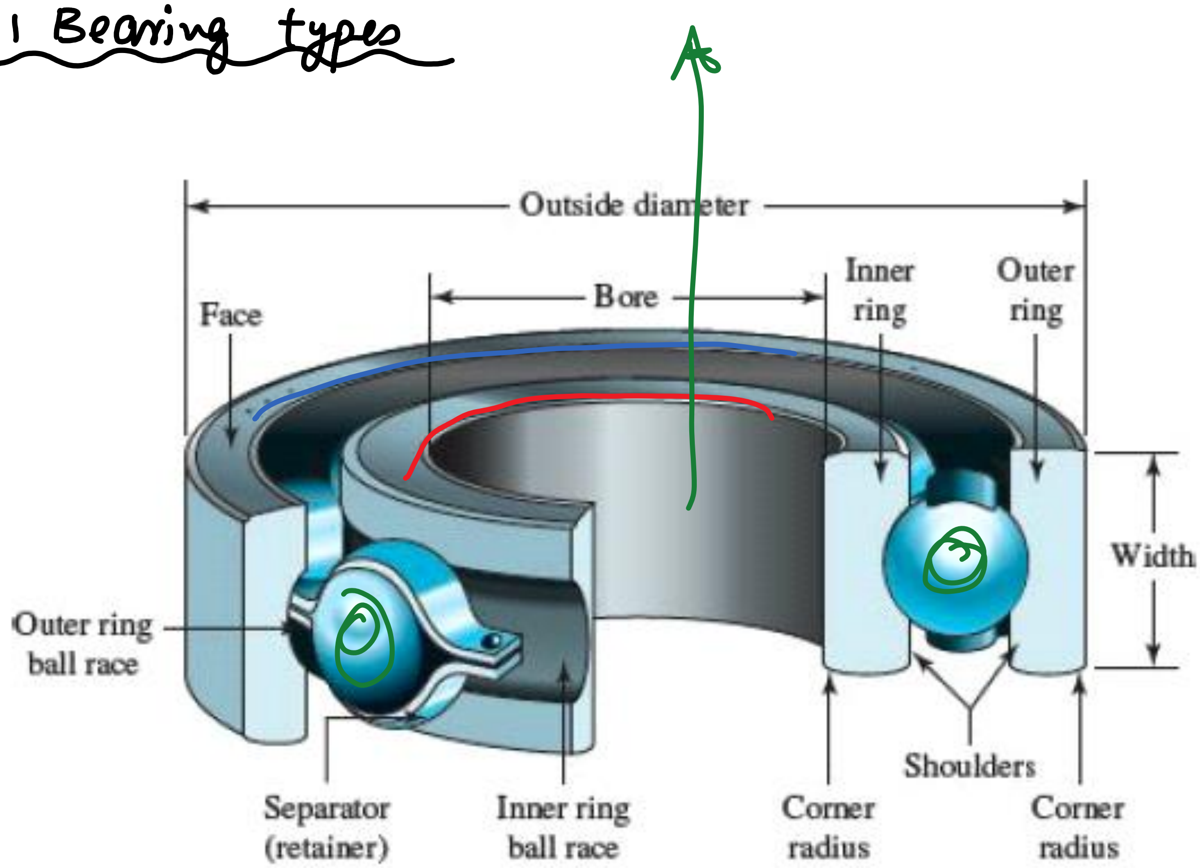
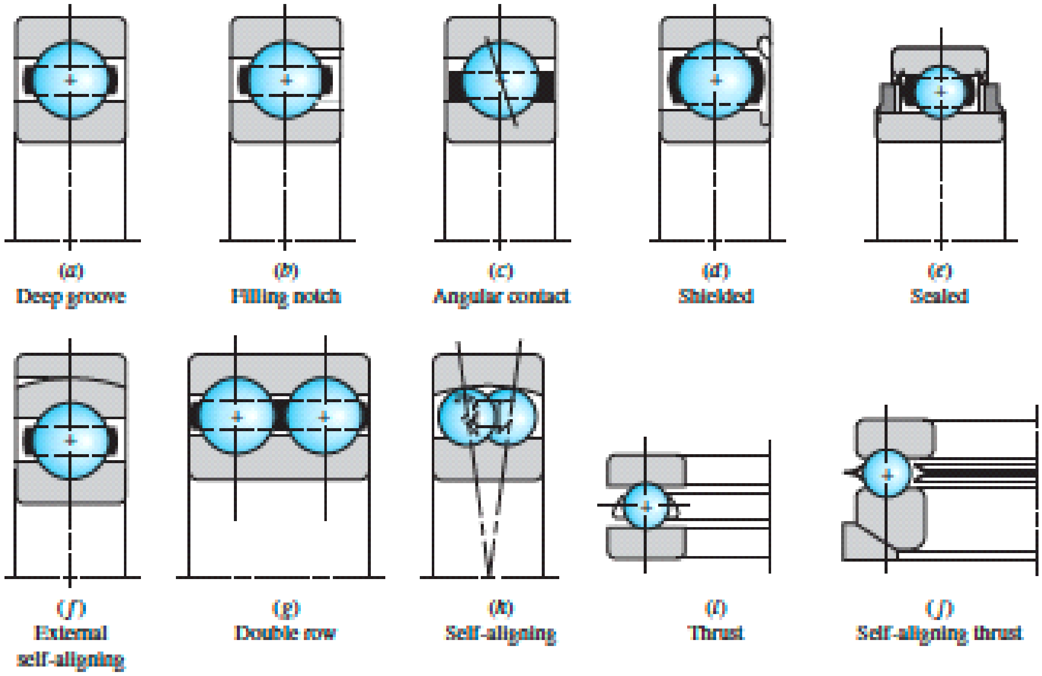
11-1 Bearing types



