Chapter IV. Rolling contact Bearings and Plain Surface Bearings

IV.1. Discussion Map

- Bearings are used to support a load while permitting relative motion between two elements of a machine.
- Some bearings use rolling elements, such as spherical balls or cylindrical or tapered rollers. This results in a very low coefficient of friction.

IV.2. Objectives of this Chapter

After completing this chapter, you will be able to:
1. Identify the types of rolling contact bearings that are commercially available, and select the appropriate type for a given application, considering the manner of loading and installation conditions.
2. Use the relationship between forces on bearings and the life expectancy for the bearings to determine critical bearing selection factors.
3. Use manufacturers' data for the performance of ball bearings to specify suitable bearings for a given application.
4. Recommend appropriate values for the design life of bearings.
5. Compute the *equivalent load* on a bearing corresponding to combinations of radial and thrust loads applied to it.
6. Specify mounting details for bearings that affect the design of the shaft onto which the bearing is to be seated and the housing into which it is to be installed.
7. Compute the equivalent loads on tapered roller bearings.
8. Describe the special design of thrust bearings.
9. Describe several types of commercially available mounted bearings and their application to machine design.
10. Understand certain practical considerations involved in the application of bearings, including lubrication, sealing, limiting speeds, bearing tolerance classes, and standards related to the manufacture and application of bearings.
11. Consider the effects of varying loads on the life expectancy and specification of bearings.

IV.3.Types of Rolling Contact Bearings

Here we will discuss seven different types of rolling contact bearings and the applications in which each is typically used. Many variations on the designs shown are available. As each is discussed, refer to Table IV–1 for a comparison of the performance relative to the others.

Table IV.1 Comparison of Bearing Types

Bearing type	Radial load capacity	Thrust load capacity	Misalignment capability
Single-row, deep-groove ball	Good	Fair	Fair
Double-row, deep-groove ball	Excellent	Good	Fair
Angular contact	Good	Excellent	Poor
Cylindrical roller	Excellent	Poor	Fair
Needle	Excellent	Poor	Poor
Spherical roller	Excellent	Fair/good	Excellent
Tapered roller	Excellent	Excellent	Poor

Radial loads act toward the center of the bearing along a radius. Such loads are typical of those created by power transmission elements on shafts such as spur gears, V-belt drives, and chain drives. *Thrust loads* are those that act parallel to the axis of the shaft. The axial components of the forces on helical gears, worms and wormgears, and bevel gears are thrust loads. Also, bearings supporting shafts with vertical axes are subjected to thrust loads due to the weight of the shaft and the elements on the shaft as well as from axial operating forces. *Misalignment* refers to the angular deviation of the axis of the shaft at the bearing from the true axis of the bearing itself. An excellent rating for misalignment in Table IV–1 indicates that the bearing can accommodate up to 4.0° of angular deviation. A bearing with a fair rating can withstand up to 0.15°, while a poor rating indicates that rigid shafts with less than 0.05° of misalignment are required. Manufacturers' catalogs should be consulted for specific data.

IV.3.1. Single-Row, Deep-Groove Ball Bearing

Sometimes called *Conrad bearings*, the single-row, deep-groove ball bearing (Figure IV–1) is what most people think of when the term *ball bearing* is used. The inner race is typically pressed on the shaft at the bearing seat with a slight interference fit to ensure that it rotates with the shaft. The spherical rolling elements, or balls, roll in a deep groove in both the inner and the outer races. The spacing of the balls is maintained by retainers or "cages." Although designed primarily for radial load-carrying capacity, the deep groove allows it to carry a fairly sizable thrust load. The thrust load would be applied to one side of the inner race by a shoulder on the shaft. The load would pass across the side of the groove, through the ball, to the opposite side of the outer race, and then to the housing. The radius of the ball is slightly smaller than the radius of the groove to allow free rolling of the balls. The contact between a ball and the race is theoretically at a point, but it is actually a small circular area because of the deformation of the elements. Because the load is carried on a small area, very high local contact stresses occur. To increase the capacity of a single-row bearing, a bearing with a greater number of balls, or larger balls operating in larger diameter races, should be used.

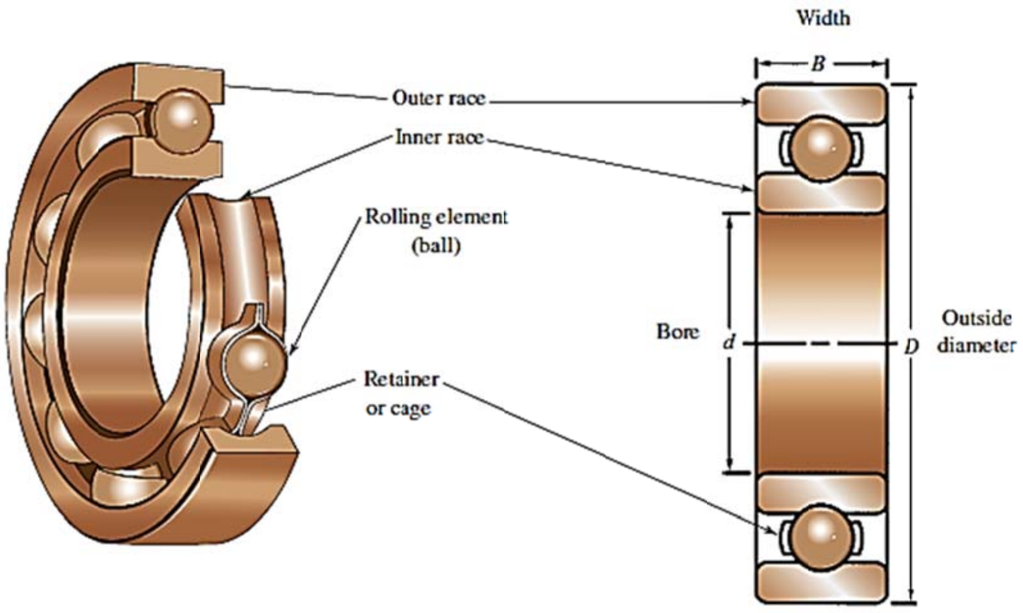


Fig. IV–1 Single-row, deep-groove ball bearing

IV.3.2. Double-Row, Deep-Groove Ball Bearing

Adding a second row of balls (Figure IV–2) increases the radial load-carrying capacity of the deep-groove type of bearing compared with the single-row design because more balls share the load. Thus, a greater load can be carried in the same space, or a given load can be carried in a smaller space. The greater width of double-row bearings often adversely affects the misalignment capability.

Fig. IV–2 Double-row, deep-groove ball bearing

IV.3.3. Angular Contact Ball Bearing

One side of each race in an angular contact bearing is higher to allow the accommodation of greater thrust loads compared with the standard single-row, deep-groove bearing. The sketch in Figure IV–3 shows the preferred angle of the resultant force (radial and thrust loads combined), with commercially available bearings having angles of 15° to 40°.

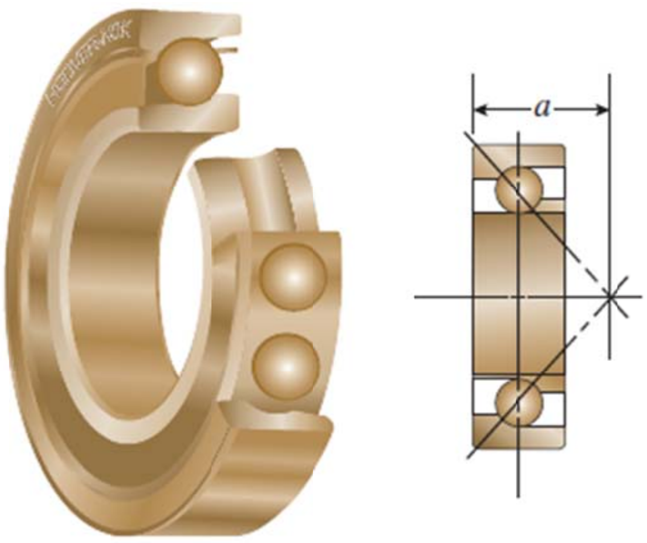


Fig. IV–3 Angular contact ball bearing

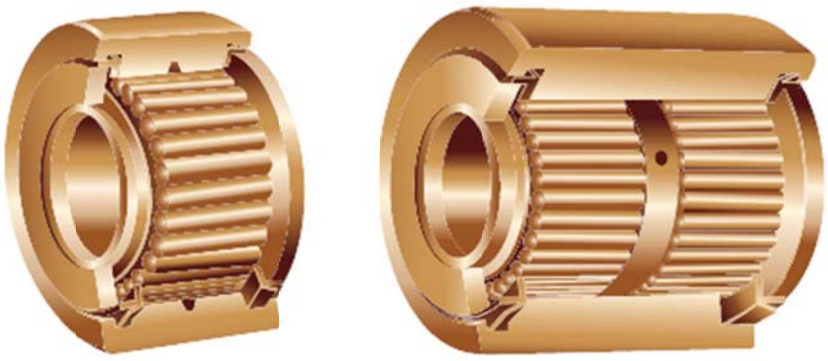
IV.3.4. Cylindrical Roller Bearing

Replacing the spherical balls with cylindrical rollers (Figure IV–4), with corresponding changes in the design of the races, gives a greater radial load capacity. The pattern of contact between a roller and its race is theoretically a line, and it becomes a rectangular shape as the members deform under load. The resulting contact stress levels are lower than for equivalent-size ball bearings, allowing smaller bearings to carry a given load or a given size bearing to carry a higher load. Thrust load capacity is poor because any thrust load would be applied to the side of the rollers, causing rubbing, not true rolling motion. It is recommended that no thrust load be applied. Roller bearings are often fairly wide, giving them only fair ability to accommodate angular misalignment.

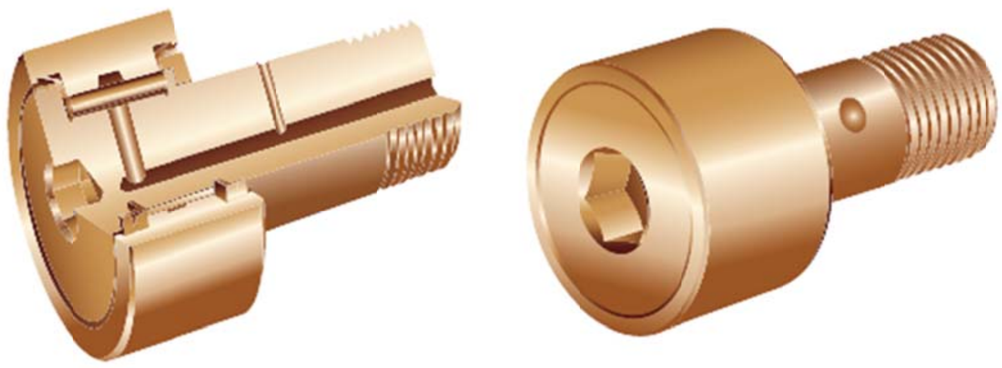
Fig. IV–4 Cylindrical roller bearing

IV.3.5. Needle Bearing

Needle bearings (Figure IV–5) are actually roller bearings, but they have much smaller diameter rollers, as you can see by comparing Figures IV–4 and IV–5. A smaller radial space is typically required for needle bearings to carry a given load than for any other type of rolling contact bearing. This makes it easier to design them into many types of equipment and components such as pumps, universal joints, precision instruments, and household appliances. The cam follower shown in Figure IV–5(b) is another example in which the antifriction operation of needle bearings can be built in with little radial space required. As with other roller bearings, thrust and misalignment capabilities are poor.



