BEARING LOAD CALCULATION

To compute bearing loads, the forces which act on the shaft being supported by the bearing must be determined. These forces include the inherent dead weight of the rotating body (the weight of the shafts and components themselves), loads generated by the working forces of the machine, and loads arising from transmitted power.

Bearing load distribution

For shafting, the static tension is considered to be supported by the bearing, and any loads acting on the shafts are distributed to the bearings. The applied bearing loads can be found by using following formulas:

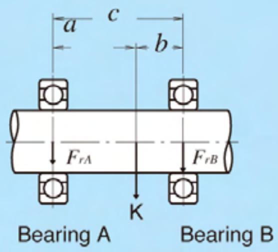
$$F_{rA} = \frac{b}{c} K \qquad F_{rB} = \frac{a}{c} K$$

where

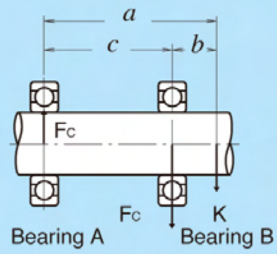
F_{rA} : Radial load applied on bearingA(N), {kgf}

F_{rB} : Radial load applied on bearingB (N), {kgf}

K : Shaft load (N), {kgf}



Radial Load Distribution (1)



Radial Load Distribution (2)

When two or more loads are applied simultaneously, The radial loads on bearings A and B can be calculated using the following equations:

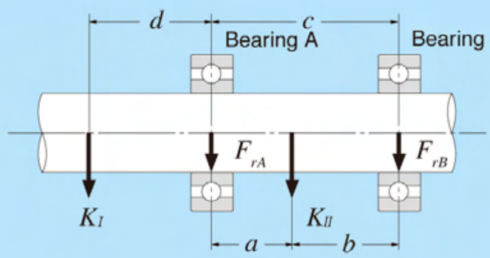
$$F_{rA} = \frac{d+c}{c} K_I + \frac{b}{c} K_{II} \qquad F_{rB} = -\frac{d}{c} K_I + \frac{a}{a+b} K_{II}$$

Where,

F_{rA} : Radial load on bearing A, N

F_{rB} : Radial load on bearing B, N

K_I , K_{II} : Radial load on shaft N



Chain / belt shaft load

The tangential loads on sprockets or pulleys when power (load) is transmitted by means of chains or belts can be calculated by formula:

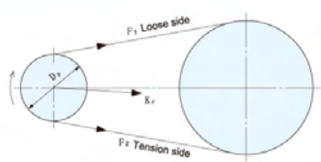
$$K_t = \frac{19.1 \times 10^6 \cdot H}{Dp \cdot n} \text{ N} = \frac{1.95 \times 10^6 \cdot H}{Dp \cdot n} \text{ kgf}$$

where,

K_t : Sprocket/pulley tangential load, N

H : Transmitted force, kW

D_p: Sprocket/pulley pitch diameter, mm



$$K_r = f_b \cdot K_t$$

where,

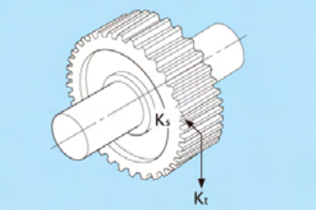
K_r : Sprocket or pulley radial load, N

f_b : Chain or belt factor

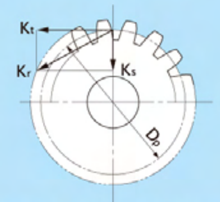
For belt drives, an initial tension is applied to give sufficient constant operating tension on the belt and pulley. Taking this tension into account, the radial loads acting on the pulley are expressed by formula. For chain drives, the same formula can also be used if vibrations and shock loads are taken into consideration.