- inner ring
- outer ring
- ball or roller bearing
- separator (eliminated in cheap bearings)

goal of a bearing is to constrain motion to rotation about the bearing axis



- more balls, greater is the load carrying capacity.

- need to carry radial and axial loads.

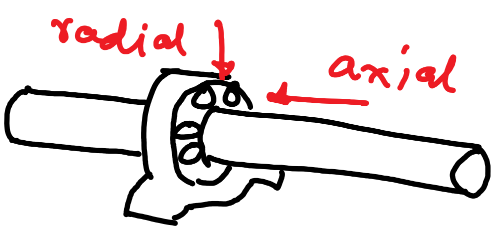
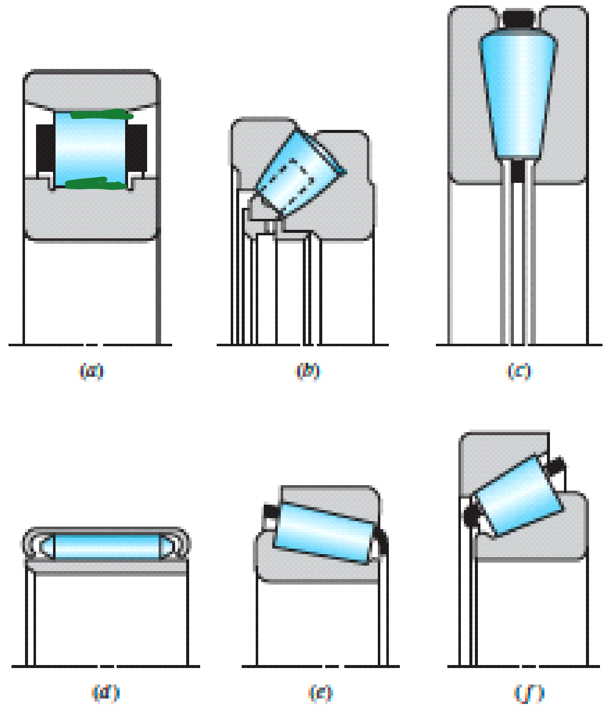


Figure 11–3

Types of roller bearings: (*a*) straight roller; (*b*) spherical roller, thrust; (*c*) tapered roller, thrust; (*d*) needle; (*e*) tapered roller; (*f*) steep-angle tapered roller. *(Courtesy of The Timken Company.)*



- roller bearings can carry greater loads than ball bearings due to larger contact area

