(1)

Rolling contact Bearing

Function:

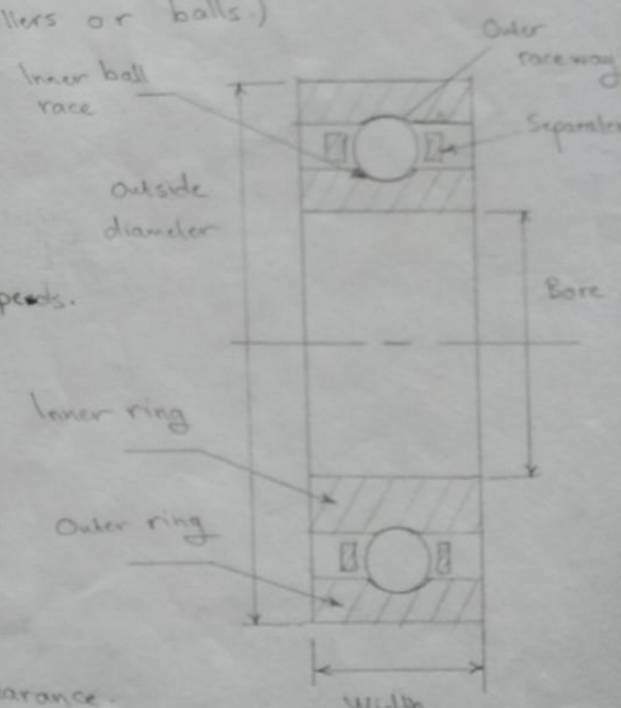
Separates the shaft and outer member by balls or rollers and substitute rolling friction for sliding friction

→ Anti-friction Bearing.

The contact area is small → higher stresses → Bearing element are made of high strength material.

Bearing component:

- Inner and outer rings (races)
- Balls or rollers.
- Retainer or separator (separates rollers or balls)



Advantage of Rolling contact Bearing:

1- Suitable for high starting loads. (low starting friction)
Sliding Bearing → efficient at high speeds.

2- Cost is lower than sliding bearing

3- More precise (mating elements are preloded)
Operating with small clearance
Sliding bearing → operates with high clearance.

Disadvantage: Require more radial space and noisey.

Types of Rolling Bearings:

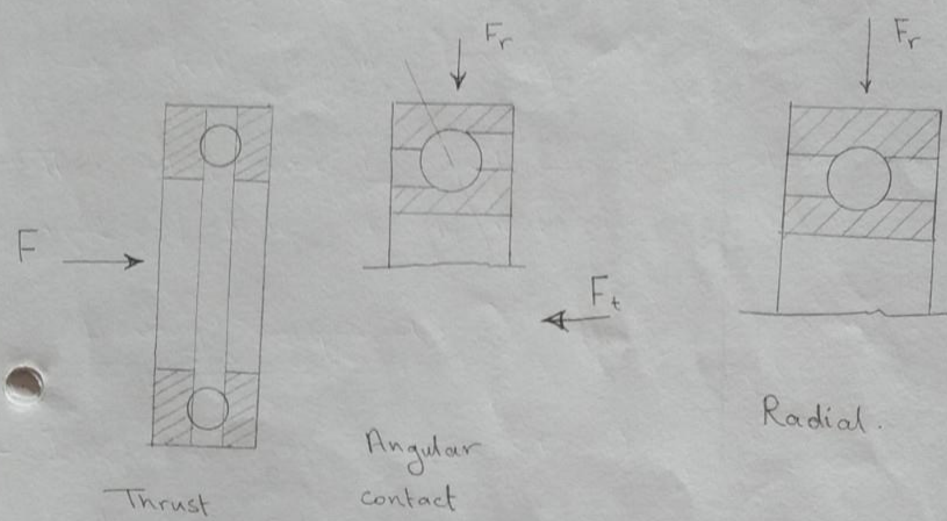
1- Ball Bearing [used with high speeds]

2- Roller Bearing [Used with greater loads]

2020/3/22 07:40

Classifications of ball Bearings:

- Radial (carry radial load).
- Thrust, axial contact (carry axial loads).
- Angular - contact (Carry axial and radial loads)



Roller Bearing

1- Cylindrical (straight roller). [carry more load than ball bearing].
2 - Spherical [used when heavy loads and misalignment occur].
3 - Tapered [Carry both radial and thrust loads, carry heavier loads].
4 - Needle [cylindrical, $\frac{\text{Length}}{\text{Diameter}} > 4$]
Used when radial space is limited.

