11 Bearing life

11.1 Life

Even in regular condition, because of contact stress, material will flake from the rolling surface of inner or outer rings or rolling elements by fatigue. Fatigue flaking is the main phenomenon of bearing failures therefore , generally , the life of bearing refers to its fatigue life .Fatigue life expressed in terms of revolution which one bearing ring or washer continues to operate before another bearing ring (or washer) or rolling element appears fatigue flaking.

In some particular cases, bearing is likely to flake because of precision reduction caused by abrasion, or exceed the noise scope required by machine, here, life refers to accuracy life or noise life .

Furthermore, bearing may fail because of burn, abrasion , crack , seizure and rust, Rustiness etc. but these should be considered as failures. Fatigue life is different from failures. Improper choice, mounting , lubricant and seals are all factors to failures. Paying attention to these factors can avoid failures.

1) Reliability

In practical situations, same bearings may have different actual life under the same condition. Fatigue life of bearing is in accordance with specified probability distribution; therefore, bearing life is expressed by failure probability, and also can be judged by reliability. It refers to the percentage which bearing can reach or exceed the theoretical life when they are applied under same condition. Reliability of a single bearing is the probability of reaching or exceeding its theoretical life.

2) Basic life and correction rating life

What we called rating Fatigue life refers to the total revolution of 90 %the same type bearings are used for operation under the same condition without rolling fatigue.

Considering the required reliability , special bearing performance and specific operation condition, what we get after correction to basic rating life is correction rating life.

11 .2 Basic load rating

Basic load rating contains basic dynamic load and static load rating. In which the load capacity of bearings under rotational conditions (n>10r/min) is called basic dynamic load while the bearing in stationary conditions or rotating slowly (n ≤ 10r/min) called static load rating.

1) Radial basic dynamic load rating

Radial basic dynamic load rating refers to the constant radial load that a bearing can take, under which the basic rating life is one million revolutions. As to single row angular contact ball bearing , this load refers to the radial load causing pure radial movement between bearing rings.

2) Axial basic dynamic load rating

Axial basic dynamic load rating refers to central axial load of constant magnitude in a constant direction, under which the basic rating life is one million revolutions.

3) Radial static load rating

Radial static load rating refers to the radial static load (similar to the following contact stress) caused by the maximum load of rolling bearing in the center of contacting stress surface between in of rolling element and raceway, while the bearing is in stationary conditions or rotating slowly.
4600 MPa spherical roller bearing
4200 MPa all other annular ball bearing
4000 MPa all the radial roller bearing
As to single row angular contact ball bearing, its radial static load rating refers to radial load causing relative pure radial movement between bearing rings.

4）Axial specified static load rating

Axial direction specified static load refers to virtual central axis static load (similar to the following contact stress) caused by rolling bearing in the contact center of maxima rolling body and raceway groove.
4200 MPa thrust ball bearing
4000 MPa all the thrust roller bearing

C&U®

11.3 Bearing dimension selection according to dynamic load rating

11.3.1Dynamic equivalent load rating

Basic dynamic load rating is defined under assumed running conditions .The load condition is: radial bearing only takes pure radial load, thrust bearing only takes pure axial load .In most application situations, bearing actually take both radial load and axial load. Therefore, when calculating bearing life, we must change actual load into dynamic equivalent load in accordance with load condition of dynamic load rating. Equivalent dynamic radial load refers to radial load. Axial direction equivalent dynamic load refers to constant central load. So under this load rolling bearing has the same life as under actual load.

