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Deduction of Reliability Parameter for Spherical Roller Bearing

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Abstract: To establish the reliability assessment technology of spherical roller bearing, we performed the major failure analysis, and then produced the reliability parameters for spherical roller bearing. As a first step, we made out the failure analysis data of roller bearing. And then, we decided the reliability parameters of spherical roller bearing by using of MINITAB software. Then we verified propriety the reliability parameters by comparison of pre-performed test results and MINITAB analysis. In this paper, we proposed a method of the reliability assessment technology of spherical bearing, and showed the reliability parameters of roller bearing by use of 8-samples spherical roller bearing. And also, we presented the useful reliability parameters for roller bearing test, which are produced by MINITAB analysis and marking of Weibull probability paper using the measured some life points, and also verified the propriety of reliability parameters by some kinds of complex tests.

Keywords: Spherical Roller Bearing, Reliability, Failure Mode, Life Test, Weibull Distribution

1. Introduction

Bearings are a main components part of rotation equipments. Roller and the raceway surface of the inner and outer ring of the spherical bearing is spherical shape. The barrel type roller configured in two rows has a function of adjusting the rotation center of axis in the outer ring raceway surface. So, the spherical bearing can correct the center error of the shaft and the housing. The spherical roller bearing is used to support pure radial loads as like the large gearbox, industrial conveyors, rolling machines and power axis of wind turbine. Roller bearing life is drastically reduced by excessive misalignment or deflection; hence, when using spherical roller bearing, the stack-up of tolerances contributing to misalignment and the shaft or housing deflections should be carefully considered. To compensate for some degree of misalignment or deflection and to carry heavy radial loads, spherical roller bearing is in complete to prevent the phenomenon known as end loading. [1]

Since the failure of the bearing is directly related to the fault for the entire system, the life of the bearing is predicted and on the basis of this, the conservation plan should be established prevention to avoid getting a great loss. However, bearing-related standards such as ISO have proposed that the guarantee applies to life assurance, confidence level, and life time distribution in batches for the life of the bearing. [2]

In this study, failure analysis, test method and life distribution for the reliability assessment of the spherical bearing have been proposed. Through the failure analysis, the main failure mode of the bearing was confirmed and through the QFD, the test items for the reliability assessment were determined. And then, no-failure life test time was calculated through the field operation time, confidence level and some parameters. This study developed test equipment which adapted the field condition for the life test of spherical roller bearing and life test was performed. Finally, the life distribution analysis was based on the reliability test results for the eight samples, it could be predict the life trend of the bearing through the calculating the related parameters.

2. Specimen and Test Equipment

The shape of the spherical roller bearing is shown in Fig. 1. Spherical roller bearing is double row, self-retaining units comprising solid outer ring with a concave raceway, solid inner ring and barrel rollers with cages. The symmetrical barrel rollers freely align themselves to the concave outer ring raceway. As a result, shaft deflections and misalignments of the bearing seats are compensated. Self-aligning capability is reduced when the inner and outer ring are unstable. The normal operating condition can be corrected by misalignment 0.5°, it can be allowed up to 2° when the load is small.

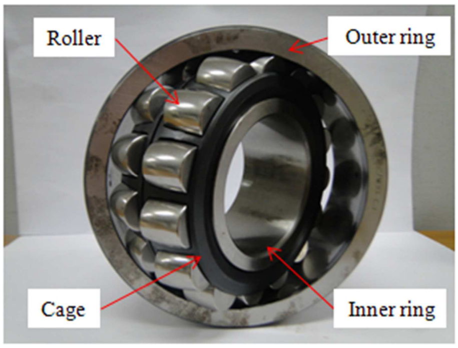

Figure 1. *Spherical roller bearing.*

The primary failure mode of the spherical roller bearing is the spalling of roller contact area due to repetitive loads. The stress factor that can accelerate the main failure modes in life test were selected radial direction loads. The test equipment for spherical roller bearing is shown in Figure 2. The motor rotates the specimen with the radial direction load applied by hydraulic servo cylinders. The hydraulic cylinders are controlled by the servo valve with response to the output value of load cell. Therefore, the test equipment can realize normal use conditions of spherical roller bearing. [3-5]