Bearing life:

Bearing failure is caused by fatigue loading as a result of repeated contact stress between ball / rollers and races.

Failure occurs by: flaking, pitting, spalling of inner and outer races.

Bearing Life:

Number of revolutions or (no. of hours at constant speed) required to cause failure.

2020/3/22 07:40

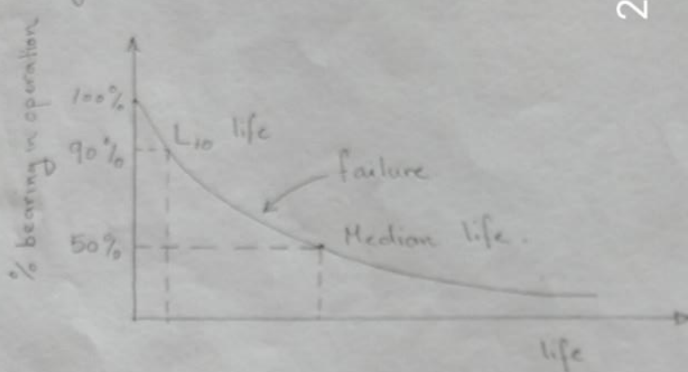
Rating life:

Number of revolutions or (no. of hours at constant speed), that 90% of a group of ball or roller bearings will exceed before failure.

Rating life = L_{10} life

Median life = Average life = L_{50} life = Number of revolutions or hrs at constant speed, that 50% of a group of bearing completes before failure.

$L_{50} = (4-5)\, L_{10}$



Bearing Life:

$$L = L_R \left(\frac{C_R}{F_r} \right)^a$$

L = life = { millions of revolutions / hrs at constant speed (rev/min).

F_r = applied radial load

a = { 3, ball bearing. / $\frac{10}{3}$, roller bearing.

C_R = basic load rating (rated capacity).

Rated capacity:-

Constant radial force that cause failure of a group of identical bearings for a rating life of one million revolutions of inner ring. [load and outer ring are stationary].

$L_R = L_{10}$ = life corresponding to rating capacity $= 1 \times 10^6$ revolutions.

Rated capacity:

$$C_R = F_r \left(\frac{L}{L_R} \right)^{1/a}$$

If L = million revolutions → $L_R = 1.0$.

Some manufacturers use rating corresponding to life in hrs at constant speed. For example Timken uses $L_R = 3000$ h at 500 rev/min.

Bearing Selection:

It is required to find the rating capacity = Radial load that can be carried by the bearing

Required design values:

F_D = Required Design Force (radial).

L_D = Design life, (hrs)

n_D = Design speed (rev/min).

Catalog values:

F_R = Catalog radial load (KN/lb).

L_R = Catalog rated life (hrs).

n_R = Catalog rated speed (rev/min).

If L = hrs → L = rev.

$L\,(\text{rev}) = \text{rating (hrs)} \times 60 \frac{\text{min}}{\text{hr}} \times n\left(\frac{\text{rev}}{\text{min}}\right)$ = life in revolutions.

⇒ N_D = Design revolutions = $60\, L_D\, n_D$.

N_R = Revolutions of catalog bearings. = $60\, L_R\, n_R$.

$$\Rightarrow \frac{L_D}{L_R} = \left(\frac{F_R}{F_D}\right)^a$$

$$\frac{N_D}{N_R} = \left(\frac{F_R}{F_D}\right)^a \Rightarrow F_R = F_D \left(\frac{N_D}{N_R}\right)^{1/a} = F_D \left(\frac{L_D\, n_D}{L_R\, n_R}\right)^{1/a}$$

From catalog: Selected a bearing load rating $\geq F_R$

2020/3/22 07:41

Example: Roller bearing is to withstand radial load $F_r = 4$ KN. and have a life, $L_{10} = 1200$ h at $n = 600$ rev/min. What value of load rating you will select from Timken Eng Catalog.

Solution:

$F_R = ?$

$L_R = 3000$ h

$n_R = 500$ rev/min

$F_D = 4$ KN

$L_D = 1200$ h

$n_D = 600$ rev/min.

