Machine Components: Rolling-Element Bearings

ME 72 Engineering Design Laboratory

Function of Bearings

- A bearing permits relative motion between two machine members while minimizing frictional resistance.
- A bearing consists of an inner and outer member separated either by a thin film of lubricant, or a rolling element.

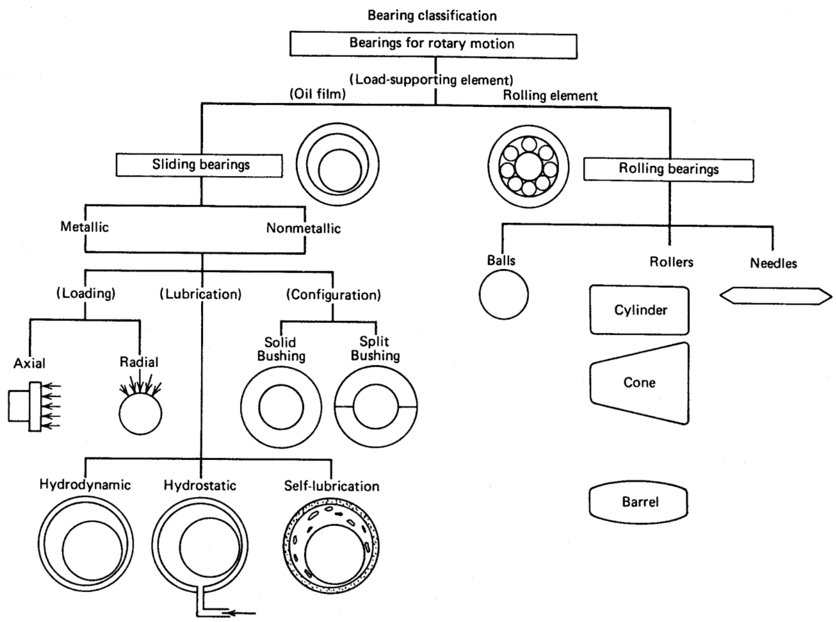


Figure 17-1 Bearing classification.

Comparison Table

TABLE 17-1 Characteristics of Sliding and Rolling Contact Bearings

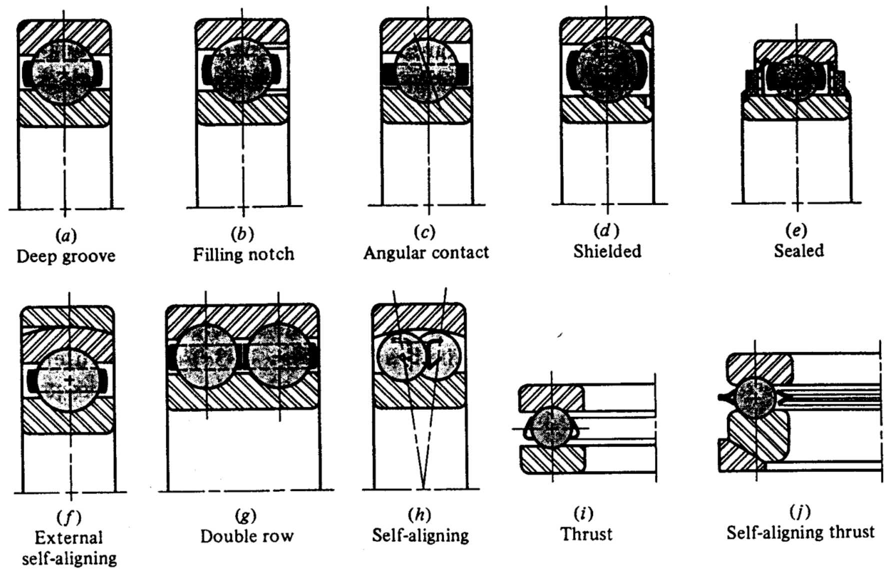
Bearing Characteristics	Sliding Bearings: Hydrodynamic	Sliding Bearings: Hydrostatic	Rolling Bearings
Load carried by	Oil film generated by rotation journal and suitable oil grooves	Oil film generated by a pump placed outside the bearing	Bodies capable of rolling under load
Friction at start-up	Large, due to direct contact between journal and sleeve	Zero; journal and sleeve are separated by an oil film	Low
Friction during operation	Moderate; bearing acts as a pump with low efficiency	Low (fluid friction)	Low (rolling friction)
Life	Limited due to wear at start-up and stop	Unlimited; no contact between metallic parts during operation	Limited (material fatigue in the races)
Relative cost of lubrication	Low	High	Low

Rolling-Element Bearings

- Pros
  - Low starting and running friction
  - Easy lubrication
  - Small axial space
  - Radial and axial loads
  - Predictable failure
  - Standards (ABEC)
  - Can be preloaded
  - Easy mounting
- Cons
  - Greater diametrical space
  - More expensive
  - Noisy
  - Finite life
  - Vulnerable to dirt
  - Limited shock loading