11-3 Bearing load life at rated reliability

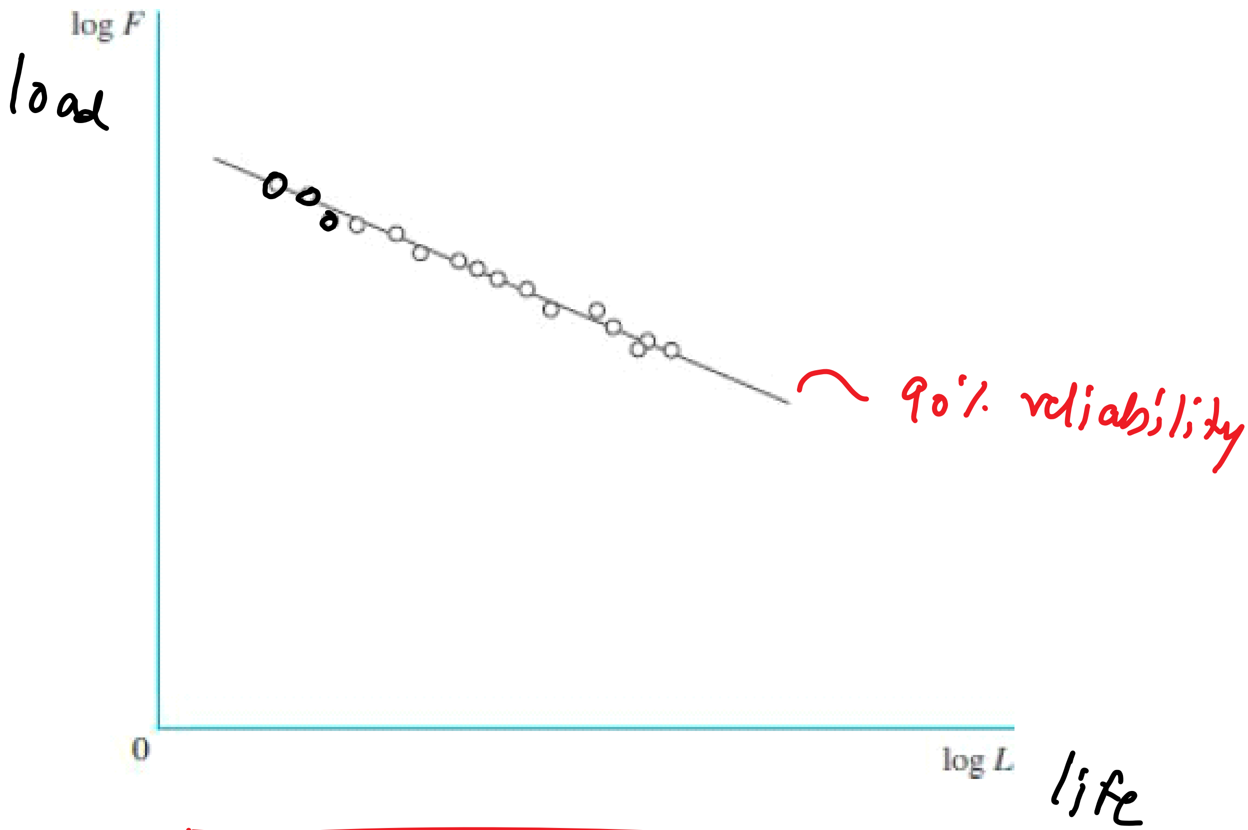
Bearing life is the total number of revolutions (or hours at a constant speed) of bearing operation until failure is developed.

Rated life: is the number of revolutions (or hours at a constant speed) that 90% of a group of bearings will achieve or exceed before failure develops.

This is also known as minimum life, L_{10} life, or B_{10} life

The most common rating life is 10^6 revs.

fig



$$FL^{1/a} = \text{constant} \qquad a = \text{constant}$$

$a = 3$ ball bearing

$a = 10/3$ roller bearing

Catalog load rating (C_{10})

It is the radial load that causes 90% of bearings to survive at the bearing manufacturers rating life.

C_{10} $\quad$ revs

$\quad$ || $\quad$ "

F_R, L_R catalog load rating & life

F_D, L_D desired load ratting & life

$$F L^{1/a} = \text{constant}$$

$$\Rightarrow \boxed{F_R L_R^{1/a} = F_D L_D^{1/a}}$$

✓ ✓ $\quad$ ✓ ?

Sometimes it is more convenient to express life in hours ($\mathcal{L}$) at a given speed in revs/min (n)

$$\boxed{\begin{aligned} L\,(\text{revs}) &= \mathcal{L}\,(\text{hrs})\; n\,(\text{rev/min})\,(60\,\text{min/hr}) \\ L &= 60\,\mathcal{L}\,n \end{aligned}}$$

$$F_R L_R^{1/a} = F_D L_D^{1/a}$$

$$F_R (60\, n_R \mathcal{L}_R)^{1/a} = F_D (60\, n_D \mathcal{L}_D)^{1/a}$$

$$\boxed{\begin{aligned} \underline{F_R} &= F_D \left(\frac{L_D}{L_R} \right)^{1/a} = F_D\, x_D^{1/a} \\ &= F_D \left(\frac{\mathcal{L}_D n_D}{\mathcal{L}_R n_R} \right)^{1/a} \end{aligned}}$$

$x_D = \dfrac{L_D}{L_R}$ multiple of rating life

Q1

A bearing company rates its ball bearings for 1 million revolutions. For 90% reliability, a desired life of 5000 hours at 1725 rev per min, and a load of 400 lbf, compute the catalog rating

$C_{10} = F_R = ?$

$L_R = 10^6$ revs

$\mathcal{L}_D = 5000$ hours

$n_D = 1725$ rev/min

$F_D = 400$ lbf.

