STUDY OF NON-METALLIC ROLLING-ELEMENT BEARINGS

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Abstract: *The widely used metal rolling bearings are only suitable for use in a process fluid by solving serious difficulties in sealing. Process fluids (water, alkali or acid fluids, apple juice, wine or perhaps milk…) have an adverse effect on the operation of bearings. In these cases, on the one hand the occurring corrosive effects must be expected as well as the inadequate lubrication of bearings. By now, due to the large development of materials science and manufacturing processes bearings with plastic outer and inner race and some kind of aseptic rolling element (e.g. glass, acid-resistant steel or ceramic) have appeared in the areas of rolling bearings. In the Institute of Mechanics and Machinery of Gödöllő Szent István University there are studies conducted as to how these bearings made of non-standard materials behave in different process fluids.*

Keywords: Plastic rolling bearings, Thermal imaging camera, Thermal imaging camera tests, Bearing geometry

1. Timeliness and significance of the study of rolling-element bearings

The use of rolling bearings plays an important role in all areas of technological life. A wide range of rolling-element bearings has been used for the energetically active support of the rolling parts of machinery and equipment. These machine elements must be adequate for a wide variety of load conditions and operating media without failure. Rolling bearings can be found in a laboratory environment as well as in extreme weather conditions or in installed, fixed manufacturing lines or mobile machines.

Since they have become widely used, adequate attention has been paid to their improvement and study in technology. When rolling bearings appeared, materials science and engineering were not at such a high level as today. In the 1960s there were efforts to make rolling bearings from new materials (plastic) versus metal. However, these efforts proved unsuccessful as plastics used and manufactured at the time did not meet the requirements of being used as the materials of bearings. Because of these failures only a few large companies continued developing plastic rolling bearings further, but non-metallic bearings were not capable of fulfilling a good position in technology.

However, nowadays thanks to the strong development of materials science and manufacturing processes new materials have also appeared in the areas of rolling bearings. The rapid development of plastics and the appearance of technical plastics have made it possible to use new materials in the case of rolling bearings as well. Today, bearings are available in different materials for the technology for designers and users from plastic through glass and ceramic to conventional metals. These new materials have made it possible to apply rolling bearings in new areas of use, such as in the textile industry, pharmaceutical industry and increasingly in the food industry (R.G. Mirzojev, 1974).

Although the technical development of non-metallic bearings and the extent of their use have shown a clearly growing trend in the past 20 years, these directions of development have not been accompanied by laboratory research. Current research deals with either the properties of specific non-metallic bearing materials or the comparison of metal and non-metallic bearings. The fundamental direction of research by C. Morillo and fellow researchers was the comparison of non-metallic bearings to metal ones based on certain bearing features. (C.Morillo et al., 2013). The findings by Hitonobu Koike PEEK-PTFE were aimed at bearing wear (Hitonobu Koike, 2013). The efficiency of certain lubricants in the case of plastic bearing races was studied by J. Sukumaran et al. The primary focus of their work was the analysis of water lubrication, however the effects of other process fluids were not studied (J. Sukumaran et al., 2012). The self-lubricating ability of non-metallic bearings was studied by K. Kida, whose suggestion was that the PEEK bearing could be outstanding among plastic bearings due to its self-lubricating property (K. Kida et al., 2011). The question, problem of how bearings behave in process fluids (different liquid materials) has not been studied by any researchers in the case of the basic properties of bearings. Therefore, this topic can be considered rather timely, its significance is far-reaching.

2. The objective of the analyses

The aim of our study is to conduct a research program whose result can provide a tool for designers and operators using non-metallic bearings. It is important to define the limits of operations of these machine parts made of unconventional materials essentially on the basis of their operating temperature. Another direction of research could provide results for the selection of proper fitting joints in the case of different process fluids.

3. Material and method

It is important that we should be able to examine the operation of bearings among industrial operating conditions and then these conditions could be reproduced with the help of laboratory background thus the data and information experienced during the operation can be validated. The plant measurements are taken in the Bosch RUR washer machine operating in the LIO and CITO section of the LIO and Eye Drop plant of TEVA Pharmaceutical Factory in Gödöllő, and the control tests are performed under laboratory conditions.