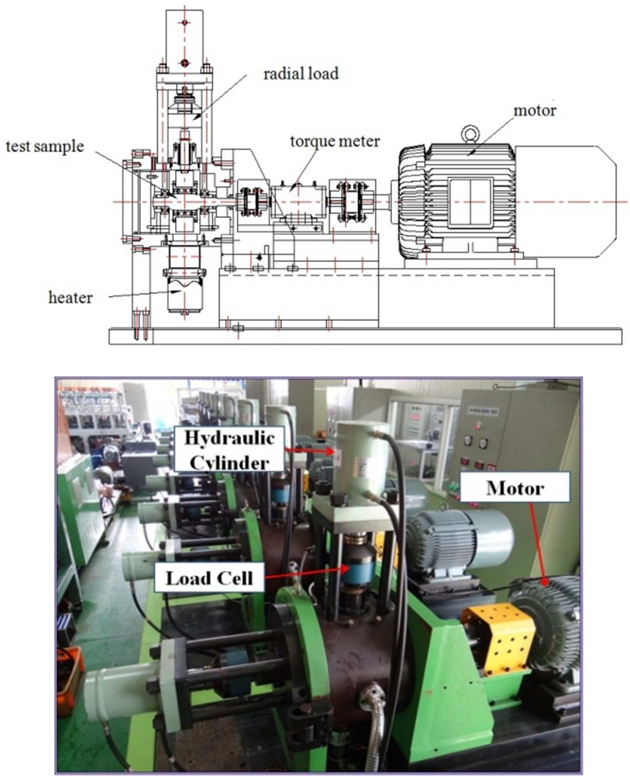

Figure 2. *Test equipment for spherical roller bearing.*

As shown in figure 3, the test jig is structured to support both ends of the bearing shaft. The roller bearings more durable than test specimen are adopted at both ends bearing shafts.

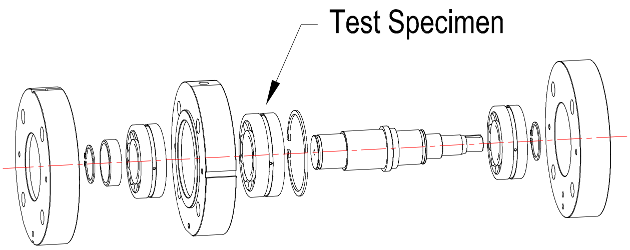

Figure 3. *Test jig for spherical roller bearing.*

3. Failure Analysis and Test Items

The main failure modes of a spherical roller bearing are deformation, fracture and crack caused by the repeated load on the raceway surface of the inner and outer ring, and spalling due to crack propagation of surface. This failure mode is usually caused by bearing exposure to an excessive load for an extensive period of time. The failure modes and mechanisms analysis for spherical roller bearing are listed in Table 1. [6-7].

Table 1. *Analysis of failure modes and mechanisms.*

Primary components	Function	Failure modes	Failure mechanisms
Outer ring, Inner ring, Roller, Cage	Smooth rotation	Fusion	Wearing
		Deformation	Brinelling
		Separation	Crack
		Fracture	Smearing
			Spalling
			Fretting
		Crack	Fatigue
Lubrication	Reduced friction	Lubricant degradation	Thermal destruction

Here the spalling is defined as subsurface chipping or breaking which is the result of poor lubrication or surface damage interrupts the lubricant film. Scores and scratches are usually caused by hard particles being trapped in a bearing. Test items are determined by test effectiveness score of spherical roller bearings, and then test ranking is decided according to the scores order. Test effectiveness rank is listed in Table 2. In this study, the representative performance test item is friction torque test which is used to confirm the spalling phenomenon of bearing and also used for life test. As environmental tests, the vibration and low temperature test are selected by consideration of field using conditions of test items.

