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Chapter · November 2022

DOI: 10.1007/978-3-031-21429-5_12

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Selection, Dimensioning and Maintenance of Roller Bearings

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Abstract. Knowledge of issues related to the selection and dimensioning of roller bearings is extremely important in the work of engineers and designers, and from the point of view of the availability of available literature in this area, in general, is not at the level it should be. The main goal of this paper is to present the current procedures for the selection of roller bearings, to point out the most important factors to consider when choosing standard types of roller bearings, based on which their further selection can be significantly facilitated. Each type of bearing shows characteristic features, based on its design, which more or less make, or more or less correspond to the given conditions of application. Current methods and procedures for diagnosing the condition and maintenance of roller bearings as well as trends in their development will be presented. The paper deals with topics that show historical development of roller bearings, basic characteristics and types of roller bearings, selection and dimensioning of bearings, a diagnostic bearing condition inspection as a maintenance procedure is presented and described.

Keywords: Roller bearings · Selection and dimensioning of bearings · Condition diagnostic · Maintenance

1 Introduction—History of Roller Bearings

Bearings as elementary parts of every machine have a significant role in the functioning of machines, its maintenance and reliability, because they have the task of applying the load from the power transmission [1]. The reliability of the machine depends on the reliability of each of its individual parts, especially the moving components and elements, including roller bearings [2]. Bearings are standard assemblies and standards prescribed way of marking them [3]. The bearing designation consists of the basic markings that are fully stated in the technical documentation at the time of purchase and the supplementary markings that are listed as needed.

Little is known about the origin of this machine element, which is essential today for our daily social and professional life. Rolling as a physical phenomenon is almost as old

D. Blažević et al. (Eds.): OTO 2022, LNNS 592, pp. 133–142, 2023.
https://doi.org/10.1007/978-3-031-21429-5_12

as our civilization, and the first serious application is related to the period of construction of the first larger buildings, i.e. for the moment when a man decided to move those burdens that he himself could not carry. The first described mechanisms date from the 3rd century BC. At that time, various tools were known as simple machines, such as: wheel, pulley, winch, mill, screw, auger, gear, catapult, etc. Greek mathematicians and physicists of that time, such as Aristotle, Archimedes, Heron and others, are responsible for the analysis and realization of these devices [4].

The further development of the theory of mechanisms and machines went side by side with the development of society. The stagnation of the progress of scientific thought was evident from the beginning of the new era until almost the 14th century. There were no significant discoveries or great developments in science during that period. The improvement and development of all mechanisms and machines is closely related to the development of roller bearings. Today, almost no machine can be imagined without a roller bearing as the most vital work piece, starting with those light household machines all the way to heavy industrial machines.

We are witnessing from year to year that the same dimensions of certain types of roller bearings permanently reduce the weight of bearings, with constant improvements in terms of self-maintenance, higher load capacity, reduced vibration and noise, longer service life, etc. [5]. These and other similar reasons are very important from the aspect of further improvements in the process of designing roller bearings, therefore it is extremely important for designers to get acquainted with the development roller bearings throughout history [6] (Figs. 1 and 2).

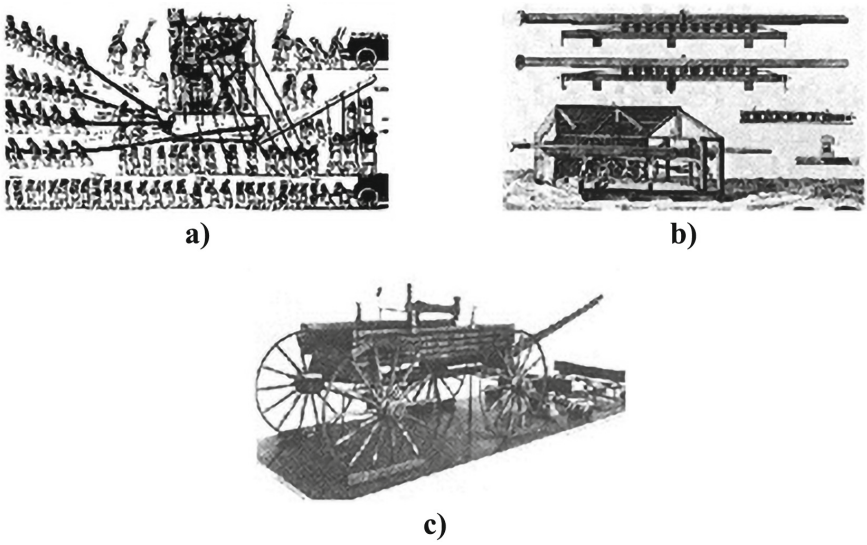
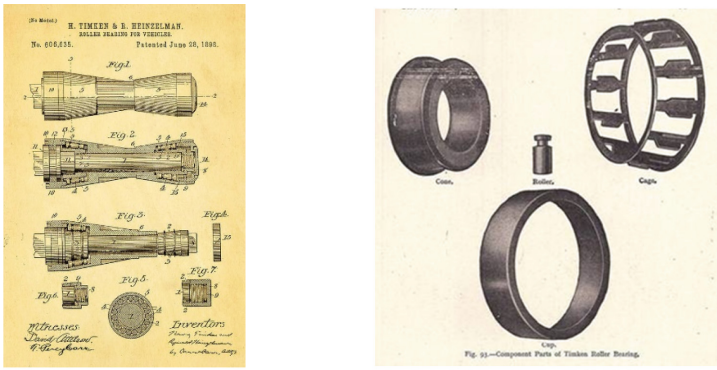