Two main sets of tests were conducted. The temperature change in non-metallic rolling-element bearings was monitored with different load and run (revolution) settings during operation in a dry environment. In the design phase of the bearing test bench built in the Institute of Machinery of Szent István University it was an important aspect that the parameters basically impacting the operation of bearings like radial load, axial load or revolution should be freely adjustable and verifiable. The other criterion was that during the test runs performed in process fluids the test bench should be capable of receiving a climatic chamber which would function as a climatic cabinet, where the cabinet air humidity, dry matter content or temperature can be programmed under controlled conditions. Where appropriate, there may be flood tests in which the non-metallic bearings would operate in a process fluid and at this time the climatic cabinet would even function as a pool.

In addition to the temperature measurements of bearings the geometric parameter change of bearings was also tested in different process fluids. These measurements are interesting because of one of the most characteristic properties of plastics, the tendency of swelling. The change in those four main bearing geometrical parameters must be tested which fundamentally influence the operation of bearings – not only the operation of non-metallic bearings. These are the change in the diameter of the inner and outer race of the bearing due to the effect of the process fluid, which basically influence bearing installation instructions. If these parameters change, the tolerance pairs, fits recommended by the bearing manufacturer can also change. The change in these parameters puts the questions of installation technology into a new perspective. In addition to the outer and inner diameter the change in the clearance of bearing was measured since the change in this parameter impacts the running accuracy of bearings. The fourth tested geometric parameter is the change in bearing weight because of the process fluid. Although it can be felt the extent of change in weight resulting from swelling will not impact the proper operation of the bearing, still it may be interesting since the assumption that non-metallic rolling bearings are prone to moisture absorption, consequently swelling i.e. size change may be substantiated with this data.

4. Equipment used during the laboratory tests of non-metallic rolling bearings

A test bench capable of examining non-metallic bearings was created in the Department of Machine Structures in the Faculty of Mechanical Engineering of Szent István University (Figure 1).

When the technical documentation was prepared the fundamental goal was to be able to adjust the radial and axial load as well as the revolution affecting the bearing running parameters and to be able to monitor the changes in these data in real time with the help of load cells and rotary encoder and also to be able to collect these data for later processing.

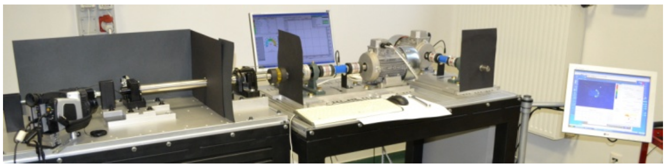

***Figure 1**: Special purpose equipment for testing non-metallic bearings*

The other important criterion was that the structure of the test bench should be constructed of corrosion resistant materials so it cannot be damaged by the corrosive fluid to be used as planned. The base plate of the test bench was made of high precision aluminium preform, and due to the plate structure the other parts were also made of aluminium preforms. One of the most important construction elements of the test bench is the axle which was made by a high-precision manufacturing process from acid resistant steel. In the case of the axle and the axle lead-in the robust, rigid axle guide must be mentioned as an important construction criterion. High precision is significant in order to exclude any improper bearing operation due to axle faults (Figure 2).

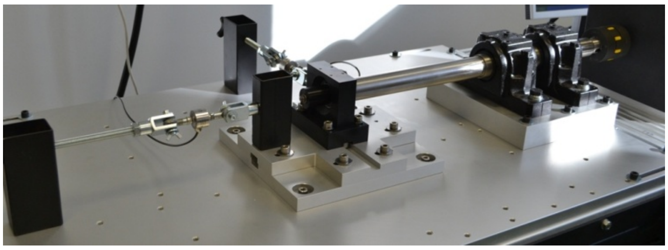

***Figure 2**: The input axle and the axial and radial tensioning unit*

The adjustment of accurate test revolution is done manually on the drive unit for the time being. There is a more interesting solution for the programming of the other two parameters to be adjusted (radial and axial load). The adjustment of the parameters affecting the operation can be realized by pulling, displacing axially and perpendicularly to the axle the bearing housing created for the geometry of the bearing to be tested. The bearing housing can move on a guided course, the adjustment of the load of the tested bearing can be fixed with the help of a screw-spindle actuator (Figure 3).