(*a*) Single- and double-row needle bearings



(*b*) Needle bearings adapted to cam followers

Fig. IV–5 Needle bearings

IV.3.6. Spherical Roller Bearing

The spherical roller bearing (Figure IV–6) is one form of *self-aligning bearing,* so called because there is actual relative rotation of the outer race relative to the rollers and the inner race when angular misalignments occur. This gives the excellent rating for misalignment capability while retaining virtually the same ratings on radial load capacity.

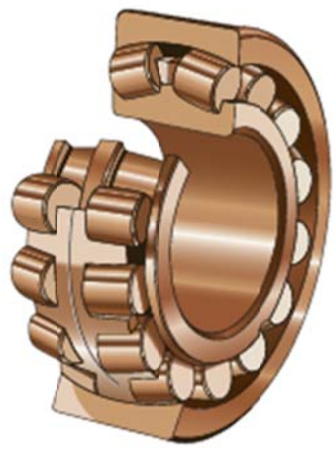


Fig. IV–6 Spherical roller bearing

IV.3.7. Tapered Roller Bearing

Tapered roller bearings (Figure 14–7) are designed to take substantial thrust loads along with high radial loads, resulting in excellent ratings on both. They are often used in wheel bearings for vehicles and mobile equipment and in heavy-duty machinery having inherently high thrust loads. Section 14–13 gives additional information about their application.

Fig. IV–7 Tapered roller bearing

IV.4.Thrust Bearings

The bearings discussed so far in this chapter have been designed to carry radial loads or a combination of radial and thrust loads. Many machine design projects demand a bearing that resists only thrust loads, and several types of standard thrust bearings are commercially available. The same types of rolling elements are used: spherical balls, cylindrical rollers, and tapered rollers (see Figure IV–8).

Most thrust bearings can take little or no radial load. Then the design and the selection of such bearings are dependent only on the magnitude of the thrust load and the design life. The data for basic dynamic load rating and basic static load rating are reported in manufacturers' catalogs in the same way as they are for radial bearings.

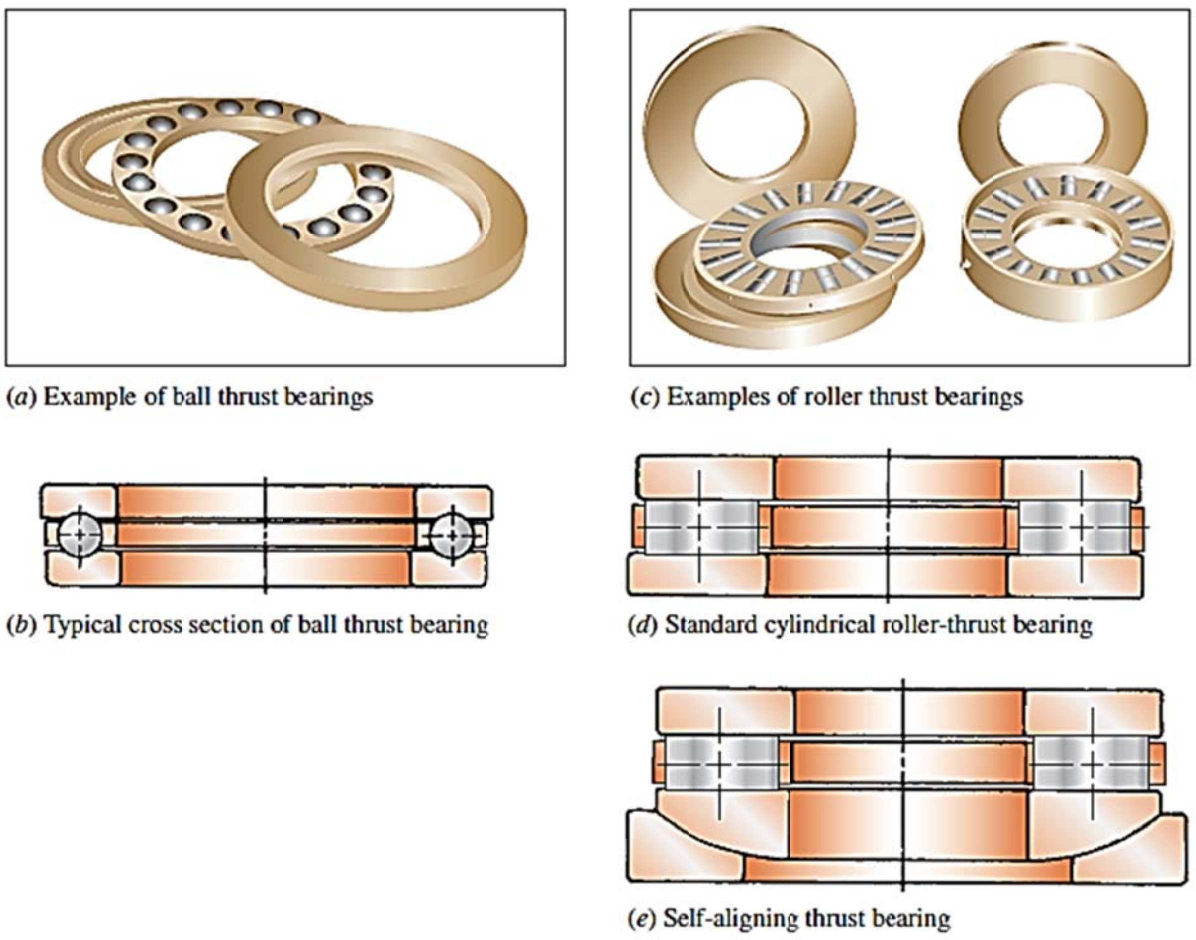


Fig. IV–8 Thrust bearings

IV.5.Mounted Bearings

In many types of heavy machines and special machines produced in small quantities, mounted bearings rather than unmounted bearings are selected. The mounted bearings, sometimes called housed bearings, provide a means of attaching the bearing unit directly to the frame of the machine with bolts rather than inserting it into a machined recess in a housing as is required in unmounted bearings.

Figure IV–9 shows the most common configuration for a mounted bearing: the *pillow block*. The housing is made from formed steel, cast iron, or cast steel, with holes or slots provided for attachment during assembly of the machine, at which time alignment of the bearing unit is adjusted. The bearings themselves can be of virtually any of the types discussed in the preceding sections; ball, roller, tapered roller, or spherical roller. Misalignment capability is an important application consideration because of the conditions of use of such bearings. This capability is provided either in the bearing construction itself or in the housing as shown in Figure IV–9.

Because the bearing itself is similar to those already discussed, the selection process is also similar. Most catalogs provide extensive data listing the load-carrying capacity at specified rated life values.

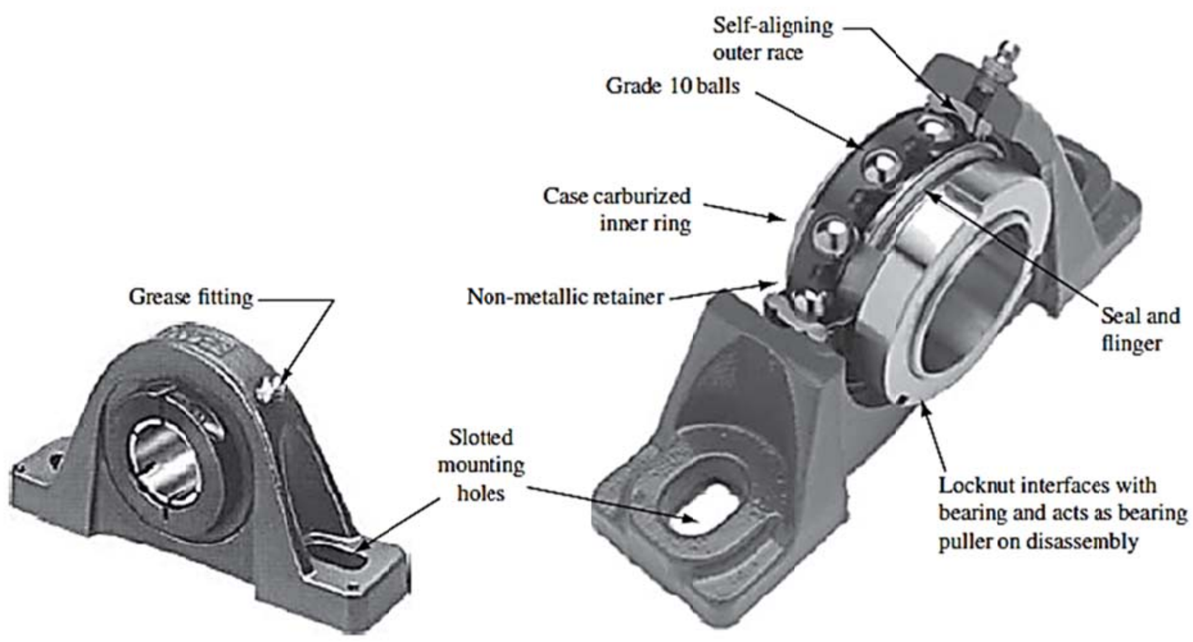


Fig. IV–9 Ball bearing pillow block (Baldor/ Dodge, Greenville, SC)

Other forms of mounted bearings are shown in Figure 14–10. The *flange units* are designed to be mounted on the vertical side frames of machines, holding horizontal shafts. Again, several bearing types and sizes are available.

The term *take-up unit* refers to a bearing mounted in a housing, which in turn is mounted in a frame that allows movement of the bearing with the shaft in place. Used on conveyors, chain drives, belt drives, and similar applications, the take-up unit permits adjustment of the center distance of the drive components at the time of installation and during operation to accommodate wear or stretch of parts of the assembly.