Fig. 1. Some of the earliest examples of rolling applications **a** the first example of the application of rolling (Assyria around 700 BC), **b** log for breaking (Greek design 330 BC) and **c** carriages similar in design to the "CART II" carriages (used between 300 and 100 BC) [7].



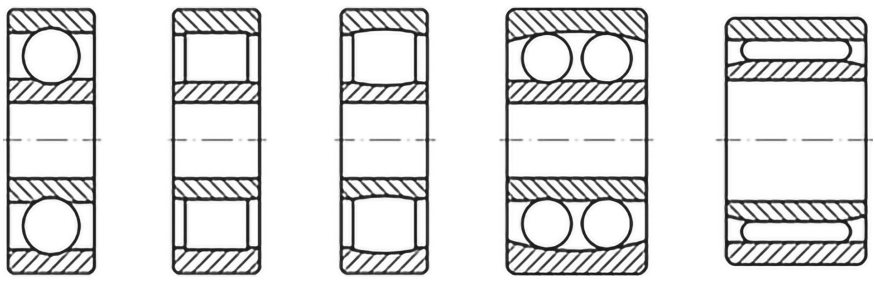
a) b)

Fig. 2. **a** Original drawing of the first patent of a tapered roller bearing, no. 606,635, from year 1898 [8] and **b** a drawing of a Timken tapered roller bearing (with cut rollers) [7].

2 Basic Characteristics and Types of Roller Bearings

Rolling bearings are used to provide conditions for the relative movement of rotating parts [9] and to transfer loads from moving to stationary parts or vice versa. In addition to sufficient bearing capacity, the bearing should provide the required accuracy of the position of the axis of the rotating parts in the state of rotation, high enough speed of rotation and to allow possible deviation of the position of the axis of rotation which may be due to deviations in production or elastic deformations. The extremely complex function of the bearings has imposed the need for the application of special manufacturing technologies and they are made by specialized manufacturers. A wide range of construction solutions has also been developed [10].

Shapes and dimensions of roller bearings, tolerances of dimensions and shapes, material, quality, method of installation and control are prescribed by standards. The bearings are delivered assembled and ready for installation, so that only the appropriate bearing is selected during construction (Fig. 3).



a) **b)** **c)** **d)** **e)**

Fig. 3. Rolling bearings: **a** ball bearing, **b** roller bearing, **c** barrel bearing, **d** self-adjusting double row ball bearing and **e** needle bearing [11].

The division of roller bearings can be done in several different ways:

- According to the direction of force, they are divided into: radial (transmitting force in the radial direction); axial (transmitting force in the axial direction) and radial-axial (transmitting force in the radial and axial directions) [12].
- Depending on the mounting method, they can be: fixed, which transmit radial and axial force in one or both directions, and free, which transmit only radial force and allow axial movement [13].
- According to the shape of the rolling elements, they are divided into: spherical and cylindrical (cylindrical, depending on the shape of the rolling elements, they can be cylindrical-cylindrical, conical-cylindrical, barrel-shaped and needle-shaped).
- According to the number of rows of rolling elements, the bearings can be: single-row and multi-row [7].
- Depending on whether they are disassembled or not (during installation), they can be: detachable and non-detachable.
- According to the ability to adapt to the deformation of the shaft in the support are divided into: rigid (non-adjustable) and articulated (adjustable).