Ball Bearings

- Ball Bearings
  - Point contact; support radial and axial loads
- Angular Contact Bearings
  - Designed for axial loading; used in pairs
- Self-Aligning Bearings
- Double Row Bearings
  - Support higher loads
- Thrust Bearings
  - Designed for pure axial loading



Roller Bearings

- Straight
  - Supports high radial loads; slower speed ratings
- Tapered
  - High radial and axial load ratings; used in pairs
- Spherical
  - Allows for misalignment
- Needle
  - Thrust and radial types; typically no inner race

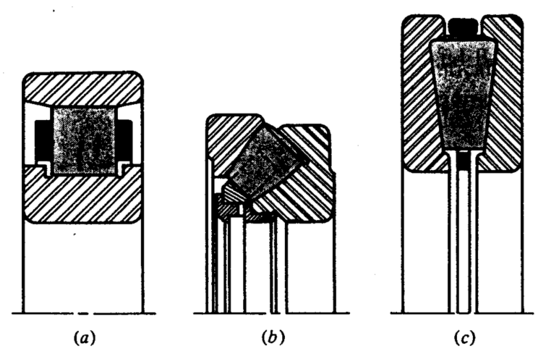
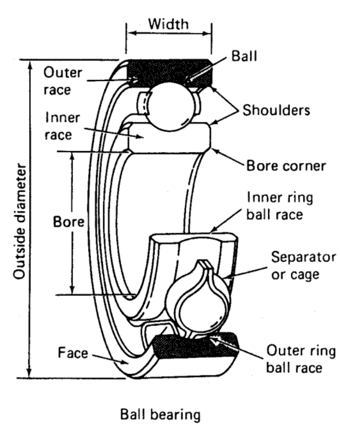


FIGURE 11-3

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.)*

Terminology

- Inner race
- Outer race
- Inner and outer diameters
- Width
- Options
  - Open, shielded, sealed
  - grooves, flanges
  - wide inner race



Bearing Specifications

- Types, series, options
- Dimensions
- Load Ratings
  - Static (C_0): maximum (pre-damage) load
  - Dynamic (C): the load that will give a life of 10^6 revolutions
  - Axial/Radial
- Speed Rating

Single Row Deep Groove Ball Bearings

Principal Dimensions			Basic load ratings		Allowable load limit	Speed ratings		Abutment and fillet Dimensions			Designation
d_b	d_a	b_w	dynamic C	static C_0	w_{all}	grease	oil	$D_{b,min}$	$D_{a.max}$	$r_{a,max}$	
mm	mm	mm	N			rpm		mm	mm	mm	
in	in	in	lbf					in	in	in	
2.5	**8**	**2.8**	**319**	**106**	**4**	67000	80000	**3.7**	**6.8**	**0.1**	**60/2.5**
0.0984	0.3150	0.1102	71.7	23.8	0.899			0.146	0.268	0.004	
5	**11**	**3**	**637**	**255**	**11**	53000	63000	**6.2**	**9.8**	**0.1**	**618/5**
0.1969	0.4331	0.1181	143	57.3	2.47			0.244	0.386	0.004	
	19	**6**	**1720**	**620**	**26**	36000	43000	**7**	**17**	**0.3**	**635**
	0.7480	0.2362	387	139	5.85			0.276	0.669	0.012	
7	**14**	**3.5**	**956**	**400**	**17**	45000	53000	**8.2**	**12.8**	**0.1**	**618/7**
0.2756	0.5512	0.1378	215	89.9	3.82			0.323	0.504	0.004	
10	**19**	**5**	**1380**	**585**	**25**	36000	43000	**12**	**17**	**0.3**	**61800**
0.3937	0.7480	0.1969	310	132	5.62			0.472	0.669	0.012	
	26	**8**	**4620**	**1960**	**83**	30000	36000	**12**	**24**	**0.3**	**6000**
	1.0236	0.3150	1040	441	18.7			0.472	0.945	0.012	
	35	**11**	**8060**	**3400**	**143**	20000	26000	**14**	**31**	**0.6**	**6300**
	1.3780	0.4331	1810	764	32.1			0.551	1.220	0.024	
15	**24**	**5**	**1560**	**800**	**34**	28000	34000	**17**	**22**	**0.3**	**61802**
0.5906	0.9449	0.1969	351	180	7.64			0.669	0.866	0.012	
	28	**7**	**4030**	**2040**	**85**	24000	30000	**17**	**26**	**0.3**	**61902**
	1.1024	0.2756	906	459	19.1			0.669	1.024	0.012	
	32	**8**	**5590**	**2850**	**120**	22000	28000	**17**	**30**	**0.3**	**16002**
	1.2598	0.3150	1260	641	27.0			0.669	1.181	0.012	
	32	**9**	**5590**	**2850**	**120**	22000	28000	**17**	**30**	**0.3**	**6002**
	1.2598	0.3543	1260	641	27.0			0.669	1.181	0.012	
	35	**11**	**7800**	**3750**	**160**	19000	24000	**19**	**31**	**0.6**	**6202**
	1.3780	0.4331	1750	843	36.0			0.748	1.220	0.024	
	42	**13**	**11400**	**5400**	**228**	17000	20000	**20**	**37**	**1**	**6302**
	1.6535	0.5118	2560	1210	51.3			0.787	1.457	0.039	