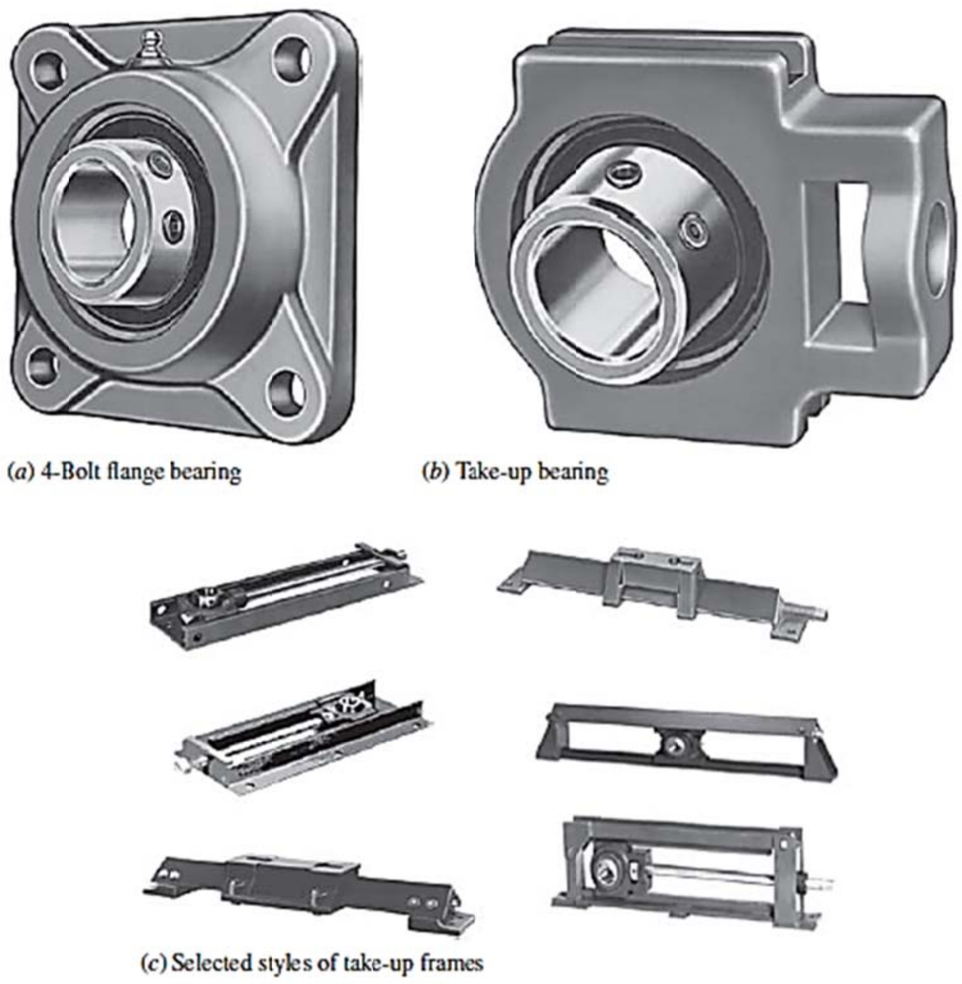


Fig. IV–10 Forms of mounted bearings (Baldor/Dodge, Greenville, SC)

IV.6.Bearing Materials

The load applied to a rolling contact bearing passes through the outer race to the rolling elements (balls or rollers) and then to the inner race, resulting in forces exerted on very small areas of contact. Contact stresses of approximately 300 000 psi (2070 MPa) are not uncommon.
To withstand such high stresses, the balls, rollers, and races are typically made from very hard, high-strength steel or ceramic. Other metallic materials used include some titanium/nickel alloys and Monel metal (alloys of primarily nickel, copper, and cobalt). Where lighter loads are encountered or when resistance to corrosion by specific materials is needed, plastic bearings can be used. See Table IV–2 for properties of selected materials.

The most widely used bearing material is SAE 52100 steel having a very high carbon content of 0.95% to 1.10% along with 1.3% to 1.6% chromium, 0.25% to 0.45% manganese, 0.2% to 0.35% silicon, and other alloying elements in low, but controlled, amounts. Impurities are carefully minimized. The steel is through hardened to the range of 58 to 65 HRC to give it the ability to resist high contact stress. Some tool steels, particularly M1 and M50, are also used. Steel alloys such as SAE 3310, 4620, and 8620, case hardened by carburizing to achieve high surface hardness and a tough core, are sometimes used. Careful control of case depth is required to withstand critical subsurface stresses. Some more lightly loaded bearings and those exposed to corrosive environments are made from SAE 440C stainless steel.

Rolling elements, races, and other components can also be made from ceramic materials such as silicon nitride (Si_3N_4), zirconia oxide (ZrO_2), alumina oxide (Al_2O_3), and silicon carbide (SiC). Compared with typical bearing steels, these materials have much lower density, higher hardness, and higher modulus of elasticity values leading to lighter weight, lower wear, and higher stiffness. They typically have better corrosion resistance and can operate at much higher temperatures as well. Their applications include machine tools, railroad equipment, semiconductor manufacturing, aerospace devices, and any equipment operating at high temperatures.

Table IV-2 Comparison of Bearing Materials

Property	Unit	Steels: Bearing Steel 52 100	Steels: Stainless Steel 440C	Titanium/Nickel: Nitinol 60NiTi	Cermics: Silicon Nitride Si_3N_4	Cermics: Zirconia Oxide ZrO_2	Cermics: Alumina Oxide Al_2O_3	Cermics: Silicon Carbide SiC	Monel: K-500 Metal	Plastic: Polyamide (Nylon 66)
Density	kg/m^3	7680	7750	6700	3230	6050	3920	3120	8434	1360
	lbm/ft^3	480	484	418	202	378	245	195	527	85
Modulus of elasticity	GPa	207	200	114	300	210	340	440	179	4.2
	ksi	30 000	29 000	16 500	43 500	30 500	49 300	63 800	25 950	610
Hardness	Vickers	700	700	650	1500	1200	1650	2800	263	—
Flexural strength	MPa	2240	1930	900	450	210	230	380	965	82
	ksi	325	280	131	65	31	33	55	140	11.9
Maximum use temperature	°C	300	350	400	1050	750	1500	1700	315	130
	°F	570	660	750	1920	1380	2730	3100	600	270

Note: Data taken from a variety of sources and are representative only. Actual properties highly dependent on specific composition, processing, thermal treatment, and form.

Ceramics can be used for all bearing elements (balls, rollers, races, cages) or hybrid designs consisting of ceramic rolling elements in steel races with steel or polymeric cages. Figure IV–11 shows examples of full ceramic bearings in radial ball type and in spherical ball type. Note that silicon nitride is shiny black, zirconia oxide is shiny white, alumina oxide is dull white, and silicon carbide is dull black. Internet site 1 shows ceramic bearings with bores as small as 3.0 mm (0.1181 in) and up to 50 mm (1.9685 in). Inch bore sizes are as small as 0.0937 in (2.38 mm) up to 1.25 in (31.75 mm).

(*a*) Full ceramic—radial ball bearings

Fig. IV–11 Ceramic bearings in radial ball and spherical ball forms (Boca Bearings Company, Delray Beach, FL)

Alloys of titanium and nickel, sometimes called Nitinol, are applied where their anti-corrosive properties are desirable. The lower density compared with steel is also advantageous. One alloy is listed in Table IV–2. Development continues for other titanium alloys.

Monel metal is an alloy of primarily nickel, copper, and cobalt, with smaller amounts of iron, silicon, manganese, carbon, aluminum, titanium, and sulfur. Its resistance to fresh water, sea water, most acids, calcium chloride, and petroleum oils make it attractive to marine applications, chemical plants, oil and gas industries, and water and wastewater treatment facilities. One alloy is listed in Table IV–2.

Bearings made from plastics are typically used for lightly loaded, moderate precision applications requiring good corrosion resistance and light weight. Several types of plastic formulations can be used such as acetal, polyamide (PA, nylon), and thermoplastic polyester (PBT). Hybrid designs using plastic housing elements with stainless steel rolling balls or rollers are often used. One glass reinforced polyamide material is listed in Table IV–2.

IV.7.Load/ Life Relationship

Despite using steels with very high strength, all bearings have a finite life and will eventually fail due to fatigue because of the high contact stresses. But, obviously, the lighter the load, the longer the life, and vice versa. The relationship between load, P, and life, L, for rolling contact bearings can be stated as

Relationship between Bearing Load and Life

$$\frac{L_1}{L_2} = \left(\frac{P_1}{P_2}\right)^k$$

Where

- k = 3.00 for ball bearings
- k = 3.33 for roller bearings

IV.8.Plan surface Bearings

IV.8.1.Discussion Map

- The purpose of a bearing is to support a load while permitting relative motion between two elements of a machine. This chapter discusses *plain surface* bearings where the two parts that move relative to each other do not have rolling elements between them.
- Both rotating and linear sliding bearing cases depend on lubrication, a part of the field of *tribology*.

IV.8.2.Objectives of this chapter

1. Describe the three modes of operation of a *plain surface bearing* (boundary, mixed-film, and full-film hydrodynamic lubrication), and discuss the conditions under which each will normally occur.
2. Discuss the significance of the *bearing parameter*, mn/p.
3. List the decisions that a bearing designer must make to completely define a plain surface bearing system.
4. List the materials often used for journals and bearings, and describe their important properties.
5. Define the *pV factor* and use it in the design of boundary-lubricated bearings.
6. Describe the operation of full-film hydrodynamically lubricated bearings.
7. Complete the design of full-film bearings, defining the size of the journal and bearing, the diametral clearance, the bearing length, the minimum film thickness, the surface finish, the lubricant, and the resulting frictional performance of the bearing system.
8. Describe a *hydrostatic bearing system* and complete the basic design of such bearings.
9. Define *tribology* and discuss the essential characteristics of friction, lubrication, and wear as applied to machinery.
10. Describe the general nature of oils and greases and their effects on lubrication and wear.

IV.9. Bearing Materials

In rotational applications, the journal on the shaft is frequently steel. The stationary bearing may be made of any of a wide variety of materials, including the following:

- Bronze
- Babbitt
- Aluminum
- Zinc
- Porous metals
- Plastics (nylon, TFE, PTFE, phenolic, acetal,
- polycarbonate, and filled polyimide)

The properties desirable for materials used for plain bearings are unique, and compromises must frequently be made. The following list discusses these properties.
1. *Strength:* The function of the bearing is to carry the applied load and deliver it to the supporting structure. At times, the loads are varied, requiring fatigue strength as well as static strength.
2. *Embeddability:* The property of embeddability relates to the ability of the material to hold contaminants in the bearing without causing damage to the rotating journal. Thus, a relatively soft material is desirable.
3. *Corrosion resistance:* The total environment of the bearing must be considered, including journal material, lubricant, temperature, air-borne particulates, and corrosive gases or vapors.
4. *Cost:* Always an important factor, cost includes not only the material cost but also processing and installation costs. A brief discussion of the performance of some of the bearing materials follows.

IV.9.1. Cast Bronze

The name *bronze* refers to several alloys of copper with tin, lead, zinc, or aluminum, either singly or in combination. The leaded bronzes contain 25% to 35% lead, which gives them good embeddability and resistance to seizing under conditions of boundary lubrication. However, their strength is relatively low. The cast bearing bronze, SAE CA932, has 83% copper, 7% tin, 7% lead, and 3% zinc. It possesses a good combination of properties for such uses as pumps, machinery, and appliances. Tin and aluminum bronzes have higher strength and hardness and can carry greater loads, particularly in impact situations. But they rate lower on embeddability. See Internet sites 1, 6, 7, 9, and 10.

IV.9.2. Babbitt

Babbitts may be lead based or tin based, having nominally 80% of the parent metal. Various alloy compositions of copper and antimony (as well as lead and tin) can tailor the properties to suit a particular application. Because of their softness, babbitts have outstanding embeddability and resistance to seizure, important properties in applications in which boundary lubrication occurs. They have rather low strength, however, and are often applied as liners in steel or cast iron housings.