$$F_D L_D^{1/a} = F_R L_R^{1/a}$$

$$F_R = F_D \left(\frac{L_D}{L_R}\right)^{1/a} = F_D \left(\frac{\mathcal{L}_D n_D 60}{L_R}\right)^{1/a}$$

$$C_{10} = F_R = 400 \left(\frac{5000 (1725) 60}{10^6}\right)^{1/3}$$

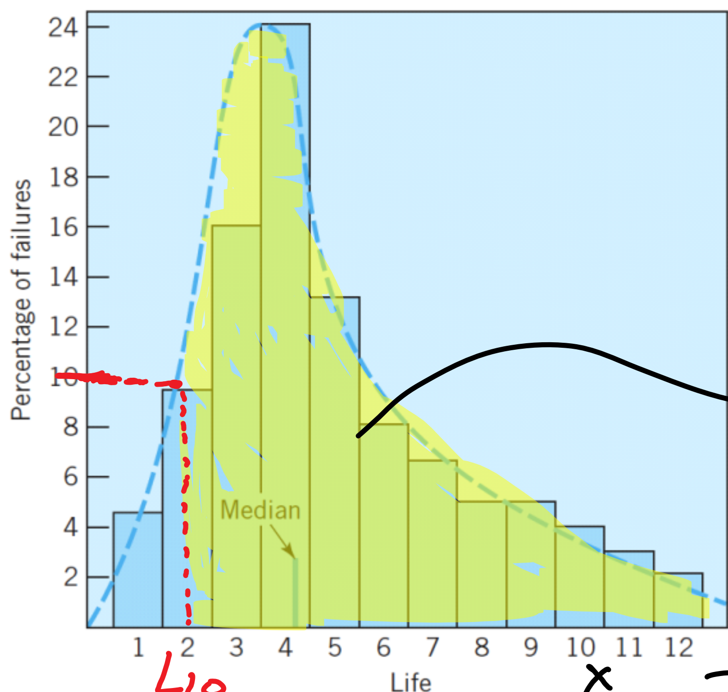
$$\boxed{C_{10} = F_R = 3211.4 \text{ lbf}}$$

Weibull distribution

11-4 Reliability vs. Life – Weibull distribution

It is empirically found that probability of failure of bearing follows a Weibull distribution.

F(x)



L_{10}

x →

f(x) probability density function

L_{10} is the coordinate on the x-axis such that 90% area is yellow

$$\boxed{R = \exp\left[-\left(\frac{x - x_0}{\theta - x_0}\right)^b\right]}$$

x - non-dimensional life $= L/L_{10}$

x_0 - minimum value of x (given)