Bearing Life

- Bearing Life-Load Equation

$$\frac{L_1}{L_2} = \left(\frac{F_2}{F_1}\right)^a$$

  - L = life, millions of revolutions
  - F = load
  - a = 3 for ball bearings, 3.33 for roller bearings

- Design Equation

$$\frac{L_1}{10^6} = \left(\frac{C}{F_1}\right)^a$$

Radial and Thrust Loads

- Equivalent Radial Load

$$P = XVF_r + YF_a$$

  - P = equivalent load
  - F_r = applied constant radial load
  - F_a = applied constant thrust load
  - V = rotation factor (1.0 IRR, 1.2 ORR)
  - X = radial factor (provided by manufacturer)
  - Y = thrust factor (provided by manufacturer)

Capacity Formulas for Radial and Angular Bearings

Bearing type		e	Single row bearings				Double row bearings			
			Pa/Pr<e		Pa/Pr>e		Pa/Pr<e		Pa/Pr>e	
			X	Y	X	Y	X	Y	X	Y
Deep groove ball bearings	P/C_0=0.025	0.22	1	0	0.56	2.0				
	P/C_0=0.04	0.24	1	0	0.56	1.8				
	P/C_0=0.07	0.27	1	0	0.56	1.6				
	P/C_0=0.13	0.31	1	0	0.56	1.4				
	P/C_0=0.25	0.37	1	0	0.56	1.2				
	P/C_0=0.50	0.44	1	0	0.56	1				
Angular contact ball bearings	β=20°	0.57	1	0	0.43	1	1	1.09	0.70	1.63
	β=25°	0.68	1	0	0.41	0.87	1	0.92	0.67	1.41
	β=30°	0.80	1	0	0.39	0.76	1	0.78	0.63	1.24
	β=35°	0.95	1	0	0.37	0.66	1	0.66	0.60	1.07
	β=40°	1.14	1	0	0.35	0.57	1	0.55	0.57	0.93
	β=45°	1.33	1	0	0.33	0.50	1	0.47	0.54	0.81
Self-aligning ball bearings		1.5 x tanβ					1	0.42 x cotβ	0.65	0.65 x cotβ
Spherical roller bearings		1.5 x tanβ					1	0.45 x cotβ	0.67	0.67 x cotβ
Tapered roller bearings		1.5 x tanβ	1	0	0.40	0.40 x cotβ	1	0.42 x cotβ	0.67	0.67 x cotβ

Mounting Bearings

- Mounting Issues
  - Design to fix relative axial/radial location
  - Avoid misalignment: maintain concentricity
  - Consider preloading (to eliminate backlash)
  - Follow Press/Slip Fit guidelines
    - Always press to a shoulder
  - Be aware of shaft hardness requirements
  - NEVER use more than 2 bearings / shaft