$a = \frac{10}{3}$ Roller bearing.

$$F_R = F_D \left(\frac{L_D n_D}{L_R n_D}\right)^{\frac{1}{a}} = F_D \left(\frac{L_D n_D}{L_R n_R}\right)^{3/10}$$

$$\Rightarrow C_R = F_R = 4 \left[\left(\frac{1200}{3000}\right)\left(\frac{600}{500}\right)\right]^{3/10} = 3.21 \text{ KN.}$$

5

2020/3/22 07:41

Selection of ball and Roller bearing with Radial and thrust load

Ball bearing carry Radial + thrust ~~load~~ (Deep groove)

Roller bearing cannot carry axial load [for sliding friction on Roller side]

Catalog rating based on Radial load. → Equivalent radial load (F_e)

$$F_e = \max \left\{ V F_r , \left(X V F_r + Y F_a \right) \right\}$$

F_e = equivalent radial load.

F_r = Applied radial load.

F_a = Applied thrust load.

- V = Rotation correction factor.

$V = \begin{cases} 1, & \text{for rotating inner ring, Self-aligning and tapered Roller} \\ 1.2, & \text{for rotating outer ring.} \end{cases}$

X = Radial factor, Y = Thrust factor } depends on the geometry of bearing and no. of balls or Rollers, and on (F_a/C_o)

, C_o = basic static load rating

C = Dynamic load rating

* Straight roller Bearing will not take axial load ⇒ $Y = 0$

Table [11–1] → [(X, Y) Vs. $\left(\frac{F_a}{C_o}\right)$]

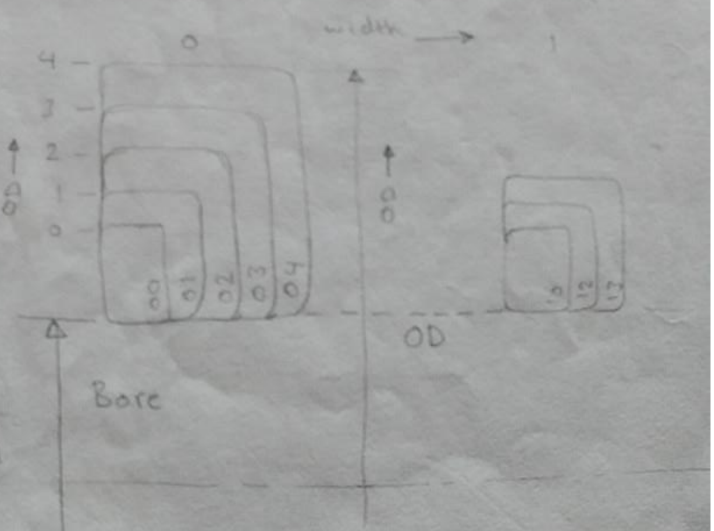
- <u>Bearing code</u>: [ball, Straight, Spherical roller]

For a particular bore

d → Bearing can have different width (w) and Outside diameter (OD)

Bearing code: d → X X

W: 0,1,2,3,4,5,6	OD: 8,9,0,1,2,3,4



Bearing Dimensions:

d_s = shaft shoulder, d_H = housing shoulder

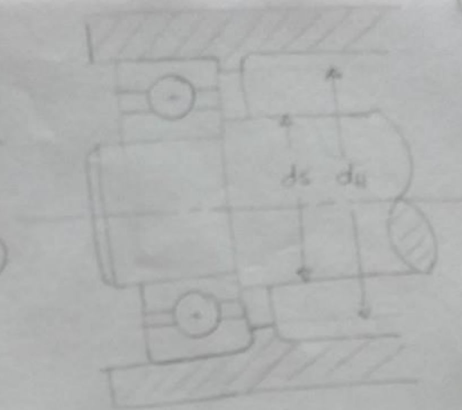


Table [11-2] (02) series of Deep grove and Angular contact ball bearing.

Table [11-3] Straight roller bearing series (02, 03)

(Bore, OD, d_s, d_H, Rating

Bearing Application:

Table [11-4] Bearing life for different applications. (life = khrs.)

