ACTA TECHNICA CORVINIENSIS
– Bulletin of Engineering
Tome X [2017]
Fascicule 2 [April – June]
ISSN: 2067 – 3809

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CALCULATION OF THE BEARING MODIFIED RATING LIFE DURING NEW BEARING DESIGN

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Abstract: Bearings, as a mechanical elements that allow relative movement of rotating parts while transferring loads between them, are primary in the most demanding sectors of machine industry, as automotive and aerospace industry, and they are required to have extremely high level of accuracy of manufacturing and meet the requirements prescribed by international standards. Producers specialized in the production of highly demanding types of bearings must prove eligibility criteria defined in ISO 281:2007 and ISO/TS 16281/2008 specification. This paper deals with the bearing testing results by manufacturer and research of the basic and modified rating life of bearings, the winning of new types of bearings, in accordance with the relevant specifications.
Keywords: bearings, modified reference rating life, testing

INTRODUCTION

It is well known the role of bearings in the engineering industry, as well as elements for rotary motion, which are represented in almost all types of machines where rotation is the basic movement of the craft. Primarily used for supporting the shaft, thereby allowing rotation of the sleeve relative to the fixed support, while the transfer of appropriate load. Of course, the application is wider at the junctions with straight and helical motion, for example threaded couple. Manufacture of bearings, especially rolling, belongs to the standard way of mass production, defined by following features of standard bearings, which can be found in any literature related to bearings or marketing material of producers, in the case of standard types of bearings.

However, the production of special-purpose bearings or bearings of high accuracy and hybrid types of bearings, which are primarily designed for the automotive or aerospace industry is a particular challenge for manufacturers. Therefore, now there is a relatively small bearing manufacturers with increase accuracy in terms of ex Yugoslavia and beyond, who are engaged in this issue and it is very difficult to achieve a higher level of knowledge and experience that is applicable in conquering new types of bearings, which refers to, for example a reduced clearance in bearings, tolerance class 4 or resistance to high temperatures.

Original car or aircraft manufacturers forming separate companies for production bearings exclusively for their needs, on a world scale, and their experience and knowledge are hard to reach for small bearings producers or companies engaged in maintenance, for example maintenance aircraft or aircraft engines. Moreover, in such cases, it is evident the problem of changes in the application of certain types of bearings, when the original manufacturer delivered only a notification (notice) about change to company for maintenance or overhaul, without adequate explanation concerning the reasons for the changes, especially if those relating to the bearing capacity (load) or his rating time.

This paper presents the results of research in the process of conquering new types of bearings for use in the aerospace industry, conditioned by international standards for bearing testing BS ISO 281:2007, Rolling bearings- Dynamic load ratings and rating life and DD ISO/TS 16281:2008, Rolling bearings - Methods for calculating the modified reference rating life for universally loaded bearings.

SPECIFICATION FOR CALCULATION RATING LIFE OF ROLLING BEARINGS

The basic specification regarding rolling bearing is ISO 281:2007, which specifies methods of calculating the basic dynamic load rating of rolling bearings within the size ranges shown in the relevant ISO publications, manufactured from contemporary, commonly used, high quality hardened bearing steel, in accordance with good manufacturing practice and basically of conventional design in regard of the shape of rolling contact surfaces.

This documents also specifies methods of calculating the basic rating life, which is the life associated with 90% reliability, with commonly used high quality material, good manufacturing quality and conventional operating conditions. In addition, it specifies methods of calculating the modified rating life, in which various reliabilities, lubrication conditions, contaminated lubricant and fatigue load of the bearing are taken into account [1].

The basic rating life is given by the life equation:

$$L_h = \left(C_r / P_r\right)^{\alpha} \quad (1)$$

» C_r is basic dynamic load rating
» P_r is dynamic equivalent load
» α - can be 3 or 10/3, depend on bearing type

Detailed calculation is described in ISO 281: 2007, depending on bearing type and and bearing combination (arrangement).

For many years the use of the basic rating life L10 as a criterion of bearing performance has proved satisfactory. However, for many applications it has become desirable to calculate the life for a different level of reliability and/or for a more accurate life calculation under specified lubrication and contamination conditions. With modern high quality bearing steel, it has been found that, under favorable operating conditions and below Hertzian rolling element contact stress, very long bearing lives, compared with the L10 life, can be obtained if the fatigue limit of the bearing steel is not exceeded On the other hand, bearing lives shorter than the L10 can be obtained under unfavorable operating conditions.

