Bearings

ME 310: Mechanical Design

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Outline

Overview of Bearings

Sliding Contact Bearings

Rolling Contact Bearings

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Sliding Contact Bearings

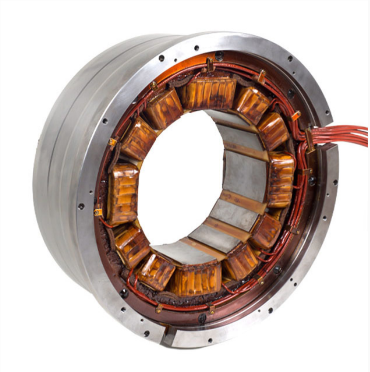
Rolling Contact Bearings

What are bearings?

- A feature that allows relative motions between components
- Linear motions
- Rotary motions

Two types of bearings

- Contact: sliding or rolling
- Non-contact: fluid film or magnetic



Overview of Bearings

Sliding Contact Bearings

Rolling Contact Bearings

Sliding Contact Bearings

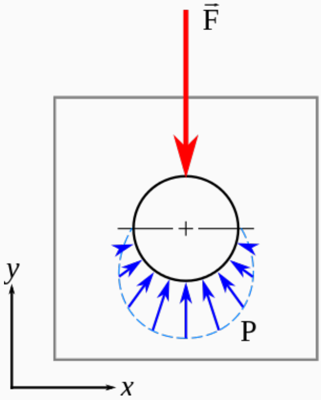
- Commonly used in low- to medium-speed applications

- Lubrication is used to reduce wear and friction

Materials for Sliding Contact Bearing

- Typically hard materials (shaft) on soft (bearing)
- Materials:
  - Polymers: nylon is king!
  - Brass
  - Ceramics
- Check on bearing stress
- Aluminum-on-aluminum is a no-no

Bearing Contact Pressure



$$P = \frac{F}{DL}$$

$$P_{\max} = \frac{4}{\pi}\frac{F}{DL}$$

Sliding Contact Materials: PV Factor

- (P)ressure $\times$ (V)elocity
- tradeoff in choosing bearing materials
- higher pressure $\rightarrow$ low speed, and vice versa

PV Table for Metals

Material	Static P MPa	Static P (ksi)	Dynamic P MPa	Dynamic P (ksi)	V m/s	V (fpm)	PV MPa • m/s	PV (ksi • fpm)
Bronze	55	(8)	14	(2)	6.1	(1200)	1.8	(50)
Lead–bronze	24	(3.5)	5.5	(0.8)	7.6	(1500)	2.1	(60)
Copper–iron	138	(20)	28	(4)	1.1	(225)	1.2	(35)
Hardenable copper–iron	345	(50)	55	(8)	0.2	(35)	2.6	(75)
Iron	69	(10)	21	(3)	2.0	(400)	1.0	(30)
Bronze–iron	72	(10.5)	17	(2.5)	4.1	(800)	1.2	(35)
Lead–iron	28	(4)	7	(1)	4.1	(800)	1.8	(50)
Aluminum	28	(4)	14	(2)	6.1	(1200)	1.8	(50)

PV Table for Nonmetals

	P		Temperature		*V*		*PV*	
Material	**MPa**	**(ksi)**	**°C**	**(°F)**	**m/s**	**(fpm)**	**MPa • m/s**	**(ksi • fpm)**
Phenolics	41	(6)	93	(200)	13	(2500)	0.53	(15)
Nylon	14	(2)	93	(200)	3.0	(600)	0.11	(3)
TFE	3.5	(0.5)	260	(500)	0.25	(50)	0.035	(1)
Filled TFE	17	(2.5)	260	(500)	5.1	(1000)	0.35	(10)
TFE fabric	414	(60)	260	(500)	0.76	(150)	0.88	(25)
Polycarbonate	7	(1)	104	(220)	5.1	(1000)	0.11	(3)
Acetal	14	(2)	93	(200)	3.0	(600)	0.11	(3)
Carbon (graphite)	4	(0.6)	400	(750)	13	(2500)	0.53	(15)
Rubber	0.35	(.05)	66	(150)	20	(4000)	—	—
Wood	14	(2)	71	(160)	10	(2000)	0.42	(12)

Example: Sleeve Bearing for a Low-speed Shaft

A 30-cm long shaft whose diameter D is 3 cm is operated at 1000 rpm. The shaft has a spur gear whose R_{pitch} = 10 cm mounted in the middle with a bearing at each end. The gear is transferring the power of 1.5 kW. The gear has pressure angle $\theta = 20°$. Determine the minimum bearing length L using nylon.