11.3.2 Life calculations

The relationship among basic rating life, basic dynamic load rating and dynamic equivalent load rating can be described as the following formula:

$$L_{10} = \left(\frac{C}{P}\right)^{\varepsilon} \quad \text{or} \quad \frac{C}{P} = L_{10}^{\frac{1}{\varepsilon}}$$

Thereinto :
L_{10} :Basic rating life million rotations
C :Dynamic basic specified load rating N
P :Dynamic equivalent load N
ε :Life coefficient ball bearing $\varepsilon = 3$
Roller bearing $\varepsilon = 10/3$

If bearing ' s rotation speed is constant , its basic rating life can be expressed by hours :

$$L_{10k} = \frac{10^6}{60n}\left(\frac{C}{P}\right)^{\varepsilon} \quad \text{or} \quad L_{10k} = \frac{10^6}{60n} L_{10}$$

There into
L_{10k} : Basic rating life h
n :Rotation speed . r/min

As to bearings applied to automotive wheel hubs, its basic rating life can be expressed by miles:

$$L_{10k} = \pi D\left(\frac{C}{P}\right)^{\varepsilon} \quad \text{Or} \quad L_{10k} = \pi D L_{10}$$

There into
L_{10k} :Basic rating life km
D : wheel diameter mm

If bearings make movement like a swing, the amplitude of swing around center is ± γ °, then:

$$L_{10osc} = \frac{180}{2\gamma} L_{10}$$

There into :
L_{10osc} : Basic rating life (Million times swing periods)
γ :Amplitude (degree)

When amplitude is small, no need to calculate basic rating life.

In order to simplify the calculation, we take 500 h as the standard of rating life, and speed coefficient f_n and life coefficient f_h :

$$f_n = \left[\frac{33\frac{1}{3}}{n}\right]^{\frac{1}{\varepsilon}}$$

$$f_h = \left[\frac{L_{10k}}{500}\right]^{\frac{1}{\varepsilon}}$$

Then life calculation can be changed :

$$C = \frac{f_h}{f_n} P$$

According to rotation speed and expected service life, values from fig. 11.1 ,we can easily get the basic dynamic load rating we applied.

1） service life of bearing

In choosing bearing, we should in advance determine proper service life according to machine type , working conditions and reliability. Usually, we can choose in accordance with maximum maintenance period of target machine. Recommending values of service life of bearing required by different kinds of machine, see table 11.1 .

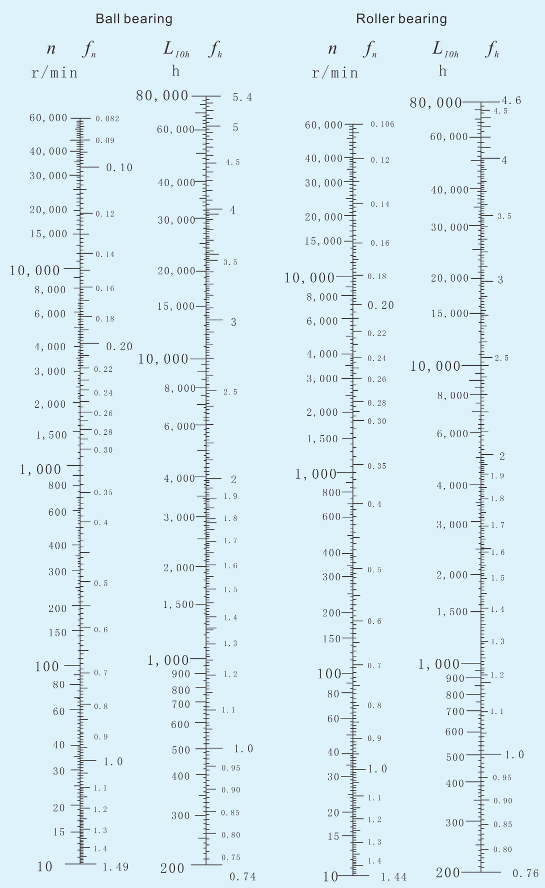


Fig. 11.1Fatigue life coefficient

Table 11.1 Recommended values of bearing service life required by different kinds of machinery