IV.9.3. Aluminum

With the highest strength of the commonly used bearing materials, aluminum is used in severe applications in engines, pumps, and aircraft. The high hardness of aluminum bearings results in poor embeddability, requiring clean lubricants.

IV.9.4. Zinc

Bearings made from zinc alloys offer good protection to running without a continuous supply of lubricant, although they perform best if lubricated. Standard bearing greases are often used. When operating on steel journals, a thin film of the softer zinc material is transferred to the steel to protect it from wear and damage. It performs well in most atmospheric conditions except forcontinuously wet environments and exposure to seawater.

IV.9.5. Porous Metals

Products of the powder metal industry, porous metals are sintered from powders of bronze, iron, and aluminum; some are mixed with lead or copper. The sintering leaves a large number of voids in the bearing material into which lubricating oil is forced. Then, during operation, the oil migrates out of the pores, supplying the bearing. Such bearings are particularly good for slow-speed, reciprocating, or oscillating motions.

IV.9.6. Plastics

Generally referred to as *self-lubricating materials*, plastics used in bearing applications have inherently low friction characteristics. They can be operated dry, but most improve in performance with a lubricant present. Embeddability is usually good, as is resistance to seizure.
But many have low strength, limiting their load-carrying capacity. Backing with metal sleeves is frequently done to improve load-carrying capacity. Major advantages are corrosion resistance and, when operated dry, freedom from contamination. These properties are particularly important in the processing of foodstuffs and chemical products.

Because of the complex chemical names for plastic materials and the virtually infinite combinations of base materials, reinforcements, and fillers used, it is difficult to characterize bearing plastics. Most are composites of several components. The group known as *fluoropolymers* is popular because of the very low coefficient of friction (0.05 to 0.15) and good wear resistance. Phenolics, polycarbonates, acetals, nylons, and many other plastics are also used for bearings. Among the chemical names and abbreviations found in this field are the following:

- ***PTFE:*** Polytetrafluoroethylene
- ***PA:*** Polyamide
- ***PPS:*** Polyphenylene sulfide
- ***PVDF:*** Polyvinylidene fluoride
- ***PEEK:*** Polyetheretherketone
- ***PEI:*** Polyetherimide
- ***PES:*** Polyethersulfone
- ***PFA:*** Perfluoroalkoxy-modified tetrafluoroethylene

Reinforcements and fillers used with plastic bearing materials include glass fibers, milled glass, carbon fibers, bronze powders, PTFE, PPS, and some solid lubricants, such as graphite and molybdenum disulfide.

IV.10. Belt Drives, Chain Drives and Wire Rope

Belt drives and chain drives represent the major types of flexible power transmission elements. Figure IV–12 shows a typical industrial application of these elements combined with a gear-type speed reducer. This application illustrates where belts, gear drives, and chains are each used to best advantage.

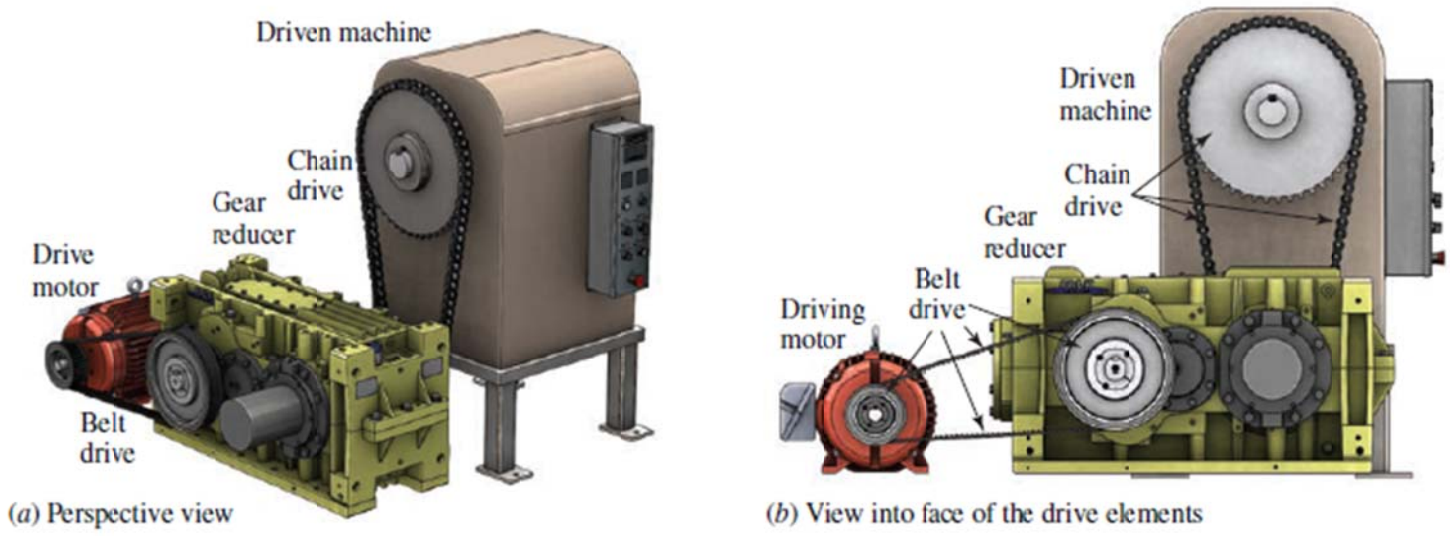


Fig. IV–12 Drive system for an industrial application employing a belt drive, a gear reducer, and a chain drive

IV.10.1. Discussion Map

- Belts and chains are the major types of flexible power transmission elements. V-belts operate on smooth sheaves or pulleys, whereas the cogs of synchronous belts operate on sprockets. Chains operate on toothed wheels also called sprockets.
- Wire rope, sometimes called cable, is another type of flexible machine element, used primarily for lifting heavy loads.

IV.10.2. Objectives of this Chapter

After completing this chapter, you will be able to:
1. Describe the basic features of a belt drive system.
2. Describe several types of belt drives.
3. Specify suitable types and sizes of belts and sheaves to transmit a given level of power at specified speeds for the input and output sheaves.
4. Specify the primary installation variables for belt drives, including center distance and belt length.
5. Describe the basic features of a chain drive system.
6. Describe several types of chain drives.
7. Specify suitable types and sizes of chains and sprockets to transmit a given level of power at specified speeds for the input and output sprockets.
8. Specify the primary installation variables for chain drives, including center distance between the sheaves, chain length, and lubrication requirements.
9. Describe the basic types of commercially available wire rope, the preferred methods of applying them, and the typical working loads.

IV.10.3. Kinematics of Belts and Chain drive Systems

Mechanical drives are used to transmit power and rotational motion. A drive system can include chain drives, belt drives, and gear drives. Gear drives will be covered in later chapters. The requirements of the application will determine the selection of the type of drive system.
A chain drive may be used when high rotational power is transmitted at relatively slow speeds and when lifting heavy loads, as on a fork-lift truck. Belt drives are typically used for higher speeds and on applications requiring accurate registration between the shafts of driving and driven machines. Belts and chains are both flexible elements that transmit power from a driver, such as an electric motor, engine, or turbine to a driven machine. Details of their design are presented in later sections of this chapter. The belts and chains are placed on rotating elements attached to the output shaft of the driver and to the input shaft of the driven machine.

- Belts have continuous cross sections that are mounted on *sheaves*, sometimes called *pulleys*. This chapter discusses two types of belt drives:
- *V-belts* that operate without slipping on smooth, V-shaped grooves in the sheaves
- *Synchronous belts* that have molded cogs that engage grooved sprockets producing positive driving
- Chains are comprised of a set of discrete links that engage teeth on *sprockets*, producing positive driving.

The kinematics of the drive system ensures correct relative positioning, angular velocity, and acceleration of the input driver and the driven machine. In each case, the flexible belt or chain has a uniform linear velocity as it passes around its sheave or sprocket. The linear velocity is often called *belt speed* or *chain speed*. The following development relates the linear velocity to the rotational speeds of the driver and the driven machine. Other relevant geometry of the drive system is also developed. Refer to Figures IV–13 to IV–15. Figure IV–13 shows a simple disk rotating about its center. If the disk (2) is rotating at an angular velocity (ω_A), the linear velocity of point A (v_A), located a distance (r_A) from its axis of rotation is given by the equation

$$v_A = r_A \cdot \omega_A$$

where

- v_A = Linear velocity of point A [in/s], [m/s], [ft/min or fpm]
- r_A = Radius to point A [in], [m], [ft]
- ω_A = Angular velocity of the disk [rad/s]

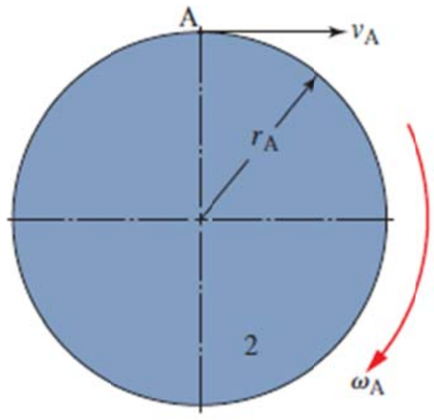


Fig. IV–13 Linear velocity related to angular velocity of a rotating disk

This equation allows us to relate the angular velocity (ω) to the linear velocity (v) based on the distance (r) from its axis of rotation. This motion corresponds to the motion of a belt or chain drive system, where the linear velocity of point A is equivalent to the belt or chain linear velocity and the angular velocity of disk 2 is equivalent to the angular velocity of the rotating sprocket or sheave of the drive system. The radius, *r,* is equal to the radius of the *pitch diameter of the sheave or sprocket*, PD, the kinematically characteristic diameter. Figure IV–14 shows the pitch diameters on a chain sprocket, synchronous belt sprocket, and a V-belt sheave. Note the following:

- The pitch diameter of a chain sprocket, also called the *pitch circle diameter*, goes through the center of the chain bearing pin when the chain is wrapped around the sprocket.
- The pitch diameter of the synchronous belt sprocket is along the theoretical belt pitch line defined by the belt manufacturer and is always greater than the outside diameter of the grooves on the sprocket.
- The pitch diameter of the V-belt sheave is slightly inside the top of the cross section of the belt near where the tensile cords are placed.

