



# ***Power Transmission Handbook***

Power Transmission  
Distributors Association

***Serving the Industrial PT/Motion Control Industry***

LIFECORE Ex. 1016

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# ***Power Transmission Handbook***

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Content compiled by the  
**Educational Resources Committee**  
**Power Transmission Distributors Association**  
with the assistance of  
**Penton Custom Publishing Group,**  
**Cleveland, Ohio.**

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# **POWER TRANSMISSION DISTRIBUTORS ASSOCIATION**

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### A Note on the Arrangement of Chapters

The Educational Resources Committee of the Power Transmission Distributors Association has arranged most chapters of the *Power Transmission Handbook* alphabetically.

These are the exceptions:

- **"Fundamentals,"** Chapter 1, Provides the reader with basic knowledge essential to understanding later chapters.

- **"Adjustable Speed Drives,"** Chapter 12, and **"Controls and Sensors,"** Chapter 13, follow **"Motors,"** Chapter 11, because these chapters are closely interrelated, and information contained in each chapter should be mastered before moving on to the next.
- **"Accessories,"** Chapter 14, is positioned last because it discusses products not discussed elsewhere in the *Power Transmission Handbook*.

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Bearings allow smooth, low-friction motion between two surfaces. The motion can be either rotary (a shaft turning in a housing) or linear (one machine element moving across another). Linear motion bearings are covered in Chapter 10.

Bearings are widely used to support shafts and allow their free rotation. Load is applied to these bearings in either of two directions, Fig. 2-1. Radial loads act at right angles to the shaft or bearing's axis of rotation.

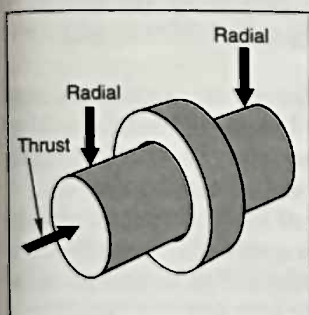


Fig. 2-1 — Types of loads handled by bearings.

For example, a belt or chain drive connected to a shaft at a right angle to the shaft applies a radial load to the supporting bearing. Axial, or thrust, loads are applied parallel to the axis of rotation. Thus, a load supported by a vertical shaft produces a thrust load on the shaft bearing. In many cases, bearings support both radial and axial loads. These combined loads are produced, for example, by certain types of shaft-mounted gears, especially helical and bevel types.

Two basic types of bearings are used for rotating-shaft applications: plain and rolling-element. Each type has inherent features that determine its suitability for an application.

The most basic type is the plain bearing, which supports loads through sliding motion. By contrast, rolling-element bearings are subject to very little

sliding motion. Here, load is supported by numerous rolling elements in the bearing. In either case, long bearing life requires proper lubrication. Plain bearings usually cost less than similarly sized rolling-element bearings, but rolling element bearings generally tolerate heavier loads and higher speeds.

Bearings that support loads perpendicular to their axis are called radial bearings. Those that support loads parallel to their axis of rotation are termed thrust bearings. Both types are rated according to their load and speed capabilities and the required life for the application. Other factors affecting bearing selection include temperature, type of lubrication, degree of contamination, and cost.

## Plain Bearings

Plain bearings, Fig. 2-2, are widely used in industrial machinery, automobiles, home appliances, and construction equipment. These bearings are generally limited to lighter loads and slower speeds than comparable rolling-element bearings.

A plain bearing functions as a tight-fitting cylinder, usually stationary, that encloses and supports a moving member, generally called the

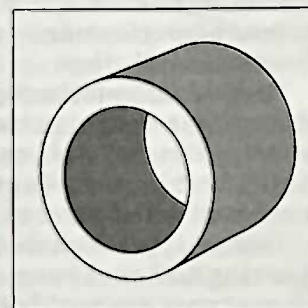


Fig. 2-2 — Plain bearing.

TABLE 2-1 — Comparison of plain bearing alloys

| Bearing material                           | Load carrying capacity, lb/in. <sup>2</sup> | Maximum operating temperature, F | 1 = Best, 5 = Worst |                                 |                      |                  |
|--|---|----------------------------------|---------------------|---------------------------------|----------------------|------------------|
|  |   |                                  | Compatibility*      | Conformability & embeddability* | Corrosion resistance | Fatigue strength |
| Tin-base babbitt                           | 800-1,500                                   | 300                              | 1                   | 1                               | 1                    | 5                |
| Lead-base babbitt                          | 800-1,200                                   | 300                              | 1                   | 1                               | 3                    | 5                |
| Three-component bearings, babbitt surfaced | 2,000-5,000+                                | 300                              | 1                   | 2                               | 2                    | 2                |
| Cadmium base                               | 1,500-2,000                                 | 500                              | 1                   | 2                               | 5                    | 4                |
| Copper-lead                                | 1,500-2,500                                 | 350                              | 2                   | 2                               | 5                    | 3                |
| Lead bronze                                | 3,000-4,000                                 | 450                              | 3                   | 4                               | 4                    | 2                |
| Tin bronze                                 | 4,000+                                      | 500+                             | 5                   | 5                               | 2                    | 1                |
| Aluminum alloy                             | 5,000+                                      | 250                              | 4                   | 3                               | 1                    | 2                |
| Silver (overplated)                        | 5,000+                                      | 500                              | 2                   | 3                               | 1                    | 1                |

\* Compatibility indicates anti-welding and anti-scoring characteristics.

