$$\delta t \fallingdotseq 12.5 \times 10^{-6} t \left(\frac{4D+d}{5}\right) \cdots\cdots\cdots\cdots (7.1)$$

Here, t : Temperature differance between the inner and the outer race (℃)
d : Inner race inside diameter (mm)
D : Outer race outside diameter (mm)

The axial clearance can also be insufficient when the bearing units are mounted far apart along the shaft. In this case, the axial expansion and ball bearing axial clearance must be carefully matched for proper operation.

The shaft expansion. $\Delta \ell$, can be calculated by the following equation.

$$\Delta \ell = \alpha \cdot \Delta t \cdot \ell \cdots\cdots\cdots\cdots (7.2)$$

Here, α : expansion coefficient (1/℃)
t : temperature difference (℃)
ℓ : distance between units (mm)

8. Bearing life

8.1 Life

Bearing life is defined for each bearing as the total number of revolutions made by the bearing before failure. The failure is usually due to rolling fatigue on the orbiting races or on the balls. It can also be defined as the total number of hours of operation before failure when the bearing is operated at a constant speed.

8.2 Rated life

Rated life for a bearing unit is defined from a set of identical bearings operating in identical conditions. It is the total number of revolutions (or number of hours when operated at the same speed) made by the bearing before failure that is exhibited by 90% of the bearing in the tested set.

8.3 Dynamic radial load rating

Dynamic radial load rating for a bearing is determined by applying a constant radial load during rotation of the inner race with the outer race in fixed position. It is the radial load in constant direction and magnitude that gives the bearing a rated life of 1 million revolutions.

In other words, the dynamic radial load rating for a bearing is the maximum allowable load that gives the bearing a rated life of 1 million revolutions.

8.4 Relationship between rated life and dynamic radial load rating

The following relationship exists for the ball bearing unit's rated life, the dynamic radial load rating (or basic load rating) and the actual load on the bearing.

$$L = \left(\frac{C}{P}\right)^3 \cdots\cdots\cdots\cdots (8.1)$$

Here, L : Rated life (unit 10^6 revolution)
P : Bearing load (equivalent radial load) Kg
C : Dynamic radial load rating Kg

Or, since the rated life is easier to express in terms of operating time rater than in number of revolutions, the following equation applies.

$$Lh = \frac{10^6 \cdot L}{60 \cdot n} = \frac{10^6}{60 \cdot n} \cdot \left(\frac{C}{P}\right)^3 = \frac{50000}{3 \cdot n} \cdot \left(\frac{C}{P}\right)^3 \cdots\cdots\cdots (8.2)$$

Here, n : Rotation speed (rpm)
Lh : Reted life (h)

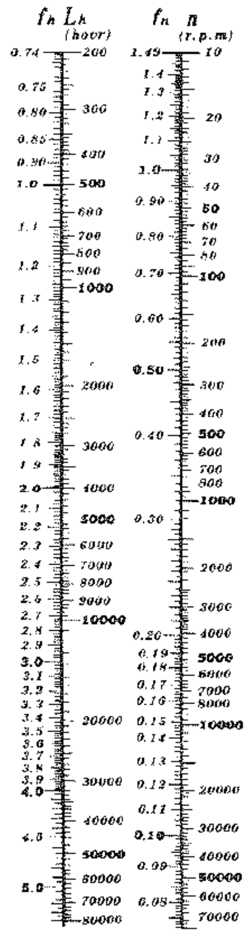
The above equation can be expressed in easier forms for use in real designing problems.

$$Lh = 500 \cdot fh^3 \cdots\cdots\cdots (8.3)$$

$$fh = \frac{C}{P} \cdot fn \cdots\cdots\cdots (8.4)$$

$$fn = \left(\frac{33.3}{n}\right)^{\frac{1}{3}} \cdots\cdots\cdots (8.5)$$

Here, fh and fn are life and speed factors, respectively. The rated life time can be approximately determined from fh, fn and rotation speed by referring to the scale shown in figure 8.1



[FIGURE 8.1]

8.5 Static radial load rating

Static radial load rating is the static load that permanently deforms the contact point (maximum stress point) between the race diameter and the ball by 0.0001 times the ball diameter.