Table 2. Table effectiveness rank.

components	failure mechanisms	Test items						
		Precision	Friction torque	Rigidity	High Temp.	Vibration	Low Temp.	Life
Outer ring,	Wearing	▲	●	▲				◎
Inner ring,	Brinelling	▲	●			▲		●
Roller,	Crack	●	●	▲	●	●		◎
Cage	Smearing	●	●	●	▲	●	▲	▲
	Spalling	●	●	●	●	●	●	◎
	Fretting	●	●	●	▲		▲	●
	Fatigue	▲	◎	●	◎		◎	●
Lubrication	Thermal destruction		●				● ▲	
test effectiveness rank		3	2	5	4	7	5	1

Table 3. Table effectiveness rank.

Test item	Test method	Failure criterion
Precision test	Measurement tolerances of the inner and outer rings	<0.01 mm
Maximum friction torque test	Test load: 30% of dynamic load rating, Test speed: 1700 r/min	Operating noise < 85 dB(A) Maximum friction torque <110% of the initial value
Rigidity test	Test load: Static load rating, measurement displacement	
High temp. oil test	Lubrication temp.: (120±2)°C	
Vibration test	Acceleration: 50 m/s^2, Amplitude: 15 mm	
Life test	Test load: 30% of dynamic load rating, Test cycle: 1700 r/min	

Test items were listed in table 3 to assess the reliability of spherical roller bearing. Maximum friction torque test is representative of the performance test.

Fault tree analysis (FTA) is performed to represent the cause of spherical roller bearing failure logically. FTA is a structured top down method to determine causes, lead to a defined state of the spherical roller bearing. This method can be expressed various combinations of fault cause compactly. The bearing failure is caused faulty assembly, over load and lack of lubrication of spherical roller bearing. Also, the faulty assembly is caused misalignment and fitting. [8-9]

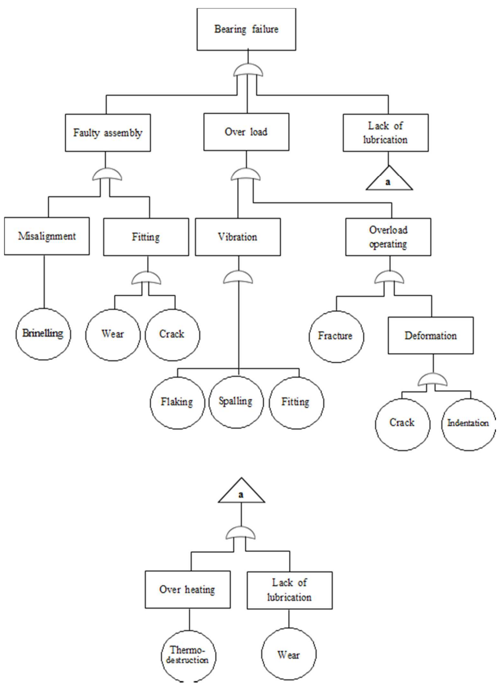

Figure 4. Fault tree analysis for spherical roller bearing.

4. No-Failure Life Test Time

The assurance life time of spherical roller bearing is 1.0×10^6 cycles (B_{10} life) at 90% confidence level. The shape parameter is 1.3. The calculation of no failure life time is shown in equation (1).

$$t_n = B_{100p} \bullet \left[\frac{\ln(1-CL)}{n \bullet \ln(1-p)}\right]^{\frac{1}{\beta}} \quad (1)$$

$$= 1.0\times10^6 \bullet \left[\frac{\ln(1-0.9)}{8 \bullet \ln(1-0.1)}\right]^{\frac{1}{1.3}} = 2166352 \cong 2.2\times10^6 cycles$$

Where, t_n is no failure test time, B_{100p} is the assurance life time, p is the unreliability (if B_{10}, p=0.1) and β is the shape parameter.