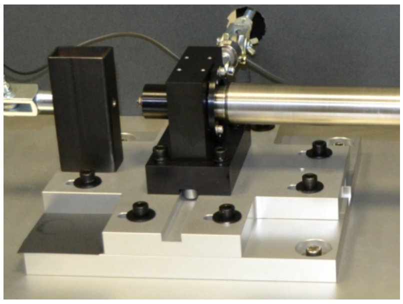

***Figure 3**: Bearing housing and base plates capable of moving axially and radially*

In the construction design phase of the test bench it was a basic condition that during the measurements all the variable bearing properties (e.g. change in bearing temperature) should occur by adjusting the test parameters according to the researcher's intention and no uninterpretable factors should get into the experimental system due to some construction fault or non-compliance (e.g. undersized axle or improper support).

The measurements related to the temperature change in bearings are performed with the NEC thermal imaging camera of the Institute of Machinery (Figure 4), the images are processed with the default software of the camera, Image Processor Pro II (Figure 4) and then the data are evaluated. The measurements of the temperature change are taken while constantly monitoring the radial and axial loads and the revolution. Data acquisition is performed by a SPIDER 8 data acquisition system, and data processing is done by the HBMI CATMAN system (Figure 4).

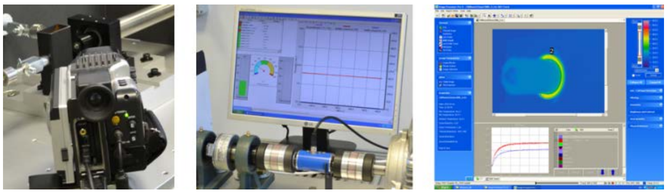

***Figure 4**: (From left to right) NEC thermal imaging camera, CATMAN monitoring system, Image Process Pro II*

The other main experimental direction recently has been the study of the size changes of rolling bearings due to the effect of process fluids of different properties. The size change in the weight, inner and outer race and clearance of bearings was measured at predetermined intervals. Weight measurements were taken using a KERN PCB with a readout accuracy of 0.01 grams (every 48 hours), the change in outer and inner diameter was measured with a micrometer and inside micrometer with a readout accuracy of 0.01 mm (Figure 5).

***Figure 5**: Measuring instruments used in the measurement of geometry change*

During the measurements of the geometrical parameters of bearings the most complex task was the inspection of bearing clearance change since the feeler gauge with blades generally accepted and easily usable in the industry did not prove appropriate to measure the clearance of bearings with plastic outer and inner race. The main reason for this is the vulnerability of polyamide bearing races. So in this case the solution was to use a custom-designed measuring target device. The construction requirements of the device were the following: the high strength, robust securing of the axle ends manufactured according to factory recommended tolerances fitting the bearings to be tested. This is an important criterion because the measuring target device should stand stable on the measuring island against the measuring power. The dial gauge with readout accuracy of 0.01 mm was placed on this unit (Figure 6).