Typical Mountings

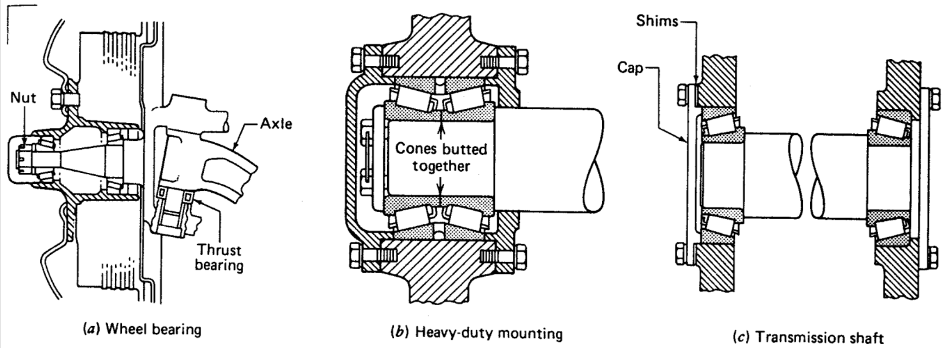
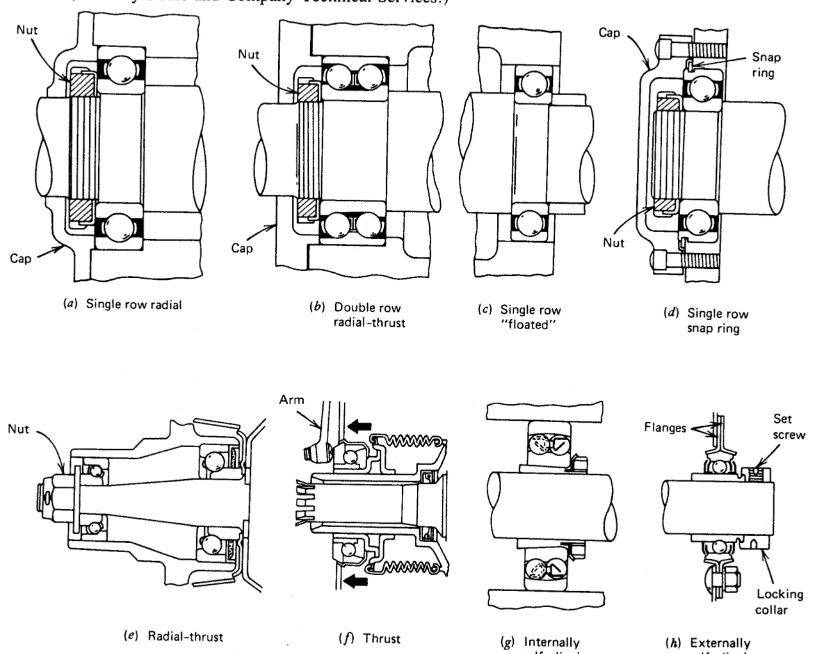


Figure 18-23 Typical roller bearing mountings, showing different means of adjustment. (Courtesy The Timken Company.)

Figure 18-24 Typical ball bearing mountings, showing different means of axial location. (Courtesy Deere and Company Technical Services.)



Classes of Fit

Class	Description	Type	Applications
1	Loose	Clearance	Where accuracy is not essential, such as in road-building and mining equipment.
2	Free	Clearance	In rotating journals with speeds of 600 rpm or greater, such as in engines and some automotive parts.
3	Medium	Clearance	In rotating journals with speeds under 600 rpm, such as in accurate machine tools and precise automotive parts.
4	Snug	Clearance	Where small clearance is permissible and where moving parts are not intended to move freely under load.
5	Wringing	Interference	Where light tapping with a hammer is necessary to assemble the parts.
6	Tight	Interference	In semipermanent assemblies suitable for drive of shrink fits on light sections.
7	Medium	Interference	Where considerable pressure is needed to assemble and for shrink fits of medium sections; suitable for press fits on generator and motor armatures and for car wheels.
8	Heavy force or shrink	Interference	Where considerable bonding between surfaces is required, such as locomotive wheels and heavy crankshaft disks of large engines

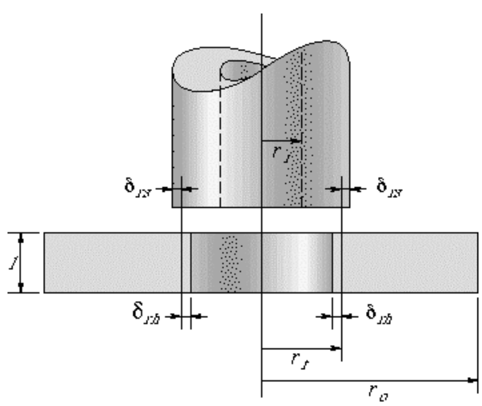
Interference Fits

- Pressure created by a press fit

$$p = \frac{0.5\delta}{\frac{r}{E_o}\left(\frac{r_o^2 + r^2}{r_o^2 - r^2} + \nu_o\right) + \frac{r}{E_i}\left(\frac{r_i^2 + r^2}{r_i^2 - r^2} + \nu_i\right)}$$

- Torque transmitted

$$T = 2\pi r^2 \mu p l$$



Summary

- Sliding bearings use hydrodynamic forces to support loads and lubricant shear to provide low friction.
- Rolling element bearings are configured to support a variety of axial and radial loads and provide low rolling friction between a shaft and hub.
- Bearings are typically press fit into a housing and slip fit onto a shaft.

References

- Hindhede, U., Zimmerman, J., Hopkins, B., et al., *Machine Design Fundamentals: A Practical Approach*, Englewood Cliffs: Prentice Hall, 1983.
- Shigley, J., and Mischke, C., *Mechanical Engineering Design*, 5th Ed., San Francisco: McGraw-Hill Inc., 1989.
- Norton, R., *Machine Design: An Integrated Approach*, Upper Saddle River: Prentice-Hall, 1998.
- Hamrock, B., Jacobson, B., and Schmid, S., *Fundamentals of Machine Elements*, San Francisco, WCB McGraw-Hill, 1999.