**Tribol. Lubr., Vol. 40, No. 5, October 2024, pp. 145~150**
**Tribology and Lubricants**

ISSN 2713-8011(Print) • 2713-802X(Online)
http://Journal.tribology.kr

**DOI https://doi.org/10.9725/kts.2024.40.5.145**

# Estimation of Rolling Bearing Life under the Environment of Electrical Erosion using Accelerated Life Test

**Ji Su Park[1], In Gyung Cho[2], Yejin Kong[2], Jong Won Lee[2], Jeong Hyeon Bae[2] and Choong Hyun Kim[3] †**

*[1]Senior Research Scientist, Safety Component R&D Center, Gyeonggi Regional Division,*
*Korea Automotive Technology Institute*
*[2]Research Scientist, Center for Bionics, Bionics Research Institute, Korea Institute of Science Technology*
*[3]Principal Research Scientist, Center for Bionics, Bionics Research Institute, Korea Institute of Science and Technology*

(Received August 20, 2024; Revised October 28, 2024; Accepted October 28, 2024)

**Abstract:** This study experimentally investigates the life of rolling bearings in electric vehicles under electrical erosion. The design and preparation of an electrical erosion simulation test rig, setting of accelerated life test conditions and test methods, and results of life analysis under electrical erosion are described. We selected a constant current as the acceleration factor for life under electrical erosion, and an electrical erosion life test was conducted using three current values. The bearing was determined to have failed when the root mean square value of the acceleration data from the bearing was 4 g or higher. Based on the test data, a formula to predict life under electrical erosion was developed and used to estimate life under electrical erosion when the bearing was exposed to a random current value. The Weibull distribution was used to estimate the life of the bearing under electrical erosion based on the results of the statistical analysis that used the accelerated life test data. The estimated values were presented considering the shape parameter, acceleration index for a constant current, and the uncertainty of the estimated life value. The acceleration indices for the shape parameter of the electrical erosion life data distribution and constant current were 3.391 and 0.776, respectively. The B10 life values were 51.7, 14.8, and 8.7 h when the supplied currents were 0.1, 0.5, and 1, respectively. This study provides empirical guidelines for predicting the life of ball bearings under electrical erosion.

**Keywords**: Ball bearing, Electrical erosion, Accelerated life testing, Reliability assessment

## 1. Introduction

Bearings are the mechanical components of rotating bodies, and more than 40% of rotating machine failures are related to bearing failure [1,2]. The causes of bearing failure include excessive loads, poor alignment caused by incorrect assembly, and improper lubrication. Electric vehicles (EVs) use bearings in their drive shafts, and current leakage from the motor creates an arc that leads to electrical erosion, causing the metal in the bearing to wear or dislocate [3]. In the case of a bearing failure caused by electrical erosion, the electrical charges introduced through the drive shaft and inner race of the bearing accumulate in the bearing grease. The charges are discharged into the metal components around the bearing when a certain electric potential is exceeded, thereby damaging the surface of the material. Because repeated discharges lead to complete bearing failure and degrade the overall performance of the rotating machine, a technology for estimating the life of EV bearings under electrical erosion should be developed.

Im et al. (2018) conducted a durability test by supplying

---

†Corresponding author: Chung Hyun Kim
Tel: +82-2-958-5668
E-mail: chkim@kist.re.kr
https://orcid.org/0000-0002-0162-6342

a current of 20A to a ball bearing that rotated at 3,600 rpm and evaluated the bearing life by determining the bearing failure when the acceleration exceeded 5 g [4]. Yudong et al. (2016) supplied a current of 0.49A to a bearing used in a fan to evaluate its life under electrical erosion [5].

However, few studies have simulated the electrical erosion of bearings for EVs.

In this study, a test rig was designed and fabricated to simulate the electrical erosion that occurs in bearings for EVs. The test rig was used to conduct an accelerated life test to estimate the life of a bearing under electrical erosion.

## 2. Test Setup and Bearing Specimen

### 2.1. Test rig configuration

Fig. 1 shows a schematic of the test rig used to simulate the electrical erosion of bearings. The drive shaft was vertically arranged in this test rig, and the rig comprised the following main components: driving unit (13,14), loading unit (2,3,4,8,11), measurement sensors (1,10), and direct current (DC) supply unit (7,15,16).