3 Selection and Dimensioning of Bearings

The choice of bearing is conditioned by its application, i.e., operational characteristics and requirements. The choice of roller bearings can be made according to the load spectrum for a modified service life, where the probability of destruction can be chosen arbitrarily and where the operating conditions are taken into account.

The question is always present: What type of bearing to use? It is necessary to choose quality bearings adapted to the working conditions in which there will be no damage before the projected time of use, because only such a bearing will justify the funds invested in it and in the equipment.

When dimensioning bearings, it is necessary to set goals related to long service life, high safety and economy. In order to meet these goals, the designer needs to know the conditions in which the bearing works and the requirements it needs to meet. Environment, such as shaft, housing, fastening parts, sealing, lubrication, therefore, everything that makes the bearing suitable for the given application conditions [14].

When constructing shaft bearings, mechanisms and machines, the most relevant exploitation characteristic on the basis of which the selection of roller bearings is made is bearing capacity. One of the most important factors influencing the load distribution on the rolling elements, and thus on the bearing capacity, is the internal radial clearance.

The dimensioning flow should take place in a certain order. We start from the most precise determination of all in influential factors. The type, layout and size of the bearing are then chosen with many alternatives in mind. The following is a selection of specific bearings (with their markings, dimensions, tolerances, clearance, type of cage, etc.) for connection parts (fitting, fastening, sealing, etc.) and lubrication. When dimensioning the bearings, it is necessary to take into account the conditions of assembly and disassembly of the bearings.

When dimensioning bearings, it is primarily necessary to know the influences [7]:

- Machinery, mechanisms or place of bearings,
- Working conditions (forces, speed of rotation, installation space, temperature, conditions environment, shaft position, stiffness of elements, etc.),
- Various requirements (service life, accuracy, noise, friction, operating temperature, lubrication, maintenance, assembly and disassembly, etc.) and
- Commercial benefits (cost limits, economic justification, quantities, etc.).

All of the impacts need to be familiarized in detail before approaching bearing sizing. Sizing of bearings consists of defining the following phases:

- Choice of bearing type,
- Choice of bed layout,
- Determination of bearing size (service life and static safety),
- Determination of other bearing parameters,
- Determination of other parts in assembly,
- Choice of lubrication and maintenance methods and
- Determining the method of assembly and disassembly.

4 Lubrication and Maintenance of Bearings

In addition to the inner ring, outer ring, roller elements and cage, each roller bearing also has a fifth element—lubricant. Unfortunately, in practice, the lubricant is not given much attention. This is best shown by the statistics that almost 50% of all damage to the bearings comes from inadequate lubrication.

The service life of roller bearings is significantly reduced if the thickness of the oil film is not sufficient to protect the metal-to-metal contact [15]. One of the ways to overcome this is certainly the selection and use of appropriate lubricants or additives that eliminate high temperatures caused by local contacts and sealants that prevent the entry of impurities. The use of these additives means an increase in the wear of the oil film at the points of contact, the end result of which is lower contact pressure and an increase in the lifespan of the bearings [13].

Long-term practice has shown that every third roller bearing fails due to poor lubrication, which certainly raises the question of justification for the use and improvement of new technologies in production and procedures in calculating tribological parameters for roller bearings. From the aspect of improving the lubrication of roller bearings, the emphasis is increasingly placed on constant increases in the performance of materials and lubricants [16].

The general opinion is that the performance of today's bearings is significantly higher than those obtained on the basis of the nominal age calculation. The reason for this should be sought in the current trends that are present in the development of bearings. Bearing development activities can be related to:

- Research and improvements in the field of materials,
- Improvement of construction and production technology,
- Clear definition of bearing operating parameters,

- Environmental impact analysis and
- Bearing sealing efficiency.

Improvements made in the field of roller bearings have reflected their increasing reliability and longer service life. However, further progress in the development of roller bearings is limited by tribological barriers, so current research focuses on solving tribological problems, primarily on the application of EHD lubrication theory (macro and micro) clearer definitions of surface fatigue causes, and analysis of the impact of working conditions and environment on roller bearing damage.

The following lubricants are used to lubricate roller bearings:

- Fats (oils + thickeners) in 90%,
- Oils in 9% and
- Other lubricants up to 1% (graffiti MoS_2, sliding varnishes, silver, etc.) (Fig. 4).