$$Po\ max = \frac{Co}{Sf} \cdots\cdots\cdots (8.6)$$

Here,
Po max : Maximum static equivalent radial load (Kg)
Co : Static radial load (Kg)
Sf : Safety factor

<TABLE 8.1> Safety factor (Sf)

Operationg condition	Sf
Normal operation with small amount of permanent deformities	0.5 ~ 1.0
Normal operation	1.0 ~ 1.2
Operation with vibration and shock	1.5 ~ 2.5
Operation requiring low noise	2.0 ~ 3.0

8.6 Equivalent radial load

The total load on the bearing is made of the radial laod directed in the perpendicular direction of the shaft axis, and the thrust load directed in the axial direction of the shaft axis, The load, P, used in the calculation of rated life is only the radial component of the load.

But, in real situations where a combination of radial and thrust load is applied to the bearing, both loads are combined and converted to a single basic load for convenience in calculation and manipulation.

This basic load is called the equivalent radial load and it is determined by the following equation.

$$Pr = XVFr + YFa \cdots\cdots\cdots(8.7)$$

Here, Fr : Actual radial load (Kg)
Fa : Actual thrust load (Kg)
X : Radial factor
Y : Thrust factor
V : Speed factor

<TABLE 8.2> X, Y and V factors

$\frac{Fa}{Co}$	V		Fa/VFr > e		e
	Inner race	Outer race	X	Y	
0.014	1.0	1.2	0.56	2.30	0.19
0.028				1.99	0.22
0.056				1.71	0.26
0.084				1.55	0.28
0.11				1.45	0.30
0.17				1.31	0.34
0.28				1.15	0.38
0.42				1.04	0.42
0.56				1.00	0.44

Remark : 1) Co = Static radial load (Kg)

2) When $\frac{Fa}{V \cdot Fr} \leq e$, then X=1 and Y=0

3) If the exact number of $\frac{Fa}{Co}$ is not listed in Table 8.2, use interpolation to determine the factor quantity.

8.7 Static equivalent radial load

Static equivalent radial load is the actual load that is required to permanently deform the maximum contact stress point between the race wheel and the ball. The static equivalent radial load is determined by taking the maximum value from the following two equations.

$$Po = XoFr + YoFa \cdots\cdots\cdots(8.9)$$

$$Po = Fr \cdots\cdots\cdots\cdots\cdots\cdots(8.9)$$

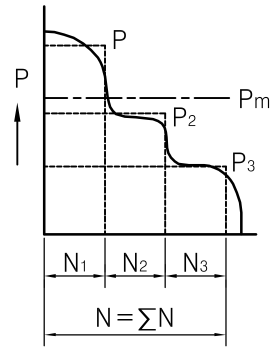
Here, Po : Static equivalent radial load (Kg)
Fr : Actual radial load (Kg)
Fa : Actual thrust load (Kg)
Xo : Static radial factor
Yo : Static thrust factor

The commonly used values for Xo and Yo are 0.6 and 0.5 respectively

8.8 Average load

The average load is used to easily calculate the life time of the bearing which is equal to the actual life time when the bearing is operating with pulsating loads.

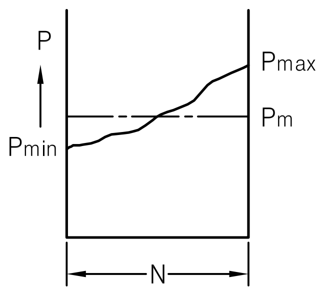
The average load can be calculated by the method in equation 8.10 if the actual load and the total number of revolution is known [Figure 8.2]



[FIGURE 8.2]

$$Pm = 3\sqrt{\frac{\sum_i (Pi^2 \cdot Ni)}{\sum_i Ni}} \cdots(8.10)$$

Here,
Pm : Average load (Kgf)
Pi : Load (Kgf)
Ni : Total number of revolutions with Pi load



[FIGURE 8.3]