The driving unit is operated using an electric motor (14), and the drive shaft (13) rotates the inner race of the test bearing (9).

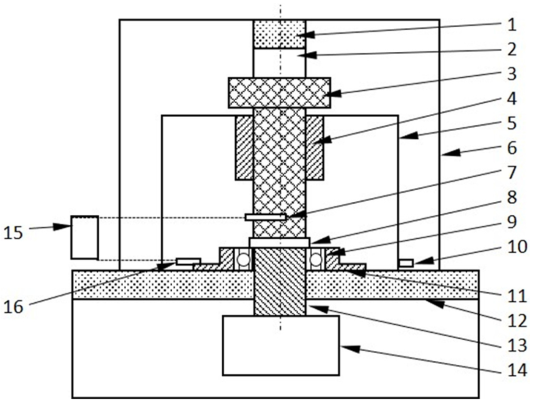

**Fig. 1. Test rig for measuring lifetime of ball bearing under electrical erosion: 1-load cell, 2-loading plate, 3-loading shaft, 4-linear bushing, 5-housing, 6-support plate, 7-slip ling, 8-loading plate, 9-test bearing, 10-acceleration sensor, 11-bearing loading plate, 12-base plate, 13-drive shaft, 14-electric motor, 15-power supply, 16-current terminal.**

**Table 1. Test conditions**

| Stress Factor | Stress Level | | No. of samples |
|---|---|---|---|
| Constant current | $1^{st}$ | 3 A | 7 |
| | $2^{nd}$ | 7 A | 7 |
| | $3^{rd}$ | 15 A | 10 |

The movement of the loading shaft (3) in the radial direction was limited by the linear bushing (4). The vertical load and DC were transferred to the test bearing (9) through a loading plate (2) and slip ring (7), respectively. A load within the range of 135–165 N was applied to the bearing depending on the load values presented in Table 1 of KS B ISO 15242-2. In this case, because the weight of the loading shaft (3) was approximately 30 N, an additional load within the range of 110 N–120 N was applied via the loading plate (2).

Power was supplied (15) using a DC power supply system (Model E36231A, Keysight Technologies, Santa Rosa, CA, USA). The supplied current formed a closed circuit as it returns to the power supply (15) via the loading shaft (3), test bearing (9), and bearing loading plate (11). To prevent leakage of the supplied current, an insulation was inserted between the loading plate (2) and loading shaft (3), between the bearing loading plate (11) and base plate (12), and between the drive shaft (13) and electric motor (14).

During the test, the load applied to the test bearing (9) and its acceleration (9, were measured and examined in real time using a load cell (1, Kistler 8640A, Kistler Instrumente GmbH, Sindelfingen, Germany) and accelerometer (10, Kistler-9306A).

### 2.2 Test method

Stable rotation was achieved by mounting the test bearing (9) on top of the drive shaft (13) and operating the electric motor (14). The loading plate (2) was lowered to apply a load, and then DC from the power supply (15) was supplied through the slip ring (7).

If the acceleration data from the bearing fall within the range of 3.5-6.5 g, the bearing is faulty [7]. We selected 4 g as the acceleration limit. Therefore, when the root mean square (RMS) of the acceleration data collected from the acceleration sensor (10) exceeded 4 g

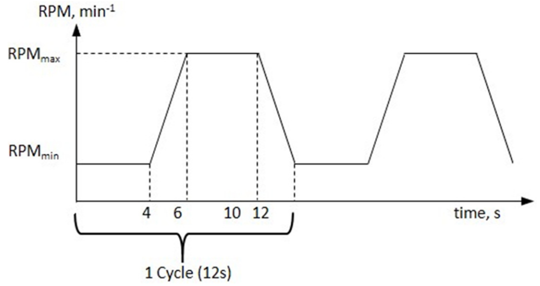

**Fig. 2. Composition of electric motor drive cycle.**

more than ten times within 1 min, bearing failure occurred and the test was stopped.

In the electrical-erosion simulation test, the rotational speed of the drive shaft was set to reciprocate from 1,000 rpm to 3,000 rpm, as shown in Fig. 2, to reflect the acceleration and deceleration conditions under the actual operating conditions of the EVs. The low-speed ($RPM_{min}$) and high-speed ($RPM_{max}$) sections were maintained for 4 s, and the acceleration/deceleration sections were maintained for 2 s.