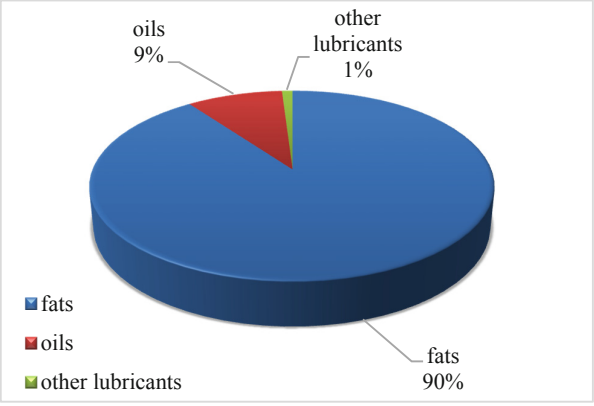


Fig. 4. Percentage display of used lubricants for lubrication of roller bearings [7].

The application of modern methods and procedures in the maintenance of roller bearings, multifunctional solutions for sealing and lubrication, has certainly paved the way for safer and more efficient operation of bearings as prevailing in industrial production. Further operation and maintenance of bearings should primarily indicate the reduction of damage to roller bearings by introducing new seals and lubricants in operation or increasing their lifespan.

Based on the experience gained so far, it can be freely concluded that the service life of roller bearings is unpredictable. The possibility of failure of this element is very high. Analyzes show that possible deviations range up to 20 times in relation to the theoretical service life. However, with the right choice of bearings, adequate operation and maintenance, they can only move in a positive direction.

5 Diagnostic Inspection of Bearing Condition

The diagnostic inspection of the bearing condition will be shown on the example of monitoring the operating conditions of the annular ball bearing 6212 on the centrifugal pumps using the software program "Lubmaster". Shock analyzer pulse A2011 every three months the condition of the bearing was monitored. Measurement results, such as bearing temperature and other required lubrication data entered were used for evaluation modified nominal bearing life. In the program "Lubmaster" for estimating the lifetime using the "Life time graph", based on the calculated value of the kappa factor (κ), the factor *a23* was shown for materials and lubricants, which was necessary for calculation modified nominal bearing life in hours. In Figs. 5, 6 and 7 is given representation of the modified nominative age L*10ah* and other sizes. In the first measurement for bearing temperature of 82 °C, the modified nominal age was 24.000 h, in the second measurement for a bearing temperature of 84 °C, the modified nominal age was 22.000 h and in the third measurement for the bearing temperature of 92 °C, the modified nominal age was 16.000h.

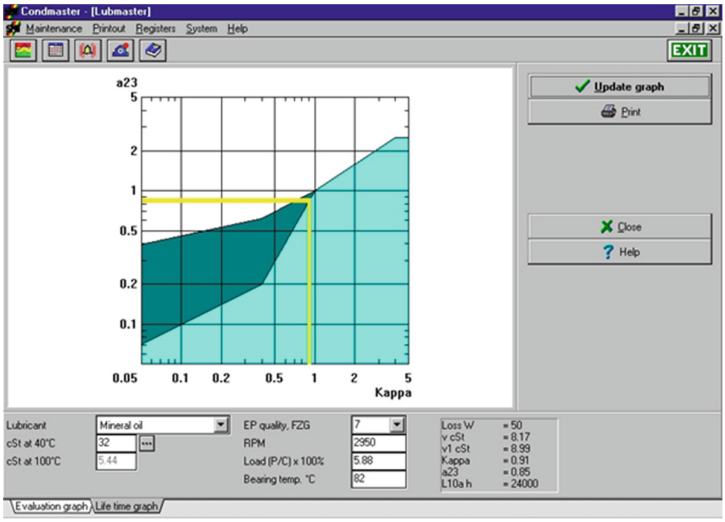


Fig. 5. Modified nominal life values on bearing 6212—first measurement.

The input values that are entered into the software when estimating the service life of the bearing are:

- Lubricant—the type of lubricant is selected from the menu: mineral oil, synthetic oil and polyglycol,
- cSt at 40 °C—viscosity of lubricant in cent stocks at 40 °C,
- cSt at 100 °C—viscosity of lubricant in cent stocks at 100 °C,
- EP qual FZG—(FZG) numbers express the quality of the high-pressure additive in the lubricant, (for oils without additives the FZG = 7) and
- Load ratio P/S × 100—percentage amount of load capacity.