θ - characteristic parameter

$= 63.21$ percentile for roller bearing

b - shape parameter

$= 1.5$ for roller bearing

11.5 Relating Load Life and Reliability

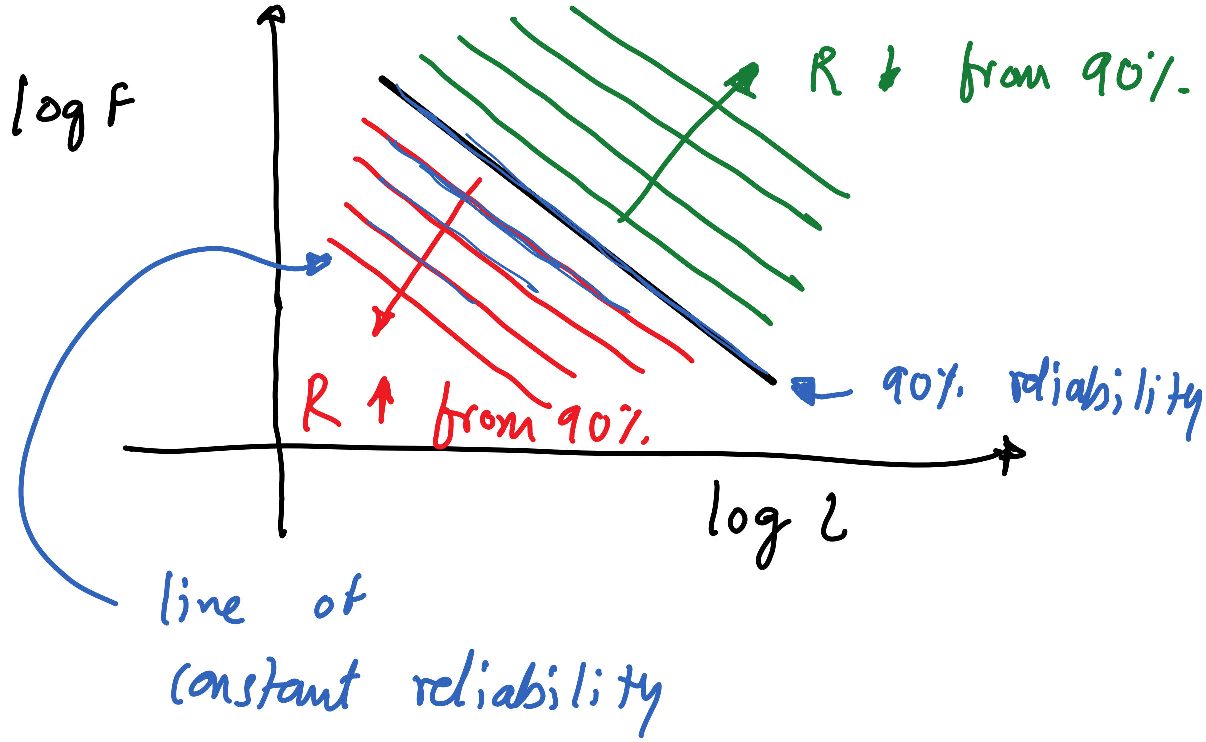
So far, at 90% reliability

$$F_D L_D^{1/a} = F_R L_R^{1/a} = F_{10} L_{10}^{1/a}$$

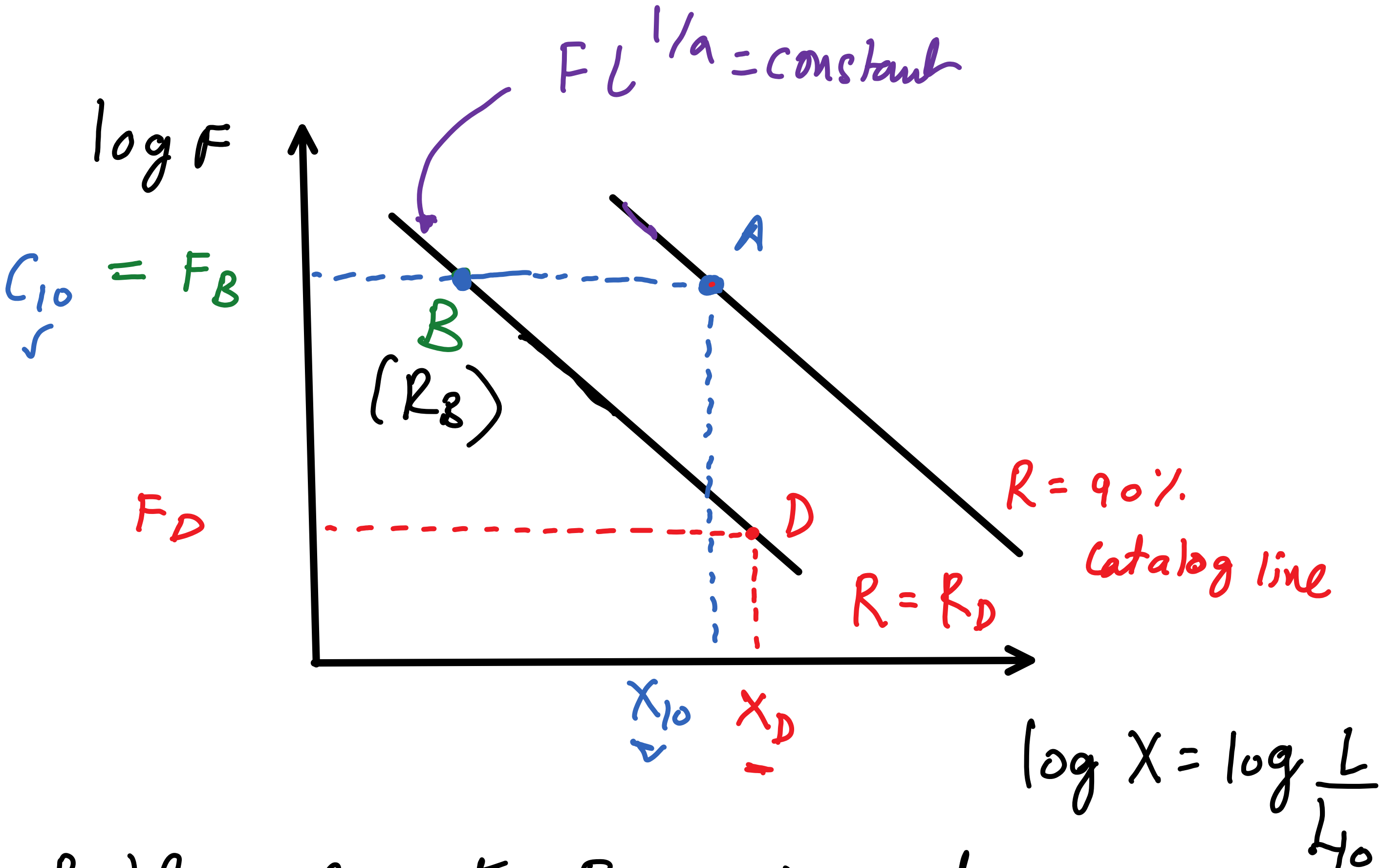
R = rated or 10

given in the catalog number

How do we compute F_D, L_D at 95% or 99% reliability?



We will use Weibull distribution and load line to compute C_{10} at a different reliability.



Problem: compute F_D or X_D at $R = R_D \neq 90\%$

Solution:

1) Use Weibull to relate A and B along same load $F_B = C_{10}$
2) Use $FL^{1/a} = \text{constant}$ to relate B and D.

