Analysis of Rolling Contact Bearings Test Data by the Bımodal Method

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Abstract

Lieblein J. and Zelen A. conducted a study of the fatigue life of deep groove ball bearings. This study was based on data of 4948 bearings as obtained from 5 companies and 213 test groups. Among these data is a detailed test report #3183, lot 73, consisting of 23 failed bearings. This report states that the Weibull slope of this group is 2.23, meaning that this distribution is mono sloped. These test data were plotted by the author on a bilinear scale plane, of endurance life versus bearing number and proved to be distinctly bi sloped. This basic difference prompted a wide study resulting in several new findings and set the grounds for a new analysis method.

Keywords

Bimodal Fatigue Mechanism, Deep Groove Ball Bearings, Mechanical Mode, Hydraulic Mode, Relative Intensity, Cavitation Erosion

1. Introduction

Rolling contact bearings operate at high stress levels, causing them to have no endurance limit, and having a finite service life. This life is rather dispersed, reaching a ratio of 20:1 between the extreme life values. The problem of finite life under fatigue loads becomes a problem of statistics, or as far as design is concerned, a question of reliability [1].

One of the methods to analyze bearing failures is the Weibull method [2]. The two-parameter Weibull distribution is by far the most widely used distribution function for life data analysis. The Weibull cumulative distribution function (CDF) has an explicit function: $F(t) = F \max\left[1 - \exp-(t/T)\right]$. Slope values from 1.0 to 4.0 imply early wear-out, and characterize many mechanical failure modes, including most bearing failures. The ball bearing test report [3] presents the slope value of 2.23, thus fitting well with the above mentioned Weibull range.

The mono sloped Weibull plot does not diagnose the failures and their origin, requiring a further engineering study. The following study supplies several answers in order to diagnose these failures, and suggests a new method for bearing failure analysis. The new method is based on the bimodal failure concept, which considers both liquid and solid phases in the bearings as active participants in the failure process.

2. Discussion

2.1. Lubricant

The lubricant designated in the test report for bearings #3183 lot 73 is jet oil [3]. Since this information is very limited additional data were compiled from similar present products, covered by MIL-PRF-23699-HTS. As a synthetic lubricant it has an ester base stock and several additives such as: anti-oxidants, metal passivator, defoamant, anti-wear and extreme pressure materials. Synthetic lubricants are known as highly hygroscopic liquids. The additives increase their water absorption. The water content of synthetic lubricants easily reaches levels that were found to have detrimental effect on RC bearing life [4]. Water content as low as 25 ppm has shortened bearing service life in nearly 30%. This effect is explained by the cavitation of water, which has a higher vapor pressure causing it to be more volatile [5]. Since water absorption by jet oil to dangerous levels is unavoidable, it is necessary to incorporate effective dehydration systems for the lubricant, such as Compact Membrane System (CMS) [6].

2.2. Bearings

The bearings studied in this paper are deep-groove ball bearings, as described in **Appendix A**. Designation of the test is #3183, lot 73. The name of the company is not mentioned. Original test data are presented in Table 1, consisting of the endurance life and failed item for each bearing. The test began with 25 bearings. Two units were omitted due to bore failures, leaving a total of 23 units. The test data were potted on linear scales, see Figure 1. The plot divides the plane into three distinct zones:

1) Zone **A**: The no-failure zone reaching 17.88 million revolutions, about 10% of the total test duration.

2) Zone **B**: The steep part of the plot extends to 50.76 million revolutions, about 30% of the total test duration.

3) Zone **C**: The shallow part of the plot extends to 104.76 million revolutions, about 60% of the total test duration.

For each part of the plot the failed items are listed separately, see Table 2. The steep part of the plot contains only balls and inner rings, items that are in contact during operation. This part of the plot contains 56.5% of the tested bearings. The shallow part of the plot contains 43.5% of the bearings and two types of items which are not in contact with moving parts, namely the bore and the disc. These items fail under cavitation erosion which develops in the water-containing

Table 1. Test data of deep groove ball bearings # 3183, lot 73.

Bearing number	Endurance Life Million revs.	Failure type	Notes
16	17.88	Ball	
10	28.92	Ball	
5	33.00	Ball	
19	41.52	Inner ring	
9	42.12	Ball	
11	45.60	Ball	
15	48.48	Ball	
12	51.84	Ball	
20	51.96	Ball	
18	54.12	Inner ring	
13	55.56	Inner ring	
1	67.80	Ball	
2	67.80	I. Bore	Omitted
3	67.80	Bore	Omitted
4	68.64	Ball	
6	68.64	L. Bore	
25	68.88	Disc	
22	84.12	Ball	
17	93.12	Ball	
7	98.64	Inner ring	
23	105.12	Inner ring	
24	105.84	Disc	
21	127.92	Ball	
8	128.04	Outer ring	
14	173.40	Disc	

Table 2. Failed items classification and location.