Solution

First, let us determine the force on the bearing. Since spur gears don't generate any axial load, the forces will simply be the radial + tangential load, perpendicular to the shaft.

$$
\begin{aligned}
T &= \frac{P}{\omega} \\
&= \frac{1500}{1000(2\pi/60)} = 14.3 \text{ N-m} \\
F &= \frac{T}{R_{\text{pitch}} \cos\theta} \\
&= \frac{14.3}{0.1 \cos 20^\circ} = 152 \text{ N}
\end{aligned}
$$

Solution

Since the gear is mounted in the middle, the force on each bearing is half of the force.

$$F_{bearing} = \frac{152}{2} = 76 \text{ N}$$

We can't determine the bearing pressure yet since we don't know the bearing length. We can determine the surface velocity, however.

$$v = \omega(D/2) = 1000(2\pi/60)(0.03/2) = 1.57 \text{ m/s}$$

Solution

We double-check that $v < V_{nylon} (1.57 < 3.0)$ so nylon is an acceptable choice. The length of bearing, then should be

$$
\begin{aligned}
P_{bearing} v &< (PV)_{nylon} \\
\frac{F_{bearing}}{DL} v &< 0.11 \times 10^6 \\
\frac{76}{0.03L} 1.57 &< 1.1 \times 10^5 \\
L &> 0.036 = 3.6 \text{ cm}
\end{aligned}
$$

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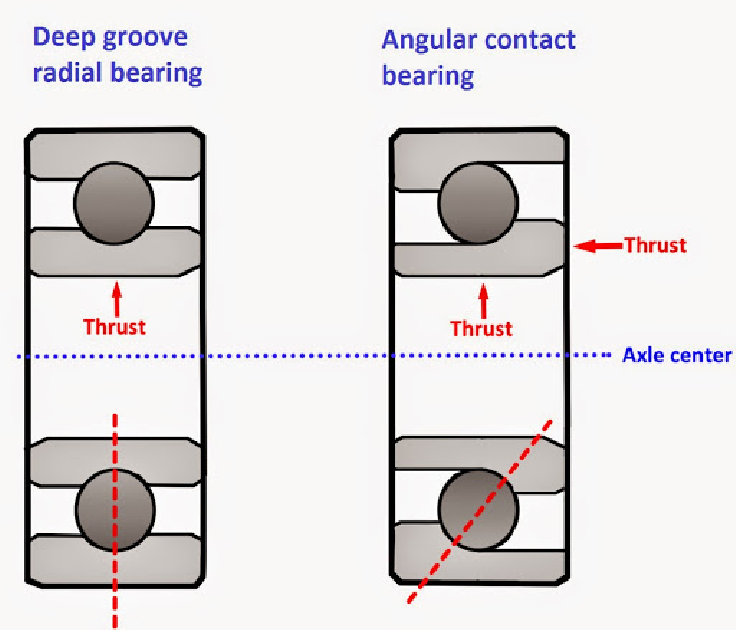
Rolling Contact Bearings

Rolling Elements

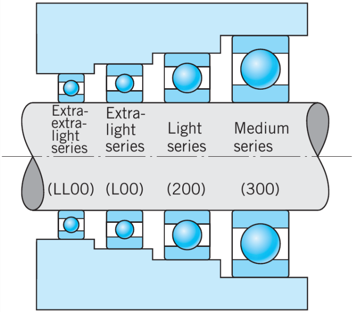
- suitable for medium- to high-speed applications
- use balls or rollers to avoid friction
- load: roller $>$ ball
- friction: ball $<$ roller