\* Conformability and embeddability represent ability to compensate for misalignment and ability to absorb foreign particles without scoring and wearing.



shaft or journal. These bearings support radial or thrust loads on sliding surfaces. Radial-type plain bearings are often called journal or sleeve bearings.

Plain bearings are made of various types of metals, plastics, carbon, graphites, and even wood. Metallic types, the most common, are classified by material, manufacturing process, and design type.

Metallic materials for plain bearings include iron, bronze, copper alloys, aluminum alloys, silver, and babbitt. Tin and lead-based babbitts, the softest materials, are widely used for their ability to imbed foreign particles. This characteristic helps prevent shaft scoring (grooves or scratches) and thus extends bearing life.

Compared to babbitts, copper alloys generally have higher load capacity, better high-temperature characteristics, and better wear resistance, but poorer scoring resistance.

Harder materials, such as bronzes, aluminum, and silver, carry higher loads and offer better fatigue strength. Bronze alloys are used in high-speed, light-load applications. Table 2-1 summarizes the performance characteristics of typical bearing-metal alloys.

Several manufacturing methods are used to produce these bearings including cast alloy, rolled sheet, extruded rod, and sintered powder metal. Many bearings consist of a soft bearing material combined with a strong backing, usually steel.

Design types include full 360-deg bearings, half bearings, thrust bearings, and linear bearings. Some types support both radial and thrust loads with both rotational and linear shaft motion. Plain, flat thrust bearings have low load-carrying ability, but the design can be enhanced to increase capacity.

### Plain-Bearing Lubrication

Friction in metal bearings is minimized by maintaining a film of lubricant between the rotating and stationary members, Fig. 2-3. These bearings generally are lubricated with grease, which has less tendency than oil to leak from between the bearing and shaft.

Modes, or degrees, of lubrication in a plain bearing are:

- Boundary — bearing and shaft rub together with

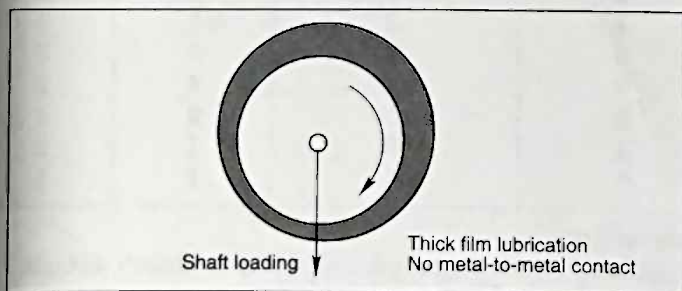


Fig. 2-3 — Film lubrication for plain bearings.

only a thin film of lubricant on the surfaces. Grease-lubricated bearings generally operate this way.

- Mixed-film — part of the load (where shaft and bearing are closest) is supported on a boundary film and the remaining part is supported by hydrodynamic pressure.

- Full-film or hydrodynamic — a thick, continuous film of self-pressurized lubricant separates the shaft from the bearing with no metal-to-metal contact.

- Hydrostatic — external pumps supply pressure to the lubricant, providing a full film to prevent metal-to-metal contact.

The first two levels of lubrication, boundary and mixed-film, can be upgraded to full-film lubrication by increasing lubricant viscosity, improving shaft finish, decreasing the load, or increasing speed.

The load-carrying ability of hydrodynamic or full-film bearings increases with speed. Because there is no metal-to-metal contact, full-film bearings offer the least friction and require less energy to rotate.

Hydrostatic bearings exhibit high load capacity at all speeds. Load and speed are limited only by the ability of the external pump to supply enough pressure and supply a flow rate sufficient to carry away generated heat. But these bearings are impractical in many applications because an external pump, motor, and other support devices are required.

Plain metallic bearings 1-in. long or less typically have a lubrication hole in the center. Oil generally flows up to 1/2 in. axially to either side of the hole. Bearings longer than 1 in. (excluding the hole) usually provide grooves along the inner surface to provide lubricant throughout the length of the bearing, Fig. 2-4.

Grooves are also generally provided in oil-lubricated bearings with a length-to-diameter ratio of more than 1:1 and grease-lubricated bearings with a ratio over 1.5:1. Type and number of grooves depend on load, speed, and type of lubricant (grease requires a wider groove than oil).

High-temperature conditions may require cast bronze-alloy bearings containing graphite or other solid lubricants pressed into grooves or holes. These bearings are also used in low-speed or high-load applications, or where bearings are inaccessible for lubrication.