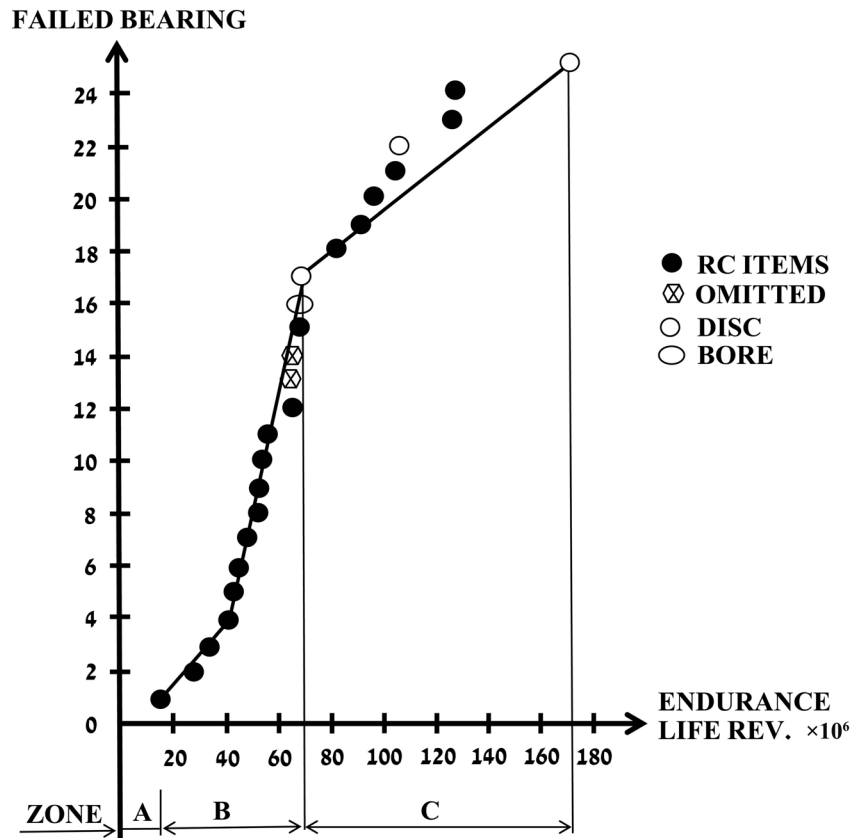| Number	Item	Zone **B**	Zone **C**	Total	Notes
		Steep slope	Shallow slope		
1	Ball	10	3	13	
2	Inner ring	3	2	5	
3	Disc	0	3	3	no contact item
4	Outer ring	0	1	1	
5	Bore	0	1	1	no contact item
	Total	13	10	23	

Figure 1. Test data of deep-groove ball bearıngs #3183, lot 73.

lubricant. As a result of this analysis the plot is considered Bimodal. Both mechanical and hydraulic failure modes prevail throughout the test simultaneously.

In estimating the relative intensity of each failure mode in this test we can apply the number of relevant failed items in each category, namely:

1) The items in-contact for the mechanical mode,

2) The non-contact items for the hydraulic mode.

From **Table 2** we can obtain the following data: In zone **B** there are only in-contact items—13. While in zone **C** there are failed items of both categories—10, and all of the non-contact items—4. These estimates require further confirmation. However, they indicate that the intensity of failure mode M is considerably the larger.

Life span, the ratio between the extreme life values, is 3.84 for zone **B**, 2.53 for zone **C** and 9.7 over all the test. This relative life is nearly half of that stated by SKF as an overall range for RC bearings.

3. Conclusions

3.1. Test Omission

Bearings #2 and #3 (see **Table 1**), were omitted from the test after 67.8 million revolutions due to bore failures. The bore is in no contact with the rotating bearing parts. Therefore, the only way by which it can be damaged is by cavita-

tion erosion of the lubricant. These failures occurred after a rather long exposure of 565 hours to cavitation erosion and can therefore be considered as legitimate failures of mode **H**. These omitted bearings are inconsistent with the approval of bearing #6, which had bore failure, too.

3.2. Similarities of Test Results

RC bearing life is assessed by several methods, three of which are further compared: Statistics, Weibull and the bimodal method. They all bear a high degree of similarity concerning the following aspects of this analysis:

1) The median is 68 million revolutions, the mean is 71 million revolutions and the transition point between both slope lines is at 68.8 million revolutions.

2) The Weibull slope is 2.28 and the slope of zone **B** with most mechanical failures is 2.3.

3.3. Dissimilarities of Test Results

Test report 3183 states that the Weibull slope of the test results is 2.23. This infers that the distribution of this group of bearings is unilineal. However, the plot in Figure 1 clearly indicates that it is bilinear and bimodal. This is a significant difference which is the basic cause of this analysis. It further enables comparing both zones, via slopes contents and densities. Comparison of these parameters indicates that the intensity of mode **M** in this test is larger than that of mode **H**.

3.4. Test Data

This analysis is based on limited data that enable internal comparisons between types of failed items and between failure modes. It clearly indicates the existence of water in the lubricant and its detrimental effect in causing cavitation erosion on bearing parts. Test data are proprietary and scarce. Much more is required for additional quantitative evaluations.

3.5. Water Contaminated Lubricant

Jet oil was used to lubricate the bearings in test #3183 [3]. The lubricant is synthetic and contains several additives. As such it is hygroscopic and may cause cavitation erosion and damage in the bearings.

The quantity of water in the lubricant is further estimated by applying a di-ester lubricant #9, studied by Cantley [4]. Exposure of this liquid to air with a relative humidity of 20% caused the water content to reach 750 ppm. This value is much higher than that tested in full-scale RC bearings, 25 ppm, and found to shorten their service life appreciably. This study clearly indicates that the lubricant in test #3183 contained a large amount of water, thereby causing cavitation erosion in the tested bearings.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Nomenclature

C = cavitation

CDF = cumulative distribution function

CE = cavitation erosion

CMS = compact membrane system

e = base of natural logarithms

F = fraction failure %

RCB = rolling contact bearings

T = time constant

Appendix A: Deep Groove Ball Bearings Tested [3]

1) Bearing type: Deep groove

2) Ball diameter: 1/4"

3) Number of balls: 9

4) Bore diameter: 20 mm

5) Outer diameter: 42 mm

6) Test date: August 26, 1946

7) Test number: 3183

8) Lot number: 73

9) Load: 500 R.L

10) Rotation Speed: 2000 rpm

11) Report date: March 22, 1956