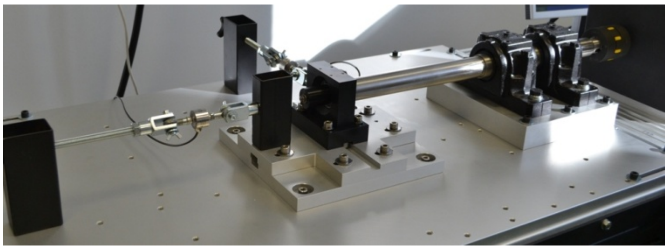

Figure 6*: Target device for measuring bearing clearance*

The measurements of the temperature change in bearings were taken with a NEC thermal imaging camera owned by the Institute of Mechanics and Machinery of Szent István University, the images were processed with the default software of the camera and then the processed data were evaluated. The measurement of temperature change was performed under radial and axial loads and the continuous monitoring of revolution. Data acquisition was performed by a SPIDER 8 data acquisition device and data processing was performed by the HBMI CATMAN system. The measurement of geometrical dimensions was taken with conventional measuring devices, inner micrometer, micrometer and dial gauge, the data were entered in the database management software manually and then they were processed with mathematical statistical methods. During the evaluation of both series of measurements basic statistical correlations are used, the results are illustrated in diagrams.

5. Results of the laboratory tests of non-metallic rolling bearings

Dry run tests of non-metallic rolling-element bearings

During the run tests performed so far the aim was that the measurement of the temperature change of non-metallic rolling-element bearings should be performed in the most unfavourable conditions regarding the operation of the bearing. It was assumed that during the tests of the temperature change of non-metallic rolling-element bearings the lack of wet process media can be considered the most unfavourable condition. Wet process media can provide more favourable lubrication for the bearing and can provide cooling for the bearing. These aspects can prove to be very important during the operation of elements made of construction materials whose softening temperature is around 150°C.

The adjustment of measurement parameters during temperature measurements

With extreme revolution values based on catalogue data, both the axial and radial load parameters were set near the maximum load values (based on catalogue parameters) separately too, but there were such set points in the measurement series when the bearing received loads from both radial and axial directions.

Before the presentation of the results it is necessary to explain the choice of the area of the temperature measurement and the measurement interval. The temperature of area marked 2 in Figure 7 was measured, this covers the most loaded environment of the rolling-element and the running tracks. Within this area the average temperature, maximum temperature and minimum temperature were sampled at a resolution of 1 second. The duration of one measurement with one test setting was 10 minutes (600 s) in all cases since after 5 minutes (300 s) the temperature converges to a constant value asymptotically.

The evaluation of the temperature change of bearings was performed following the experimental method developed by Gárdonyi, which, similarly to this research program, was used to study the losses of machine elements (Gárdonyi et al., 2013, 2015).

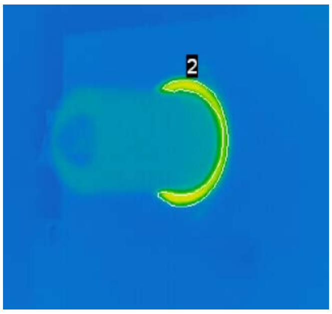

Figure 7*: Defining the measurement area in the evaluation software of the thermal imaging camera*

The following must be highlighted among the results acquired during the measurement of temperature change.

The nature of temperature change

Due to the effect of each parameter setting affecting bearing operation a dramatic increase in temperature can be observed, and then each temperature curve converges to a constant value asymptotically. It can be assumed that the temperature change occurs along the function of saturation. The mathematical proof of this is necessary and planned.