A system approach to the fatigue life calculation has been used in this specification and this paper. That means, the influence on the life of the system due to a variation and interaction of interdependent factors is considered by referring all influence to the additional stress they give rise to in the rolling element contacts and under the contact regions [1].

A life modification factor, a ISO is introduced, based on a system approach of life calculation, together with modification factor a1, in this specification. These factors are applied in the modified rating life equation:

$$L_{nm} = a_1\, a_{ISO}\, L_{10} \quad (2)$$

These factors are described in the specification in details. This document does not cover the influence of wear, corrosion and electrical erosion on bearing life.

ISO/TS 16281:2008 is specification which describes methods for calculating the modified reference rating life for universally loaded bearings. This specification taking into consideration lubrication, contamination and fatigue load limit of bearing material, as well as tilting of misalignment, operating clearance of the bearing and internal load distribution on rolling elements. The calculation method provided in this specification covers influencing parameters additional to those described in ISO 281.

It is very important to mention here: this TS (technical specification) is primarily intended to be used for computer programs and together with ISO 281 covers the information needed for life calculation. For accurate life calculation under the operating conditions which has been specified in this specification, it is recommended that either this TS or advanced computer calculation provided by bearing manufacturers, for determining the dynamic equivalent reference load under different loading conditions, to be used [2].

A system approach of the fatigue life calculation is therefore appropriate, as long as the influence on the life of the system from variation and interaction of interdependent factor will be considered. For example, the life modification factor also can be expressed as a function of σ_u/σ, the fatigue stress limit divided by the real stress with as many influencing factors as possible considered.

$$a_{ISO} = f\left(\sigma_u / \sigma\right) \quad (3)$$

But, this ratio can then (in accordance with ISO 76) be sufficiently approximated by the ratio C_u/P, fatigue load limit divided by dynamic equivalent load and the life modification factor can be expressed as

$$a_{ISO} = f\left(C_u / P\right) \quad (4)$$

In the calculation of C_u the following influences have to be considered:
- The type, size and internal geometry of the bearing,
- The profile of rolling elements and raceway
- The manufacturing quality
- The fatigue limit of raceway material

That means, qualified bearing manufacturers can use both of these specifications, together with chosen computer program (as MESYS) for calculating bearing life, under specific testing (load) conditions, defined and provided by manufacturer.

Also, modern technology makes possible to determine a_{ISO} by combining computer supported theory with empirical test and practice experience.

Besides bearing type, fatigue load and bearing load, the factor a_{ISO} considers influence of:

- Lubrication (type of lubrication, viscosity, bearing speed, bearing size, additives)
- Environment (contamination level, seals)
- Contaminant particles (hardness and particle size in relation to bearing size, lubrication method, filtration)
- Mounting (cleanliness during mounting)

That means, modification factor a_{ISO} can be derived from the following equation:

$$a_{ISO} = f\left(e_c c_u / P, \kappa\right) \tag{5}$$

e_c is contamination factor , κ is viscosity ratio

Simplifying theory regarding rating bearing life which is commonly used for describing and calculating L_{10} is not enough for bearing manufacturer and it can provide wrong calculating results, during first step of bearing design and adopting.

TECHNICAL ACCEPTANCE CONDITIONS FOR TESTING DEEP GROOVE BALL BEARING WITH SOLID BRASS CAGE

In this paper, production and testing of Rolling bearings signed with PLC 04-200, single-row ball bearing with massive brass cage, has been used as a main example for calculating rating life. Bearings provide rotation fit of parts of engine based of principle of rolling friction inside the bearings.

Basic characteristics of material used for bearing production are remelted quality bearing steel with designation 100Cr6 in accordance with ISO 683-17. Technical parameters of cage are not important for this paper.

Table 1. Hardness of components and heat stabilization, load rating and working speed of bearings

Bearing designation	Ring hardness [HRc]	Rolling elements hardness [HRc]	Heat stabilization	Load rating		Working speed RPM [min^{-1}]
				dynamical C_r [kN] ISO281	statical C_{or} [kN] ISO 76	
PLC 04-200	61÷65	61÷65	n/a	9,04	5,53	4 000

n/a-bearing can be used up to 120°C operation environment

Main bearing dimensions and tolerances are part of construction drawing, created by customer (aviation industry). Main parameters of assembled bearing are part of customer requirements, based on specific usage of bearings (specific working conditions and function).