Oil-filled sintered bronze bearings are also employed where periodic lubrication is not possible. These powder-metal bearings are made from a porous material with oil impregnated in the pores to create a built-in reservoir of lubricant, which is typically about 20% of the volume. Their load-carrying

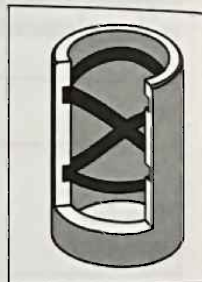


Fig. 2-4 — Grooves in plain-bearing inside surface direct lubricant flow.



ability is less than that of cast bronze alloys. But, in smaller sizes, they are less costly than other bearing types. Sintered bearings are used in office machines, textile machinery, and home appliances.

### Self-Lubricating Bearings

In applications where relative motion is insufficient to circulate oil or grease through a bearing, self-lubricating bearings or non-metallic (plastic) bearings are most effective.

Self-lubricating bearings are also often used where temperatures exceed the scope of conventional lubricants. They are well-suited for some corrosive environments.

In some cases, these bearings perform better than fully lubricated ones. For example, with hydrodynamic lubrication, self-lubricating bearings provide longer life because they resist wear at startup when lubricants are not fully effective. Another advantage is lower startup torque, which reduces power requirements.

Friction, coupled with rapid wear, limits the application of self-lubricated bearings. The energy lost due to friction in the bearing is converted to heat, which must be dissipated.

Common self-lubricating materials include polytetrafluoroethylene (PTFE), graphite, and molybdenum disulfide ( $\text{MoS}_2$ ). These materials are usually combined with others to improve strength.

Plastic bearings offer several advantages over other plain bearings. They run maintenance-free in applications where access is difficult and in applications such as the food-industry where oil or grease would act as a contaminant. Plastic bearings resist chemicals that would corrode metallic bearings, and they operate in environments that would contaminate oil lubricants. Also, plastic bearings have an ability to absorb some vibration and shock.

Plastic bearings, however, exhibit limited load capacity. Therefore, load and speed requirements as well as temperature, which affects load capacity, should be carefully evaluated.

## Rolling-Element Bearings

To support loads, rolling-element bearings rely on either balls or rollers. Their rolling motion produces less friction than plain bearings. Both ball and roller bearings have low starting friction. Thus, rolling-element bearings are often called anti-friction bearings.

Rolling-element bearings are available for radial loads, thrust loads, or a combination of radial and thrust loads. These bearings generally consist of one

or two circular rows of steel balls or rollers positioned between inner and outer rings, Figs. 2-5 and 2-11. Grooves or raceways in the inner and outer rings guide the rolling elements. Typically, a retainer is used to equally space these rolling elements. Ball and roller bearings that are properly mounted, adequately lubricated, and suitably sealed, generally perform satisfactorily throughout their expected service life and fail only because of material fatigue.

### Ball Bearings

In general, ball bearings cost less than roller types, and are normally used for light to moderate loads. These bearings have a small area of contact between balls and raceways. This arrangement enables them to operate at high speeds with minimal fatigue damage and less heat generation than roller bearings.

**Radial ball bearings.** There are two basic types of radial ball bearings: the nonfilling-slot or Conrad type, Fig. 2-5, and the filling-slot or maximum-capacity type, Fig. 2-6. The non-filling-slot or Conrad bearing has a deep, uninterrupted raceway in inner and outer rings. It carries high radial loads plus moderate thrust loads in either direction.

The filling-slot bearing contains more balls than an equivalent non-filling type and, therefore, has a higher radial load capacity. Because of the filling slots, however, thrust loads must be light and applied only in combination with a heavy radial load.

From these two basic types, other ball bearings have evolved to handle specific situations. For example, the double-row, deep-groove ball bearing, Fig. 2-7, handles higher radial loads than a single-row bearing.

Another type, the self-aligning radial ball bearing, compensates

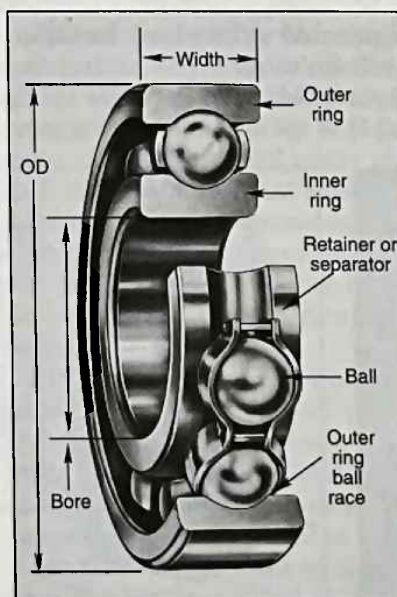


Fig. 2-5 — Components of a non-filling-slot (Conrad) ball bearing.

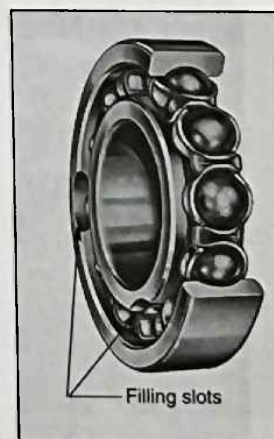


Fig. 2-6 — Filling-slot radial ball bearing.



for misalignment between shaft and housing bores. These are available in both internal and external self-aligning versions. The internal type has two rows of balls between a grooved, double-row inner ring and an outer ring with a spherical race (contacting the balls). They are capable of accommodating shaft misalignments up to a few degrees and carrying light shafts that vibrate and deflect under load. External self-aligning bearings are identical to single-row, deep-groove bearings except that the outer ring has a spherical outer surface.