Chain or belt type	f_b
Chain (single)	1.2~1.5
V-belt	1.5~2.0
Timing belt	1.1~1.3
Flat belt (w / tension pulley)	2.5~3.0
Flat belt	3.0~4.0

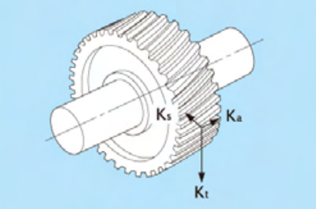
Load generated under gear transmission



Spur gear loads



Radial resultant forces



Helical gear loads

The loads operating on gears can be divided into three main types according to the direction in which the load is applied; i.e. tangential (Kt), radial (Kr), and axial (Ka). Loads acting on planetary shaft gears are depicted in the pictures.The load magnitude can be found by using or formulas:

$$K_t = \frac{19.1 \times 10^6 \cdot H}{D_p \cdot n} \text{ N} = \left\{ \frac{1.95 \times 10^6 \cdot H}{D_p \cdot n} \right\} \text{ kgf}$$

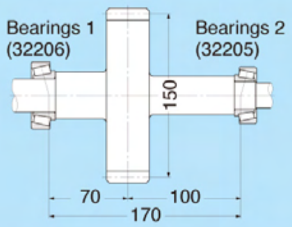
$$K_s = K_t \cdot \tan\alpha \text{ (Spur gear)} = K_t \cdot \frac{\tan\alpha}{\cos\beta} \text{ (Helical gear)}$$

$$K_r = \sqrt{K_t^2 + K_s^2} \qquad K_a = K_t \cdot \tan\beta \text{ (Helical gear)}$$

where,

- K_t : Tangential gear load (tangential force), N
- K_s : Radial gear load (separating force), N
- K_r : Right angle shaft load (resultant force of tangential force and separating force), N
- K_a : Parallel load on shaft, N
- H : Transmission force , kW
- n : Rotational speed, r/min
- D_p : Gear pitch circle diameter, mm
- α : Gear pressure angle
- β : Gear helix angle

Spur gear diagram



Example: What are the rated lives of the two tapered roller bearings supporting the shaft shown in left chart? Bearing1 is an 32206 with a Cr = 54.5 kN, and bearing 2 is an 32205 with a Cr = 42.0 kN. The spur gear shaft has a pitch circle diameter Dp of 150 mm, and a pressure angle of 20°. The gear transmitted force HP = 150 kW at 2,000 r/min (speed factor n).

The gear load from formulas is:

$$K_t = \frac{19.1 \text{ X } 10^6 \cdot H}{D_p \cdot n} = \frac{19{,}100 \text{ X } 150}{150 \times 2{,}000} = 9.55\text{kN } \{974\text{kgf}\}$$

$$K_s = K_t \cdot \tan\alpha = 9.55 \text{ X } \tan 20^\circ = 3.48\text{kN } \{355\text{kgf}\}$$

$$K_r = \sqrt{K_t^2 + K_s^2} = \sqrt{9.55^2 + 3.48^2} = 10.16\text{kN } \{1040\text{kgf}\}$$

The radial loads for bearings are:

$$F_{r1} = \frac{100}{170} K_r = \frac{100}{170} \text{ X}10.16 = 5.98\text{kN } \{610\text{kgf}\}$$

$$F_{r2} = \frac{70}{170} K_r = \frac{70}{170} \text{ X}10.16 = 4.18\text{kN } \{426\text{kgf}\}$$

$$\frac{0.5F_{r1}}{Y_1} = 1.87 > \frac{0.5F_{r2}}{Y_2} = 1.31$$

The equivalent radial load is:

$$P_{r1} = F_{r1} = 5.98\text{kN } \{610\text{kgf}\}$$

$$P_{r2} = XF_{r2} + Y_2 \frac{0.5F_{r1}}{Y_1} = 0.4\text{x}4.18 + 1.67\text{x}1.87 = 0.466\text{kN } \{475\text{kgf}\}$$

