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MAINTENANCE IMPROVEMENT OF BALL BEARINGS FOR INDUSTRIAL APPLICATIONS

Mohammad Riahi & M. Ansarifard

Abstract: *In this research, the life expectancy of ball bearings in industrial applications is estimated based on known parameters. The overall mathematical calculation of such behavior is based on the theory of Lundberg and Palmgren. The proposed life estimation equation however lacks certain points to make it qualified as universal. A firm conclusion therefore could not be obtained on the basis of this equation alone, particularly when different operating conditions are involved. One such example is the life of ball bearings while operating in clean lubricant environment, which is approximately up to 20 times longer than the calculated life based on the previously prescribed equations. On the other hand, active life under contaminated lubricants is nearly close to one-tenth of the calculated life originally thought to be correct.*

Keywords: *Life Estimation, Ball bearing Performance, Metal Surface, Bearing Maintenance*

1. Introduction

As ball bearings are inseparable elements of all industries, they are integrated into all machines for transferring rotational energy with minimal loss while guiding rolling movements precisely as designed. Being indispensable to machinery and equipment, ball and roller bearings promote conservation of natural resources.

The main focus of this study was to bring about a promotion in energy conservation and subsequently, preservation of natural resources by enhancing the bearing's service life determination to avoid premature replacement.

A procedure has been aimed in which manufacturing as well as maintenance of machinery sector in addition to the industrial products would be benefactors. The overall procedure includes materials selection, heat treatment, surface optimization, design, life estimation, and special consideration for the environment [1].

Two-level factorial design is a statistical method involving simultaneous adjustment of experimental factors at any two levels categorized as: high and low [2]. This approach known as two-level design approach offers a parallel testing scheme that is by far more efficient than one factor at a time approach. By restricting the tests to only two levels, the number of experiments to be conduct would become minimized.

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Mohammad Riahi, Department of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran, Riahi@iust.ac.ir

M. Ansarifard, Department of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran

2. Enhanced Service Life

2-1. Materials and Heat Treatment

The severity of flaking is usually a determinant in the remaining life of a ball bearing. This is a fatigue phenomenon where a part of the bearing surface peels off in small flakes as a result of repeated stress loads.

Ball bearing life could be prolonged by diagnosing the causes of flaking and subsequently taking necessary preventive actions accordingly. Flaking could be caused as a result of two types of bearing defects. First one is known as internal defects which are direct outcome of nonmetallic inclusions in the bearing material.

The second defect is the external type known as existence of defects in the bearing's raceway caused by dents made via foreign particles in the bearing lubricant.

The first type of flaking could be improved by using more refined steel through reducing nonmetallic inclusions that cause defects. Metals such as Z steel or EP steel fall in this category. This action directly contributes to the life extension of ball bearing (figure 1). Flaking caused by raceway surface defects can be improved by optimizing retained austenite content in the bearing raceway surfaces (TF, HTF, and STF steels). As a result, stress

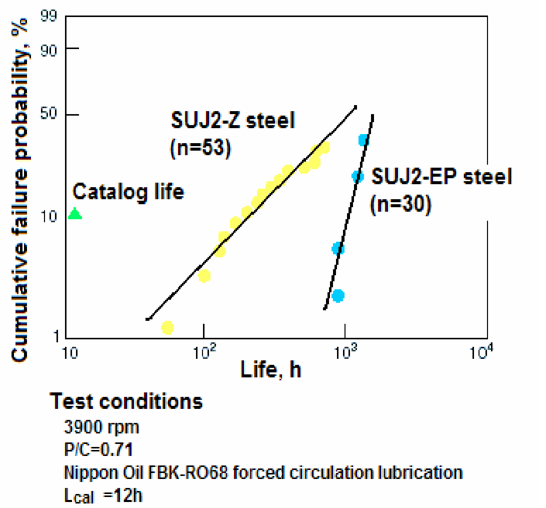

Fig. 1. Rolling Contact Fatigue Life of Deep Groove Ball Bearings (6206) made of SUJ2-EP on Radial Type Test rig.

concentration caused by dent would be reduced enormously (figure2). Bearings manufactured with extra fine and cleaner steel expose a much longer service life [3].