Table [11-5] Load factor for different applications (Safty factor). (K_a)

$$F_R = (K_a)(F_D)\left(\frac{L_D\, n_D}{L_R\, n_R}\right)^{1/a}$$

$$F_R = K_a F_r \left(\frac{L}{L_R}\right)^{1/a}$$

$F_R = K_a F_e$ —— For axial and thrust loading

Reliability factor:

Rated bearing life for any reliability > 90 %

$$L = K_r L_R \left(\frac{C}{F_r}\right)^a \quad , \quad C_R = K_a F_r \left(\frac{L}{K_r L_R}\right)^{1/a}$$

K_r = Reliability factor. Table [11-1] [R vs $\frac{L}{L_{10}} = K_r$]

Note: when calculating F_e = equivalent of F_r and F_a. Substitute F_e for F_r in the equation.

$$L = L_R \left(\frac{C}{K_a F_e}\right)^a$$

$$C_R = K_a F_e \left(\frac{L}{L_R}\right)^{1/a}$$

Reliability factor = K_r

$$K_r = x_0 + (\theta - x_0)[1 - R]^{1/b}$$

x_0 = min. value of variate

θ = characteristic parameter

Example: (11-14) page 477

worm gear , Power = 1.35 hp , $n = 600$ rpm

Bearing at A : Angular contact ball carry Axial + Radial.

Bearing at B : Straigh Roller only Radial load.

For $K_a = 1.3$, Life , [L = 25 kh , R = 99%]

• Specify each Bearing.

Solution:

Bearing at A: Angular ball.

$F_r = \sqrt{(35)^2 + (212)^2} = 215$ lb

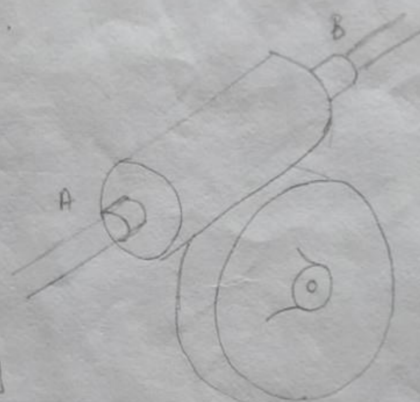
$F_a = 555$ lb , $\frac{F_a}{F_r} = 2.58$

$\frac{F_a}{C_o} = ??$

Initial guess: Table [11-3]

$d = 85$, $C_o = 63$ KN (Angular ball B.)

$\frac{F_a}{C_o} = \frac{0.555(4.45)}{63} = 0.0392.$



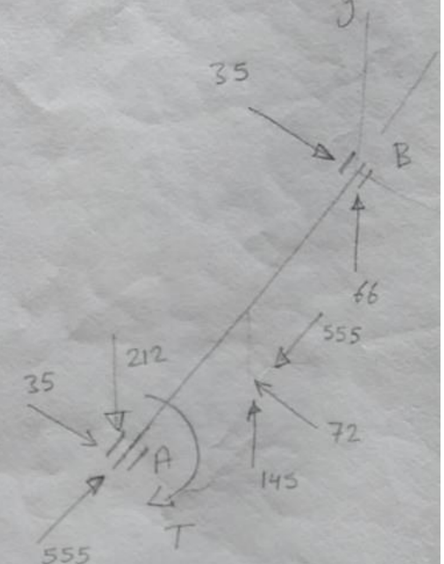


Table [11-2] $0.028 < \frac{F_a}{C_o} < 0.042$

$\frac{F_a}{C_o} = 0.042 \rightarrow \frac{F_a}{F_r} = 2.58 > e\,(0.24)$

$\Rightarrow X_2 = 0.56,\ Y_2 = 1.85$

$F_e = V X F_r + Y F_a$

$F_r = 215 \times \frac{4.45}{1000} = 0.957$ KN.

$F_a = 555 \times \frac{4.45}{1000} = 2.47$ KN. $V = 1$ [Inner ring rotation]

$F_e = 0.56(0.957) + 1.85(2.47) = 5.1$ KN.

$K_a = 1.3$

$\Rightarrow F_e > F_r \Rightarrow$

$K_r = 0.2$ for $R = 99\%$.. $\Rightarrow$ Life $(N) = 25000 \times 600 \times 60 = 900 \times 10^6$ rev

$F_R = K_a F_e \left(\frac{L}{K_r L_R}\right)^{1/3} = 1.3(5.1)\left(\frac{900}{0.2 \times 1}\right)^{1/3} = 109.5$ KN

From table [11-3] for $d = 85 \rightarrow C = 90.4$ KN.

