: Structure property and performance relations in selflubricating bronze bearings: commercial pre-mixes. The International Journal of Powder Metallurgy, vol.22, No.3. 1986.

[3] Marinkovic A., Lazovic T., Stankovic M.: Experimental Investigation of Porous Metal Bearings. Proceedings of the 15th International Conference on Experimental Mechanics – ICEM15, pp.2718/1-2718/6, Porto, 2012.

[4] Momčilo R. Janković: Exploitation Performances of Plastic Radial Sliding Bearings made in Yugoslavia. Master Thesis, Mechanical Engineering Faculty, University of Belgrade, Belgrade, 1976.

[5] Marinković A., Stanković M.: Advantages and Applications of Self-Lubricating Plastic Bearings. Proceedings of 13th International Conference on Tribology Serbiatrib 2013, Kragujevac, pp. 247-250, 2013.

[6] A. V. Anisimov, V. E. Bakhareva, and G. I. Nikolaev: Antifriction Carbon Plastics in Machine Building. Journal of Friction and Wear, Vol. 28, No. 6, pp. 541–545, Allerton Press, Inc., 2007.

[7] Janković M.: Project of Bearing test rig USL1. Mechanical Engineering Faculty, University of Belgrade.

[8] Marinković A., Vencl A., Wallace P.: Portable DAQ equipment with Lab VIEW as a tool for tribology experiments and condition monitoring. Proceedings of 10th International Conference on Tribology Serbiatrib '07, Kragujevac, pp.105-108 , 2007.

[9] Stanković M., Vencl A., Marinković A.: A Review of the Tribological Properties of PTFE Composites Filled with Glass, Graphite, Carbon or Bronze Reinforcement. Proceedings of International Conference in Tribology, Serbiatrib 2013, pp.135–140, 2013.

[10] SKF Catalogue Composite plain bearings, Compact and maintenance-free. SKF Group, 2012