SKF 6007 open ball bearing was used as the test bearing (9).

LabVIEW (NI, Austin, Texas, USA) was used to operate the motor and collect test data at a sampling rate of 10 kHz.

## 3. Accelerated Life Test

### 3.1. Test condition

A constant current was selected as the acceleration factor of bearing life in this study because the current density per unit area (A/mm$^2$) causes the electrical erosion of bearings [6]. In other words, an accelerated test was conducted using three DC values, and the results were analyzed. Table 1 presents the accelerated-life test conditions.

### 3.2. Test results

Typical acceleration data over time in the bearing electrical erosion simulation test are shown in Fig. 3. The acceleration value at the beginning of the test was less than 1 g. It slowly increases over time and sharply increases during failure.

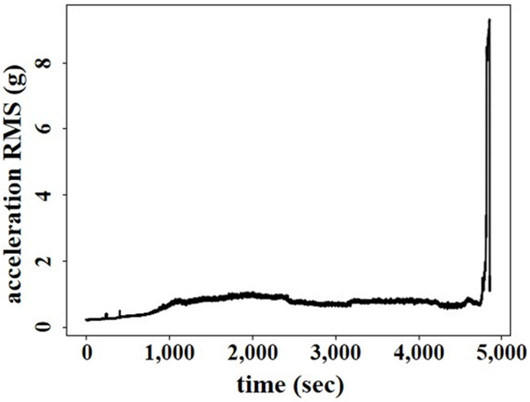

**Fig. 3. Typical acceleration data measured in the bearing life test using the electrical erosion simulator.**

**Table 2. Bearing life from the accelerated life test**

| Stress level | 3 A | 7 A | 15 A |
|---|---|---|---|
| Bearing life (s) | 41,068 | 14,715 | 5,859 |
| | 20,821 | 13,682 | 4,580 |
| | 29,357 | 9,895 | 11,760 |
| | 20,793 | 9,170 | 9,476 |
| | 20,009 | 11,580 | 7,254 |
| | 17,169 | 9,789 | 5,733 |
| | 16,590 | 9,325 | 6,865 |
| | - | - | 5,498 |
| | - | - | 6,842 |
| | - | - | 5,383 |

The bearing failure time at each stress level was calculated using Python, and the results are presented in Table 2.

### 3.3. Statistical analysis

Maximum likelihood estimation (MLE) was applied as a goodness-of-fit test method for the life data obtained using the accelerated life test. MLE is a statistical method used to determine the parameter values that best describe the given data. It indicates that the model with a small log-likelihood function value (-2*log-likelihood function) is suitable for the data. Fig. 4 shows the bearing life under electrical erosion using the lognormal, Weibull, exponential, and normal distributions. The log-likelihood function value is presented in Table 3.

In the goodness-of-fit test results, the lognormal distribution showed the lowest log-likelihood function

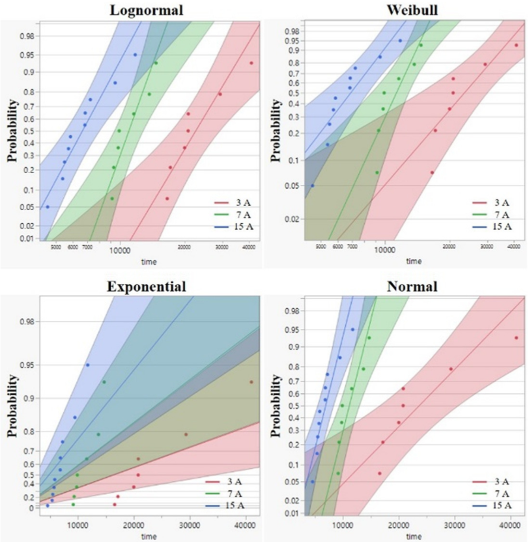

**Fig. 4. Distribution goodness-of-fit test plots: Lognormal, Weibull, exponential, and normal distributions.**

**Table 3. Conformance results of bearing life distribution**

| Life distribution | Log-normal | Weibull | Expo-nential | Normal |
|---|---|---|---|---|
| -2*log-likelihood function | 447.32 | 453.58 | 496.36 | 453.58 |

value. Because the Weibull distribution has been widely used as the life distribution of mechanical components and the log-likelihood function value of the Weibull distribution of electrical erosion life data is similar to that of the lognormal distribution, the Weibull distribution was selected as the bearing life distribution in this study.