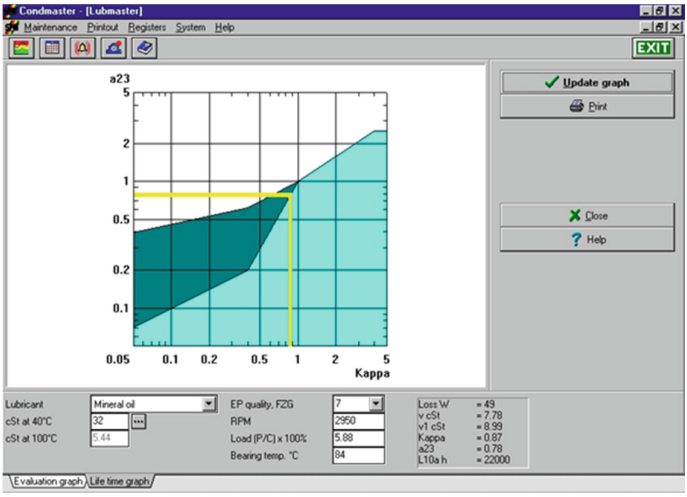


Fig. 6. Modified nominal life values on bearing 6212—second measurement.

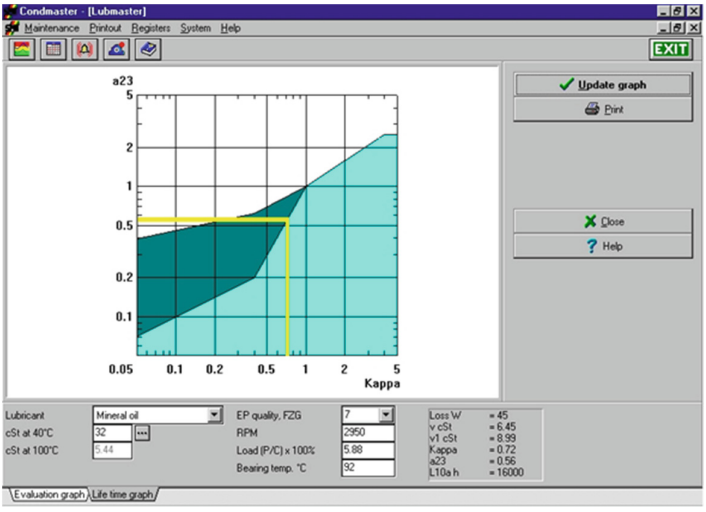


Fig. 7. Modified nominal life values on bearing 6212—third measurement.

The output values obtained after data processing were:

- Bearing temp °C—bearing temperature, ranging from (0–200) °C,
- Loos—friction loss, in relation to bearing type, lubricant load and viscosity (W),
- ν—working viscosity of the lubricant (kinematic viscosity), depends on the bearing temperature, can be obtained from the tables of the lubricant manufacturer (cSt),
- ν—viscosity required to create an oil film, allowing prevention of excessive wear (cSt),

- kappa—a factor that describes the oil film (-), in the literature is often denotes as a factor κ,
- a_{23} durability factor (-) and
- L_{10ah}—modified nominal bearing life (h), (max. 900.000 h).

6 Conclusion

Rolling bearings are unique machine elements, which have an almost paradoxical combination of unity and inexhaustible possibilities for further improvements. Seemingly simple construction, which consists of only four elements, roller bearings in the micro domain open a huge space that extends through the entire engineering disciplines. It is on this fact that large bearing manufacturers build their technological excellence.

The process of developing new technologies in the field of design and production of roller bearings today is a very inspiring research task. This is most pronounced primarily in design, where good financial effects and great time savings can be achieved. We are witnesses that for the same dimensions of certain types of roller bearings from year to year, the mass of bearings is permanently reduced, with constant improvements in terms of self-maintenance, higher load capacity, reduced vibration and noise, longer service life, etc.

The application of any method for diagnostic analysis of bearing condition, indicates better information about the condition of roller bearings and other parts on technical systems, which allows us to raise much greater availability and functionality of technical systems. New methods and techniques in the field of technical diagnostics allow us to better plan, reduce overtime, significantly increase the time between two failures, and knowing the condition of bearings on technical systems allows us to increase profits.

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