2) For line BD, $(R = R_D)$ $F L^{1/a} = \text{constant}$

$$\boxed{F_B = F_D \left(\frac{x_D}{x_B}\right)^{1/a}} \quad \text{— I}$$

1) For B and A along constant F_B

$$R_B = \exp\left[-\left(\frac{x_B - x_0}{\theta - x_0}\right)^b\right]$$

Solve for x_B and note that $R_B = R_D$

$$\boxed{x_B = x_0 + (\theta - x_0)\left[\ln\left(\frac{1}{R_D}\right)\right]^{1/b}} \quad \text{II}$$

Combining I and II

$$\boxed{(C_{10})_{R=R_D} = F_B = F_D \left[\frac{x_D}{x_0 + (\theta - x_0)\left[\ln\left(1/R_D\right)\right]^{1/b}}\right]^{1/a}}$$

$\uparrow$ $\neq 90\%$

Q2

The design load on a ball bearing is 413 lbf. The speed of the shaft is specified as 300 rev/min, the expected life is 30 kilo hours at a reliability of 0.99. Compute C10 catalog entry on the basis of 10^6 revolutions of rating life. The Weibull parameters are x0 = 0.02, (theta-x0) = 4.439 and b = 1.483

$F_D = 413 \text{ lbf}; \quad n_D = 300 \text{ rev/min}$

$\mathcal{L}_D = 30\,(10^3) \text{ hours.}$

$R_D = 0.99$

$(C_{10})_{R=0.99} = ?$

$x_0 = 0.02$

$\theta - x_0 = 4.439$

$b = 1.483$

$L_R = 10^6 \text{ revs}$

$a = 3$

$$C_{10} = F_D \left[\frac{x_D}{x_0 + (\theta - x_0)\left[\ln\left(1/R_D\right)\right]^{1/b}} \right]^{1/a}$$

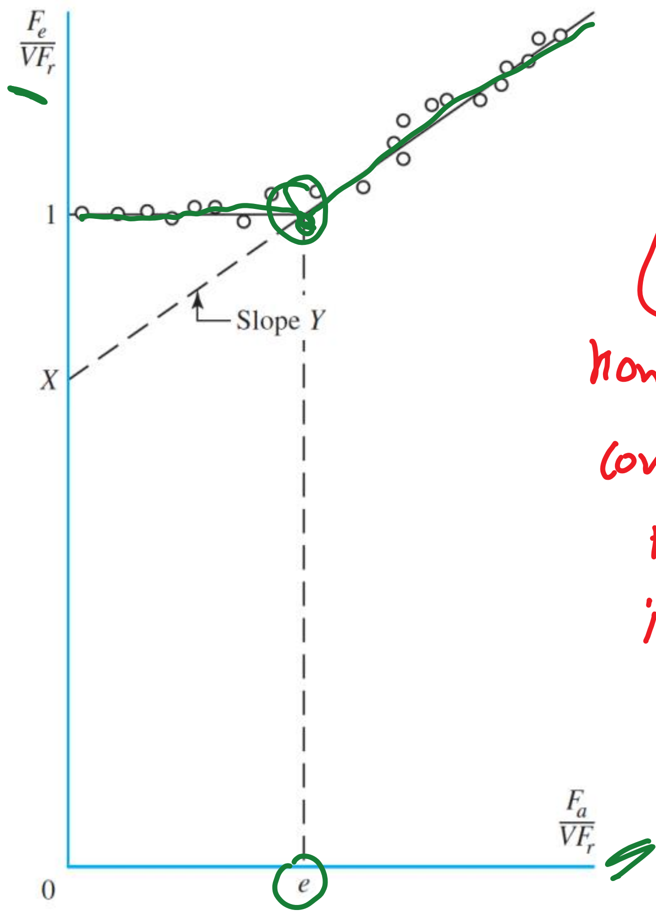
$$x_D = \frac{L_D}{L_R} = \frac{60\,\mathcal{L}_D\, n_D}{L_R} = \frac{60\,(30)(10^3)(300)}{10^6} = 540$$

$$C_{10} = 413 \left[\frac{540}{0.02 + 4.439\left(\ln\left(1/0.99\right)\right)^{1/1.483}} \right]^{1/3} \Rightarrow \boxed{C_{10} = 5580 \text{ lbf}}$$

$$C_{10} = \ldots \left[0.02 + 4.439 \left(\ln \left(\frac{1}{0.99} \right) \right)^{1/1.483} \right] \Rightarrow \boxed{C_{10} = 5580\,lbf}$$

Combined loads

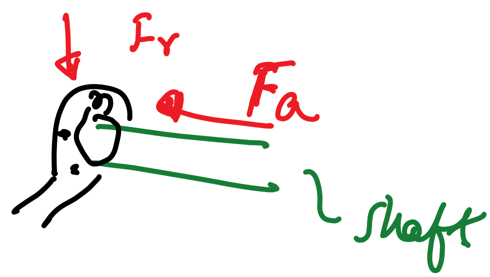
11-06 Combined loading : radial and thrust.



$F L^{1/a} = \text{constant}$

radial

how to combine F_r and F_a to use in the above formula.