Radial ball bearings have internal clearances between rings and balls to absorb the effects of press fitting the bearings on shafts. These clearances also compensate for thermal expansion of bearing, shaft, and housing. Before mounting, check the manufacturer's specifications for required shaft and housing tolerances.

Manufacturers offer a guide for maximum safe operating speed of ball bearings. This speed value (DN) for inner ring rotation is the product of bearing bore diameter (mm), and shaft speed (rpm). Typical values range from about 200,000 to 750,000 depending on the type of ball bearing and lubricant (grease or oil).

**Angular-contact bearings.** The single-row, angular-contact bearing, Fig. 2-8, accepts high thrust load in combination with moderate radial load. The ratio of thrust to radial load depends on the angle of contact between the races and the bearing axis. Available designs can handle thrust loads from 150% of the radial load to more than 300%. Bearings of this type are mounted singly, back-to-back, face-to-face, or in tandem.

**Thrust ball bearings.** Some applications are best served by thrust bearings, which carry primarily thrust loads and provide axial shaft location. These bearings differ from other types in that the space between rings is oriented perpendicular to the axis of rotation, Fig. 2-9. A thrust ball bearing gen-



Fig. 2-7 — Double-row, deep-groove radial ball bearing.



Fig. 2-8 — Single-row, angular-contact ball bearing.

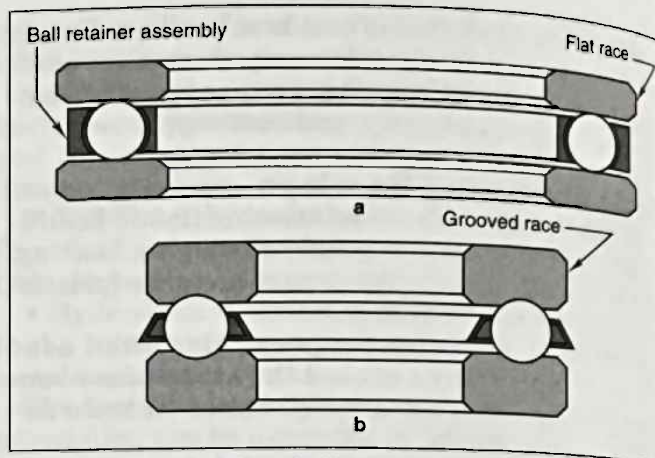


Fig. 2-9 — Flat-seat thrust ball-bearing types include flat-race(a) and grooved-race(b).

erally contains two races, either flat or grooved, separated by a ball-bearing retainer assembly.

Thrust bearings are classified by the race contour (ball contact surface), which is either flat or grooved.

**Flat-race, flat-seat bearings,** Fig. 2-9a, consist of two flat washers and a ball-retainer assembly. This assembly carries thrust loads without restraining shaft oscillation or flexing. Best suited for light loads, these bearings have a load capacity about 28% of that of comparable grooved-race bearings.

**Grooved-race, flat-seat bearings,** Fig. 2-9b, are the most common type of thrust ball bearings. They consist of two grooved washers, one shaft-mounted and one bore-mounted, plus a ball-retainer assembly.

Other thrust bearings for special applications include banded and aligning types. Banded types have both stationary and rotating grooved races and are encased in a band. They are commonly used where the bearing's outer circumference must be protected from contamination, for blind installation, or where separating forces cause substantial axial motion of bearing components.

**Aligning type, grooved-race bearings** are available in single and double-acting types. A single-acting type, Fig. 2-10a, consists of a flat-seat washer and a ball-retainer assembly, plus a spherical aligning seat and matching aligning washer. The aligning members compensate for misalignment due to shaft deflection or mismatch and provide uniform load distribution through the bearing. The aligning washer is soft to enable proper seating through wear-in.

The double-acting type, Fig. 2-10b, has two retainer assemblies and it carries thrust loads in either direction.

**Unground ball bearings.** The bearings described previously are precision-ground, which pro-



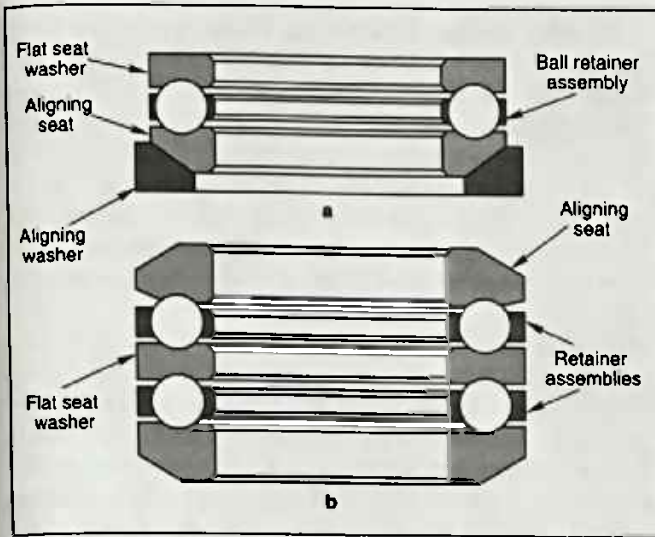


Fig. 2-10 — Aligning, single-acting, grooved-race thrust bearing (a) has one aligning washer. Double-acting version (b) is shown without aligning washers at ends.

vides high-speed and high-load-carrying capabilities. Ball bearings are also furnished in more economical unground types for less demanding applications. Unground bearings have fewer parts, cost less, and can reduce installation costs. Because tolerances are much looser than in precision bearings, extra parts for locking the bearing on the shaft are often unnecessary.