Table 2. Testing parameters for test certificate

Bearing designation	dimensions	Radial play [mm]	Axial Play [mm]	Acceptable vibration	Residual magnetism
PLC 04-200	Δd_{mp}, ΔD_{mp}	Yes	Yes	Yes	Yes

Predominant test is testing of bearings in engine. Range of the tests is prescribed by a costumer. Testing of bearings on testing device of producer are performed based on quality management system testing plan in accordance to customer's order.

Validation tests for standard test of achieving 100% basic dynamical capacity (basic dynamical load rating C based from ISO 281) for each type are provided by manufacturer in range 4-8 pieces selected by a costumer from first batch.

Medium for vibration testing was FAMKORTIL 235 viscosity 40 mm2/sec on 40°C.

TESTING FACILITY

The testing was performed according to bearing test regulations for the manufacturer company, in own test facility. The purpose of the test performed is to verify the function of the bearing design using the test for basic dynamic load capacity (BDLC) of bearings in the manufacturer testing facility.

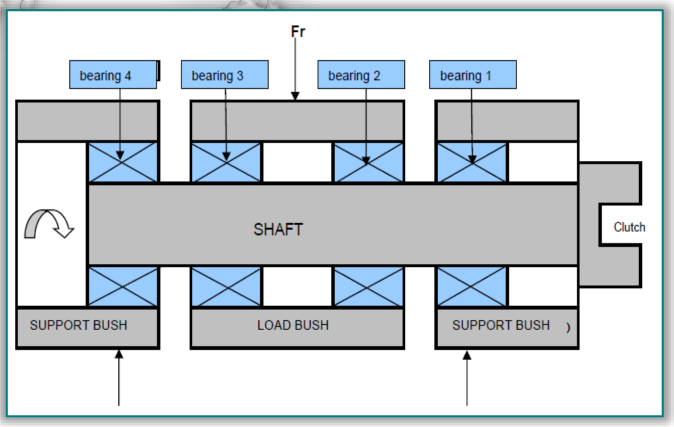

Figure 1. Testing facility station scheme

Table 3. Testing parameters

Parameter	Indication	Value	Unit
Radial Load	F_r	1700	N
Axial Load	F_a	0	N
Equivalent Load	P_r	3,4	bar
Testing ratio		5,3	
Boundary rotational frequency	C_r/F_r	4000	min^{-1}
Test speed	n_k	4800	min^{-1}
Test speed ratio	n_{sk}	0,8	
Calculated resistance %	L_h	522,1	hrs

Figure 2. Testing facility station

To perform the official test under manufacturer Operating procedure, a testing batch of 25 pieces of identical bearings is required, necessary to verify the quality of bearings collected in random selection from production batch. On trial, pcs of bearings PLC 04-200 were delivered by the manufacturer, it is thus a nonstandard testing within the operating procedure and the above mentioned, the test was performed under manufacturer's requirements and decisions stated in the test specification. The test was performed in two testing station (one test station picture 2.) of testing facility in the operating mode of the working week of continues operation , i.e. 24 hours a day, from the beginning of the working week to the end of the working week. On days off, the testing facility was not in operation due to insufficient protection system of its operation.

BEARING TESTING

During the bearing testing, the previously described test bench created by the manufacturer, it was established way of determining the service life of the bearing, by defining C_s% - dynamic load capacity, displayed in%. C_s represents the ratio of dynamic load capacity achieved during the test (tests on the test bench) and the catalogue value of the dynamic load capacity for the type of bearing:

$$C_{s\,\%} = \left(C_S / C_R\right)\cdot 100\% \qquad (6)$$

When the first group of test bearings of the same type, under defined conditions of testing, 8 bearing from each type, 4 bearing on each shaft (picture 1, 2), which are defined and adopted by the manufacturer, is being tested, the method used to calculate the lifetime for terms bearings defined in ISO 281: 2007 specification.

Thus obtained values are compared with the catalogue values for a given type of bearing, and the calculated value of dynamic load capacity C_s.

In this way, the calculated values do not reach 100% capacity, which according to the manufacturer's recommendations are not permitted in the conquest of new types of bearings (Table 4).

Table 4. Load capacity test

P/N	C_r (Kn)	Calculated L_{10} (hrs)	RPM	Achieved C_r
PLC 04-200	10,12	732,5	4000	91,2

Then team (manufacturer and customer participants) analyzed the possible reasons for the appearance of non-conforming bearings, according to the defined acceptance criteria (min. 100% C_s).

