4. Rolling bearing load and life, and limit speed

4.1 Rolling bearing basic load rating

4.1.1 Temperature modification for bearing basic dynamic load rating

When the bearing is used in high temperature condition, the structure of material will be changed, and the rigidity will decline, and then the bearing basic dynamic load rating will decrease compared with used in normal condition.

Once the structure of material changed, the structure can't be recovered even if the temperature comeback to normal temperature.

Therefore, when the bearing is used in high temperature situation, it must be temperature adjusted to basic dynamic load rating in table of bearing dimension, that is to say, the dynamic load rating multiply by temperature factor list in table4-1.

Table 4-1 temperature coefficient

Bearing temperature ℃	125	150	175	200	250
Temperature coefficien	1	1	0.95	0.90	0.75

To these bearings, that used in above 120 centigrade situation long time, the change of dimension will be large just encounter normal heat treatment. So the stabilization treatment to dimension must be taken.

The code of dimension stabilization treatment and the range of usage temperature listed in table4-2.But after the dimension stabilization treatment, the rigidity of bearing will be reduce, sometimes the basic rating dynamic load will decrease.

Table 4-2 Dimension stabilization treatment

The code of dimension stabilization treatment	The range of usage temperature
S0	Exceed 100℃ to 150℃
S1	150℃ 200℃
S2	200℃ 250℃

4.1.2 Basic static load rating

The partly permanence distortion will occur between roller and the interface of raceway when the bearing encountered too large static load, or to be subjected to pulse load at very slow speed.

The basic static load rating is used in calculations tangency stress between roller and the raceway center of raceway, the roller is subjected to largest load.

- Ball bearing 4200MPa (except self aligning bearing)
- Roller bearing 4000MPa

$$f_s = \frac{C_0}{P_0} \quad \text{(formula 4-1)}$$

Where : f_s: Safety factor
C_0: Basic static load rating
P_0: Equivalent static load

The permission value of bearing equivalent static load depends on the bearing basic load rating. But the limit of bearing usage that depends on the permanence distortion (partly sunken) will be changed, when the requirement of bearing performance and the usage condition of bearing varies.

Therefore, to analyze the safety degree of bearing basic load rating, the safety factor was established based on experience. The formula 4-1 is calculation method, and the safety factor of varies work environment list in table 4-3.

Table 4-3 Safety factor f_s

Usage Conditions		f_s (minimum) Ball Bearing	f_s (minimum) Roller Bearing
General rotation	General usage condition	1	1.5
	Shock load	1.5	3
Seldom rotation (sometimes oscillate)	General usage condition	0.5	1
	Shock load or non-uniformity load	1	2

Note: To Thrust self-aligning roller bearing, the $f_s \geq 4$

4.2 Rolling bearing equivalent load

4.2.1 Equivalent dynamic load

Many bearings encounter combined load which combined by radial load and axial load. Moreover, there are varies condition of load, for example, the value of load changed.

So, it can't direct compare reality bearing load with basic dynamic load rating.

Therefore, the supposed load can be used to analyze and compare, which through the center of bearing, and transformed by reality load, the value and direction are fixed. In the case of tentative load, the bearing has the life same as the situation of reality load and speed.

The supposed load can be regarded equivalent dynamic load, and can be expressed as P.

4.2.2 Equivalent static load

The equivalent static load is assumption load. When the bearing is stationary or rotates at very low speed, and under the assumption load, it will cause the contact stress between the rolling element to which the maximum load is subjected and interface center of raceway. This contact stress is the same as the actual load to which the bearing is subjected.

The radial load which go through the center of bearing and the axial load which through the center line of bearing are applied respectively for the equivalent of radial bearing and thrust bearing.

(Notes) The equation used for equivalent load is listed in table of dimension classified by bearing type.

4.2.3 Calculation of bearing load

The load to which the bearing is subjected includes the weight of bearing backstop, the transfer impetus of gear or belt and the load induced during machine rotation.

Due to the bearing load varies mostly, and the degree or value of change is hardly determined, so it's impossible to estimate the bearing load by simple calculation.

Therefore, we usually calculate the load of bearing by theoretical value multiplying experience factor.