Select Angular Ball Brg. – $d = 95$ mm, $C_o = 85$ KN, $C = 121$ KN.

$\frac{F_a}{C_o} = 0.029$ From table [11-2] $X_2 = 0.56,\ Y_2 = 1.99$

$F_e = 0.56[0.957] + 1.99[2.47] = 5.45$ KN

$F_R = 1.3 \times 5.45 \left(\frac{900}{0.2}\right)^{1/3} = 117.0$ KN

For $d = 95$ mm $\rightarrow C = 121$ KN $> F_R$ $\Rightarrow$ use a Angular B. Brg $d = 95$ mm

Bearing at B: Straight Roller Brg.

$F_r = \sqrt{(35)^2 + (66)^2} = 74.7$ lb. **No Thrust load.**

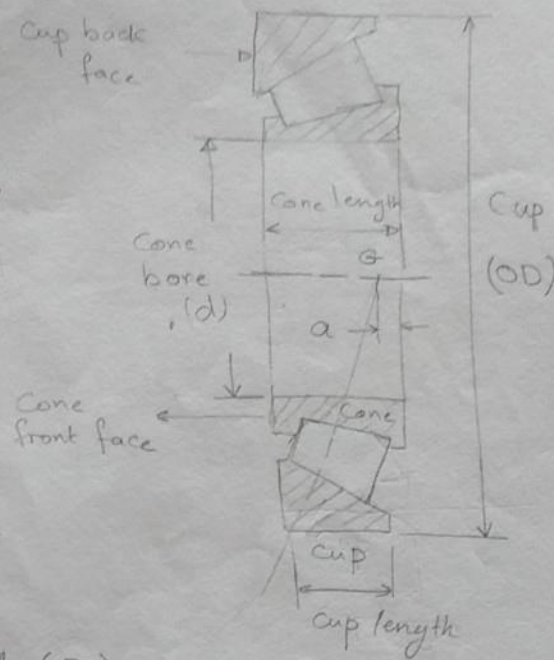
$F_R = 1.3\left(\frac{74.7 \times 4.45}{1000}\right)\left(\frac{900}{0.2}\right)^{3/10} = 5.4$ KN

From Table [11-4] 02-series cylindrial Roller Brg. with $d = 25$ mm
$C = 16.8$ KN

2020/3/22 07:44

Tapered Roller Bearing:

G = effective load center.
used to calculate Bearing Reaction.



Carry Radial, Axial or combination of both.

Radial load induce thrust reaction:
To avoid separation of rollers and races using two tapered roller bearing.

Direct mounting: cone backs facing each other

Indirect mounting: cone fronts facing each other

F_a = Thrust produce by pure radial load (F_r)

$$F_a = \frac{0.47\ F_r}{K} \quad \text{[Timken company]}$$

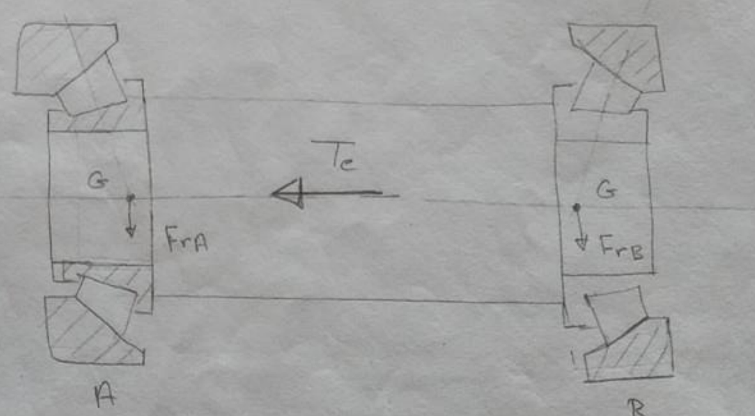
$K = 0.389 \cot \alpha$ [given by manufactur catalog]

α = half of inclined cup angle.