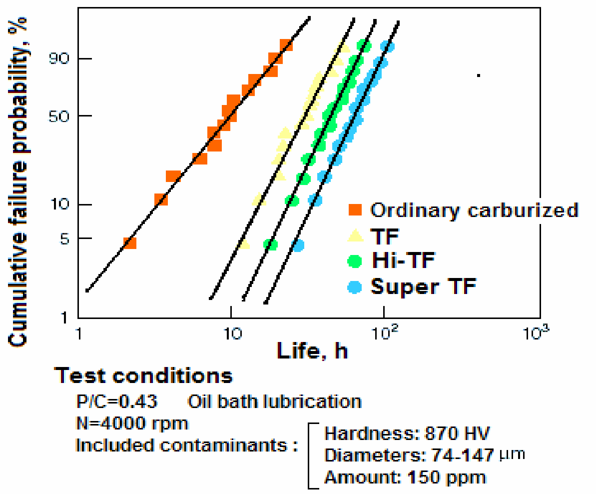

Fig. 2. Rolling Contact Fatigue Life of Tapere Roller Bearings under Contaminated Lubrication.

3. Surface Optimization

The existing surface optimization methods are comprised of physical as well as chemical means. Surface physical properties include characteristics such as: roughness, hardness, modulus of elasticity, hence, surface chemical properties are related to molecular layer interactions. These points are important in surface design to ensure longer bearing life machining processes. A well planned surface geometry provides assurance for optimum film formation while the machining process is used for suitable compressive stress levels and higher resistance to abrasion and excessive wear [4].

4. Design

A longer life for ball bearings could be achieved through improvements made in different stages of production. From design to material selection and from machining to lubrication method, each is capable of contributing to the durability. Dynamic load carrying capacity is perhaps the single most influential on the life of bearings which is determined by the points explained above.

Global standardization has become a vital feature in bearings; therefore, any increase in the dynamic load rating must be achieved exclusively through modification of internal design without any changes in the dimensions. In other words, any increase in the rating of dynamic load translates into design bearings having a maximum number of rolling elements at maximum size.

Theoretically, ball bearings or roller bearings of full-type with no cage have a large load carrying capacity. At the same time, these have a high possibility of seizure due to direct contact among their rolling elements. To avoid this undesired outcome, bearings with a cage assembly have become the most common alternatives. An important key to the design of bearings with a cage and yet an extended life time, is increasing the number of rolling elements and consequently, ensuring optimum cage geometry without reducing its strength [5].

5. Life Prediction Technology

Roller or ball bearings are designed to stand small amount of stress. Consequently, the life expectancy in them is a function of the amount and the type of stress distribution. Weibull statistical distribution is perhaps a suitable means for determining the actual life of the bearings under analysis. Subsequently, the life values of different bearings are arranged statistically according to the weibull distribution and are defined in form of a basic rated life (L_{10}) as a life value with a cumulative failure rate of 10%.

Depending on the work conditions and operating environment, the life span of a roller or ball bearing could fluctuate significantly. As a result, it becomes necessary to use calculations for determining L_{10}. This is in spite of complexity in quantifying the operation's environmental parameters [6]. Load and running speed are the only two operating conditions considered while approximating L_{10} with safety factor set at its highest possible value.

In making a comparison between L_{10} life approximation and actual life, empirically gathered data indicated that based on bearing endurance of tests conducted in ideally lubricated conditions; the actual life is by far greater than the calculated L_{10} life (figure 3). This vivid difference in values is indicative of the existence of fatigue limit load that was considered non-existing previously in the roller's fatigue. On the other hand, most bearings operate in conditions where contaminants exist and contribute to as much as 90% reduced actual bearing life (figure 4).