Working conditions	Service life (h)
Seldom utilized instrument and equipment	300～3000
Short intermittent utilized machinery, will not create serious results after stopped, such as manual machinery, agricultural machinery, heavy cargo hoisting equipment crane, automatic feeding device	3000～8000
Intermittent utilized machinery, will create serious results after stopped like power station equipment, conveyers, belt-type transportation machine, cranes, workshop crane	8000～12000
Daily operation 8h but not always fully loaded like electric motors, gear device, crushers, cranes and ordinary machinery.	10000～25000
Daily operation 8h fully loaded , like machine tool, woodworking machine, engineering machinery, printing machinery, separators, and centrifugal machine .	20000～300000
24h operation , such as compressor, pump, electric motor, rolling mill gear device, and textile machinery	40000～50000
24h operation no failure allowed, such as fibre machinery, paper manufacturing machinery, major equipment of power station, water supply facilities drainage plant, mine pump, and mine water discharge facilities.	≈100000

2) Calculations of dynamic equivalent load

When bearing works under constant load in constant direction, its dynamic equivalent load can be calculated according to the formula below:

$$P = XF_r + YF_a$$

In the equations:
P: Dynamic equivalent load N
Fr: Radial load N
Fa: Axial load N
X: Radial dynamic load coefficient
Y: Axial dynamic load coefficient

For dynamic equivalent load caculation and the specific value of radial dynamic load coefficient and axial dynamic load coefficient, please refer to specification table of all types of bearings.

$$P_m = f_m P$$

When bearing takes constant torque load, dynamic equivalent load can be calculated according to the formula below:

In the equations:
P_m: Dynamic equivalent load considered torque load N
f_m: see table 11.2 for torque load coefficient

Table 11.2 torque load coefficient f_m

Load condition	f_m
Torque load small	1.5
Torque load big	2

When bearing take impact load, dynamic equivalent load can be calculated according to the formula below:

$$P_d = f_d P$$

In the equations:
P_d: Dynamic equivalent load (N) considered impact load
f_d: Impact load coefficient, see table 11.3

Table 11.3: f_d value

Loading type	f_d	Example
No impact or slight impact	1.0~1.2	Electric motor, steam turbine, ventilator
Medium impact load	1.2~1.8	Automotive, machine tool, crone, metallurgical equipment, internal combustion engine
Strong impact	1.8~3.0	Crusher, rolling mill, petroleum drill, vibration screen

If bearing works under variable load and speed, mean dynamic equivalent load and mean rotation speed should be used to calculate bearing service life. Normally mean dynamic equivalent load should be calculated according to the equation below:

$$P_m = \sqrt[3]{\frac{1}{N}\int_0^N P^3 dN}$$

In the equations:

P_m: Mean dynamic equivalent load N
P: dynamic equivalent load N (functional equations)
N: total revolutions (r) within one period of load variation

For the relationship between load and rotation speed as show in Figure 11.2, the equation of mean dynamic equivalent load should be:

$$P_m = \sqrt[3]{\frac{N_1P_1^3 + N_2P_2^3 + N_3P_3^3 + \cdots}{N}}$$

In the equation, P1, P2, P3... Is the dynamic equivalent load at revolution N1, N2, N3....

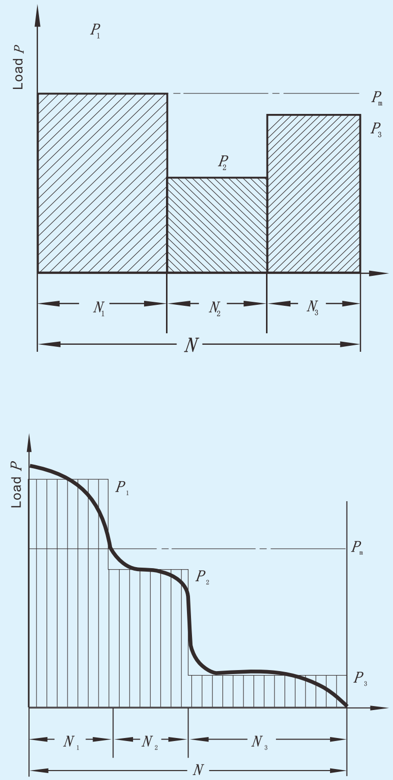


Fig. 11.2 Relations between bearing load and rotation speed

C&U®

When bearing's rotation speed remains constant and the load varies continuously and periodically with time changes, the mean dynamic equivalent load could be determined by of reduction simple formula. See Fig. 11.3 for example.