Initial Estimation, $K = \begin{cases} 1.5 & \text{— Shallow angle Bearing} \\ 0.75 & \text{— Steep angle bearing.} \end{cases}$

Bearing load calculation:

Taking moments about G

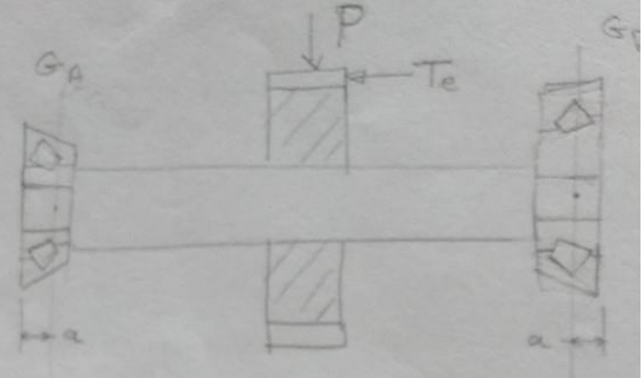


$$F_e = X\ F_r + Y\ F_a \quad (V = 1.0)$$

$$F_{eA} = 0.4\,F_{rA} + K_A\left(\frac{0.47\,F_{rB}}{K_B} + T_e\right)$$

$$F_{eB} = 0.4\,F_{rB} + K_B\left(\frac{0.47\,F_{rA}}{K_A} - T_e\right)$$

Bearing Reaction for Tapered Roller. B. Under Radial and Thrust



1- Calculate Radial Reactions at A and B. using G_A, G_B. F_{rB}, F_{rA}.

2- From the equations:

$$F_{eA} = 0.4\, F_{rA} + K_A \left(\frac{0.47\, F_{rB}}{K_B} + T_e \right)$$

$$F_{eB} = 0.4\, F_{rB} + K_B \left(\frac{0.47\, F_{rA}}{K_A} - T_e \right)$$

$$C = K_a\, F_e \left[\frac{L_D\, n_D}{f_t f_v K_r L_R n_R} \right]^{3/10}$$

For Timken catalog:

$L_R = 3000$ hr , $n_R = 500$ rpm.

$K_r = 4.48\, [1 - R]^{2/3}$

If we have two Brgs, over all reliability

$R = R_A R_B$

f_t = Temp. factor → Fig. [11-16] [η v_s T_o]

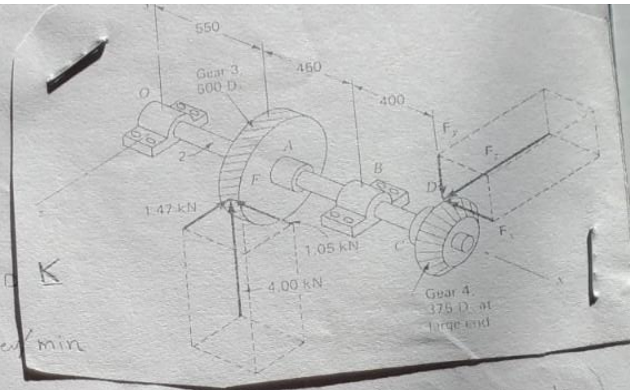
f_v = viscosity factor of oil used with tapered Brg Fig. [11-17]

Example:

Tapered Roller Bearing at O and B

Bearing at O take the major Thrust load.

Dimension are to effective load centers of Gears and Bearings.



$F_D = -0.242\, F_D\, i - 0.242\, F_D\, J + 0.94\, F_D\, K$

life = 36 kh , R = 90% , n = 900 rev/min

Bearing Bore for both Brg. ⇒ d = 25.4 mm

load factor : $K_a = 1.0$, $K = 1.5$ (Initial estimation)

Bearing are direct mounting.

Bearing Reactions:

$\Sigma M_o = R_{oF} \times F_F + R_{oB} \times F_B + R_{oD} \times F_D = 0$

$R_{oF} = 550\, i + 250\, K$, $R_{oB} = 1600\, i$, $R_{oD} = 1400\, i + 187.5\, J$

$R_{oF} \times F_F = -1000\, i + 546\, J + 2200\, K \quad (N.m)$

$R_{oB} \times F_B = -1600\, F_B^z\, J + 1000\, F_B^y\, K$

$R_{oD} \times F_D = 176.25\, F_D\, (i) - 1316\, F_D\, (J) - 293.4\, F_D\, (K)$

$\Sigma\, i$ component $= 0 \Rightarrow -1000 + 176.25\, F_D = 0 \Rightarrow F_D = 5.67$ KN.

$\Sigma\, J$ component $= 0 \Rightarrow 546 - 1000\, F_B^z - 1316\,(5.67) = 0 \Rightarrow F_B^z = -6.92$ KN.