The Weibull distribution defines the form of the failure rate as a probability density function f(t) using the shape and scale parameter values. The distribution function F(t), reliability function R(t), and failure rate function h(t) are expressed as follows:

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

$$F(t) = \int_0^t f(x)\,dx = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{2}$$

$$R(t) = 1 - F(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{3}$$

$$h(t) = \frac{f(t)}{R(t)} = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \tag{4}$$

where the shape parameter $\beta$ and the scale parameter $\eta$ represent the shape and dispersion degree of the distribution, respectively. Importantly, the scale parameter of the Weibull distribution is referred to as the characteristic life, and 63.2% of the parameters indicate the time of failure.

The validity of acceleration for the test data should be examined to ensure the reliability of the accelerated life test results. First, the failure mode of the failed component must be identified. Statistically, this can be determined by verifying the shape parameter of the Weibull distribution. Because the shape parameter represents the failure mode of the component, the validity of acceleration can be confirmed by verifying that the shape parameter is identical to the accelerated test data obtained at each stress level.

In this study, the failure mode of the failed component was identical at three accelerated stress levels, and the shape parameter at each stress level was identified by conducting a likelihood ratio test using the JMP software.

Table 4 presents the shape parameter of the Weibull distribution at each stress level with a 95% confidence interval. The likelihood ratio test results showed that $T = 2.515 < x^2 = 5.992$ at the 5% significance level. This confirms the validity of the acceleration because no statistically significant difference in the shape parameter was observed for each stress level.

In addition, reliability analysis was conducted at the three stress levels of bearing electrical erosion. The shape parameter $\beta$ of the Weibull distribution was 3.391, and the 95% confidence interval for $\beta$ was (2.494, 4.396). The life distribution of the bearing was assumed to be a Weibull distribution, and a constant current was selected as the accelerated stress factor that could accelerate the

**Table 4. Estimation of parameters ($\beta$, $\beta_0$, $\beta_1$)**

| Parameter | Point estimate | 95% lower confidence limit | 95% upper confidence limit |
|---|---|---|---|
| $\beta$ | 3.391 | 2.494 | 4.396 |
| $\beta_0$ | 11.011 | 10.647 | 11.398 |
| $\beta_1$ | –0.776 | –0.952 | –0.604 |

**Table 5. Estimation of parameters (K, n)**

| Parameter | Point estimate | 95% lower confidence limit | 95% upper confidence limit |
|---|---|---|---|
| K | $\frac{1}{60007.93}$ | $\frac{1}{88990.64}$ | $\frac{1}{42017.55}$ |
| n | 0.776 | 0.604 | 0.952 |

main failure mode of the bearing. The resulting relationship between the life and stress factors is expressed by Equation (5), and the value of the parameter at the 95% confidence level is presented in Table 4. Similarly, the relationship between the life and stress factors was expressed as the inverse power model shown in Equation (6). The accelerated life model of the Weibull distribution can be expressed using Equation (7). Table 5 presents the parameter values of the inverse power model.

$$\eta = \exp(\beta_0 + \beta_1 Log(Stress)) \tag{5}$$

$$L = \frac{1}{K(Stress)^n} \tag{6}$$

$$X \sim Weibull(\eta(Stress), \beta) \tag{7}$$

Fig. 5 shows the lifeWhen the virtual bearing current values are set to 0.1, 0.5, and 1.0 A, the bearing life calculated using Equations (5) and (6) is presented in Table 6.

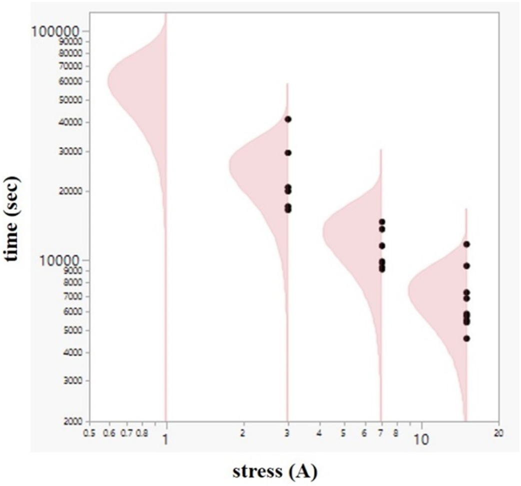

**Fig. 5. Stress-life curve of the accelerated life test.**

**Table 6. Estimation of characteristic life**

| Stress (A) | Characteristic life (s) | 95% lower confidence limit | 95% upper confidence limit |
|---|---|---|---|
| 0.1 | 361,535 | 215,201 | 607,374 |
| 0.5 | 103,663 | 71,374 | 150,559 |
| 1.0 | 60,530 | 42,423 | 56,365 |