(1) load factor

Though the radial load or axial load on bearing can be calculated by common mechanical method, but the actual load to which the bearing is subjected is larger than the calculated value due to the reason of vibration or shock. Therefore, we calculate the load of bearing by theoretical value multiplying load factor related vibration or shock.
It is obtained from the equation 4-2, and the load factor listed in table 4-4.

$$F = f_w \cdot F_c \quad \text{(formula 4-1)}$$

Where : F: Actual load, N
F_c: Theory load,N
f_w: Load factor

(2) The load in belt or chain drives

The theoretical load on the belt axle can be obtained by calculation of effective belt drive force.

But the actual load can be obtained by theoretical load multiplying load factor above and belt factor, which related to belt strain.

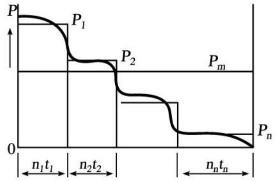
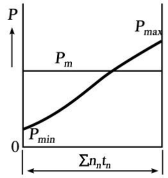
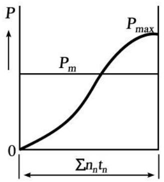
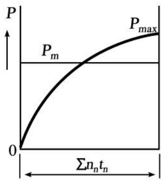
Table 4-4 Load factor f_w

Usage Condition	Purpose	f_w
Almost non vibration or shock	Motor, Machine tool, Instrument	1.0-1.2
General rotation (Slight shock)	Railway vehicle, Auto, Paper machine, Fan, Compressor, Agriculture machine	1.2-2.0
Intensity vibration or shock	Rolling mill, Muller, Architecture machine, Vibration screen	2.0-3.0

4.2.4 Equivalent dynamic load in load change

When the bearing under the load which magnitude or direction variety, it need to calculate the averaging of equivalent dynamic load, which makes bearing having the same life as under actual condition.
The method for calculation of average equivalent dynamic load Pm illustrated in (1)-(4).

(3) Sine transformation

(1) Ladder transformation	(2) humdrum transformation
	
$P_m = \sqrt[P]{\dfrac{P_1^P n_1t_1+P_1^P n_2t_2+\cdots\cdots+P_n^P n_nt_n}{n_1t_1 + n_2t_2 + \cdots\cdots n_nt_n}}$ ...... (5.2)	$P_m = \dfrac{P_{min} + 2P_{max}}{3}$ ...... (5.3)
(3) Sine transformation	**(4) Sine transformation (1/4 cycle of Sine wave)**
	
$P_m = 0.68\ P_{max}$ ...... (5.4)	$P_m = 0.75\ P_{max}$ ...... (5.5)

In (1)~(4)

- P_m: The average of equivalent dynamic load, N
- P_1: The equivalent dynamic load on loading time t_1 at speed n_1, N
- P_2: The equivalent dynamic load on loading time t_2 at speed n_2, N
- : :
- P_n: The equivalent dynamic load on loading time tn at speed nn, N
- P_{min}: The minimum of equivalent dynamic load, N
- P_{max}: The maximum of equivalent dynamic load, N
- $\sum_{niti}$: The total rotation on $t_1+t_2+\ldots t_n$
- P: Index
  - Ball bearing……….P=3
  - Roller bearing……..P=10/3

The average of speed can be calculated by

$$n_m = \frac{n_1t_1+n_2t_2+\cdots\cdots+n_nt_n}{t_1+t_2+\cdots\cdots\cdots\cdots+t_n}$$

4.3 Rolling bearing life

The life of a rolling bearing is defined as the number of revolutions at ideal condition, which the bearing is capable of enduring before the first sign of metal fatigue occurs on one of its inner rings, outer ring or rolling elements (or the number of operating hours at a given speed).

The identical bearings operating under identical conditions, such as dimension, structure, material, the method of manufacture, have different individual endurance lives. The life of bearing can only be predicted statistically, because the fatigue of material has discrete. Life calculations refer only to a bearing population in same running condition, and a given degree of reliability, i.e. 90 %.

Furthermore field failures are not generally caused by fatigue, but are more often caused by wear, corrosion, rupture, impress, burn.