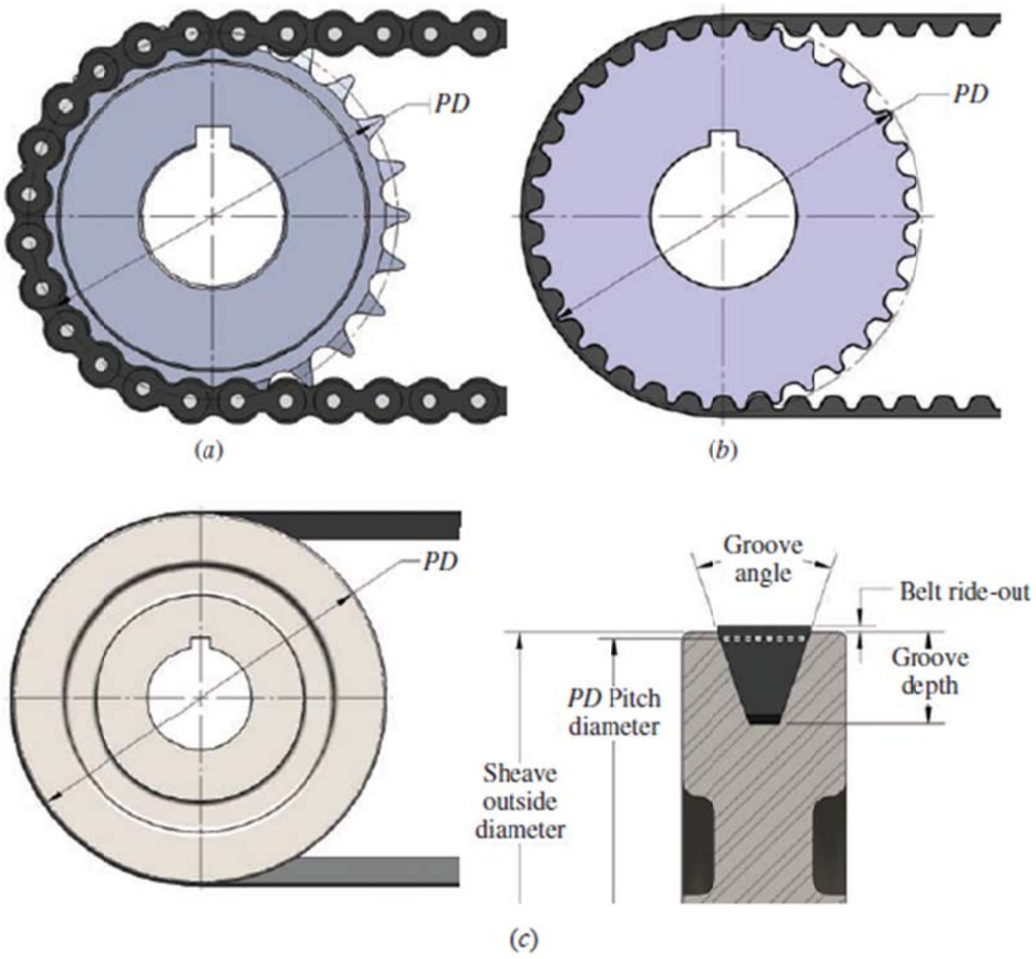


Fig. IV–14 Pitch diameter on a (a) chain sprocket, (b) synchronous belt sprocket, and (c) V-belt sheave with section view

Typically the input sprocket/sheave is rotating at a faster speed than the output sprocket/sheave. This is called a *speed reducer* and is very common in many applications. When the belt or chain is used for a speed reduction, the smaller sprocket/sheave is mounted on the high-speed shaft, such as an electrical motor. The larger sprocket/sheave is mounted on the driven machine where the shaft is turning at a slower speed. The other scenario is when the output sprocket is rotating faster than the input sprocket and is called a *speed increaser*. In this case, the larger sprocket/sheave is mounted on the input shaft and the smaller sprocket/sheave is mounted on the output shaft.

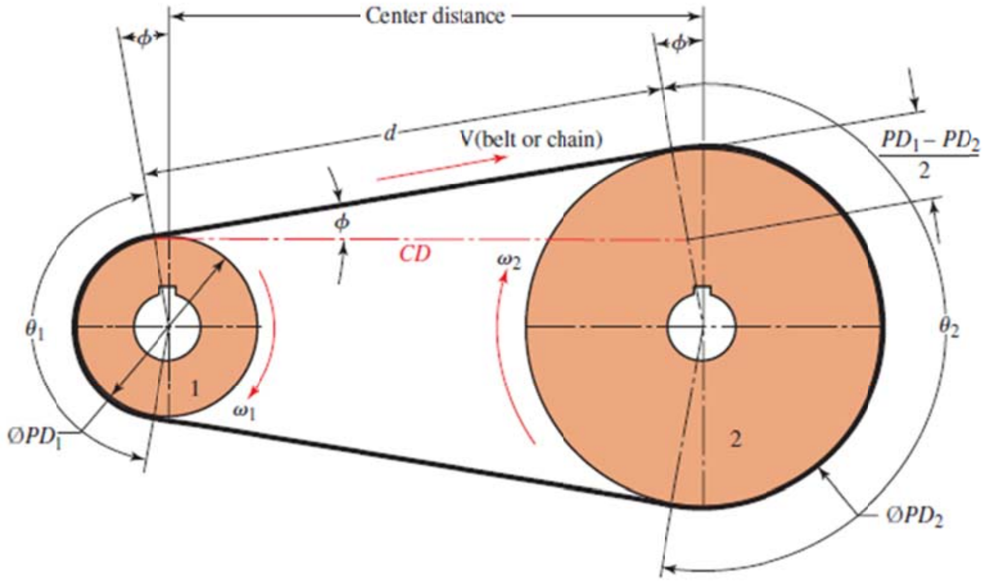


Fig. IV–15 Belt/chain drive configuration

The belt or chain linear velocity is uniform throughout its length, and it can be related to the angular velocities of the driving sprocket and driven sprocket using the following equation, based on last Equation developed earlier. Figure IV–15 shows the basic layout where v1 is equal to the input angular velocity (ωdriving) and v2 is equal to the output angular velocity (ωdriven).

$$v\,\frac{belt}{chain} = \frac{PD_{driving}}{2} . \omega_{driving} = \frac{PD_{driven}}{2}\,\omega_{driven}$$

Letting the driving member to be 1 as used in Figure IV–15 and the driven member to be 2, we can restate Equation

$$v\,\frac{belt}{chain} = \frac{PD_1}{2} = \omega_1 = \frac{PD_2}{2}\,\omega_2$$

Since the belt or chain linear velocity is the same for both the driving and driven sprockets, we can equate the last two parts of last Equation and define the velocity ratio, *VR*, which is the driving angular velocity over the driven angular velocity. The angular velocity ratio can also be expressed by the ratios of the pitch diameters or the numbers of teeth of the driving and driven sprockets.

$$VR = \frac{\omega_{driving}}{\omega_{driven}} = \frac{\mathrm{PD}_{driven}}{\omega_{driving}} = \frac{\mathrm{N}_{driven}}{\mathrm{N}_{driving}}$$

The angle of wrap on the driving and driven sprockets can be found from,

$$\sin(\emptyset) = \frac{(\frac{PD_2 - PD_1}{2})}{CD}$$

The angle of wrap on sprocket (1)

$$\theta_1 = 180° - 2.\,\emptyset$$

The angle of wrap on sprocket (2)

$$\theta_2 = 180° + 2.\,\emptyset$$

The length of the belt or chain wrap on sprocket 1 and sprocket 2 is the arc length s_1 and s_2.

$$S_1 = (PD_1/2)\,.\,\theta_1$$

$$S_2 = (PD_2/2)\,.\,\theta_2$$

where θ_1 and θ_2 are in radians. The distance, *d*, represents the belt or chain length that is tangent to sprocket 1 and sprocket 2.

$$D = CD\,.\cos\emptyset$$

The belt or chain perimeter length, *Lp*, can now be calculated.

Belt or chain perimeter length = Lp

$$Lp = 2\,.\,d + s_1 + s_2$$

The distance, *d*, is often called the *span* of the belt or chain drive system, giving the unsupported length of the belt or chain. Long spans sometimes lead to vibration during operation, called *whip*, and should be avoided where possible.

IV.10.4. Types of Belt Drives

A belt is a flexible power transmission element that seats tightly on a set of pulleys, sprockets, or sheaves. Figure IV–15 shows the basic layout.

Many types of belts are available: flat belts, grooved or cogged belts, standard V-belts, double-angle V-belts, and others. See Figure IV–16 for examples.

The *flat belt* is the simplest type, often made from leather or rubber-coated fabric. The sheave surface is also flat and smooth, and the driving force is therefore limited by the pure friction between the belt and the sheave. Some designers prefer flat belts for delicate machinery because the belt *will* slip if the torque tends to rise to a level high enough to damage the machine. The design of flat belt drives is not covered in this book.

Synchronous belts, sometimes called *timing belts* [see Figure IV–16(b)], ride on sprockets having mating grooves into which the teeth on the belt seat. This is a positive drive, limited only by the tensile strength of the belt and the shear strength of the teeth.

The belt is installed by placing it around the two sheaves while the center distance between them is reduced. Then the sheaves are moved apart, placing the belt in a rather high initial tension. When the belt is transmitting power, friction causes the belt to grip the driving sheave, increasing the tension in one side, called the "tight side," of the drive. The tensile force in the belt exerts a tangential force on the driven sheave, and thus a torque is applied to the driven shaft. The opposite side of the belt is still under tension, but at a smaller value. Thus, it is called the "slack side."

Some cog belts, such as that shown in Figure IV–16(a), are applied to standard V-grooved sheaves. The cogs give the belt greater flexibility and higher efficiency compared with standard belts. They can operate on smaller sheave diameters.

A widely used type of belt, particularly in industrial drives and vehicular applications, is the *V-belt drive*, shown in Figures IV–16 (a) and IV–16 (c). Figure IV–17 shows the V-belt section seated in its groove in the sheave. The V-shape causes the belt to wedge tightly into the groove, increasing friction and allowing high torques to be transmitted before slipping occurs. Most belts have high-strength cords positioned at the pitch diameter of the belt cross section to increase the tensile strength of the belt. The cords, made from natural fibers, synthetic strands, or steel, are embedded in a firm rubber compound to provide the flexibility needed to allow the belt to pass around the sheave. Often an outer fabric cover is added to give the belt good durability. The belt is designed to ride around the two sheaves without slipping.

The groove angle ranges from 34° to 42° depending on the belt cross-section style and the pitch diameter. Refer to manufacturer's data for sheaves.