Like precision types, these unground ball bearings are available in radial, thrust, and combination types, but all of these are best suited to light loads and low speeds. A typical unground bearing is made of a machined or stamped inner race, hardened steel balls, and an outer race of one or more machined or stamped parts. Because surfaces are unground and some parts are stamped, the bearing has more radial and axial freedom than a precision bearing.

**Thin-section bearings.** Where space and weight must be conserved, thin-section bearings are often used. Available in both ball and roller types, these bearings have a lower inertia than conventional types of equal bore diameter. They require smaller envelopes, which reduces both the drive weight and size. Cross-sectional area of thin-section bearings remains constant within a series, regardless of bore diameter.

Thin-section bearings have a lower load capacity than comparable conventional bearings. But they enable lighter, more compact designs than conventional types, even extra-light bearings, Table 2-2.

Thin-section bearings are designed for light to medium-duty drives operating at medium and slow speeds. They are not well suited for heavy-duty or high-speed drives operating continuously.

Because rolling elements and races are so small

TABLE 2-2 — Weight comparison between extra-light and thin-section bearings

| Bore, in. | Thin-section weight, lb | Extra-light weight, lb | Weight savings, lb |
|-----------|-------------------------|------------------------|--------------------|
| 2.0       | 0.038                   | 0.430                  | 0.392              |
| 4.0       | 0.19                    | 2.76                   | 2.57               |
| 6.0       | 0.28                    | 10.60                  | 10.32              |
| 8.0       | 3.5                     | 27.0                   | 23.5               |
| 12.0      | 5.2                     | 85.0                   | 79.8               |
| 16.0      | 12.3                    | 170.0                  | 157.7              |
| 24.0      | 19.0                    | 443.0                  | 424.0              |
| 32.0      | 25.0                    | 1,000.0                | 975.0              |
| 40.0      | 31.0                    | 1,779.0                | 1,748.0            |

in thin-section bearings, they must be properly supported in the drive assembly. Be sure that axial, radial, or moment deflection of the thin-section bearing does not prohibit its use. Also, imperfections in the bore or shaft diameter may reduce life or increase torsional drag of the bearing.

## Roller Bearings

Because roller bearings have more rolling surface area in contact with inner and outer races, they generally support heavier loads than comparably sized ball bearings. Roller bearings, Fig. 2-11, handle moderate to heavy loads and are capable of handling high-impact or shock loads. They exhibit less elastic deformation than ball bearings because contact stresses for rollers are lower.

Roller types are divided into four main categories: cylindrical, needle, spherical, and tapered.

**Cylindrical roller bearings.** Of the four types, cylindrical bearings have the highest radial load capacity and speed capability. A non-locating type of cylindrical bearing, Fig. 2-11, enables axial movement of the inner and outer ring to accommodate both thermal and axial expansion of the shaft and tolerances in the assembly. Cylindrical bearings with ridges on the inner and outer rings, Fig. 2-12, accommodate some thrust loading, but this is limited by the amount of heat generated and dissipated.

Limiting speed of a cylindrical roller bearing depends on the roller length-to-diameter ratio, precision grade, roller guidance, type of cage, type of lubrication, shaft and housing accuracy, and heat dissipation of the mounting assembly. For general use, a roller length equal to the roller diameter provides the best balance of load and speed capabilities. The limiting speed of this "square" roller bearing is considered equal to that of a comparable series ball bearing. Because limiting speed depends