After testing the eight specimens, if they work during 2.2×10^6 cycles without failure, the life of spherical bearing is guaranteed the work time 1.0×10^6 cycles (B_{10} life) at 90% confidence level. In order to increase the efficiency of the test and reproduce the main failure mode in the actual use conditions, the equivalent load is calculated as 30% of the dynamic load rating. Equation (2) represents the rating life. Attempting to estimate the fatigue life of an individual bearing is not very practical because of the large number of design parameters to consider in relation to the sensitivity of the operating environment. Instead, statistical methods are used to rate bearings based on the results of large groups of the same type of bearing tested to failure under controlled laboratory conditions to establish a fatigue life rating. This rating, known as the B_{10} life, is defined as the number of hours that 90% of the bearings operating at their rated load and speed, can be expected to complete or exceed before exhibiting the first evidence of fatigue. Standard equations have been developed to extend the B_{10} rating to determine the statistical rated life for any given set of conditions. These equations are based on an exponential relationship of load to life. [10-11]

$$L_{10} = \left(\frac{C}{P_{eq}}\right)^{m} \tag{2}$$

Where, L_{10} is rating life, C is dynamic load rating. The dynamic load rating is determined through tests based upon the B_{10} life. This rating can be found in manufacturer's catalogs or engineering drawings. P_{ea} is equivalent load. So, the life test life of spherical roller bearing can be calculated like followings.

$$L_{test} = L\left(\frac{C}{P_{test}}\right)^{\frac{10}{3}} \tag{3}$$

$$= 2,166,352 \times \left(\frac{C}{0.3C}\right)^{\frac{10}{3}} = 119,456,522 \cong 1.2 \times 10^{8} cycles$$

After testing the eight specimens, if they work for 1.2×10^{8} cycles without failure, the life of spherical bearing is guaranteed to work time 1.0×10^{6} cycles (B_{10} life) at 90% confidence level.

5. Test Result

The maximum friction torque of bearing is measured by the torque measuring test. The spherical roller bearing is connected to the torque measurement equipment on the bearing testing machine. And 30% of dynamic load rating applied at 1700 r/min. After the life test, the friction torque of spherical roller bearing was determined to be 28 N.m. As test result, Fig. 5 shows that the measured maximum friction torque is 28 N.m.

The operating noise was measured as about 80 dB(A). Fig. 6 shows operating noise of spherical roller bearing. The Maximum torque and operating noise is satisfied the test criteria of spherical roller bearing.

