4. Calculation of Bearing Load

In order to obtain the values of loads applied to a bearing, all of weight of rotating element, transmitting force by gear or belt, and load generated by the machine have to be calculated first. Some of these loads are theoretically calculable, but the others are difficult to obtain. So, various empirically obtained coefficients have to be utilized.

4-1 Load Applied to Shaft

4-1-1 Load Factor

The actual load applied to the bearing mounted on the shaft could be bigger than theoretically calculated value. In this case, following equation is used to calculate the load applied to the shaft.

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

Where,

F : Actual load applied to the shaft

f_w : Load factor(Refer to Table 4-1)

F_c : Theoretically calculated load

Table 4-1 Load Factor f_w

Operating Conditions	Typical Applications	f_w
Smooth Operation withoutSudden Impact	Motor, machine tools, air-conditioner	1..........1.2
Normal Operation	automotive vehicle paper-making machine, elevator, crane	1.2.......1.5
Operation with vibration and sudden impact	Crusher, construction equipment, farming equipment	1.5.......3

4-1-2 Load Applied to Spur Gear

Calculation methods for loads applied to gears vary depending on gear types of different rolling methods, but for the simplest spur gear, it is done as follows.

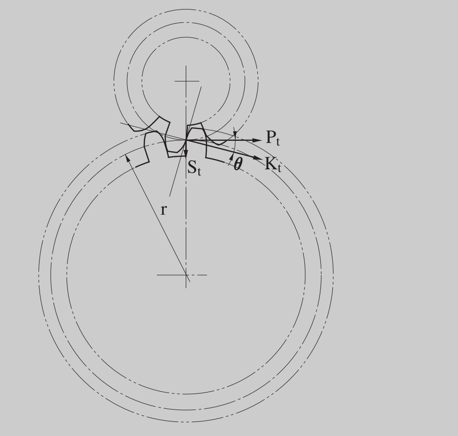


Fig. 4-1 Combined Forces Applied to Spur Gear

$$M = 9{,}550{,}000 \cdot H / n \quad \text{(Equation 4-2)}$$

$$P_t = M / r \quad \text{(Equation 4-3)}$$

$$S_t = P_t \cdot \tan\theta \quad \text{(Equation 4-4)}$$

$$K_t = \sqrt{P_t^2 + S_t^2} = P_t \cdot \sec\theta \quad \text{(Equation 4-5)}$$

Where,

M	:	Torque applied to gear	[N·mm]
P_t	:	Tangential force of gear	[N]
S_t	:	Radial force of gear	[N]
K_t	:	Combined force applied to gear	[N]
H	:	Rolling force	[kW]
n	:	Rotating speed	[rpm]
r	:	Pitch circle diameter of driven gear	[mm]
θ	:	Pressure angle	

Other than the theoretical loads obtained above, vibration and/or impact are also applied to the gear depending on its tolerances. Therefore, the actually applied loads are obtained by multiplying theoretical loads by gear factor, f_g(Refer to the

Table 4-2).

Here, when accompanied by vibration, following equation can be used to obtain the load by multiplying gear factor, f_g, by load factor, f_w.

$$F = f_g \cdot f_w \cdot K_t \quad \text{(Equation 4-6)}$$

Table 4-2 Gear Factor f_g

Gear Types	f_g
Precision Ground Gear (Below 0.02mm of pitch error and form error)	1...... 1.1
Normal Cutting Gear (Below 0.01mm of pitch error and form error)	1.1....1.3

4-1-3 Loads Applied to Chain and Belt

Loads applied to sprocket or pulley, when power is transmitted through chain or belt, are as follows.

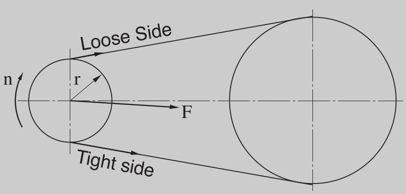


Fig. 4-2 Loads Applied to Chain and Belt

$$M = 9{,}550{,}000 \cdot H / n \quad \text{(Equation 4-7)}$$

$$K_t = M / r \quad \text{(Equation 4-8)}$$

Where,

- M : Torque applied to sprocket or pulley [N·mm]
- K_t : Effective transmitting force of chain or belt [N]
- H : Transmitting power [kW]
- n : Rotating speed [rpm]
- r : Effective radius of sprocket or pulley [mm]

The actually applied loads are obtained, as shown in the following equation, by multiplying factor, f_b, (For chain transmission, vibration/impact loads have to be considered, and for belt transmission, initial tension.) by effective transmitting force.

$$F = f_b \cdot K_t \quad \text{(Equation 4-9)}$$

Table 4-3 Chain/Belt Factor, f_b

Chain/Belt Types	f_b
Chain	1.5
V Belt	2.....2.5
Fabric Belt	2.....3
Leather Belt	2.5.....3.5
Steel Belt	3.....4
Timing Belt	1.5........2

4-2 Average Load

Loads applied to a bearing usually fluctuate in various ways. At this time, loads applied to the bearing are transformed to mean load, which yields same life, to calculate the fatigue life.