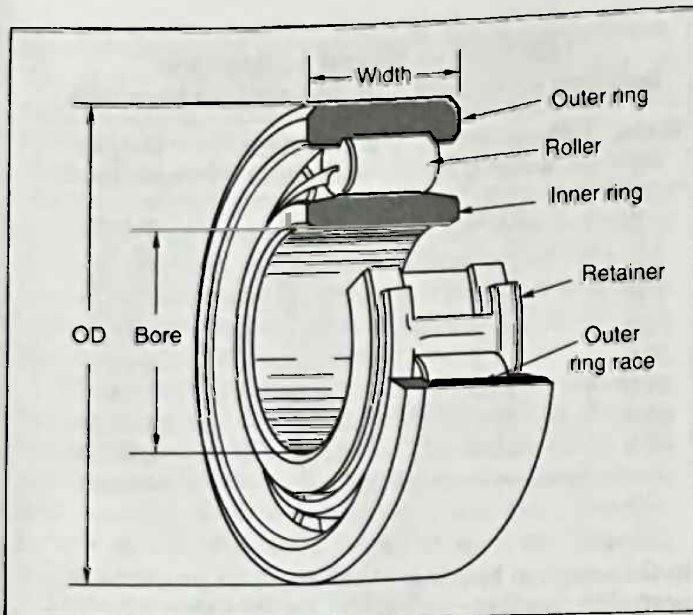
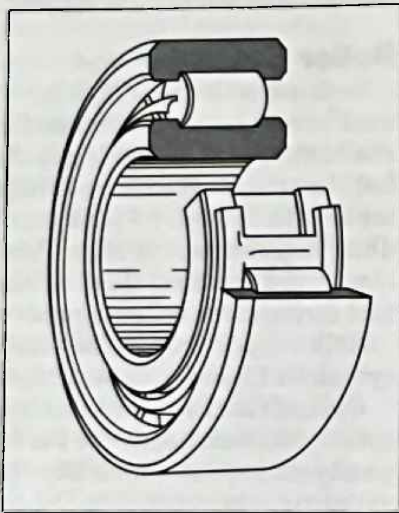


Fig. 2-11 — Components of a cylindrical roller bearing. This non-locating cylindrical type accommodates axial movement by not restraining rollers on the inner ring.

Fig. 2-12 — Cylindrical roller bearing with axially fixed inner and outer rings. This type of bearing allows no axial movement of the shaft and is normally used in conjunction with an axially free bearing such as the one in Fig. 2-11.



on so many variables, consult the manufacturer's catalog for specific values.

Bearings must position a shaft in a housing so that the shaft rotates freely with minimum radial and axial movement. To do this, the bearings must support the shaft at only two points — usually at each end of the shaft. One bearing locates the shaft axially; whereas the other bearing allows axial expansion or contraction.

Though roller bearings support more load than ball bearings, roller types are more sensitive to misalignment. For example, angular misalignment between the shaft and housing causes non-uniform loading of rollers, which reduces bearing life. Poor bearing alignment on the shaft causes misaligned inner and outer rings, even with unloaded bearings. Also, an external load may deflect the shaft or housing, another source of misalignment.

**Needle roller bearings.** Though similar to cylindrical roller bearings, needle bearings have a much smaller diameter-to-length ratio. (The word "needle" was originally used where the roller length was at least six times the diameter.) Though many do not require separators, needle bearings are available with separators for higher-speed applications. The separators control circumferential clearance between needles and keep the needles parallel to the shaft axis.

Needle bearings can carry heavy radial loads in a minimal amount of radial space. Their load capacity is higher than most single-row ball or roller bearings of comparable outside diameter (OD). This bearing type permits the use of larger, stiffer shafts for a given OD and provides a low-friction rolling bearing in about the same space as a plain bearing.

In the basic drawn-cup needle bearing, Fig. 2-13, the outer race is a thin, drawn cup with a hardened surface. Roller ends are shaped so that lips on the outer race keep them from falling out. Because the outer race is thin, it must be installed in a correctly sized and properly backed-up housing to transmit load effectively. Generally, a hardened shaft acts as the bearing's inner race, although an inner race can be supplied if the shaft cannot be hardened.

The grease-retained, drawn-cup needle bearing, Fig. 2-14, is applied without an inner ring by fitting the rollers directly onto a hardened shaft. This design is not used as extensively as the basic version because rollers may fall out if the shaft is removed. Also, the grease that retains rollers in the cup is incompatible with some applications. This bearing has higher load-carrying capacity than the basic type because the grease-retained rollers have spherical ends.

A caged needle roller bearing, Fig. 2-15, is designed for heavy-duty, high-speed applications. The heaviest-duty version of this type has a machined cage. Both machined outer-race and drawn-cup caged bearings have sufficient voids to allow pre-greasing the bearing for lifetime lubrication. Even here, operating life can be extended by periodic lubrication.

When selecting needle roller bearings, consider these guidelines:

- The most compact and economical arrangement uses the equipment shaft as the bearing's inner race. In this situation, manufacturer's requirements for shaft hardness and surface finish must be followed. Typical values for hardness range from Rockwell 58 to 60C; surface finish is 16  $\mu$ in. or better. Keep shaft parallelism within 0.0003 in. for the full length of the bearing or within half the shaft tolerance, whichever is less.

- Do not exceed 0.0002-in. total indicator reading



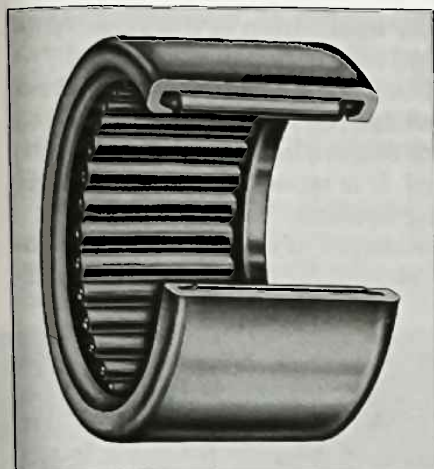


Fig. 2-13 — Drawn-cup needle roller bearing. Rollers are retained by lips at the ends of the outer casing.