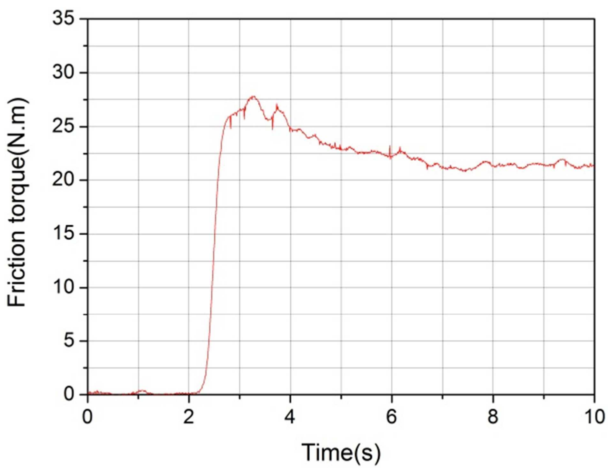

Figure 5. *Friction torque of spherical roller bearing.*

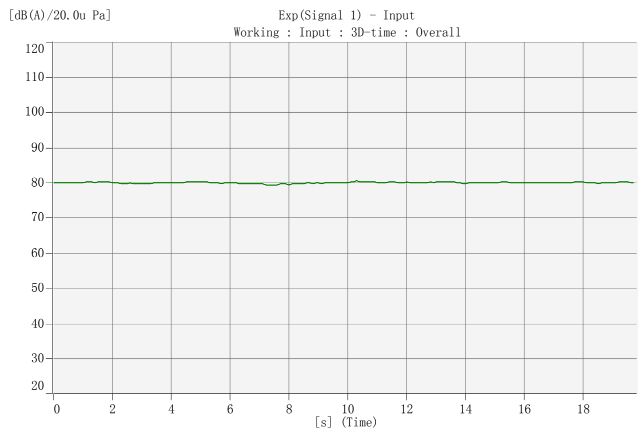

Figure 6. *Operating noise of spherical roller bearing.*

Table 4. *Analysis of failure modes and mechanisms.*

Specimen No.	Failure cycle	Result	Failure mode
S1	139,536,000	Fail	Frictional torque and noise exceeding
S2	222,773,100	Fail	
S3	362,089,800	Fail	
S4	366,723,660	Fail	
S5	445,536,000	Fail	
S6	445,536,000	Censored	-
S7	445,536,000	Censored	-
S8	445,536,000	Censored	-

The cycle to failures obtained by conducting life test is shown in Table 4. The specimen number S1 through S5 are failed and S6 through S8 are not the cycle to failure, but censoring life cycle

Figure 7. *Spalling due to crack of roller surface.*

Through the failure analysis, it was confirmed the spalling occurs on the edge of the roller. The spalling of the roller is shown in Fig. 7.

6. MINITAB Analysis for Decision of Reliability Parameters

6.1. Goodness-of-Fit Analysis of Life Data Distribution

To decide the most suitable life distribution for life data as the first step of statistical analysis, we performed goodness-of-fit examination about three kind of typical life distribution such as Weibull distribution, Lognormal distribution and Exponential distribution. The result is shown in Fig. 8. Since the censoring data is included in the life data, the maximum likelihood method was applied. Anderson-Darling (hereinafter A-D) distribution goodness of fit test was performed over a black, and this statistic is a value that measures the difference between the corresponding points of the illustrated points and whether those suitable linear probability. Among the candidate having distribution it means that the distribution is well suited to a less A-D statistic.

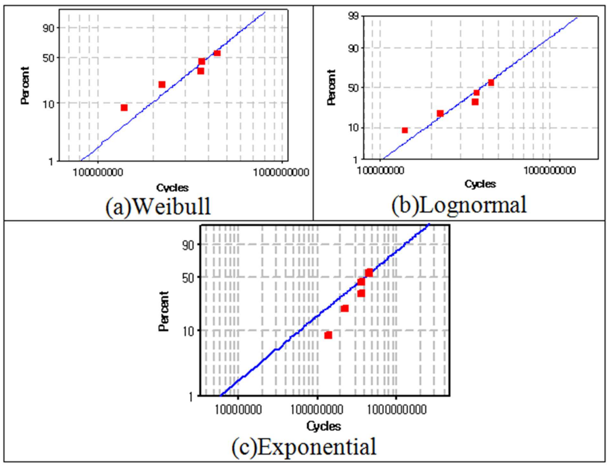

Figure 8. *Goodness of fitness test.*

An Figure 8 in the results goodness-of-fit, the A-D statistic of Weibull distribution is 24.831, lognormal distribution is 24.857, and exponential distribution is 25.071. Therefore, Weibull distribution of the most small A-D statistics is most appropriate to the life distribution of the spherical bearing.

6.2. Deduction of Major Reliability Parameters

For selected Weibull distribution using the MINITAB software, a shape of probability density function, Weibull probability paper, reliability function, and hazard function are approximatively shown in figure 9. The functions of the Weibull distribution are follows

$$f(t)-\frac{\beta}{\eta}\left(\frac{t}{\beta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad \beta>0,\eta>0 \qquad (4)$$

Where, $f(t)$: probability density function, β :shape parameter, η :scale parameter.

$$F(t)=\int_0^t f(x)dx=1-e^{-\left(\frac{t}{\eta}\right)} \qquad (5)$$

$$R(t)=1-F(t)=e^{-\left(\frac{t}{\eta}\right)} \qquad (6)$$

$$h(t)=\frac{f(t)}{R(t)}=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \qquad (7)$$

Where, $F(t)$: unreliability function, $R(t)$: reliability function, $h(t)$: hazard function.