**Table 7. Estimation of MTTF**

| Stress (A) | MTTF (s) | 95% lower confidence limit | 95% upper confidence limit |
|---|---|---|---|
| 0.1 | 324,753 | 157,612 | 669,141 |
| 0.5 | 93,116 | 58,450 | 148,344 |
| 1.0 | 54,372 | 38,010 | 77,776 |

**Table 8. Estimation of $B_{10}$ lifetime**

| Stress (A) | $B_{10}$ lifetime (s) | 95% lower confidence limit | 95% upper confidence limit |
|---|---|---|---|
| 0.1 | 186,200 | 80,049 | 399,565 |
| 0.5 | 53,389 | 29,580 | 88,403 |
| 1.0 | 31,174 | 19,096 | 46,579 |

The use of characteristic life data enabled the mean time to failure (MTTF) and $B_{10}$ life to be calculated using Equations (8) and (9): The results were consistent with the values calculated using the JMP software. The calculated lifetimes are presented in Tables 7 and 8.

$$MTTF = \eta \cdot \Gamma(1 + \frac{1}{\beta}) \tag{8}$$

$$B_{10} = \eta \times (-\ln(1-p))^{\frac{1}{\beta}} \tag{9}$$

## 4. Conclusions

This study developed a test rig to simulate the electrical erosion of bearings and conducted an accelerated life test using DC stress to estimate bearing life.

The Weibull distribution was used to estimate the life of the bearing under electrical erosion based on the results of the statistical analysis that used the accelerated life test data. The estimated values were presented considering the shape parameter, acceleration index for a constant current, and the uncertainty of the estimated life value.

The acceleration indices for the shape parameter of the electrical erosion life data distribution and constant current were 3.391 and 0.776, respectively. The $B_{10}$ life values were 51.7, 14.8, and 8.7 h when the supplied currents were 0.1, 0.5, and 1, respectively.

In the future, additional test data will be gathered to provide systematic data on the life of rolling bearings for EVs under electrical erosion.

## Acknowledgments

This research was supported by the Standardisation Technology Improvement Program of the Ministry of Trade, Industry and Energy (Grant Number: 20020865).

## References

[1] Albrecht, P. F., Appiarius, J. C., McCoy, R. M., Owen, E. L., Sharma, D. K., "Assessment of the reliability of motors in utility applications-Updated.", *IEEE Trans. Energy Convers.*, Vol. 1, pp. 39-46, 1986.

[2] Zhang, P., Du, Y., Habetler, T. G., Lu, B., "A survey of condition monitoring and protection methods for medium-voltage induction motors.", *IEEE Trans. Ind. Appl.*, Vol. 47, no. 1, pp. 34-46, 2010.

[3] Ludois, D. C., Reed, J. K., "Brushless mitigation of bearing currents in electric machines via capacitively coupled shunting.", *IEEE Trans. Ind. Appl.*, Vol. 51, no. 5, pp. 3783-3790, 2015.

[4] Im, J., Park, J., Hur, J., "Accelerated life test of bearing under electrical stress.", In 2018 21st International Conference on Electrical Machines and System (ICEMS), Harbin, China, October 2018.

[5] Yudong, F., Zhenhuan, W., Lixin, W., Guoan, Y., "Research on the fan bearing reliability of the Weibull distribution." In 2016 IEEE Information Technology Networking Electronic and Automation Control Conference, Chongqing, China, May 2016.

[6] Muetze, A., Strangas, E. G., "The useful life of inverter-based drive bearings: Methods and research directions from localized maintenance to prognosis.", IEEE Ind. Appl. Mag., Vol. 22, no. 4, pp. 63-73, 2016.

[7] Illig, M., Brown, T., Limburg, R., Robinson, J., "A New Approach to Predicting Bearings Failure." IMI Sensors-A PCB DIVISON, NY 14043 USA, 2021.