F_e - equivalent load

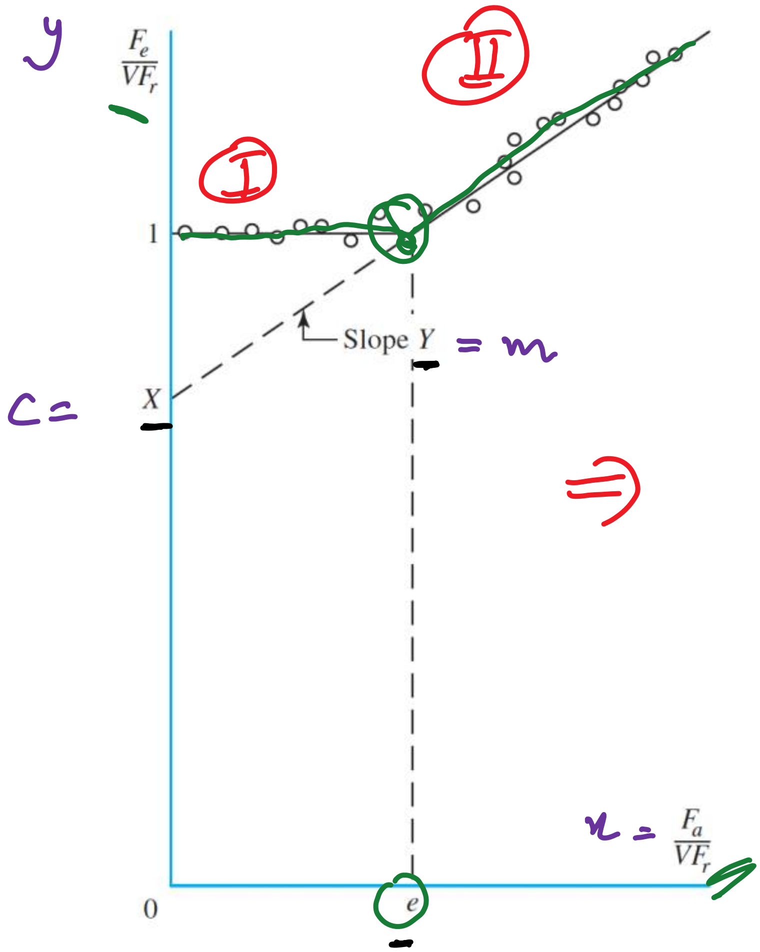
F_a - axial load

F_r - radial load

V - rotation factor $\begin{cases} 1 & \text{inner ring rotates} \\ 1.2 & \text{outer ring rotates} \end{cases}$

(y) $\frac{F_e}{VF_r}$ and (x) $\frac{F_a}{VF_r}$

Combined loads



(I)

$$\frac{F_e}{VF_r} = 1 \; ; \quad \frac{F_a}{VF_r} \le e$$

(II)

$$\Rightarrow \quad \frac{F_e}{VF_r} = X + Y \frac{F_a}{VF_r} \; ; \quad \frac{F_a}{VF_r} > e$$

$$(y) = c + m\,(x)$$

Combine equations (I) and (II)

$$\boxed{\begin{aligned} & F_e = X_i\,(VF_r) + Y_i\,(F_a) \\ & i=1 \; ; \; X_1, Y_1 \text{ for } \frac{F_a}{VF_r} \le e \\ & i=2 \; ; \; X_2, Y_2 \text{ for } \frac{F_a}{VF_r} > e \end{aligned}}$$

Tables

Compute F_e

C_o = constant static loading

I

II

Table 11–1

Equivalent Radial Load Factors for Ball Bearings

		$F_a/(VF_r) \le e$		$F_a/(VF_r) > e$	
F_a/C_0	e	X_1	Y_1	X_2	Y_2
0.014*	0.19	1.00	0	0.56	2.30
0.021	0.21	1.00	0	0.56	2.15
0.028	0.22	1.00	0	0.56	1.99
0.042	0.24	1.00	0	0.56	1.85
0.056	0.26	1.00	0	0.56	1.71
0.070	0.27	1.00	0	0.56	1.63
0.084	0.28	1.00	0	0.56	1.55
0.110	0.30	1.00	0	0.56	1.45
0.17	0.34	1.00	0	0.56	1.31
0.28	0.38	1.00	0	0.56	1.15
0.42	0.42	1.00	0	0.56	1.04
0.56	0.44	1.00	0	0.56	1.00

*Use 0.014 if $F_a/C_0 < 0.014$.