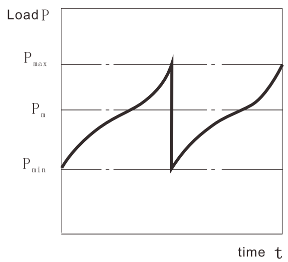
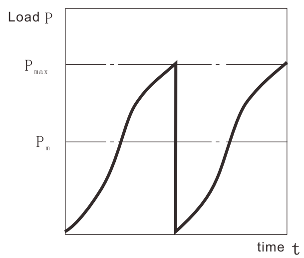
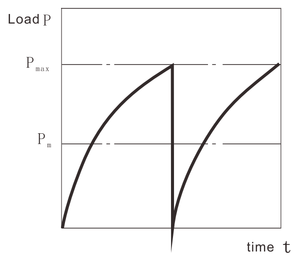
Normal curve	Sine curve	Upper half of sine curve
		
$P_m = \frac{1}{3}(P_{min} + 2P_{max})$	$P_m = 0.65P_{max}$	$P_m = 0.75P_{max}$

Fig. 11.3

If bearing load is composed of Load F_1 whose magnitude and direction are both constant (e.g. rotor weight) and rotation Load F_2 whose size is unaltered (e.g. centrifugal force caused by imbalance) (as shown in Figure 11.4), its mean load F_m can be calculated through the following equation:

$$F_m = \varphi_m = \vec{F}_1 + \vec{F}_2$$

In the equation:

φ_m coefficient can be determined in accordance with Fig. 11.5.After F_m is determined, we can change F_m into mean dynamic equivalent load P_m according to the plane direction of combined load by F_1 and F_2.

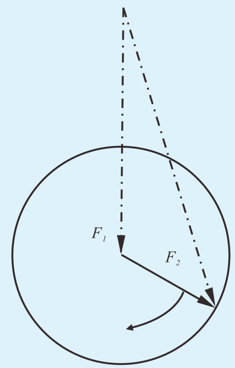


Fig. 11.4 bearing load composed of F1 and F2.

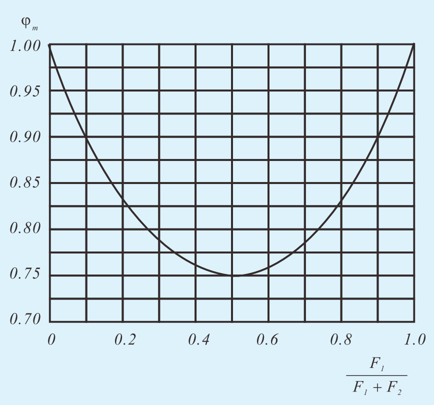


Fig. 11.5 Curve

11.3.3 Main factors that influence bearing's dynamic load capacity

The calculation method for bearing's basic dynamic load rating is applicable to the high quality quenched steel structures(i.e. the high quality vacuum degassed steel). Which is widely used today responding to the machining method and shape design for rolling bearings.

1）Materials

The magnitude, distribution and content of non-metallic inclusions in materials is different from steel smelting method. The difference in materials take either positive or negative effect on the load capacity of bearings. The basic dynamic load rating listed in specification table of all types of bearings in our catalogue are all made by vacuum degassed bearing steel. The load capacity of bearings will be decreased if electric is applied. By contrary, if bearing steel smelted by means of vacuum remelting, electroslag remelting etc. or other equivalent material is applied, the load capacity of bearings would be improved to certain degree.

2) Temperature

The work temperature that ordinary bearing might take can reach 120 ℃(Outer ring is 100 ℃).For special working condition with high temperature, bearings that have special (stabilization) heat treatment or are made of special (heat-resistant) materials are used.