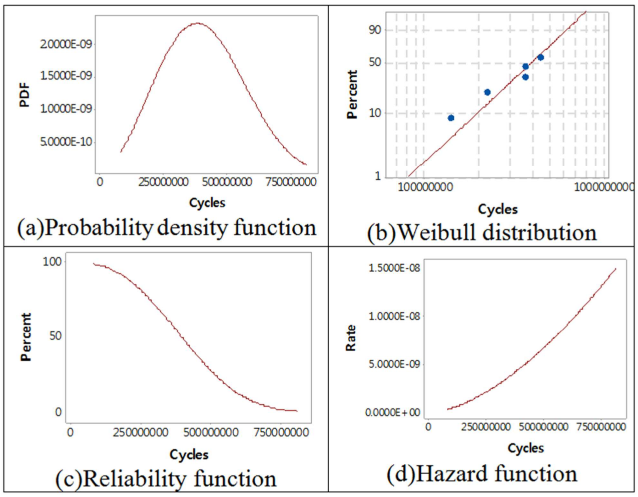

Figure 9. *Summary of Weibull distribution.*

In figure 10, we can deduce the values of reliability parameters, as it were, the shape parameter β as 2.65, scale parameter η as 457,963,175 cycles. And also, the mean time to failure (MTTF) is 407,020,433 cycles, median value is 398,865,366 cycles, B_{10} and is 99,160,243 cycles. The prediction results of major reliability parameters obtained from this study are shown in Table 5.

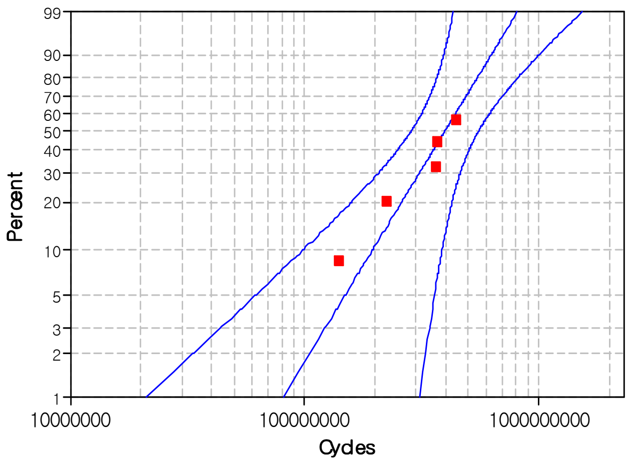

Figure 10. *Probability plot for cycles (Weibull-95% CI)g.*

Table 5. *Table information.*

Table of statistics	
Shape	2.65
Scale	457,963,175
Mean	407,020,433
Standard deviation	165,163,257
Median	398,865,366

7. Conclusion

This paper presents the failure analysis results and major reliability parameters about the spherical roller bearing.

1) For reliability assessment of spherical roller bearing, we draw out the failure analysis data and determined main performance test items for reliability test of roller bearing by composition of 2-stage QFD.
2) We can predict the life trend by analysis of performance degradation data of roller bearing, and can know that 3-parameter Weibull distribution is the most suitable for life distribution of roller bearing through the probability plotting.
3) As used roller bearing in the test is recently development step, 8-samples are performed on the test and analysis. Although it is guaranteed accuracy of reliability parameters, we will perform the study that is added number which is able to guaranteed accuracy of reliability parameters.

Nomenclature

B_{100p} : assurance life time

C : dynamic load rating

CL : Confidence Level

L_{test} : test life

P_{test} : test load

p : unreliability

t_n : no failure test time

β : shape parameter

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