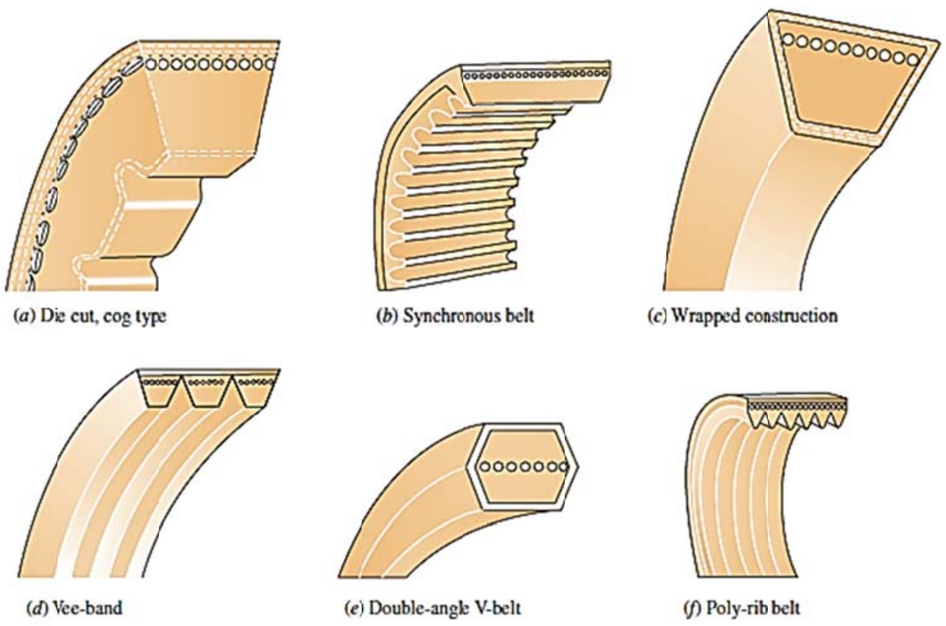


Fig. IV–16 Examples of belt construction

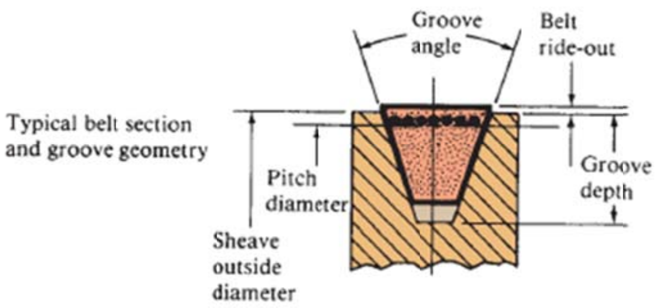


Fig. IV–17 Cross section of V-belt and sheave groove

IV.11.Chain Drives

A chain is a power transmission element made as a series of pin-connected links. The design provides for flexibility while enabling the chain to transmit large tensile forces.

When transmitting power between rotating shafts, the chain engages mating toothed wheels, called sprockets. Figure IV–18 shows a typical chain drive. The most common type of chain is the *roller chain,* in which the roller on each pin provides exceptionally low friction between the chain and the sprockets.

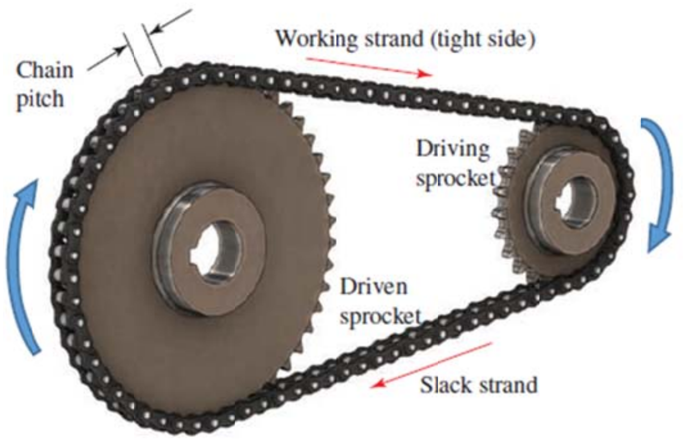


Fig. IV–18 Basic arrangement of an industrial chain drive

Roller chain is classified by its *pitch,* the distance between corresponding parts of adjacent links. The pitch is usually illustrated as the distance between the centers of adjacent pins. U.S. Standard roller chain carries a size designation from 40 to 240, as listed in Table IV–3.

The digits (other than the final zero) indicate the pitch of the chain in eighths of an inch, as in the table. For example, the no. 100 chain has a pitch of 10/8 or 1 1/4 in. A series of heavy-duty sizes, with the suffix *H* on the designation (60H–240H), has the same basic dimensions as the standard chain of the same number except for thicker side plates. In addition, there are the smaller and lighter sizes: 25, 35, and 41.

Table IV-3 8M GT Style Belt Length Correction Factor

Pitch/Length designation	No. of teeth	Correction factor	Pitch/Length designation	No. of teeth	Correction factor	Pitch/Length designation	No. of teeth	Correction factor	Pitch/Length designation	No. of teeth	Correction factor
384-8MGT	48	0.70	920-8MGT	115	1.00	1440-8MGT	180	1.10	2600-8MGT	325	1.20
480-8MGT	60	0.80	960-8MGT	120	1.00	1512-8MGT	189	1.10	2800-8MGT	350	1.20
560-8MGT	70	0.80	1040-8MGT	130	1.00	1584-8MGT	198	1.10	3048-8MGT	381	1.20
600-8MGT	75	0.80	1064-8MGT	133	1.00	1600-8MGT	200	1.10	3280-8MGT	410	1.20
640-8MGT	80	0.90	1120-8MGT	140	1.00	1760-8MGT	220	1.10	3600-8MGT	450	1.20
720-8MGT	90	0.90	1160-8MGT	145	1.00	1800-8MGT	225	1.20	4400-8MGT	550	1.20
800-8MGT	100	0.90	1200-8MGT	150	1.00	2000-8MGT	250	1.20			
840-8MGT	105	0.90	1224-8MGT	153	1.00	2200-8MGT	275	1.20			
880-8MGT	110	0.90	1280-8MGT	160	1.10	2400-8MGT	300	1.20			

The average tensile strengths of the various chain sizes are also listed in Table IV–4. These data can be used for very-low-speed drives or for applications in which the function of the chain is to apply a tensile force or to support a load. It is recommended that only 10% of the average tensile strength be used in such applications. For power transmission, the rating of a given chain size as a function of the speed of rotation must be determined, as explained later in this chapter.

Table IV-4 U.S. Roller Chain Sizes

Chain number	ISO 10823	Pitch (in)	Average tensile strength (lb)
25	4A	1/4	925
35	6A	3/8	2100
41		1/2	2000
40	8A	1/2	3700
50	10A	5/8	6100
60	12A	3/4	8500
80	18A	1	14 500
100	20A	$1\frac{1}{4}$	24 000
120	24A	$1\frac{1}{2}$	34 000
140	28A	$1\frac{3}{4}$	46 000
160	32A	2	58 000
180	36A	$2\frac{1}{4}$	80 000
200	40A	$2\frac{1}{2}$	95 000
240	48A	3	130 000

Reference: ANS1 Standard B29.1.

ISO standards define several different chain types, data for three of which are listed in Table IV–5. One commonly used style from ISO-606 has basically the same design dimensions as for many of the standard U.S. roller chains. Then the pitch and dimensions for sprocket features and bore sizes are listed in the metric unit of mm making it more convenient to integrate familiar chain designs into an all-metric piece of equipment. ISO-3512 includes eight sizes of chain used for heavy-duty power transmission and lifting equipment. Some of the pitches for these chains are also equal to common U.S. sizes. Agricultural equipment such as tractor accessories, planters, harvesters, and mowers employ many chain drives to actuate moving systems. ISO-487 defines eight S-designations that cover a wide range of power transmission and tension pull applications.

Table IV-5 Metric Roller Chain Sizes and Strength Ratings

General-Purpose power transmission

ISO 606

Chain number	Pitch in	Pitch mm	Breaking strength lb	Breaking strength kN	Alternate designation
04B	0.250	6.350	—	—	—
05B	0.315	8.000	989	4.4	—
06B	0.375	9.525	2 001	8.9	Metric 35
08B	0.500	12.700	4 002	17.8	Metric 40
10B	0.625	15.88	4 991	22.2	Metric 50
12B	0.75	19.05	6 497	28.9	Metric 60
16B	1.00	25.40	9 510	42.3	Metric 80
20B	1.25	31.75	14 501	64.5	Metric 100
24B	1.50	38.10	22 010	97.9	Metric 120
28B	1.75	44.45	29 002	129.0	Metric 140
32B	2.00	50.8	37 995	169.0	Metric 160
40B	2.50	63.5	58 993	262.4	Metric 200
48B	3.00	76.2	89 996	400.3	Metric 240
56B	3.50	88.9	122 010	542.7	—
64B	4.00	101.6	160 004	711.7	—
72B	4.50	114.3	202 001	898.5	—

Heavy-Duty power transmission

ISO 3512

Chain number	Pitch in	Pitch mm	Breaking strength lb	Breaking strength kN
2010	2.500	63.5	58 903	262.0
2512	3.067	77.9	84 982	378
2814	3.500	88.9	116 007	516
3315	4.073	103.5	133 993	596
3618	4.500	114.3	183 004	814
4020	5.000	127.0	236 960	1054
4824	6.000	152.4	341 951	1521
5628	7.000	177.8	464 928	2068

Power transmission for agricultural uses

ISO 487

Chain number	Pitch in	Pitch mm	Breaking strength lb	Breaking strength kN
S32	1.150	29.2	1 799	8.0
S42	1.375	34.9	6 003	26.7
S45	0.843	21.4	4 002	17.8
S52	1.500	38.1	4 002	17.8
S55	1.630	41.4	4 002	17.8
S62	1.650	41.9	6 003	26.7
S77	2.297	58.3	10 004	44.5
S88	2.609	66.3	10 004	44.5

Notes: Not all suppliers offer all sizes.
Breaking strength data must be verified with specific supplier.

Another ISO document that is closely related to U.S. roller chain sizes is ISO 10823 and those designations are shown in Table IV–4. The designations are very similar to those listed in Table Table IV–5f rom ISO 606, except the letter following the number is A instead of B.

Other types of chains include multiple strand designs, heavy series chains, double-pitch chains, and double-pitch conveyor chains as shown on the left side of Figure IV–19. A wide variety of attachments are available to facilitate the application of roller chain to conveying or other material handling uses. Usually in the form of extended plates or tabs with holes provided, the attachments make it easy to connect rods, buckets, parts pushers, part support devices, or conveyor slats to the chain. The right side of Figure IV–19 shows some attachment styles.

Figure IV–20 shows a variety of chain types used especially for conveying and similar applications. Such chain typically has a longer pitch than standard roller chain (usually twice the pitch), and the link plates are heavier. The larger sizes have cast link plates.