4.3.1 The calculation of bearing life

Basic dynamic load rating

The basic dynamic load rating is the capability of enduring the rolling fatigue (the capability of load). It is assumed that the load is constant in magnitude and direction and is radial for radial bearings and axial, centrically acting (for thrust bearings), the basic rating life is 1 000 000 revolutions. The basic dynamic load rating of radial bearing and thrust bearing is defined as the radial basic dynamic load rating and the axial basic dynamic load rating respectively, and can be marked as Cr and Ca, and its value listed in the table of bearing dimension.

Basic rating life

The formula (4-3) explains the relationship between the bearing basic rating life, basic dynamic load rating and equivalent dynamic load. If the speed is constant, it is often preferable to calculate the life expressed in operating hours, using the equation (4-4).

(Revolution) $L_{10}=\left(\frac{C}{P}\right)^P$ ———— (formula 4-3) (Time) $L_{10h}=\frac{10^6}{60n}\left(\frac{C}{P}\right)^P$ ———— (formula 4-4)

where:
- L_{10}: basic rating life, millions of revolutions
- L_{10h}: basic rating, operating hours
- C: basic dynamic load rating, N
- P: equivalent dynamic bearing load, N
- n: rotational speed, r/min
- p: exponent of the life equation
  3 for ball bearings 10/3 for roller bearings

4.3.2 Rating life modification

L10 is the basic rating life at 90% reliability, but sometimes the higher reliability than 90% is needed based on the different usage.

Furthermore, the bearing life can be extended by using special material, and also be influenced by usage condition, such as lubricant.

Considered of these factors mentioned above, the basic life rating named modification rating life.

$L_{na}=a_1a_2a_3L_{10}$ ———— (formula 4-5)

where:
- L_{na}: modification rating life, millions of revolutions. Lna is life at 100-n%reliability considered of bearing characteristic and usage condition. N% is the failure rate.
- L_{10}: basic rating life (at 90% reliability), millions of revolutions
- a_1: reliability coefficient
- a_2: bearing characteristic coefficient
- a_3: usage condition coefficient

{Note} More attention should be paid to the intensity of shaft and shell, when selecting bearing dimension based on the reliability higher than 90%.

(1) **Reliability Factor a_1**

When calculating the bearing life based on the Reliability>=90% (Failure Probability<=10%), choose the Reliability Factor a_1 in Table 4-5.

Table 4-5 Reliability factor a_1

Reliability %	L_{na}	a_1
90	L_{10a}	1
95	L_{5a}	0.62
96	L_{4a}	0.53
97	L_{3a}	0.44
98	L_{2a}	0.33
99	L_{1a}	0.21

(2) **Characteristic Factor a_2**

According to the material, designation and manufacturing process, the characteristic related to the life of bearing may be changed. We use a_2 for correction.

It tested that high quality vacuum carbon deoxidized steel, as a standard bearing material, can obviously extend the bearing life. All the basic dynamic load rating in the table of bearing dimension are base on this material, and now a_2=1.

Otherwise, to those materials which designed for extending the bearing life, a_2 >1.

(3) **Application Environment Factor a_3**

The application environment (especially the lubrication) has a direct influence on the bearing life. We use a_3 for correction.

When lubricated correctly, a_3=1. And we use a_3>1 when with excellent lubrication.

But to the below condition, a_3 <1.

- kinematic viscosity is decreasing when running.
  For ball bearing, viscosity is less than 13mm²/s;
  For roller bearing, viscosity is less than 20mm²/s.
- There is contamination in the lubricant.
- When inner ring is quite oblique compared with the outer ring, and the rigidity is decreasing when in high temperature environment, we must correct the basic dynamic load rating with temperature factor. (according to the Table 4-1).
- The speed is quite lower, as the pitch diameter of the roller element multiplied by the speed is less than 10000.

[Note] Even with special material (a_2>1), $a_2 x a_3$>1 can not stand if without proper lubrication. Consequently, in this situation (a_3<1), $a_2 \leqslant 1$.

Because we can not separate a_2 with a_3, someone recommends correction factor a_{23} as combined.

4.4 Limit speed of rolling Bearing

The speed of bearing is restricted by the heat caused by friction. After over-speed, bearing will stop because of burned.