From formula the life factor, fh, for each bearing is:

$$f_{h1} = f_n \frac{C_{r1}}{P_{r1}} = 0.293 \text{ X}54.5/5.98 = 2.67$$

$$f_{h2} = f_n \frac{C_{r2}}{P_{r2}} = 0.293 \text{ X}42.0/4.66 = 2.64$$

Therefore: Tapered roller bearings life

$$L_{h1} = 13{,}200 \text{ X } a_2 = 13{,}200 \text{ X } 1.4 = 18{,}480 \text{ ore}$$

$$L_{h2} = 12{,}700 \text{ X } a_2 = 12{,}700 \text{ X } 1.4 = 17{,}780 \text{ ore}$$

The combined bearing life, Lh, from formula is:

$$L_{h1} = \frac{1}{\left[\frac{1}{L_{h1}^{e}} + \frac{1}{L_{h2}^{e}}\right]^{1/e}} = \frac{1}{\left[\frac{1}{18{,}480^{9/8}} + \frac{1}{17{,}780^{9/8}}\right]^{8/9}} = 9{,}780 \text{ hour}$$

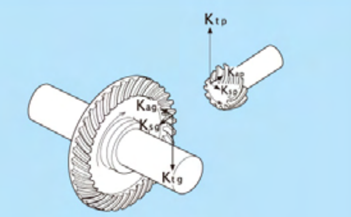
● Gear factor f_g

Because the actual gear load also contains vibrations and shock loads as well, the theoretical load obtained by the above formula should also be adjusted by the gear factor f_g as shown in the table below:

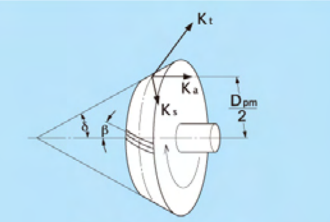
Gear type	f_g
Precision ground gears (Pitch and tooth profile errors of less than 0.02mm)	1.05~1.1
Ordinary machined gears (Pitch and tooth profile errors of less than 0.1mm)	1.1~1.3

● Load on bevel gears

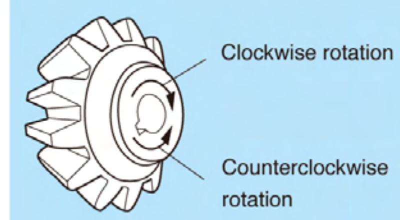
For spiral bevel gears, the direction of the load varies depending on the direction of the helix angle, the direction of rotation, and which side is the driving side or the driven side. The directions for the separating force (Ks) and axial load (Ka) shown in the left picture are positive directions. The direction of rotation and the helix angle direction are defined as viewed from the large end of the gear. The gear rotation direction in the picture is assumed to be clockwise (right).



Loads on bevel gears



Bevel gear diagram



The calculation methods for these gear loads are shown in table as following:

Pinion		Rotation direction	Clockwise	Counter clockwise	Clockwise	Counter clockwise
		Helix direction	Right	Left	Left	Right
Tangential load K_t			$K_t = \frac{19.1 \times 10^6 \cdot H}{D_{pm} \cdot n} \left\{ \frac{1.95 \times 10^6 \cdot H}{D_{pm} \cdot n} \right\}$			
Straight[1] bevel gears	Separating force K_s	Driving side	$K_s = K_t \left[\tan\alpha \frac{\cos\delta}{\cos\beta} \right]$			
	Axial load K_a	Driven side	$K_a = K_t \left[\tan\alpha \frac{\sin\delta}{\cos\beta} \right]$			
Spiral[1),2)] bevel gears	Separating force K_s	Driving side	$K_s = K_t \left[\tan\alpha \frac{\cos\delta}{\cos\beta} + \tan\beta \sin\delta \right]$		$K_s = K_t \left[\tan\alpha \frac{\cos\delta}{\cos\beta} - \tan\beta \sin\delta \right]$	
		Driven side	$K_s = K_t \left[\tan\alpha \frac{\cos\delta}{\cos\beta} - \tan\beta \sin\delta \right]$		$K_s = K_t \left[\tan\alpha \frac{\cos\delta}{\cos\beta} + \tan\beta \sin\delta \right]$	
	Axial load K_a	Driving side	$K_a = K_t \left[\tan\alpha \frac{\sin\delta\delta}{\cos\beta\beta} - \tan\beta \cos\delta \right]$		$K_a = K_t \left[\tan\alpha \frac{\sin\delta}{\cos\beta} + \tan\beta \cos\delta \right]$	
		Driven side	$K_a = K_t \left[\tan\alpha \frac{\sin\delta}{\cos\beta} + \tan\beta \cos\delta \right]$		$K_a = K_t \left[\tan\alpha \frac{\sin\delta}{\cos\beta} - \tan\beta \cos\delta \right]$	