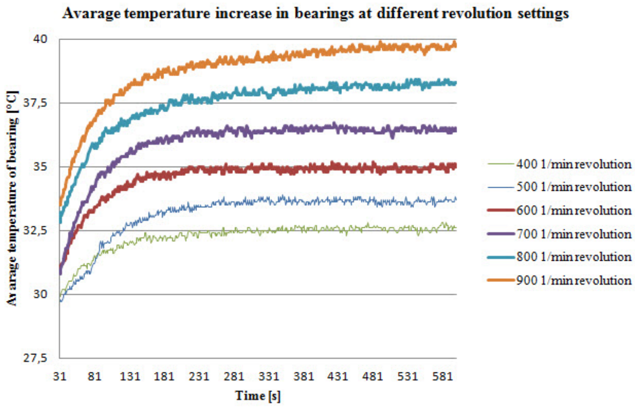

Figure 8*: Bearing temperature change as a function of time*

The connection between temperature change and revolution

The aim of the experiment was to see a correlation how revolution affects the temperature change in bearings with constant load settings (both radial and axial load of 90N) and revolution values increased incrementally (400, 500, 600, 700, 800, 900min-1). The below diagram (Figure 9) shows the average temperature change of the rolling track as a function of the specific revolution. Four different temperature-time ranges were selected. During the measurements the average temperature of the period between 30 s and 600 s was calculated, the maximum temperature was processed similarly. The average and maximum temperature of the last 100-sec period (500 s-600 s) was determined separately. Figure 9 shows that regardless of the measurement time setting, the connection between the revolution and temperature shows a linear relationship. Even in the most different case (AVERAGE 500s-600s) the value of the correlation coefficient R2=0.9939. Since the measured points are located along the line with great statistical certainty, it can be concluded that the temperature-revolution relationship is linear.

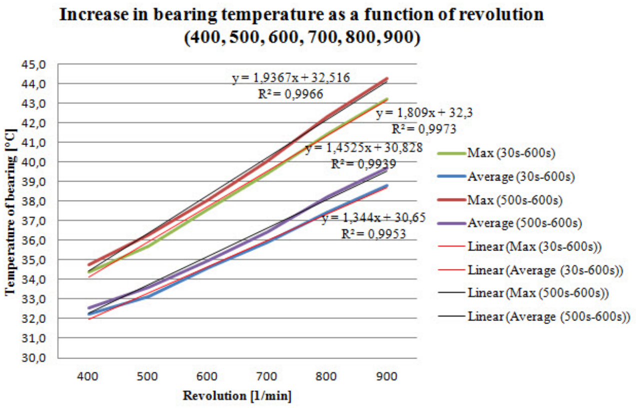

Figure 9: Bearing temperature change as a function of time

Flood tests of non-metallic rolling-element bearings

The aim of the tests is to determine what effect the specific property of plastics of being capable of absorbing fluid in a wet medium and so creating a change in size can have on the geometrical properties of bearings. The tested bearing parameters are the change in the diameter of the inner and outer races, the change in weight and bearing clearances.

Determining the measurement conditions during flood tests

The tests were carried out with two bearing sizes, one bearing was an IGUS BB 6005 with an inner diameter of 25mm, the other one was an IGUS BB 6001 with an inner diameter of 12 mm. The inner and outer races of the bearings are made of polyamide, and the rolling elements (bearing balls) are made of glass. In the flood tests the parameter change of bearings was tested in four process fluids with totally different chemical properties. The four selected process fluids were RO water (pure H_2O), SIÓ 100% “Mosolygós” Apple Juice, household chlorine bleach (alkaline pH 12.5) and one of last year’s successful white wines from GERE Winery, Sauvignon Blanc. Three bearings from both bearing sizes were placed in all the four process fluids, and the parameter change was checked with measurements repeated every 48 hours for 240 hours (10 days).

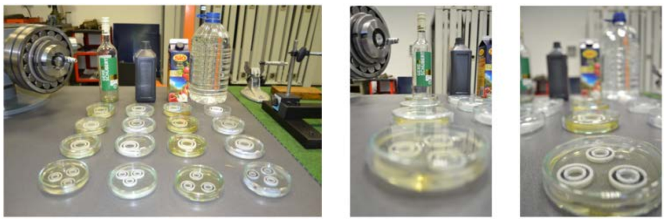

Figure 10: Bearings in different process fluids

The extent and nature of bearing geometry change

It can be observed in all the four properties affecting the operation of bearings, regardless of the process fluid. All of these properties show a clear increase, and when their structure is presumably saturated with the process fluid, the data converge to a constant value asymptotically (Figure 11) (Dr. Sváb János, 1976).

The issue of fitting the axle in the inner race

If we interpret the geometry change as the percentage of the original, measured property (Table 1), the values obtained are not expressive enough. The value of 0.8% increase in the inner race of bearing IGUS 6005, and the 1.25% increase in bearing 6001 cannot be considered outstanding, but this actual increase can affect installation technology to a large extent.