4-2-1 Fluctuation by Stages

When fluctuating by stages like in the Fig. 4-3, the below equation is used to get the mean load, P_m.

$$P_m = \sqrt[p]{\frac{t_1 n_1 P_1^{\,p} + t_2 n_2 P_2^{\,p} + \dots + t_n n_n P_n^{\,p}}{t_1 n_1 + t_2 n_2 + \dots + t_n n_n}} \quad \text{(Equation 4-10)}$$

Where,

p : 3 for ball bearing

10/ 3 for roller bearing

Average speed, n_m, can be obtained from the Equation 4-11.

$$n_m = \frac{t_1 n_1 + t_2 n_2 + \dots + t_n n_n}{t_1 + t_2 + \dots + t_n} \quad \cdots\cdots \text{(Equation 4-11)}$$

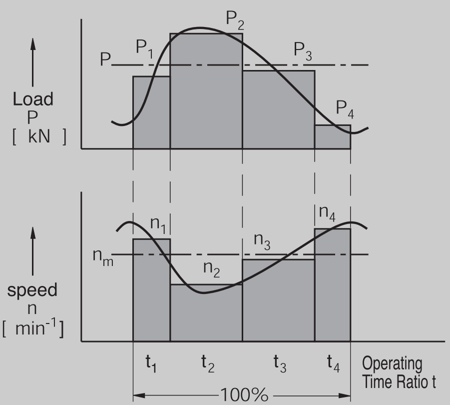


Fig. 4-3 Load and Speed Fluctuating by Stages

4-2-2 Rotating and Static Loads

When both rotating and static loads are applied at the same time, the mean load, P_m, can be obtained by using both Equation 4-12 and 4-13.

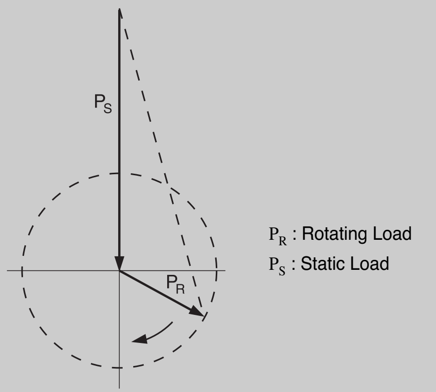


Fig. 4-4 Rotating and Static Loads

- When $P_R \geqq P_S$

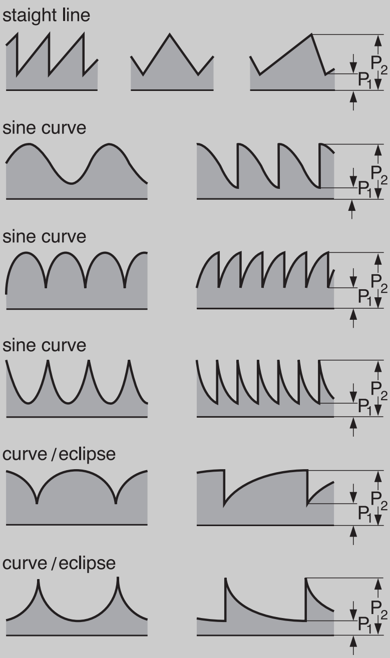
$$P_m = P_R + 0.3 \cdot P_S + 0.2 \frac{P_S^2}{P_R} \quad \cdots\cdots \text{(Equation 4-12)}$$

- When $P_R < P_S$

$$P_m = P_S + 0.3 \cdot P_R + 0.2 \frac{P_R^2}{P_S} \quad \cdots\cdots \text{(Equation 4-13)}$$

4-2-3 Continuous Fluctuation

When load is fluctuating continuously like in the Fig. 4-5, the below equations are used to get the mean loads.



$$P = 0.63 \cdot P_2 + 0.37 \cdot P_1 \quad \text{(Equation 4-14)}$$

$$P = 0.68 \cdot P_2 + 0.32 \cdot P_1 \quad \text{(Equation 4-15)}$$

$$P = 0.75 \cdot P_2 + 0.25 \cdot P_1 \quad \text{(Equation 4-16)}$$

$$P = 0.55 \cdot P_2 + 0.45 \cdot P_1 \quad \text{(Equation 4-17)}$$

$$P = 0.84 \cdot P_2 + 0.16 \cdot P_1 \quad \text{(Equation 4-18)}$$

$$P = 0.38 \cdot P_2 + 0.62 \cdot P_1 \quad \text{(Equation 4-19)}$$

Fig. 4-5 Continuously Fluctuating Loads and Average Loads

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4-3 Equivalent Load

4-3-1 Dynamic Equivalent Load

A load applied to a bearing usually is a combined load of radial and axial loads.

If this is the case, then the load applied to a bearing itself can not be directly applied to the life calculating equation.

Therefore, a virtual load, obtained assuming that it has same life as when the combined load actually applies, applied to the center of bearing has to be obtained first to calculate the bearing life. This kind of load is called as the dynamic equivalent load.

