Antifriction Bearing Life

Bearing Types

There are 3 types of bearings: Rolling element, bushings, and journal.

Antifriction bearings are commonly taken to refer to rolling element bearings. These bearing have rolling components, such as ball bearings. Lubrication is used to cool the surfaces, reduce friction and wear for the portion of sliding contact that occurs, and form a fluid film that distributes contact stress over a larger area. A hovercraft over water has a similar effect. The air cushion forms a depression larger than the craft, distributing the load over a larger area.

Bushings have surface contact between sliding components. Materials for the contact surfaces are chosen to reduce friction and reduce abrasive wear. Common materials are bronzes and Teflons. Lubricants may also be used to reduce friction and wear.

Journal bearings use a fluid film to separate sliding surfaces. This is called "boundary lubrication." The film is an effect similar to a speeding car hitting a rain puddle. The car tire has a tendency to float on a wedge of water. In a car this is called hydroplaning; in machinery it is called elasto-hydrodynamic lubrication (EHL). For EHL to be the only lubrication mode, it must generate a film thickness greater than the surface roughness of the contacting parts. Film thickness is proportional to the sliding velocity and lubricant viscosity and inversely proportional to the load. Journal bearings are bushings when starting, unless they have a externally pressurized lubricant flow. Then depending on operating conditions may partially contact.

Basis for Bearing Life

Industry practice for antifriction bearing life is a theoretical calculation of the cycles for a percentage of the population to fail from surface fatigue. Regardless of bearing size, failure is artificially defined as the development of a 0.01 $inch^2$ (6 mm^2) spall[1].

Surface contact stress induces shear stress below the surface (subsurface shear stress[2]). Materials are weakest in shear so failure is below the contact surface. Every rolling element (ex. Individual ball) in a bearing applies a surface stress each rotation. This cyclic stress causes fatigue cracks that grow and join until a small piece falls out.

Bearing Reliability

The theoretical calculation is based on 10% failure rate; referred to as B_{10} or L_{10}. Failure rate is the difference of the reliability from 100%; therefore L_{10} is equivalent to 90% reliability. Bearing life can be adjusted to different reliabilities thru the use of Equation 1 and shown graphically in Figure 1. For all bearings to fail (L_{100}) is approximately 50 times the L_{10} life. Mean Time Between Failures (MTBF) is ***5 times*** the L_{10} life. Figure shows MTBF is at approximately 1 failure out of every 1.6 units (73% failure) or 37% reliability. Bearing failures do not follow a Gaussian (normal) distribution, which would imply a MTBF at 50% reliability.

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1 A spall or pit is the volume left by removal of small pieces of material due to subsurface shear stress fatigue

2 For more information on subsurface shear stress research Mohr's Circle

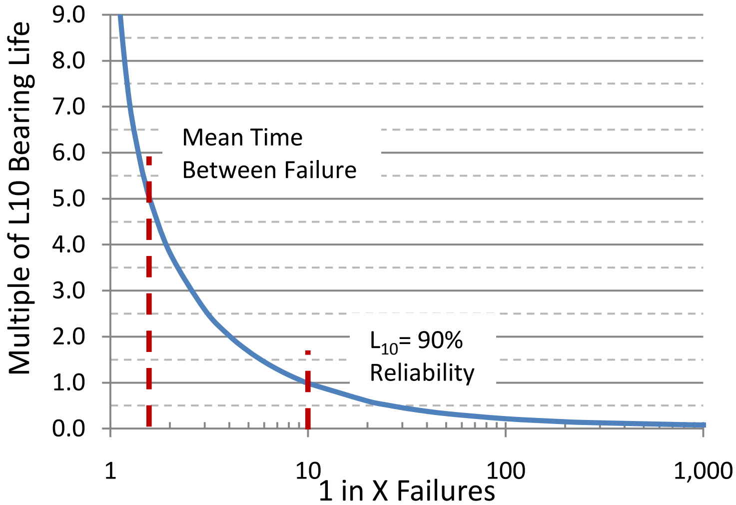

Figure 1 Failures v. Multiple of L_{10} Bearing Life

$$a_f = 4.59 \times \left(\ln\left(\frac{100}{R} \right) \right)^{0.74} + 0.05$$

$$L_{new} = L_{10} \times a_f$$

$$new = 100 - R$$

a_f = Life Adjustment Factor

R = Reliability as a Percentage (Percentage of Survivors)

L_{new} = Life at New Reliability

L_{10} = Life at 90% Reliability (B_{10})

Equation 1 Life Factor

For 100% reliability, with respect to fatigue, use a life adjustment factor of 0.05. The equation is asymptotic at this value. The Table 1 compares life and reliabilities.