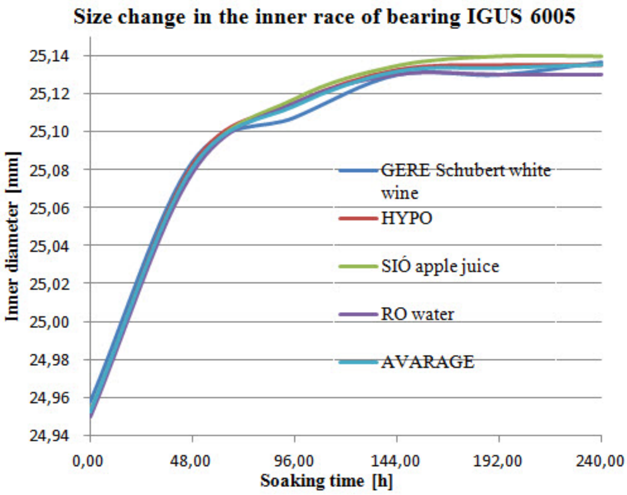

Figure 11: *Bearing temperature change as a function of time*

Table 1: *Extent of change in physical properties*

	Weight	Inner diameter	Outer diameter
IGUS 6001	1.87%	1.25%	0.28%
IGUS 6005	0.74%	0.80%	0.25%

In the case of installing plastic bearings under factory recommendation, the bearings are to be mounted on axles manufactured with h6 tolerance. In this case the manufacturer requires a slight fitting coverage and a slight fitting play for the user of the bearing (yellow area in Table 2). The table below clearly shows that the data of bearing measurements (orange area in Table 2) taken before the flood test show a high level of compliance with the factory recommendation. However, the parameters shown in the red area of the table show outstanding data. After the evaluation of these data it can be understood that after the 240-hour flooding the size of the inner race of the bearings is no longer suitable for axles of h6 tolerance. Therefore the mounting of bearings with proper fitting is not appropriate to axles manufactured with factory recommendation, so an installation technology recommendation must be created for mounting non-metallic rolling-element bearings with plastic outer and inner races. It can be concluded on the basis of the tests that in order to obtain the proper mounting clearances it is necessary to soak polyamide ball bearings to be used in a wet medium for 240 hours in advance, and then in my recommendation if the bearing is mounted on an axle manufactured with z10 tolerance, the proper inner race fitting can be achieved.

Table 2: *Data to support fitting recommendations*

	IGUS 6005 bearing			
	Axle	Bore	Clearance	Nature of connection
Catalogue parameters	25,000	24,958	-0,042	Cover
	25,000	25,042	+0,042	Play
	24,987	24,958	-0,029	Cover
	24,987	25,042	+0,055	Play
Factory (measured) parameters	25,000	24,950	-0,050	Cover
	24,987	24,950	-0,037	Cover
Parameters after soaking with h6 axle tolerance	25,000	25,140	+0,140	Play!!!
	25,000	25,130	+0,130	Play!!!
	24,987	25,140	+0,153	Play!!!
	24,987	25,130	+0,143	Play!!!
Parameters after soaking with z10 axle tolerance	25,172	25,140	-0,032	Cover
	25,172	25,130	-0,042	Cover
	25,088	25,140	+0,052	Play
	25,088	25,130	+0,042	Play

IGUS factory inner race tolerance	25 JS10	+0,042
		-0,042
IGUS factory axle tolerance recommendation	25 h6	0,0
		-0,013
Axle tolerance recommended by us for wet technology	25 z10	+0,172
		0,088

6. Summary

As a result of the research work to date a new research method was created which can assist in examining non-metallic rolling-element bearings in process fluids. A target device was designed and constructed for the created research method which device can also be installed with a climatic cabinet for bearing tests.

During the tests performed so far a conclusion was drawn regarding the changes in physical and geometrical parameters impacting the operation of bearings, due to the effect of process fluids. The main objective of the near future will be the itemized confirmation of the received partial results. In addition to the changes in physical and geometrical parameters due to the effect of process fluids, the relationship between the revolution and the inner temperature of the bearing was determined.

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