$\Sigma\, K$ component $= 0 \Rightarrow 2200 + 1000\, F_B^y - 293.4\,(5.67) = 0 \Rightarrow F_B^y = -0.536$ KN

$\Sigma \vec{F} = \vec{F_o} + \vec{F_A} + \vec{F_B} + \vec{F_D} = 0$

$\Rightarrow \vec{F_o} = 2.42\, i - 2.094\, J + 3.06\, K \quad (KN)$

$F_{ro} = \sqrt{(2.09)^2 + (3.06)^2} = 3.71$ KN , $T_e = 2.42$ KN

$F_{rB} = \sqrt{(6.92)^2 + (0.536)^2} = 6.94$ KN

Cone = 2687, Cup = 2631, $d_B = 25.4$, $K_B = 2.3$

Equivalent Radial load: Select $d_o = 25.4$

Cone	Cup
HM88630	HM88610

$K_o = 1.07$

$F_{eO} = 0.4\, F_{ro} + K_o \left(\frac{0.47\, F_{rB}}{K_B} + T_e \right) = 0.4\,(3.71) + 1.07 \left(\frac{0.47\,(6.94)}{2.3} + 2.42 \right)$

$= 5.66$ KN.

$F_{eB} = 0.4\,(6.94) + 2.3 \left[\frac{0.47\,(3.71)}{1.07} - 2.42 \right] = 0.96$ KN.

(1)

$F_D = max[F_e, F_r]$

$F_{DO} = F_{eO} = 5.6$ KN.

$F_{DB} = F_{rB} = 6.94$ KN

At O: $C_R = K_a F_D \left(\frac{L_D n_D}{L_R n_R}\right)^{3/10}$ Catalog rating

$C_{R_O} = 1 \times 5.6 \left(\frac{36 \times 900}{3 \times 500}\right)^{3/10} = 14.1$ KN

$d_O = 25.4$ mm. Cone: HM 88630, Cup: HM 88610 →

At B: $C_{RB} = 6.94 \times \left(\frac{36 \times 900}{3 \times 500}\right)^{3/10} = 17.4$ KN.

$d_B = 25.4$ mm. Cone: 2687, cup: 2631

Example: (11-14) page 477

worm gear, Power = 1.35 hp, $n = 600$ rpm

Bearing at A: Angular contact ball carry Axial + R

Bearing at B: Straigh Roller only Radial load

For $K_a = 1.3$, Life, $[L = 25$ kh, $R = 99\%]$

Specify each Bearing.

olution:

aring at A: Angular ball.

2020/3/22 07:47

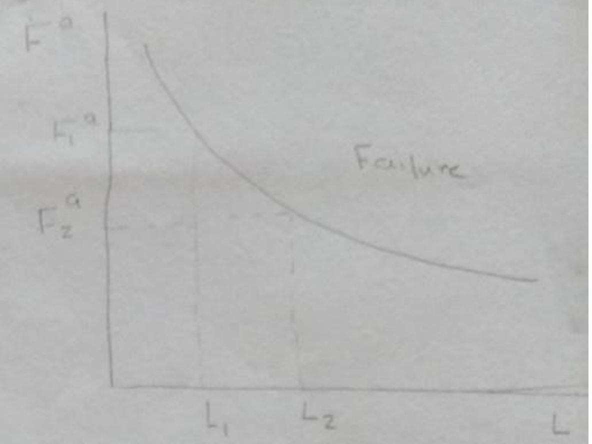
Variable loading:

Load life relation → $F^a L = \text{const.}$

F = radial or equivalent radial

Area under $F_1 - L_1 = K$

Area under $F_2 - L_2 = K$



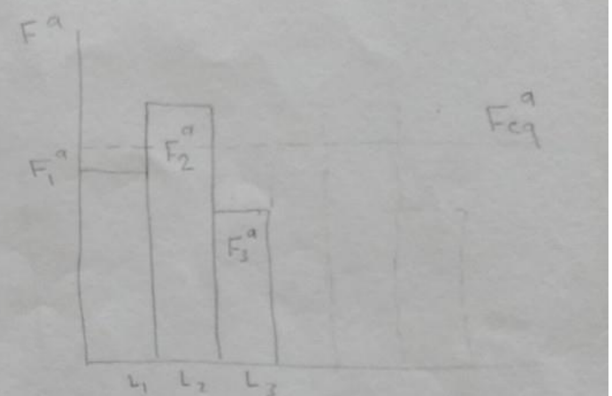
Linear damage hypothesis:

In case of Force F_1 the area under $F_1 - L_1$ does damage $\Rightarrow F_1^a L_1 = D$

piece wise continuous function.