0.09

Table 11–2

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

			Fillet	Shoulder		Load Ratings, kN			
						Deep Groove		Angular Contact	
Bore, mm	OD, mm	Width, mm	Radius, mm	Diameter, mm d_S	d_H	C_{10}	C_0	C_{10}	C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8
55	100	21	1.5	63	90	43.6	25.0	46.2	28.5
60	110	22	1.5	70	99	47.5	28.0	55.9	35.5
65	120	23	1.5	74	109	55.9	34.0	63.7	41.5
70	125	24	1.5	79	114	61.8	37.5	68.9	45.5
75	130	25	1.5	86	119	66.3	40.5	71.5	49.0
80	140	26	2.0	93	127	70.2	45.0	80.6	55.0
85	150	28	2.0	99	136	83.2	53.0	90.4	63.0
90	160	30	2.0	104	146	95.6	62.0	106	73.5
95	170	32	2.0	110	156	108	69.5	121	85.0

Q3

An angular contact ball bearing has an axial load Fa of 400 lbf and a radial load of 500 lbf applied with the outer ring stationary. The basic static load rating C0 is 4450 lbf and the basic load rating C10 is 7900 lbf. Estimate the L10 life (in hours) at a speed of 720 rev/min

$F_a = 400$ lbf ; $F_r = 500$ lbf ; $V = 1$ (outer ring stationary)

$C_0 = 4450$ lbf ; $C_{10} = 7900$ lbf

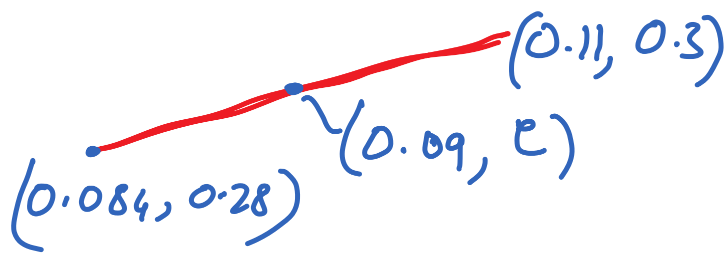
$\mathcal{L}_{10}$ (hrs) = ? $\quad n_{10} = 720$ rev/min

(i) $\dfrac{F_a}{C_o} = \dfrac{400}{4450} = 0.09$

(ii) Let us interpolate in order to compute e at $F_a/C_o = 0.09$

From table 11-1

F_a/C_o	e
0.084	0.28
0.11	0.3



$$\frac{e - 0.28}{0.09 - 0.084} = \frac{0.28 - 0.3}{0.084 - 0.11}$$

$$e = 0.2846 \simeq 0.285$$

(iii) $\dfrac{F_a}{VF_r} = \dfrac{400}{(1)\,500} = 0.8$ and $e = 0.285$

$$\Rightarrow \frac{F_a}{VF_r} = 0.8 > e = 0.285$$

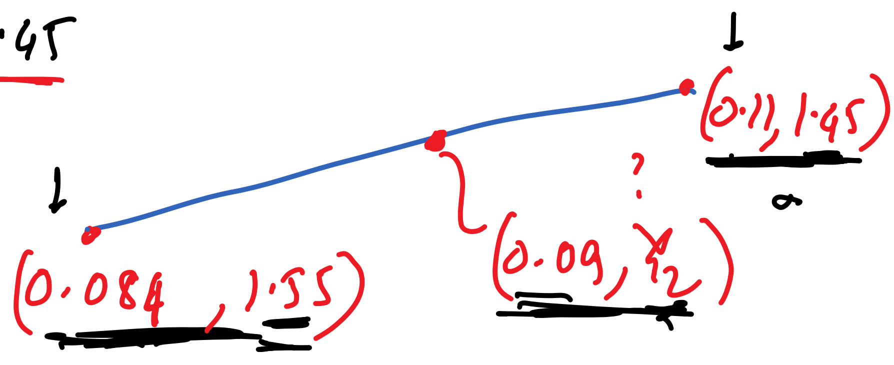
We need to use X_2, Y_2

(iv)

F_a/C_o	X_2	Y_2
0.084	0.56	1.55
0.11	0.56	1.45

0.09

Interpolating



$$\frac{1.45 - Y_2}{0.11 - 0.09} = \frac{1.45 - 1.55}{0.11 - 0.084}$$

$Y_2 = 1.5269 \simeq 1.527$

$X_2 = 0.56$

(v) $F_e = X_2 V F_r + Y_2 F_a$

$$F_e = (0.56)(1)(500) + (1.527)(400)$$
$$= 890.8 \text{ lbf} \quad \text{(equivalent load)}$$

(vi) $F L^{1/a} = \text{constant}$

$$F_R L_R^{1/a} = F_D L_D^{1/a}$$

$$\boxed{\mathcal{L}_{10}\ (\text{hrs}) = ? \quad n_{10} = 720 \text{ rev/min} \quad C_{10} = 7900 \text{ lbf}}$$

$$F_R L_R^{1/a} = F_e (60 n_{10} \mathcal{L}_{10})^{1/a}$$

For ball bearing

$$\mathcal{L}_{10} = \left(\frac{L_R}{60 n_{10}}\right)\left(\frac{F_R}{F_e}\right)^a = \frac{10^6}{60(720)}\left(\frac{7900}{890.8}\right)^3$$

$$\boxed{\mathcal{L}_{10} = 16145.7 \text{ hrs}}$$