Rolling Element Types

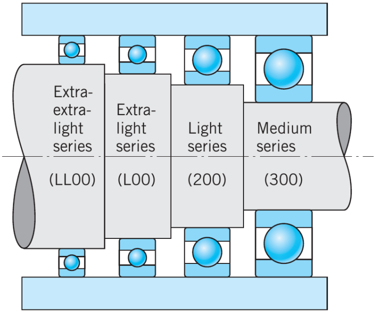
Radial vs Angular Contact Bearings



Bearing Series



(*a*)
Relative proportions of bearings with same bore dimension



(*b*)
Relative proportions of bearings with same outside diameter

Bearing Table

Bearing Basic Number	Bore (mm)	Ball Bearings OD (mm)	Ball w (mm)	Ball r^a (mm)	Ball d_S (mm)	Ball d_H (mm)	Roller Bearings OD (mm)	Roller w (mm)	Roller r^a (mm)	Roller d_S (mm)	Roller d_H (mm)
L03	17	35	10	0.30	19.8	32.3	35	10	0.64	20.8	32.0
203	17	40	12	0.64	22.4	34.8	40	12	0.64	20.8	36.3
303	17	47	14	1.02	23.6	41.1	47	14	1.02	22.9	41.4
L04	20	42	12	0.64	23.9	38.1	42	12	0.64	24.4	36.8
204	20	47	14	1.02	25.9	41.7	47	14	1.02	25.9	42.7
304	20	52	15	1.02	27.7	45.2	52	15	1.02	25.9	46.2
L05	25	47	12	0.64	29.0	42.9	47	12	0.64	29.2	43.4
205	25	52	15	1.02	30.5	46.7	52	15	1.02	30.5	47.0
305	25	62	17	1.02	33.0	54.9	62	17	1.02	31.5	55.9
L06	30	55	13	1.02	34.8	49.3	47	9	0.38	33.3	43.9
206	30	62	16	1.02	36.8	55.4	62	16	1.02	36.1	56.4
306	30	72	19	1.02	38.4	64.8	72	19	1.52	37.8	64.0
L07	35	62	14	1.02	40.1	56.1	55	10	0.64	39.4	50.8
207	35	72	17	1.02	42.4	65.0	72	17	1.02	41.7	65.3
307	35	80	21	1.52	45.2	70.4	80	21	1.52	43.7	71.4
L08	40	68	15	1.02	45.2	62.0	68	15	1.02	45.7	62.7
208	40	80	18	1.02	48.0	72.4	80	18	1.52	47.2	72.9
308	40	90	23	1.52	50.8	80.0	90	23	1.52	49.0	81.3
L09	45	75	16	1.02	50.8	68.6	75	16	1.02	50.8	69.3
209	45	85	19	1.02	52.8	77.5	85	19	1.52	52.8	78.2
309	45	100	25	1.52	57.2	88.9	100	25	2.03	55.9	90.4
L10	50	80	16	1.02	55.6	73.7	72	12	0.64	54.1	68.1
210	50	90	20	1.02	57.7	82.3	90	20	1.52	57.7	82.8
310	50	110	27	2.03	64.3	96.5	110	27	2.03	61.0	99.1
L11	55	90	18	1.02	61.7	83.1	90	18	1.52	62.0	83.6
211	55	100	21	1.52	65.0	90.2	100	21	2.03	64.0	91.4
311	55	120	29	2.03	69.8	106.2	120	29	2.03	66.5	108.7

Bearing Life Requirement

$$L = L_R K_r \left(\frac{C}{F_e}\right)^{10/3}$$

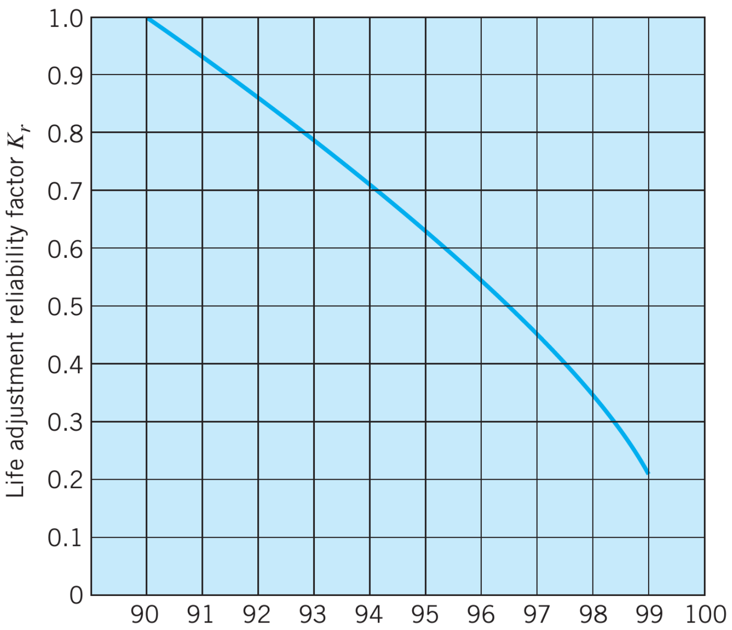
$$C = F_e \left(\frac{L}{K_r L_R}\right)^{0.3}$$