Damage done by F_1, F_2, F_3

$$D = F_1^a L_1 + F_2^a L_2 + F_3^a L_3 \quad (1)$$



Equivalent load F_{eq} give the same damage for life $= L_1 + L_2 + L_3$

$$D = F_{eq}^a (L_1 + L_2 + L_3) \quad (2)$$

From (1) and (2):

$$F_{eq} = \left[\frac{F_1^a L_1 + F_2^a L_2 + F_3^a L_3}{L_1 + L_2 + L_3} \right]^{1/a} = \left[\Sigma f_i F_i^a \right]^{1/a}$$

$$f_i = \frac{L_i}{L_1 + L_2 + L_3} = \text{fraction of life.}$$

If the life is given in hrs $= t$ and speed $= n$

$$\rightarrow F_{eq} = \left[\frac{n_i t_i F_i^a}{\Sigma n_i t_i} \right]^{1/a}$$

F_i = radial load or equivalent radial load.

K_a = application factor of each load.

$$\rightarrow F_{eq} = \left[\frac{n_i t_i K_{a_i} F_i^a}{\Sigma n_i t_i} \right]^{1/a}$$

2020/3/22 07:48

The life left if the change of stress is held to failure.

Linear Damage hypothesis

$D = F^a L$

L = no. of revolution correspond to applied load.

ℓ : No. of revolution under the applied load.

$F_{eq}^a L_{eq} = F_1^a \ell_1 + F_2^a \ell_2 + F_3^a \ell_3 = K$

But $K = F_1^a L_1 = F_2^a L_2 = F_3^a L_3$

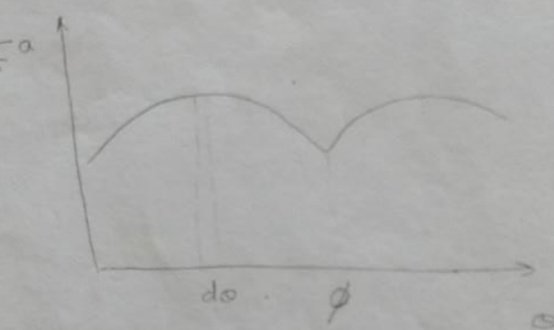
and $K = F_{eq}^a L_{eq} = F_1^a \ell_1 + F_2^a \ell_2 + F_3^a \ell_3 = \frac{K}{L_1}\ell_1 + \frac{K}{L_2}\ell_2 + \frac{K}{L_3}\ell_3$

$= K \sum \frac{\ell_i}{L_i}$

$\Rightarrow \sum \frac{\ell_i}{L_i} = 1 \rightarrow$ Palmgren – Miner rule

For continuous periodic variation.

Damage done by F^a during $d\theta$



$dD = F^a \, d\theta$

$D = \int_0^{\phi} F^a \, d\theta = F_{eq}^a \, \phi$

$F_{eq} = \left[\frac{1}{\phi} \int_0^{\phi} F^a \, d\theta \right]^{1/a}$

11-18 **Ex:** Estimate remaining life of 02-Series $d = 30$ mm angular contact Brg. Subjected to 200,000 rev. with $F_r = 18$ KN., if it is subjected to radial load $F_{r2} = 30$ KN.

Solution:

$F_1 = 18$ KN $\rightarrow \ell_1 = 2 \times 10^5$ rev.

$F_2 = 30$ KN $\rightarrow \ell_2 = ??$

For $d = 30$ mm $\rightarrow C = 20.3$ KN. 02-series angular contact. Brg.

$C \rightarrow L_{10} = 10^6 \rightarrow a = 3$ ball Brg.

$\rightarrow K = C^a L_{10} = (20.3)^3 (1 \times 10^6) = 8.365 (10^9)$

L_1 = rating life correspond to F_1

$F_1^a L_1 = K \rightarrow L_1 = 1.434 \times 10^6$ rev.

$F_2^a L_2 = K \rightarrow L_2 = 0.31 \times 10^6$ rev.