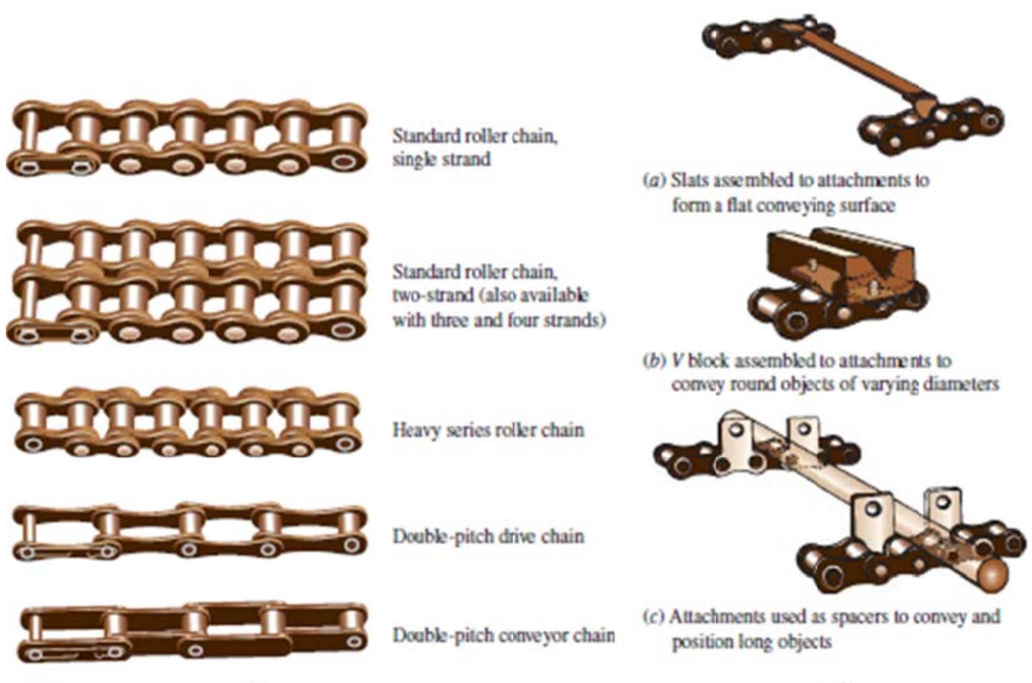


Fig. IV–19 Other roller chain and examples of attachments

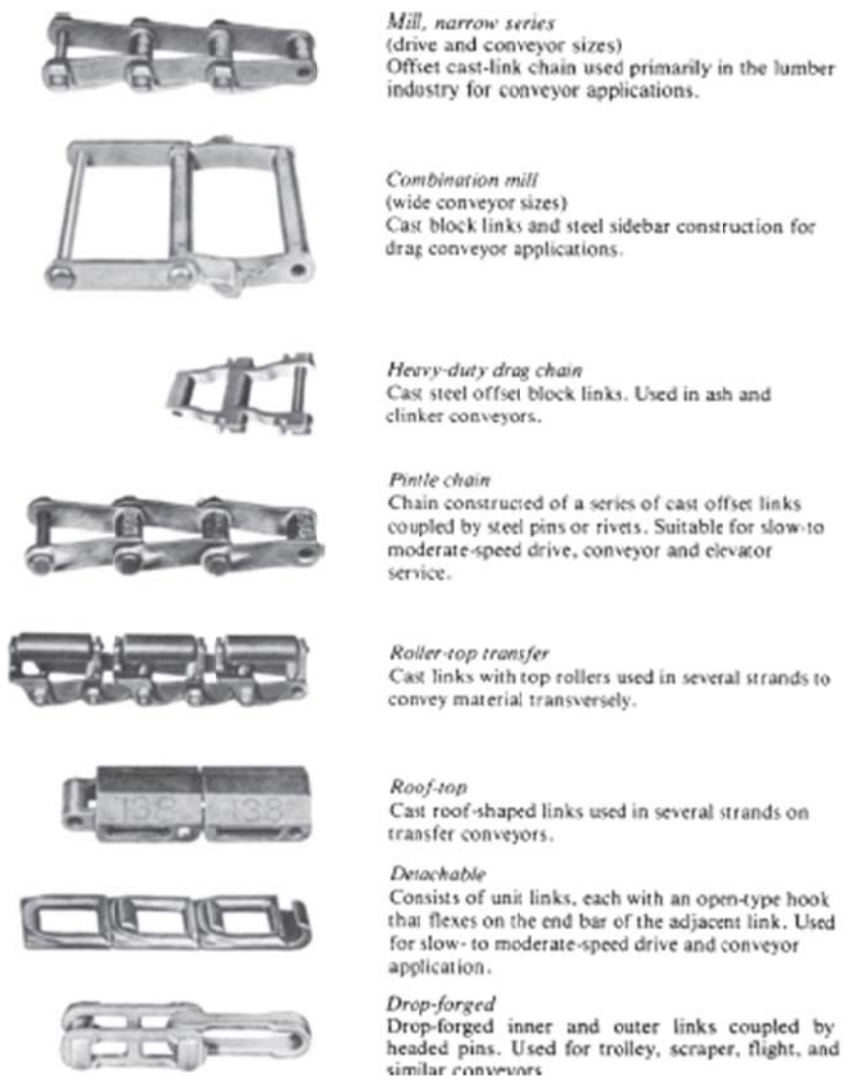


Fig. IV–20 Conveyor chains

IV.11.1. Design of Chain Drives

The rating of chain for its power transmission capacity considers three modes of failure: (1) fatigue of the link plates due to the repeated application of the tension in the tight side of the chain, (2) impact of the rollers as they engage the sprocket teeth, and (3) galling between the pins of each link and the bushings on the pins.

The ratings are based on empirical data with a smooth driver and a smooth load (service factor = 1.0) and with a rated life of approximately 15 000 h. The important variables are the pitch of the chain and the size and rotational speed of the smaller sprocket. Lubrication is critical to the satisfactory operation of a chain drive. Manufacturers recommend the type of lubrication method for given combinations of chain size, sprocket size, and speed. Details are discussed later.

Tables IV–6 to IV–8 list the rated power for three sizes of standard chain: no. 40 (1/2 in), no. 60 (3/4 in), and no. 80 (1.00 in). These are typical of the types of data available for all chain sizes in manufacturers' catalogs and can be used for problems in this book. When making final designs and specification, you should consult the catalog data for the particular manufacturer you are using. Notice these features of the data:

1. The ratings are based on the speed of the smaller sprocket and an expected life of approximately 15 000 h.
2. For a given speed, the power capacity increases with the number of teeth on the sprocket. Of course, the larger the number of teeth, the larger the diameter of the sprocket. Note that the use of a chain with a small pitch on a large sprocket produces the quieter drive.
3. For a given sprocket size (a given number of teeth), the power capacity increases with increasing speed up to a point; then it decreases. Fatigue due to the tension in the chain governs at the low to moderate speeds; impact on the sprockets governs at the higher speeds. Each sprocket size has an absolute upper-limit speed due to the onset of galling between the pins and the bushings of the chain. This explains the abrupt dropin power capacity to zero at the limiting speed.
4. The ratings are for a single strand of chain. Although multiple strands do increase the power capacity, they do not provide a direct multiple of the single-strand capacity. Multiply the capacity in the tables by the following factors.

- Two strands: Factor = 1.7
- Three strands: Factor = 2.5
- Four strands: Factor = 3.3

5. The chain manufacturer's ratings are for a service factor of 1.0. Specify a service factor for a given application as shown in Table 7–16. The combination of the nature of the driving member and thedriven machine permit the selection of the service factor. Then compute the design power, *Pdes*, from,

$$P_{des} = SF(P)$$

where

- P is the power delivered to the chain drive.

Table IV-6 Horsepower Ratings—Single-Strand Roller Chain No. 40

No. of teeth	0.500 in pitch				Rotational speed of small sprocket, rev/min																				
	10	25	50	100	150	200	300	500	700	900	1000	1200	1400	1600	1800	2100	2500	3000	3500	4000	5000	6000	7000	8000	9000
11	0.06	0.14	0.27	0.52	0.91	1.00	1.48	2.42	3.34	4.25	4.70	5.60	6.49	5.57	4.66	3.70	2.65	2.17	1.72	1.41	1.01	0.77	0.61	0.50	0.00
12	0.06	0.15	0.29	0.56	0.99	1.09	1.61	2.64	3.64	4.64	5.13	6.11	7.09	6.34	5.31	4.22	3.25	2.47	1.96	1.60	1.15	0.87	0.69	0.57	0.00
13	0.07	0.16	0.31	0.61	1.07	1.19	1.75	2.86	3.95	5.02	5.56	6.62	7.68	7.15	5.99	4.76	3.66	2.79	2.21	1.81	1.29	0.98	0.78	0.00	
14	0.07	0.17	0.34	0.66	1.15	1.28	1.88	3.08	4.25	5.41	5.98	7.13	8.27	7.99	6.70	5.31	4.09	3.11	2.47	2.02	1.45	1.10	0.87	0.00	
15	0.08	0.19	0.36	0.70	1.24	1.37	2.02	3.30	4.55	5.80	6.41	7.64	8.86	8.86	7.43	5.89	4.54	3.45	2.74	2.24	1.60	1.22	0.97	0.00	
16	0.08	0.20	0.39	0.75	1.32	1.46	2.15	3.52	4.86	6.18	6.84	8.15	9.45	9.76	8.18	6.49	5.00	3.80	3.02	2.47	1.77	1.34	0.00		
17	0.09	0.21	0.41	0.80	1.40	1.55	2.29	3.74	5.16	6.57	7.27	8.66	10.04	10.69	8.96	7.11	5.48	4.17	3.31	2.71	1.94	1.47	0.00		
18	0.09	0.22	0.43	0.84	1.48	1.64	2.42	3.96	5.46	6.95	7.69	9.17	10.63	11.65	9.76	7.75	5.97	4.54	3.60	2.95	2.11	1.60	0.00		
19	0.10	0.24	0.46	0.89	1.57	1.73	2.56	4.18	5.77	7.34	8.12	9.66	11.22	12.64	10.59	8.40	6.47	4.92	3.91	3.20	2.29	0.09	0.00		
20	0.10	0.25	0.48	0.94	1.65	1.82	2.69	4.39	6.07	7.73	8.55	10.18	11.80	13.42	11.44	9.07	6.99	5.31	4.22	3.45	2.47	0.00			
21	0.11	0.26	0.51	0.98	1.73	1.91	2.83	4.61	6.37	8.11	8.98	10.69	12.40	14.10	12.30	9.76	7.52	5.72	4.54	3.71	2.65	0.00			
22	0.11	0.27	0.53	1.03	1.81	2.01	2.96	4.83	6.68	8.50	9.40	11.20	12.99	14.77	13.19	10.47	8.06	6.13	4.87	3.98	2.85	0.00			
23	0.12	0.28	0.56	1.08	1.90	2.10	3.10	5.05	6.98	8.89	9.83	11.71	13.58	15.44	14.10	11.19	8.62	6.55	5.20	4.26	3.05	0.00			
24	0.12	0.30	0.58	1.12	1.98	2.19	3.23	5.27	7.28	9.27	10.26	12.22	14.17	16.11	15.03	11.93	9.18	6.99	5.54	4.54	0.87	0.00			
25	0.13	0.31	0.60	1.17	2.06	2.28	3.36	5.49	7.59	9.66	10.69	12.73	14.76	16.78	15.98	12.68	9.76	7.43	5.89	4.82	0.00				
26	0.13	0.32	0.63	1.22	2.14	2.37	3.50	5.71	7.89	10.04	11.11	13.24	15.35	17.45	16.95	13.45	10.36	7.88	6.25	5.12	0.00				
28	0.14	0.35	0.67	1.31	2.31	2.55	3.77	6.15	8.50	10.82	11.97	14.26	16.53	18.79	18.94	15.03	11.57	8.80	6.99	5.72	0.00				
30	0.15	0.37	0.72	1.41	2.47	2.74	4.04	6.59	9.11	11.59	12.82	15.28	17.71	20.14	21.01	16.67	12.84	9.76	7.75	6.34	0.00				
32	0.16	0.40	0.77	1.50	2.64	2.92	4.31	7.03	9.71	12.36	13.68	16.30	18.89	21.48	23.14	18.37	14.14	10.76	8.54	1.41					
35	0.18	0.43	0.84	1.64	2.88	3.19	4.71	7.69	10.62	13.52	14.96	17.82	20.67	23.49	26.30	21.01	16.17	12.30	9.76	0.00					
40	0.21	0.50	0.96	1.87	3.30	3.65	5.38	8.79	12.14	15.45	17.10	20.37	23.62	26.85	30.06	25.67	19.76	15.03	0.00						
45	0.23	0.56	1.08	2.11	3.71	4.10	6.06	9.89	13.66	17.39	19.24	22.92	26.57	30.20	33.82	30.63	23.58	5.53	0.00						
	Type A				Type B									Type C											