If bearings are often applied under the temperature above 120 ℃, or applied in extremely high temperatures in a short time bearing material will be changed, resulting in the decrease of bearing's load capacity. The influential relationship can be described by the equation below:

$$C_T = g_T C$$

In the equation:

C_T: basic load rating N after thermometric correction

g_T: temperature coefficient, please refer to value in Table 11.4

Table 11.4 g_T value

Working temperature /℃	<120	125	150	175	200	225	250	300
g_T	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.60

3)Hardness

Normally the surface hardness of bearing parts is 61-65 HRC. Yet in some occasions, the actual hardness is lower than the specified range. For example, high temperature bearing treated by high tempering, and some needle roller bearings directly using journal and bearing housing bore as raceway groove. If the surface hardness of bearing material falls, especially to lower than 58 HRC, the load capacity of bearing would decrease accordingly. Its influential relationship can be demonstrated by the following empirical formula:

$$C_H = g_H C$$

$$g_H = (HRC/58)^{3.6}$$

In the equation:

C_H: Basic dynamic load rating N after material hardness correction

g_H: Hardness coefficient

11.3.4 Correction rating life

It is usually satisfactory to use basic rating life L_{10} as the general standard for selecting and assessing bearing life. This life period is correlated to 90 degree of reliability, current material in common use, processing quality as well as routine running condition.

However, in many occasions, it is normally required to calculate the life duration of different degrees of reliability, special bearing performance and even in unusual running conditions. In such cases, we can adopt the formula below for calculating basic correction rating life:

$$L_{na} = a_1 a_2 a_3 L_{10}$$

In the equation:

L_{na}: Special bearing performance and running condition, the correction life whose degree of reliability is 100-n (million revolutions).

a_1: correction coefficient for reliability life duration
a_2: Correction coefficient for special life duration of bearing performance
a_3: Correction coefficient for life in running condition

1）Correction coefficient a_1 for reliability life

Generally, 90% degree of reliability is used to assess bearing's fatigue life, where a_1=1; yet in some occasions, it is required that the degree of reliability is higher than 90%. a_1 coefficient can be chosen by referring to Table 11.5.

Table 11.5 a_1 value

Degree of reliability (%)	90	95	96	97	98	99
a_1	1	0.62	0.53	0.44	0.33	0.21

2) Correction coefficient a_2 for special life of bearing performance

When materials with special type and quality, special processing technique and specific design are adopted to meet the requirements of special life performance, coefficient a_2 could reflect the changes of life duration value.

According to the current situations, we still cannot specify the relation between a_2 value and material characteristics or raceway . Yet when determining a_2 value, we could choose empirical value from several aspects below.

When adopting steel products with very low inclusions or special treatment, $a_2 \geqslant 1$ is acceptable. If special heat treatment brings about the decrease of material hardness, which result in the drop of bearing life, we should choose a_2 value accordingly. When choosing a_2 value, we should also consider whether the special design is in regard to improved or degraded contact stress between rolling element and raceway groove.

Value a_2 cannot be greater than 1 if special material, technique or design is adopted whereas lubrication is poor.

3) Correction coefficient a_3 for life in running condition

Running condition includes whether lubrication is adequate(under work speed and temperature), whether hazardous material from outside enters or not, as well as situations that cause change of material performance(e.g. high temperature brings about decrease of hardness).Under normal running conditions, i.e. correct bearing mounting, adequate lubrication, appropriate steps in preventing penetration of foreign matters, as well as no high temperature that cause change of material property, value a_3 can be 1 if the surface of rolling contact is separated by lubricating oil film.

When the lubricating condition is ideal enough to form elastic fluid pressure oil film on the rolling contact surface of bearings , and can greatly decrease the probability of fatigue damage caused by surface failure, value a_3 can be chosen above 1.

When the lubrication is so poor that the dynamic viscosity of lubricant under working temperature is less than 13mm²/s for ball bearing, and less than 20mm2/s for roller bearing, or rotation speed is in particularly low (n. D_{pw} <10000; "n" stands for rotation speed, D_{pw} for Pitch circle diameter of rolling group.

11.4 Bearing dimension selection according to static load rating

Under working conditions listed below, the bearing dimension should be selected according to static load rating of bearings to guarantee its good performance.