If the load is changed monotonically and continuously as shown in Figure 8.3 the average load is calculated by equation 8.11

$$Pm = \frac{Pmin + 2 \cdot Pmax}{3} \cdots\cdots\cdots(8.11)$$

8.9 Temperature dependence of radial load rating

If the rolling bearing unit is operated at high temperatures above 120℃, the bearing material's degree of hardness is reduced and thus the radial load rating is also reduced. In turn, the rated life is also reduced at high temperature operations. The temperature dependence of the radial load rating is shown in equation 8.12

$Ct = ft \cdot C$ ··················(8.12)

Here, Ct : Dynamic radial load rating at fixed operating temperature (Kg)

ft : Temperature factro (reducing factor for radial load rating)

C : Dynamic load rating (Kg)

<TABLE 8.3> Temperature factor(ft)

Bearing temperature(℃)	125	150	175	200	225	250
Temperature factor(ft)	0.95	0.90	0.85	0.75	0.65	0.6

9. Bearing load calculation

A load on a bearing is commonly produced by the weight of the supporting structure, weight of the shaft itself, power transmission of gear or belt, and loads generated by the operation of the machine. Some loads can be theoretically calculated while others are very difficult to calculate.

In addition, machine operation is usually accompanied by vibration and shocks. These affects make accurate calculation of the applied load very difficult. Therefore, in order to determine the bearing load more accurately, many calculation factors determined from experience are multiplied to the calculated loads.

9.1 Load factor

The real load on a bearing is usually greater than the calculated value because of vibrations and shocks.

Therefore, the real applied load is determined by multiplying the calculated load with load factors.

Bearing load = Load factor(fw) × calculated load ·· (9.1)

<TABLE 9.1> Load factor

Load condition	fw	Application example
Smooth operation with no shocks	1.0~1.2	Electrical machines, compressed air machines
Operation with small shocks	1.2~2.0	Power transmission, metallic machines, building machines, moving machines
Operation with frequent vibrations and shocks	2.0~3.0	Construction machines, rolling machines, agricultural machinery

9.2 Belt or chain drive load during rotation

The following method is used when belt or chain is used to transmit power. Added moment M is

$$M = 97400 \frac{H}{n} (Kg - cm) \cdots\cdots\cdots\cdots (9.2)$$

Effective transmission power P is

$$P = \frac{M}{r} (Kg) \cdots\cdots\cdots\cdots (9.3)$$

Her H : transmission horse power (KW)

n : rotation speed (rpm)

r : effective radius of pully or sproket wheel

<TABLE 9.2> Belt factor, fb

Belty type	fb
V belt	2.0 ~ 2.5
Plane belt(with tension plley)	2.5 ~ 3.0
Plane belt	4.0 ~ 5.0
Silk belt	3.5 ~ 4.5
Chain	1.25 ~ 1.5

Remark : Take the larger numbers for fb and fc for slow speed poeration and for operation with short axis to axis distance.

9.3 Gear rotation load

The calculation method for gear load is different for different styles of gear. The following method applies for the simplest style spur gear.

The gear moment M is,

$$M = 97400 \frac{M}{n} (Kg-cm) \cdots\cdots (9.4)$$

In figure 9.1, tangential force P_1 is,

$$P_1 = \frac{M}{r} (Kg) \cdots\cdots\cdots\cdots (9.5)$$

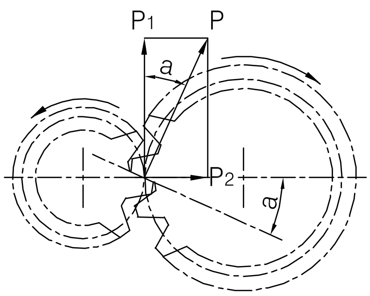
Perpendicular force P_2 is

$$P_2 = P_1 \cdot \tan\alpha \cdots\cdots\cdots\cdots (9.6)$$

Therefore, theoretical total force P applied to the bearing is calculated by

$$P = \sqrt{P_1^2 + P_2^2} = \frac{P_1}{\cos\alpha} \cdots\cdots\cdots (9.7)$$

The actual applied load on the bearing must be calculated by multiplying the gear factor, fg, listed in Table 9.3. The gear factor is based on the teeth angle and the overall quality of the gear.



[FIGURE 9.1]