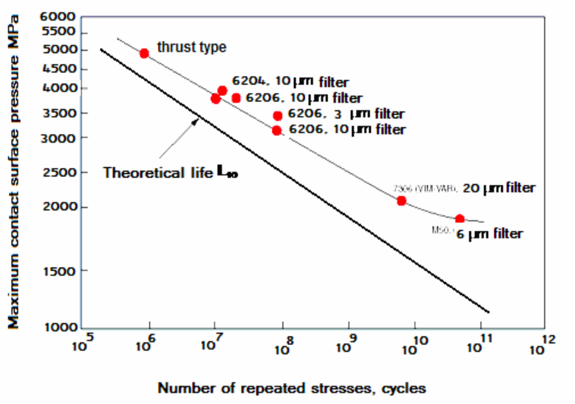

Fig. 3. Summary of Life Test Results under Clean Lubrication

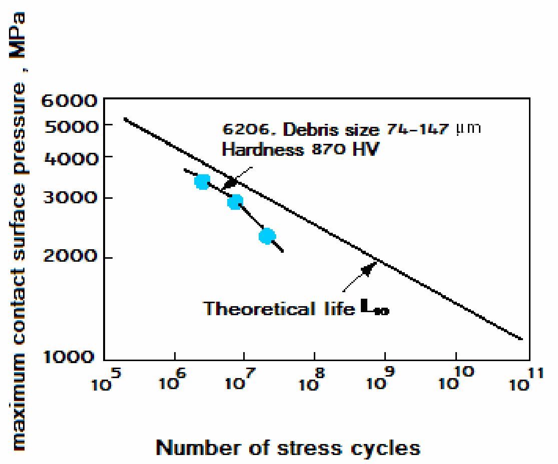

Fig. 4. Test Results under Debris Contaminated Lubrication

The existing test results indicate that bearing life can significantly vary depending on the operating conditions. Also, it shows that the accurate evaluation is in need of considering operating condition factors.

6. Design of Experiments (DOE)

6-1. DOE's Two – Factor Interaction

Generally, when conducting a test for matters such as life estimation of materials, the number of runs is equal to the total number of factors plus one. e.g. 7 factors could be tested in 8 runs. In a typical ball bearing test, three important factors are used for experiment. These factors are:

A. Osculation: two levels of the ratio of the ball radius to the outer ring raceway.

B. Heat treatment of inner ring: two levels

C. Cage design: selection of steel versus a less expensive material

All possible combinations of these factors require 8 experiments. This DOE is symbolized mathematically as 2^3. From 8 runs of experiment, eight point information is gathered. These are: three main effects, three two-factor interactions, one three-factor interaction, in addition to the overall mean. The high values at the upper right edge indicate a previously unknown interaction between osculation and heat. This discovered point was not revealed by prior one-factor at a time experimentations.

The specific design layout for the bearing case is shown in table 1. Columns A, B and C represent the controlled factors. These are laid out according to a standard order that can be obtained from DOE. Each column contains 4 pluses and 4 minuses, with a static power.

Orthogonal test matrices made effect estimation neat and easy. For example, the effect pf factor A is calculated by simply averaging the responses at the plus level and subtracting the average at the minus levels.

$$Effect = Mean\ A^{+} - Mean\ A^{-} \quad (1)$$

Tab. 1. 2^3 Design Matrix, Data and Effects for Bearing Case

Standard Order	A	B	C	AB	AC	BC	ABC	Life (hours)	Log Base 10 Life
1	-1	-1	-1	+1	+1	+1	-1	17	1.23
2	+1	-1	-1	-1	-1	+1	+1	25	1.40
3	-1	+1	-1	-1	+1	-1	+1	26	1.41
4	+1	+1	-1	+1	-1	-1	-1	85	1.93
5	-1	-1	+1	+1	-1	-1	+1	19	1.28
6	+1	-1	+1	-1	+1	-1	-1	21	1.32
7	-1	+1	+1	-1	-1	+1	-1	16	1.20
8	+1	+1	+1	+1	+1	+1	+1	128	2.11
Effect (as is)	45.25	43.25	7.75	40.25	11.75	8.75	14.75		
Effect (log 10)	0.41	0.36	-0.015	0.30	0.66	-0.001	0.13		

6-2. Simple Equation

Prior to making a final recommendation on the new factor levels, it's appropriate to examine its responsiveness. Residual analysis and its capability is a good starting point. Residuals are the difference between actual and the predicted response. Due to the number of variables present in both experimenting process as well as test procedures, it's only natural to expect errors in some runs. An important point to consider is to be certain that the residuals are close to being normal.