	Reliability			
	MTBF	90%	99%	100%
Life	5,000	1,000	200	50
	25,000	5,000	1,000	300
	50,000	10,000	2,100	500
	250,000	50,000	10,500	2,500
	500,000	100,000	21,000	5,000

Table 1 Life at Various Reliabilities

Catastrophic Failure

The life calculation is independent of the cycle rate (i.e. rotational speed). Machinery typically divides by the cycle rate (revolutions per minute) (Equation 2) to express the result in time. Vehicles divide by the wheel circumference to express the answer in distance.

$$L_{10} = \left(\frac{C_P}{F_{rmc}} \right)^x \times \left(\frac{1E6}{\omega \times 60} \right)$$

C_P = Bearing Dynamic Rating

x = Bearing Factor; 3 = Ball, $10/3$ = Roller

F_{rmc} = Root Mean Cube Force or load

ω = Revolutions per Minute

Equation 2 Life Equation

The life calculation predicts the development of a certain size spall. It is not failure of the bearing's ability to support load, which would be a catastrophic failure. It is a visually noticeable defect that if inspected would indicate it needs to be replaced. If left in service, spalls would continue to develop with deteriorating performance, marked by increasing noise, heat, and vibration. Catastrophic failure is generally **2 times** longer than the spall area criteria.

Life calculations generally use the maximum system load. But, bearing life is a function of the mean load not the maximum load. Average system loads are generally around 50% to 80% of the maximum. Ball bearing life varies inversely as the cube ($^{10}/_3$ for roller elements) of the applied load. So the "average" load is the *root mean cube* (Equation 3),; similar in concept to root mean square used in many statistical calculations. An 80% average load gives **2 times** the life; 50% average load, the life is 8 times as long (Figure 2). Combining all of the factors to estimate a true failure in a typical industrial reducer gives **20 times the L_{10}**.

$$F_{rmc} = \sqrt[3]{\frac{F_1{}^3 \times N_1 + F_2{}^3 \times N_2 ... + F_n{}^3 \times N_n}{\sum_1^n N_x}}$$

F = Force or load

N = Number of cycles at load

Equation 3 Root Mean Cube Load

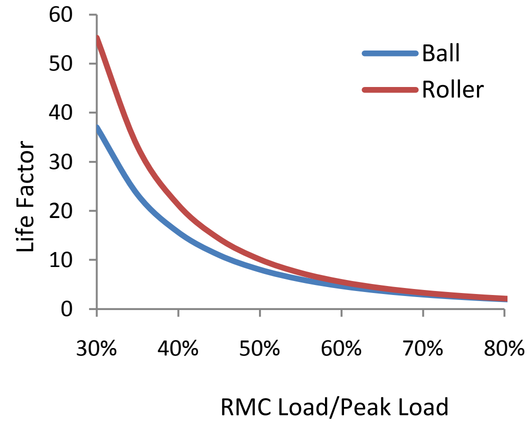

Figure 2 Mean Load versus Life Factor

Actual Bearing Life

The previous information is based on fatigue. Experience shows less than 10% of failures are due to fatigue. Other factors that affect bearing life are design (geometry, lubrication installation techniques, and environment.

Failure can still occur from unknown factors even if everything within the manufacturer's control is correct. Environment; temperature, electrical, dirt and moisture, Unknowns can be as diverse as shock loading from machine jams or hitting the reducer with a forklift. The most common cause of bearing failure is lack of proper lubrication maintenance. If you want long life change the oil.

When L_{10} results indicate bearing life of multiple years the likelihood of an unknown factor causing failure increases. In these cases the excessive life should be taken as higher reliability not that the bearing will actually last that long in service.

Reliability of Bearing Systems

All of the calculations described so far discuss individual bearings. But, machines have more than one bearing. Combining bearing reliability for multiple bearings into a single value can be done by manipulating Equation 1 to determine the reliability of each bearing at a selected target life (Equation 4). Then multiply the reliabilities together for the reliability of the system.

$$\frac{L_T}{L_{10}} = a_f$$

$$1.35 = \frac{1}{0.74}$$

$$R_T = e^{-\left(\frac{a_f - 0.05}{4.95}\right)^{1.35}}$$

R_T = Reliability at Target

L_T = Target Life

Equation 4 Reworked Reliability Equation

Table 2 Example of System Reliability

Initial Calculations		Target Calculations	
Reliability	Life	Reliability	Life
0.90	3,727,983	0.99	1,000,000
0.90	1,309,453	0.93	1,000,000
0.90	1,714,190	0.95	1,000,000
0.90	3,509,525	0.98	1,000,000
0.90	1,300,268	0.93	1,000,000
0.90	2,949,775	0.98	1,000,000
	System	0.78	1,000,000

About the author:

James K. Simonelli is a Licensed Professional Engineer with 30 years experience designing and troubleshooting machine automation, heavy duty equipment and industrial products. He has a broad background with department head roles in engineering, quality and business development in companies varying from startups, turnarounds to Fortune 100 corporations. Mr. Simonelli has served on committees developing industrial standards for the American Gear Manufacturers Association and the Hydraulics Institute.

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