1.Bearing takes continuous load or interval (impact) load when it remains still or rotates slowly (rotation speed ⩽10r/min).

2.Bearing swings slowly under

3.Bearings under normal working load will take discontinuous and relatively large impact load in rotation process.

11.4.1 Static equivalent load of bearings

The radial/axial static equivalent load is radial/axial static load that, during rotation at very slow speed or when bearings are stationary, the same contact stress as that imposed under actual loading condition is generated at the contact center between raceway and rolling element to which the maximum load is applied.

11.4.2 Determine the static load rating required for bearings

The basic formula for selecting bearings according to static load rating should be:

$$C_0 = S_0 P_0$$

In the equation:

C_0: Static load rating N
P_0: Static equivalent load N
S_0: Safety coefficirnt

If the surface hardness of bearing decreases due to special heat treatment, hot operation etc., its capacity for static load will drop accordingly. The influence that material hardness has upon static load of bearing can usually be calculated by the equation below:

$$C_{OH} = \eta_H C_0$$

$$\eta_H = f_H \left(\frac{H_V}{800}\right)^2 \leq 1$$

In the equation:

C_{0H}: Static load rating N after correction of material Hardness
η_H: Hardness coefficient
f_H: Coefficient related to contact type, see Table 11.6
H_V : Vickers hardness value

Table 11.6 f_H value

Contact type	f_H
Ball and surface contact(spherical roller bearing)	1
Ball and raceway groove contact	1.5
Roller and roller contact (spherical roller bearing)	2
Roller and surface contact	2.5

11.4.3 Calculation method for static equivalent load

1.Static equivalent load of radial bearings is calculated according to the following equation:

a=0° radial roller bearing which only takes radial load:

$$P_{0r} = F_r$$

Radial ball bearing and α ≠0° radial roller bearing:

We adopt the relatively larger value calculated by the two equations $P_{0r}=X_0F_r+Y_0F_a$ and $P_{0r}=F_r$

In the equation:

X_0: Static radial load coefficient
Y_0: Static axial load coefficient
For all values of bearing X_0 and Y_0, please refer to dimension and performance table for various bearings.

2.Axial static equivalent load for thrust bearings is calculated according to the following equation:

α = 90° thrust bearing

$$P_{0a} = F_a$$

α ≠90° thrust bearing

$$P_{0a} = 2.3F_r tg\alpha + F_a$$

11.5 The selection of safety coefficent S_0

1)Stationary bearing

For stationary bearing as well as bearings that swing or rotate very slowly, safety coefficient S_0 can be chosen according to Table 11.7.

Table 11.7 Safety coefficient S_0 for static bearing

Bearing's application	S_0
Plane laminae of variable pitch propeller	⩾0.5
Dam sluice gate Device	⩾1
Suspension bridge	⩾1.5
Heavy crane hook with small dynamic load	⩾1
Minitype handing crane hook crampon with large dynamic load	⩾1.6

2) Rotating bearing

For some swivel bearings with big change in bearing load, especially when there is major impact load in operation, we must verify the bearing in reference to static load rating after it was selected according to dynamic load rating. If bearing's rotation speed is low, and the requirement for running precision and friction moment is not high, relatively large contact stress is allowed, i.e. Can be chosen S_0< 1 . By contrary, should be chosen S_0> 1 .The safety coefficient S_0 of Swivel bearing could be determined according to Table 11.8:

For spherical thrust roller bearing, whether it rotates or not, must be chosen S_0 ⩾4.

In addition, when selecting bearing according to static load rating, we must pay attention to the rigidity of fitting position. When rigidity of bearing housing is relatively low, we could choose higher safety coefficient; contrarily, we should choose lower safety coefficient.

Table 11.8 Safety coefficient S_0 for rotating bearings

Application requirement or load characteristic	S_0	
	Ball bearing	Roller bearing
High requirement for running accuracy and smoothness, with impact load.	1.5~2	2.5~4
Normal use.	0.5~2	1~3.5
Low requirement for running accuracy and smoothness, without impact and vibration.	0.5~2	1~3