The proposed equation for the bearing case based on the predictive model is:

$$Log_{10}\ Bearing\ life = 1.49 + 0.2A + 0.18B + 0.15AB \quad (2)$$

Which by plugging in the recommended setting, the result would be:

$$Log_{10}\ Bearing\ \ life = 1.49 + 0.2(+1) + 0.18(+1) + 0.15(+1) = 2.02 \quad (3)$$

and therefore:

Bearing life = 2.02^{10} =*105 hours* (4)

This finding compares well with the observed results.

6-3. Estimation of the Fatigue Life by Computer

The ball bearing life can also be estimated very close to the actual life by utilizing the available computer software. One common brand of computer software in use for such purposes is Ansys. After modeling the components of bearing such as inner race (model shown in figure 5), its load is in axial as well as radial condition.

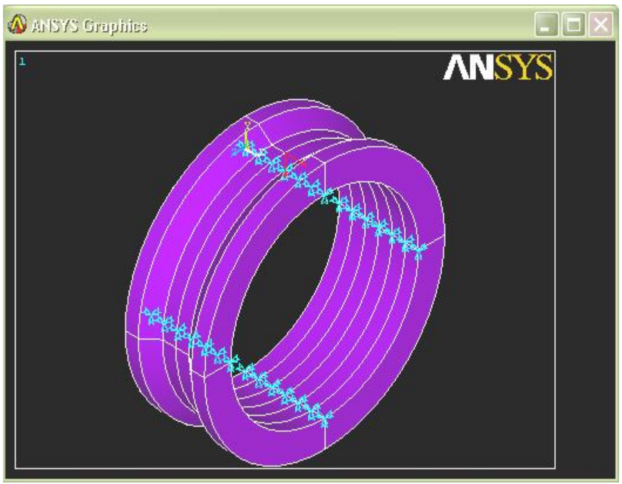

Fig. 5. Axial and Radial Loading

The axial load is fixed for all points. However, the radial load is variable for points in this experiment (209 single row radial deep-grooves). In this experiment, the ball bearing was loaded with 8700 N radial load and 3300 N axial load. By adjusting the contact angle, maximum radial load was measured to be 5100 N and the axial load was 366 N. The analysis of the inner-race part for this condition (figure6), indicated that the maximum stress is 624 Mpa.

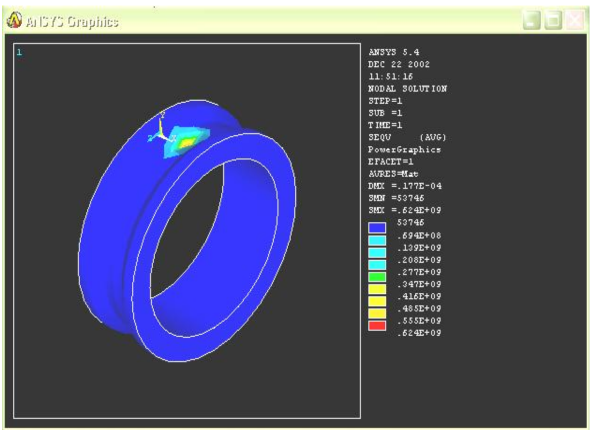

Fig. 6. Stress Analysis for Loading Condition

After exerting values resembling the fatigue conditions as depicted on a typical S-N diagram, the bearing life was measured at 11.16×10^6 revolutions. However, by calculating the ball bearing life in actual condition by using the regular life formula discussed earlier, the estimated life would be 10.8×10^6 revolutions [7].

7. Conclusion

Ball bearings have not undergone much change in appearance; however, their performance has been steadily improved by the progress in design, processing and machining, materials, and lubrication technologies. Smoothly rotating while supporting a load as being the main task of any bearing (roller or ball) in operation, manufactures of bearings have been under constant demand to produce them with longer life, higher speed and more precision. The case study presented on bearing life estimation, illustrates how two – level factorials can be applied to a design process with several variables. Moreover, the conducted experiment showed that one factor (cage design) had fewer effects. Consequently, it could be set at its most economical level. However, other factors are more important as far as design criteria are concerned. The utilized computer software in this investigation, proved handy and reliable for estimating the ball bearing life and reiterating the findings presented.

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