L	life corresponding to equivalent load F_e
L_R	life corresponding to rated capacity = 9×10^7 rev
K_r	reliability factor
C	rated capacity
F_e	equivalent load

Bearing Rated Capacity

	Radial Ball, $\alpha = 0°$			Angular Ball, $\alpha = 25°$			Roller		
Bore (mm)	L00 Xlt (kN)	200 lt (kN)	300 med (kN)	L00 Xlt (kN)	200 lt (kN)	300 med (kN)	1000 Xlt (kN)	1200 lt (kN)	1300 med (kN)
10	1.02	1.42	1.90	1.02	1.10	1.88			
12	1.12	1.42	2.46	1.10	1.54	2.05			
15	1.22	1.56	3.05	1.28	1.66	2.85			
17	1.32	2.70	3.75	1.36	2.20	3.55	2.12	3.80	4.90
20	2.25	3.35	5.30	2.20	3.05	5.80	3.30	4.40	6.20
25	2.45	3.65	5.90	2.65	3.25	7.20	3.70	5.50	8.50
30	3.35	5.40	8.80	3.60	6.00	8.80	2.40[a]	8.30	10.0
35	4.20	8.50	10.6	4.75	8.20	11.0	3.10[a]	9.30	13.1
40	4.50	9.40	12.6	4.95	9.90	13.2	7.20	11.1	16.5
45	5.80	9.10	14.8	6.30	10.4	16.4	7.40	12.2	20.9
50	6.10	9.70	15.8	6.60	11.0	19.2	5.10[a]	12.5	24.5
55	8.20	12.0	18.0	9.00	13.6	21.5	11.3	14.9	27.1
60	8.70	13.6	20.0	9.70	16.4	24.0	12.0	18.9	32.5

Reliability Factor



Equivalent Load

Let $e = F_a/F_r$

for radial ball bearings

$$F_e = \begin{cases} F_r & e < 0.35 \\ F_r\left[1 + 1.115(e - 0.35)\right] & 0.35 < e < 10 \\ 1.176F_a & e > 10 \end{cases}$$

for angular ball bearings

$$F_e = \begin{cases} F_r & e < 0.68 \\ F_r\left[1 + 0.87(e - 0.68)\right] & 0.68 < e < 10 \\ 0.911F_a & e > 10 \end{cases}$$

Typical Bearing Design Life

Type of Application	Design Life (thousands of hours)
Instruments and apparatus for infrequent use	0.1–0.5
Machines used intermittently, where service interruption is of minor importance	4–8
Machines intermittently used, where reliability is of great importance	8–14
Machines for 8-hour service, but not every day	14–20
Machines for 8-hour service, every working day	20–30
Machines for continuous 24-hour service	50–60
Machines for continuous 24-hour service where reliability is of extreme importance	100–200

Example

Select a radial ball bearing for a shaft intended for a continuous 8-hr-a-day operation at 1800 rpm with 95% reliability. Axial and radial loads are 1.2 kN and 1.5 kN, respectively.

Solution

- First, we need to calculated F_e.

$$e = \frac{F_a}{F_r} = \frac{1.2}{1.5} = 0.8$$

- For radial ball bearing,

$$\begin{aligned} F_e &= 1500\,[1 + 1.115(0.8 - 0.35)] \\ &= 2253 \text{ N} \end{aligned}$$

Solution

- Required life for 8-hr-a-day service (assumed every day) = 30000 hrs
- Life in revolutions

$$L = 1800(30000)(60) = 3.24 \times 10^9 \text{ revolutions}$$

- For 95% reliability K_r = 0.63

$$C = 2253 \left(\frac{3.24 \times 10^9}{0.63(9 \times 10^7)} \right)^{0.3} = 7583 \text{ N} = 7.58 \text{ kN}$$

Solution

- For extra-light, light, and medium series, the required bore are 55, 35, and 30 mm, respectively
- The models corresponding to the bore are L11, 207, and 306, respectively.