Non-conforming bearings were analyzed in two ways:

- Bearing side (material, heat treatment, noise level, produced geometrical parameters)
- Test side (proper loads, RPM, assembly, oil quality)

Also, detailed results analysis are going deeply under bearing side: sample bearing analysis, input control protocol, heat treatment protocol. After that analysis, using theoretical and experimental knowledge, possible failure causes are:

- initial micro - structure before heat treatment
- hardness over 65 HRc – own heat treatment
- failure of inner ring-wrong assembly on the test shaft

Results of analysis gave next results: Input material (annealing state) –reanalysis in manufacturer place gave negative result, no places found with larger cementite particles in original raw material sample. Regarding to heat treatment – hardness was measured under raceway and it increased by deformation reinforcement. Analysis of test side, especially proper loads (load equipment revision), RPM, assembly (bearing assembly plan) and oil quality (check) gave next feedback: Wrong mode assembly on the shaft was rejected. Primary cause of this is rotation connected with pitting on inner ring, which causes rotation move of inner ring and failure on the bore surface.

In the and of previous analysis, results had to give answer on question: Why bearing did not reach 100% capacity, where is the problem? The main answer was: load rating calculation and test calculation.

P/N	Ø IR	Ø OR	R
PLC 04-200	52-52,6%	52-52,6%	3,12 +0,04

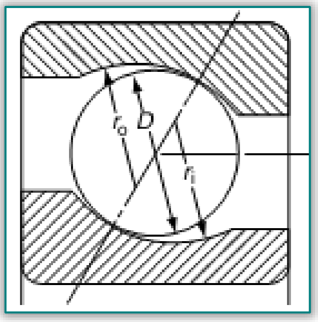

Figure 3. Geometrical parameters of PLC 04-200

Using available information and specifications relating to the subject of the research, it was found that there is a difference in the preferred mode for calculating dynamic load, between the recommendations from specification ISO 281: 2007, which had previously been used, and specification ISO / TS 16281: 2008. It was found that ISO 281 calculation is valid for nominal values and use for initial calculation.
After recalculation of dynamic load capacity, based on specification ISO/TS 16281, used software MESYS, calculated rating life is given in next tables 5 and 6.

Table 5. Load capacity recalculation

P/N	C_r new (kN)	Calculated L_{10} (hrs)	C_r old (kN)	Calculated L_{10} (hrs) old
PLC 04-200	9,04	522,1	10,12	732,5

Table 6. Test results after recalculation

P/N	C_r new (kN)	Calculated L_{10} (hrs)	Achieved C_r %	Achieved C_r old %
PLC 04-200	9,04	522,1	102,1	91,2

CONCLUSIONS

This paper presents the results of tests in the conquest of new types of bearings for industry (aviation use). The characteristics of testing facility, the basic parameters of the tests and the method of bearing testing, according to the manufacturer's recommendations and in accordance with applicable ISO specifications are the basis of this paper.
The main emphasis is put on research of the causes of failing recommended dynamic load bearing capacity (Cs%), while testing bearings on test bench, all in accordance with the requirements of ISO 281: 2007 specification. Research of potential cause of the fault (nonconformity) has been made by the team, in collaboration of manufacturer and the customer participants, and causes that were used for analysis are shown.
At the end of the set of testings that is required to use the technical specification ISO/TS 16281: 2008, which is supplement of the ISO 281: 2007 and gives recommendations for the calculation of the modified rating life, though use of appropriate software package. All possible known causes of nonconforming due to material, heat treatment and test condition were investigated and rejected.
Finally, team found that difference between standard ISO 281 calculation and adjusted calculation according to ISO/TR 1281 and ISO/TS 16281 gives approx 10% difference for dynamic load rating. Test results after recalculation shows that load capacity of the nonconforming bearings is fulfilled.
These results show that all applicable specifications and technical design specifications, which are related to the production and testing bearing in demanding industries that differ from the standard use, due to the specific conditions of use and function, have to be strictly respected. Also, the causes of the possible occurrence of nonconforming bearing need to be investigated from different aspects in detail, using the available experience and knowledge (usage of best practice), within teamwork. It is very important for the specific bearing usage, especially in aircraft industry.

Note

This paper is based on the paper presented at The 3rd International Scientific Conference on Mechanical Engineering Technologies and Applications (COMETa 2016), organized by the Faculty of Mechanical Engineering, University of East Sarajevo, in Jahorina, Republic of Srpska, BOSNIA & HERZEGOVINA, December 7–9, 2016.

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ISSN:2067-3809