Fig. 2-14 — Grease-retained, drawn-cup needle roller bearing has a slightly higher load rating than a mechanically retained bearing.



Fig. 2-15 — Drawn-cup, caged needle roller bearing.

(TIR) for shaft out-of-roundness, or 1/2 the shaft tolerance when measured by both two-point gaging and use of a 90-deg V-block in conjunction with a dial indicator.

A *cam (or track) follower* is a special, heavy-duty needle roller bearing with a heavy outer race. There are two basic mounting types: one with an integral stud for cantilever mounting, Fig. 2-16; the other, an inner race for yoke mounting. Either type may have a crowned outer surface that compensates for a moderate amount of bearing misalignment with the track or cam to prevent corner loading of the outer race. This helps maintain more uniform stress distribution over the track or cam surface, and increases assembly life. Crowning also minimizes skidding of the cam follower on flat circular tracks or cams. Typical applications include palletizers, machine tools, and material handling equipment.

**Spherical roller bearings.** Usually containing one or two rows of rollers within a spherical outer raceway, spherical roller bearings, Fig. 2-17, sup-

port high radial or combined radial and thrust loads. Because the outer raceway (roller contact) is spherical, these bearings are internally self-aligning, making them suitable for heavy-duty applications. They accommodate misalignment, usually up to 1 or 2 deg, with no decrease in rating or life. A single-row type can be used to support a predominantly thrust load, but not the double-roller type.

Radial capacity of a spherical roller bearing depends on the ratio of radial to thrust load. For satisfactory operation, a bearing of this type should have 4 lb of radial load for every 1 lb of thrust load.

In most cases, spherical roller bearings lubricated with grease are limited to a maximum safe operating speed (DN value) no greater than 100,000. Oil-lubricated bearings typically operate up to 200,000 DN. Some spherical bearings operate successfully at 1 million DN, so for speeds greater than these general guidelines, consult the bearing manufacturer.

**Tapered roller bearings.** A wide variety of equipment including appliances, machine tools, mobile equipment, turbines, and industrial machinery employs tapered roller bearings in applications ranging from low to high-speed. Tapered bearings carry heavy radial loads, thrust loads, or both.

Bearing components include an inner ring or cone, an outer ring or cup, and tapered rollers that are spaced and contained by a cage, Fig. 2-18. The bearing race and roller angles can be matched to the load — shallow angles for predominantly radial loads and steeper angles for larger thrust loads.

Tapered roller bearings tolerate misalignment because their internal clearance is adjustable during installation. This clearance can be optimized for a given application without remachining shafts or housings.

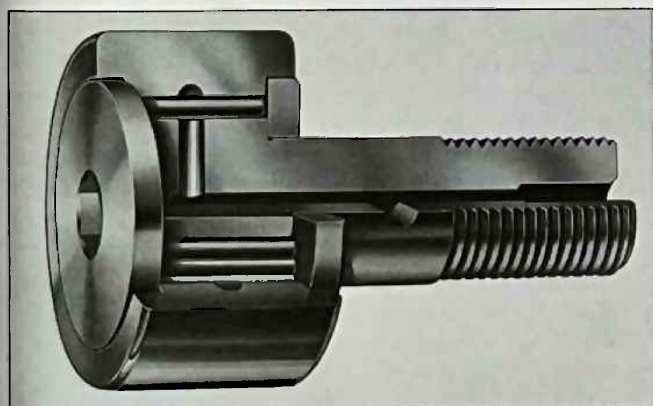


Fig. 2-16 — Stud cam follower.



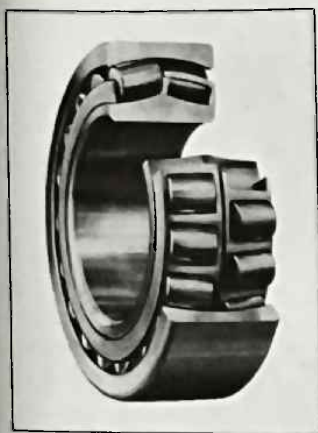


Fig. 2-17 — Double-row spherical or convex roller bearing.

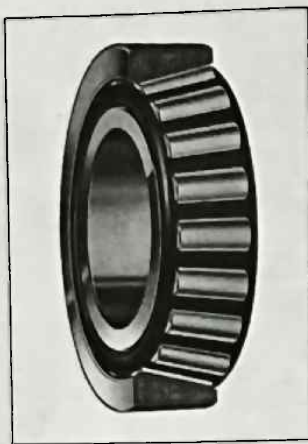


Fig. 2-18 — Tapered roller bearing.

Precision-class tapered roller bearings are limited to a maximum radial runout (out-of-round condition) of 75 millionths of an inch. Super-precision bearings, for high-accuracy applications such as machine-tool spindles, limit radial runout to 40 millionths of an inch.

Cups, cones, and rollers for tapered roller bearings typically are case carburized, a process that produces hard, long-lasting contact surfaces capable of carrying heavy loads. The tough, ductile core endures heavy shock loads.