Type A: Manual or drip lubrication
Type B: Bath or disc lubrication
Type C: Oil stream lubrication

Table IV-7 Horsepower Ratings—Single-Strand Roller Chain No. 60

No. of teeth	0.750 in pitch				Rotational speed of small sprocket, rev/min																				
	10	25	50	100	150	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000	2500	3000	3500	4000	4500	5000	5500	6000
11	0.19	0.46	0.89	1.72	2.05	3.35	4.95	6.52	8.08	9.63	12.69	15.58	11.85	9.41	7.70	6.45	5.51	3.94	3.00	2.38	1.95	1.63	1.39	1.21	0.00
12	0.21	0.50	0.97	1.86	2.24	3.86	5.40	7.12	8.82	10.51	13.86	17.15	13.51	10.72	8.77	7.35	6.26	4.49	3.42	2.71	2.22	1.86	1.59	1.36	0.00
13	0.22	0.54	1.05	2.04	2.43	3.96	5.85	7.71	9.55	11.38	15.00	18.58	15.23	12.06	9.89	8.29	7.06	5.06	3.85	3.06	2.50	2.10	1.79	0.00	
14	0.24	0.58	1.13	2.19	2.61	4.27	6.30	8.30	10.29	12.26	16.15	20.01	17.02	13.51	11.05	9.26	7.91	5.66	4.31	3.42	2.80	2.34	0.41	0.00	
15	0.26	0.62	1.21	2.35	2.80	4.57	6.75	8.90	11.02	13.13	17.31	21.44	18.87	14.98	12.26	10.27	8.77	6.28	4.77	3.79	3.10	2.60	0.00		
16	0.27	0.66	1.29	2.51	2.99	4.88	7.20	9.49	11.76	14.01	18.46	22.87	20.79	16.50	13.51	11.32	9.66	6.91	5.26	4.17	3.42	1.78	0.00		
17	0.29	0.70	1.37	2.66	3.17	5.18	7.65	10.08	12.49	14.88	19.62	24.30	22.77	18.07	14.79	12.40	10.58	7.57	5.76	4.57	3.74	0.00			
18	0.31	0.75	1.45	2.82	3.36	5.49	8.10	10.68	13.23	15.76	20.77	25.73	24.81	19.69	16.11	13.51	11.53	8.25	6.28	4.98	4.08	0.00			
19	0.33	0.79	1.53	2.96	3.55	5.79	8.55	11.27	13.96	16.63	21.92	27.16	26.91	21.35	17.46	14.65	12.50	8.95	6.81	5.40	0.20	0.00			
20	0.34	0.83	1.61	3.13	3.73	6.10	9.00	11.86	14.70	17.51	23.08	28.59	29.06	23.06	18.87	15.82	13.51	9.66	7.35	5.83	0.00				
21	0.36	0.87	1.69	3.29	3.92	6.40	9.45	12.46	15.43	18.38	24.23	30.02	31.26	24.81	20.31	17.02	14.53	10.40	7.91	6.26	0.00				
22	0.38	0.91	1.77	3.45	4.11	6.71	9.90	13.05	16.17	19.26	25.39	31.45	33.52	26.60	21.77	18.25	15.58	11.15	8.48	0.00					
23	0.40	0.95	1.85	3.61	4.29	7.01	10.35	13.64	16.90	20.13	26.54	32.68	35.84	28.44	23.26	19.51	16.66	11.92	9.07	0.00					
24	0.41	0.99	1.93	3.76	4.48	7.32	10.80	14.24	17.64	21.01	27.69	34.31	38.20	30.31	24.81	20.79	17.75	12.70	9.66	0.00					
25	0.43	1.04	2.01	3.92	4.67	7.62	11.25	14.83	18.37	21.89	28.85	35.74	40.61	32.23	26.38	22.11	18.87	13.51	10.27	0.00					
26	0.45	1.08	2.09	4.08	4.85	7.93	11.70	15.42	19.11	22.76	30.00	37.17	43.07	34.18	27.98	23.44	20.02	14.32	10.90	0.00					
28	0.48	1.16	2.26	4.39	5.23	8.54	12.60	16.61	20.58	24.51	32.31	40.03	47.68	38.20	31.26	26.20	22.37	16.01	0.00						
30	0.52	1.24	2.42	4.70	5.60	9.15	13.50	17.79	22.05	26.26	34.62	42.89	51.09	42.36	34.67	29.06	24.82	17.75	0.00						
32	0.55	1.33	2.58	5.02	5.98	9.76	14.40	18.98	23.52	28.01	36.92	45.75	54.50	46.67	38.20	32.01	27.33	19.96	0.00						
35	0.60	1.45	2.82	5.49	6.54	10.67	15.75	20.76	25.72	30.64	40.39	50.03	59.60	53.36	43.69	36.62	31.26	1.35	0.00						
40	0.69	1.66	3.22	6.27	7.47	12.20	18.00	23.73	29.39	35.02	46.16	57.18	68.12	65.22	53.38	44.74	38.20	0.00							
45	0.77	1.86	3.63	7.05	8.40	13.72	20.25	26.69	33.07	38.39	51.92	64.33	76.63	77.83	63.70	53.38	12.45	0.00							
	Type A				Type B								Type C												

Type A: Manual or drip lubrication
Type B: Bath or disc lubrication
Type C: Oil-stream lubrication

Table IV-8 **Horsepower Ratings—Single-Stand Roller Chain No. 80**

No. of teeth	1.000 in pitch				Rotational speed of small sprocket, rev/min																				
	10	25	50	75	88	100	200	300	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000	2500	3000	3500	4000	4500
11	0.44	1.06	2.07	3.05	3.56	4.03	7.83	11.56	15.23	18.87	22.48	26.07	27.41	22.97	19.61	14.92	11.84	9.69	8.12	6.83	4.96	3.77	3.00	2.45	0.00
12	0.48	1.16	2.26	3.33	3.88	4.39	8.54	12.61	16.82	20.59	24.53	28.44	31.23	26.17	22.35	17.00	13.49	11.04	9.25	7.90	5.65	4.30	3.41	2.79	0.00
13	0.52	1.26	2.45	3.61	4.21	4.76	9.26	13.66	18.00	22.31	26.57	30.81	35.02	29.51	25.20	19.17	15.21	12.45	10.43	8.91	6.37	4.85	3.85	3.15	
14	0.56	1.35	2.63	3.89	4.53	5.12	9.97	14.71	19.39	24.02	28.62	33.18	37.72	32.98	28.16	21.42	17.00	13.91	11.66	9.96	7.12	5.42	4.30	3.52	
15	0.60	1.45	2.82	4.16	4.86	5.49	10.68	15.76	20.77	25.74	30.66	35.55	40.41	36.56	31.23	23.76	18.85	15.43	12.93	11.04	7.90	6.01	4.77	0.00	
16	0.64	1.55	3.01	4.44	5.18	5.86	11.39	16.81	22.16	27.45	32.70	37.92	43.11	40.30	34.41	26.17	20.77	17.00	14.25	12.16	8.70	6.62	5.25	0.00	
17	0.68	1.64	3.20	4.72	5.50	6.22	12.10	17.86	23.54	29.17	34.75	40.29	45.80	44.13	37.68	28.66	22.75	18.62	15.60	13.32	9.53	7.25	0.00		
18	0.72	1.74	3.39	5.00	5.83	6.59	12.81	18.91	24.93	30.88	36.79	42.66	48.49	48.08	41.05	31.23	24.78	20.29	17.00	14.51	10.39	7.90	0.00		
19	0.76	1.84	3.57	5.28	6.15	6.95	13.53	19.96	26.31	32.60	38.84	45.03	51.19	52.15	44.52	33.87	26.86	22.00	18.44	15.74	11.26	0.36	0.00		
20	0.80	1.93	3.76	5.55	6.47	7.32	14.24	21.01	27.70	34.32	40.88	47.40	53.88	56.32	48.08	36.58	29.03	23.76	19.91	17.00	12.16	0.00			
21	0.84	2.03	3.95	5.83	6.80	7.69	14.95	22.07	29.08	36.03	42.92	49.77	56.58	60.59	51.73	39.36	31.23	25.56	21.42	18.29	13.09	0.00			
22	0.88	2.13	4.14	6.11	7.12	8.05	15.66	23.12	30.47	37.75	44.97	52.14	59.27	64.97	55.47	42.20	33.49	27.41	22.97	19.61	14.03				
23	0.92	2.22	4.33	6.39	7.45	8.42	16.37	24.17	31.85	39.46	47.01	54.51	61.97	69.38	59.30	45.11	35.80	29.30	24.55	20.97	15.00				
24	0.96	2.32	4.52	6.66	7.77	8.78	17.09	25.22	33.24	41.18	49.06	56.88	64.66	72.40	63.21	46.06	38.16	31.23	26.17	22.35	15.99				
25	1.00	2.42	4.70	6.94	8.09	9.15	17.80	26.27	34.62	42.89	51.10	59.25	67.35	75.42	67.20	51.12	40.57	33.20	27.83	23.76	8.16				
26	1.04	2.51	4.89	7.22	8.42	9.52	18.51	27.32	36.01	44.61	53.14	61.62	70.05	78.43	71.27	54.22	43.02	36.22	29.51	25.20	0.00				
28	1.12	2.71	5.27	7.77	9.06	10.25	19.93	29.42	38.78	48.04	57.23	66.36	75.44	84.47	79.65	60.59	48.08	39.36	32.98	28.16	0.00				
30	1.20	2.90	5.64	8.33	9.71	10.98	21.36	31.52	41.55	51.47	61.32	71.10	80.82	90.50	86.33	67.20	53.33	43.65	36.56	31.23					
32	1.28	3.09	6.02	8.89	10.36	11.71	22.78	33.62	44.32	54.91	65.41	75.84	86.21	96.53	97.31	74.03	58.75	48.08	40.30	5.65					
35	1.40	3.38	6.58	9.72	11.33	12.81	24.92	36.78	48.47	60.05	71.54	82.95	94.29	105.56	111.31	84.66	67.20	55.00	26.15	0.00					
40	1.61	3.87	7.53	11.11	12.95	14.64	28.48	42.03	55.40	68.63	81.76	94.80	107.77	120.67	133.51	103.46	82.10	40.16	0.00						
45	1.81	4.35	8.47	12.49	14.57	16.47	32.04	47.28	62.32	77.21	91.96	106.65	121.24	135.75	150.20	123.45	72.26	0.00							
	Type A				Type B									Type C											

Type A: Manual or drip lubrication
Type B: Bath or disc lubrication
Type C: Oil stream lubrication