The Equation to obtain the dynamic equivalent load of radial bearing is shown below.

$$P = X \cdot F_r + Y \cdot F_a \quad \text{(Equation 4-20)}$$

Where,

P	: Dynamic equivalent load	[N], {kgf}
F_r	: Radial load	[N], {kgf}
F_a	: Axial load	[N], {kgf}
X	: Radial load factor	
Y	: Axial load factor	

The values of X and Y are listed in the dimension tables.

For thrust spherical roller bearings, dynamic equivalent load can be obtained using following Equation.

$$P = F_a + 1.2 \cdot F_r \quad \text{(Equation 4-21)}$$

Provided, $F_r \leqq 0.55 \cdot F_a$

4-3-2 Static Equivalent Load

Static equivalent load is a virtual load that generates the same magnitude of deformation as the permanent plastic deformation occurred at the center of contact area between rolling element and raceway, to which the maximum load is applied.

For the static equivalent load of radial bearing, the bigger value between the ones obtained by using both Equation 4-22 and 4-23, needs to be chosen.

$$P_0 = X_0 \cdot F_r + Y_0 \cdot F_a \quad \text{(Equation 4-22)}$$

$$P_0 = F_r \quad \text{(Equation 4-23)}$$

Where,

P_0	: Static equivalent load	[N], {kgf}
F_r	: Radial load	[N], {kgf}
F_a	: Axial load	[N], {kgf}
X_0	: Static radial load factor	
Y_0	: Static axial load factor	

For thrust spherical roller bearings, the static equivalent load is obtained by using following Equation.

$$P_0 = F_a + 2.7 \cdot F_r \quad \text{(Equation 4-24)}$$

Provided, $F_r \leqq 0.55 \cdot F_r$

4-3-3 Load Calculation for Angular Contact Ball Bearing and Tapered Roller Bearing

The load-applied point for angular contact ball bearings and tapered roller bearings lies at a crossing point between extended contact line and center shaft line, as shown in Fig. 4-6, and the locations of load-applied points are listed in each of bearing dimension tables.

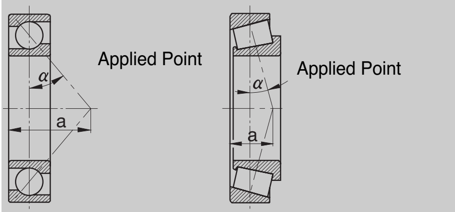


Fig. 4-6 Load Applied Point

Because the rolling areas of both angular contact ball bearings and tapered roller bearings are inclined, its radial load generates axial repulsive force, and this repulsing force has to be taken into consideration when calculating the equivalent loads.

This axial component force can be obtained by using the following Equation 4-25.

$$F_a = 0.5\ \frac{F_r}{Y} \quad \text{(Equation 4-25)}$$

Where,

F_a : Axial component force [N], {kgf}

F_r : Radial force [N], {kgf}

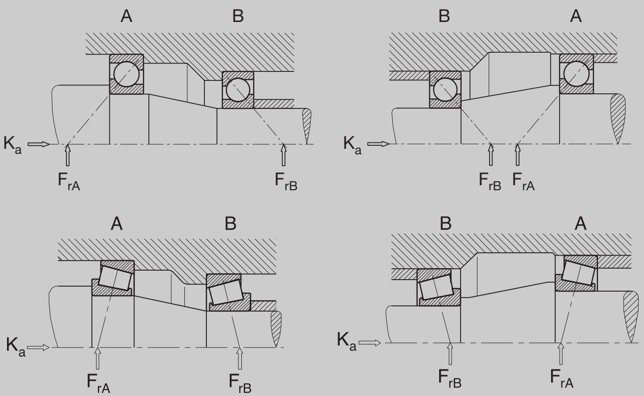
Y : Axial load factor

Axial loads are calculated by using the formula in the Table 4-4.

A bearing that receives the outside axial load K_a(No relation to axial reaction force) is marked as 'A', and the opposite bearing as 'B'.

Value Y can be calculafed by using the dynamic equivalent load equation and table dimensions Y is a given wnstant of axial load F_a

Table 4-4 Axial Loads of Angular Contact Ball Bearings and Tapered Roller Bearings



Load Conditions	Axial load F_a to be considered when calculating a dynamic equivalent load. Bearing A	Bearing B
$\frac{F_{rA}}{Y_A} \leqq \frac{F_{rB}}{Y_B}$	$F_a = K_a + 0.5 \cdot \frac{F_{rB}}{Y_B}$	–
$\frac{F_{rA}}{Y_A} > \frac{F_{rB}}{Y_B}$ $K_a > 0.5 \cdot \left(\frac{F_{rA}}{Y_A} - \frac{F_{rB}}{Y_B}\right)$	$F_a = K_a + 0.5 \cdot \frac{F_{rB}}{Y_B}$	–
$\frac{F_{rA}}{Y_A} > \frac{F_{rB}}{Y_B}$ $K_a \leqq 0.5 \cdot \left(\frac{F_{rA}}{Y_A} - \frac{F_{rB}}{Y_B}\right)$	–	$F_a = 0.5 \cdot \frac{F_{rA}}{Y_A} - K_a$