where,

D_{pm} : Mean pitch circle diameter, mm

δ : Pitch cone angle

Herein, to calculate gear loads for straight bevel gears, the helix angle β = 0.

Mean load

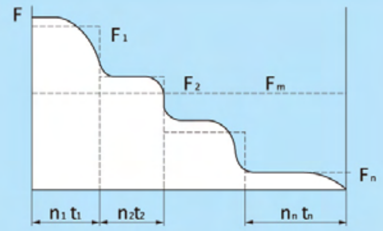
The load on bearings used in machines under normal circumstances will, in many cases, fluctuate according to a fixed time period or planned operation schedule. The load on bearings operating under such conditions can be CONVERTED TO A MEAN LOAD (Fm), this is a load which gives bearings the same life they would have under constant operating conditions.

(1) Fluctuating stepped load

The mean bearing load, F_m, for stepped loads is calculated from following formula. F_1, F_2 ...... F_n are the loads acting on the bearing; n_1, n_2......n_n and t_1, t_2....... t_n are the bearing speeds and operating times respectively.

$$F_m = \left[\frac{\sum(F_i^{\,p} n_i t_i)}{\sum(n_i t_i)}\right]^{1/p}$$

Where,
$p = 3$ For ball bearings
$p = 10/3$ For roller bearings



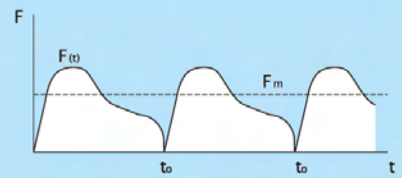
Stepped load

(2) Consecutive series load

Where it is possible to express the function $F_{(t)}$ in terms of load cycle to and time t, the mean load is found by using formula as following:

$$F_m = \left[\frac{1}{t_o}\int_o^{t_o} F(t)^p d_t\right]^{1/p}$$

Where,
$p = 3$ For ball bearings
$p = 10/3$ For roller bearings

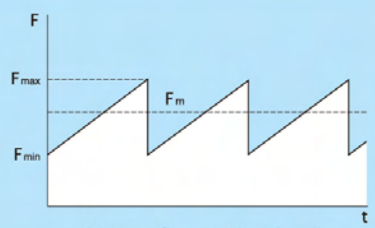


Time function series load

(3) Linear fluctuating load

The mean load, F_m, can be approximated by formula:

$$F_m = \frac{F_{min} + 2F_{max}}{3}$$



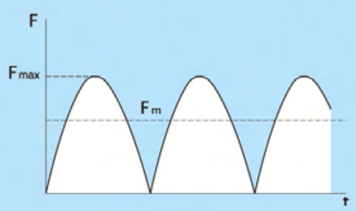
Linear fluctuating load

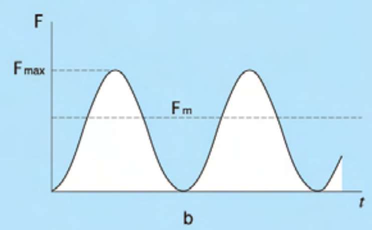
(4) Sinusoidal fluctuating load

The mean load, F_m, can be approximated by following formulas:

case (a) $F_m = 0.75\,F_{max}$

case (b) $F_m = 0.65\,F_{max}$

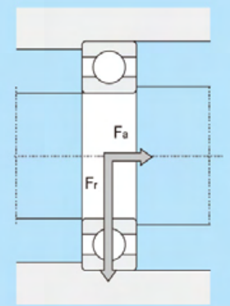




Sinusoidal variable load

Bearing size selection

Example1:



Deep groove ball bearing: 62 series
Required service life: more than 10000h

Radial load	$F_r = 2\,000N$
Axial load	$F_a = 300N$
Rotational speed	$n = 1\,600\ min^{-1}$

1.The dynamic equivalent load (P_r) is hypothetically calculated

The resultant value, F_a/F_r=300/2000=0.15, is smaller than any other values of e in the bearing specification table

Hence, HCH can consider that $P_r = F_r$= 2 000N

2.The required basic dynamic load rating (C_r) is calculated according to equation

$$G_r = P_r\left(L_{10h} \times \frac{60n}{10^6}\right)^{1/P}$$

$$= 2\,000 \times \left(10\,000 \times \frac{60 \times 1600}{10^6}\right)^{1/3}$$

$$= 19730\ N$$

3. Among those covered by the bearing specification table, the bearing of the 62 series with C_r exceeding 19730N is 6206, with bore diameter for 30mm.

4.The dynamic equivalent load obtained at step 1 is confirmed by obtaining value e for 6206.

Where C_{0r} of 6206 is l2.8 kN,and f_0 is 13.8

$$f_0 \times F_a/C_{0r} = 13.8 \times 300/12\,800 = 0.323$$

Then, value e can be calculated using proportional interpolation

$$e = 0.19 + (0.22-0.19) \times \frac{(0.323-0.172)}{(0.345-0.172)}$$

$$= 0.216$$

As a result,it can be confirmed that

F_a/F_r=0.15<e

Hence, $P_r = F_r$

Example2: Deep groove ball bearing: 63 series
Required service life: more than 10000 h

Radial load	$F_r = 4\,000N$
Axial load	$F_a = 2\,400N$
Rotational speed	$n = 1000\ min^{-1}$

1. The hypothetic dynamic equivalent load (P_r) is calculated:
Since F_a/F_r = 2 400/4 000=0.6 is much larger than the value specified in the bearing specification table, it suggests that the axial load affects the dynamic equivalent load. Hence, assuming that X = 0.56, Y=1.6 (approximate mean value of Y).

$$P_r = XF_r + XF_a = 0.56 \times 4\,000 + 1.6 \times 2\,400$$

$$= 6\,080N$$

2. The required basic dynamic load rating(G_r)is:

$$G_r = P_r\left(L_{10h} \times \frac{60n}{10^6}\right)^{1/P}$$

$$= 6\,080 \times \left(10\,000 \times \frac{60 \times 1000}{10^6}\right)^{1/3}$$

$$= 51280\ N$$

3.From the bearing specification table, a 6310 with a bore diameter of 50 mm is selected as a 63 series bearing with C_r exceeding 51 280 N

4. The dynamic equivalent load and basic rating life are confirmed,by calculating the value e for a 6310 Values obtained using the proportional interpolation are:

where

$f_0 \times F_a/C_{0r}$ = 13.2 x 2 400/35 340 = 0.89

$e = 0.27$, $Y = 1.6$

$F_a/F_r = 0.6 > e$

Using the resultant values, the dynamic equivalent load and basic rating life can be calculated as follows:

$$P_r = XF_r + XF_a$$

$$= 0.56 \times 4\,000 + 1.61 \times 2400 = 6\,080N$$

$$L_{10h} = \frac{10^6}{60n}\left(\frac{C_r}{P_r}\right)^P$$

$$= \frac{10^6}{60 \times 1\,000} \times \left(\frac{57.54 \times 10^3}{6\,080}\right)^3 = 14\,127\ h$$

5. The basic rating life of the 6309, using the same steps,is:

$L_{10h} \doteqdot 9\,000$ h which does not satisfy the service life requirement.