The limit speed of bearing is defined as that bearing can run continuously rather than burned by the heat caused by friction.

Consequently, the limit speed of bearing is determined by the type, dimension, precision of the bearing, the type, quality, quantity of the lubrication, the material, type of the cage, the loads and so on.

The limit speeds of all kinds of bearings for grease and oil lubrication showed separately at bearing dimension table, the value represent the limit value when bearing in normal condition (C/P ≥13, Fa/ Fr ≤0.25)

Besides, lubricants, according to their types and series, may excel at some functions, but it's not applicable for high-speed.

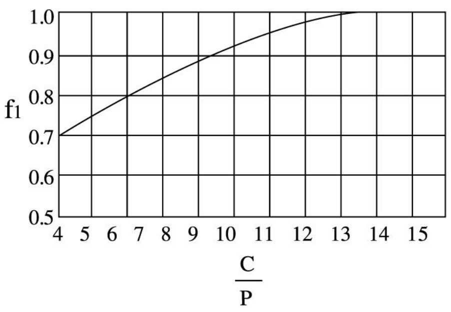
4.4.1 Correction for Limit Speed

When C/P<13 (the equivalent dynamic load is larger than 8% of the basic load rating C), or the axial load is larger than 25% of the radial load in combined load, we use function 4-6 for correction.

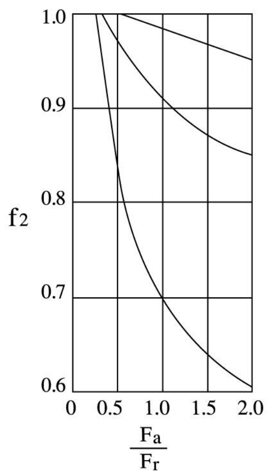
$$n_a = f1 \cdot f2 \cdot n \cdots\cdots (4\text{-}6)$$

where:
n_a: limit speed after correction, R/min
f1: correction factor related to load
f2: correction factor related to combined load
n: limit speed in normal condition, R/min
C: basic load rating, N {kgf}
P: equivalent dynamic load
Fr: radial load, N {kgf}
Fa: axial load, N {kgf}

Plot 4-1 correction factor related load f1



Plot 4-2 correction factor related synthesize load f2



4.4.2 Limit speed of Sealed Ball Bearing

The limit speed of ball bearing with contact seals (type RS) is restricted by the line speed of the seals interface. This limit of the line speed is determined by the rubber material of the seals.

4.4.3 Attentions for High Speed Application

When bearing is in high speed, especially when it's approaching or over the speed limit, attentions are listed below:

(1) use precision bearings;

(2) analysis the inner clearance (the influence of the decreased inner clearance because of the temperature increasing)

(3) analysis the material and type of cage (for high speed application, we prefer machined copper alloy and phenolic resin cage, besides, molding synthetic resin cage is applicable)

(4) analysis the lubrication (we prefer lubrications for high speed rotation, such as, cycle lubrication, injection lubrication, oil mist and oil air lubrication)

4.4.4 Friction Factor of Bearing (Reference)

Compared with sliding bearing, the friction torque of the rolling bearing can be calculated according to the inner diameter as following:

$$M= \mu P \frac{d}{2}$$

where: M: friction torque, mN, M{kgf, mm} P: load, N{kgf}
μ: friction factor, table 4-6 d: nominal bore diameter, mm

The type of the bearing, the load, the speed and the type of lubrication, all have a big influence on the friction factor. Generally, when under constant speed, the friction factor listed in Table 7.1.

Generally speaking, for sliding bearing, μ=0.01~0.02. Sometimes u=0.1~0.2.

Table 4-6 Friction coefficient of each type bearing

The type of bearing	Friction coefficient
Deep groove ball bearing	0.0010-0.0015
Angular contact ball bearing	0.0012-0.0020
Self-aligning ball bearing Cylindrical roller bearing	0.0008-0.0012
Full needle roller bearing	0.0025-0.0035
Needle roller bearing with cage	0.0020-0.0030
Taper roller bearing	0.0017-0.0025
Self-aligning roller bearing	0.0020-0.0025
Thrust ball bearing	0.0010-0.0015
Thrust self-aligning roller bearing	0.0020-0.0025