Tapered roller bearings are available in various types. The basic single-row bearing comes in many angles and roller lengths, providing a range of radial and thrust ratings. For more capacity, two-row bearings are used. Severe-service applications, such as rolling mills, require four-row bearings.

### Bearing Lubrication

Adequate lubrication is essential for bearing protection and efficiency. Lubricants reduce sliding friction and minimize rolling resistance due to deformation of rolling elements and raceways. By providing a protective film between the rolling elements and raceways, lubricants prevent wear, scoring, and seizure. They also dissipate heat, help exclude contaminants, and protect against corrosion.

Bearings may be lubricated with either oil or grease. Although oil is preferred, grease is often used for convenience. Synthetic and dry lubricants are suitable for severe applications.

Grease is a combination of petroleum or synthetic oil and a thickener. It is normally applied in low and moderate-speed applications. Because grease is easily contained within a housing, it is well-suited to the food and chemical industries, where contamination must be avoided.

Many ball bearings are supplied factory-lubri-

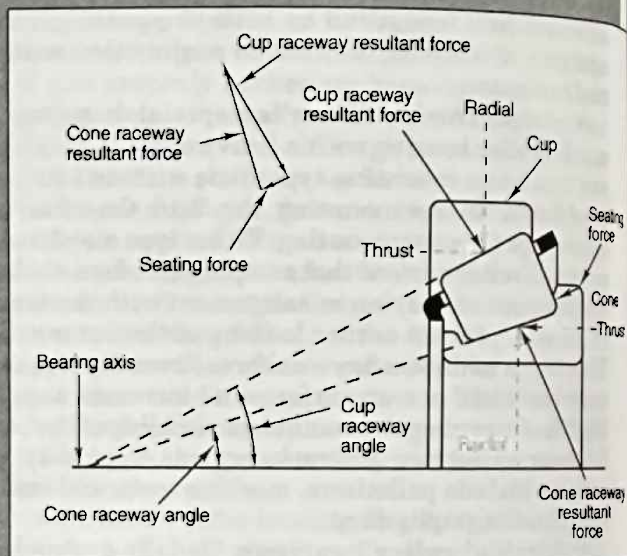
cated with grease for application in inaccessible locations or where field lubrication is impractical.

Oil is often used in high-speed or high-temperature applications where the lubricant is circulated through a bearing to remove heat. Though oil can be pumped and filtered, it is more difficult to seal and retain in the bearing housing.

Oil viscosity, a measure of oil thickness or consistency, must be selected for the expected operat-

### Cone Shape Boosts Tapered Bearing Performance

The rollers and races of tapered roller bearings are built on a cone principle where the apexes of the cones (rollers and races) meet at a common point on the bearing axis. This geometry permits tapered roller bearings to carry heavy radial or-thrust loads, or both.



Cone geometry of a tapered roller bearing enables it to accommodate any type loading, operate with true rolling motion, and provide positive alignment.

Load on a tapered roller bearing is divided into a radial component (perpendicular to the bearing axis), a thrust component (parallel to the axis), and a small roller-seating force. The seating force keeps the large end of each roller in contact with a rib on the cone, providing roller guidance and alignment.

Because the tapers of the rollers and races meet at a common apex on the bearing centerline, the rollers rotate with true rolling motion (no skidding) over the raceway, minimizing friction and wear.



ing temperatures. In rolling-element bearings, excessive oil viscosity may cause skidding of rolling elements and high lubricant friction, leading to overheating and raceway damage. Insufficient viscosity may allow metal contact and cause bearing seizure.

Lubricating oils are classified as either petroleum or synthetic. Petroleum oils, the least costly, are widely used. Synthetic oils operate over a wider temperature range than petroleum types, but they cost more — ranging from about twice to many times. Common types of synthetics include esters, ethers, halogenated compounds, silanes, and silicone polymers.

Dry lubricants are used in low-speed, high-temperature applications such as furnaces and kilns. Usually, the solid is applied in a carrier fluid, which later burns off, leaving the solid lubricant. In other cases, lubricant is applied as a dry film to bearing raceways; then it transfers to rolling elements in operation.

For rolling-element bearings operating in a housing, 1/3 to 1/2 of the diameter of the lowest rolling element should be submerged in oil. Otherwise, these bearings may overheat, causing lubricant deterioration, noisy operation, power loss, and premature bearing failure.

Bearing lubricants generally contain rust and oxidation inhibitors. However, the degree of corrosion protection varies widely with different lubricants. In cases of extreme contamination, a constant supply of pressurized lubricant to the bearing will purge the contaminants.

**Seals.** Contamination causes more bearing failures than fatigue. Contaminants such as dirt, water, and corrosive chemicals are present in most applications (to some degree) and must be excluded from bearings.

Both contact and non-contact seals and shields are used in bearings to retain lubricants and exclude contaminants, Fig. 2-19. Contact seals maintain contact with both rotating and stationary components to prevent lubricant loss. By contrast, non-contact types, such as labyrinth seals, provide a clearance between rotating and stationary parts. This arrangement eliminates rubbing friction and heat buildup, making labyrinth seals suitable for high-speed operation. See Chapter 14.

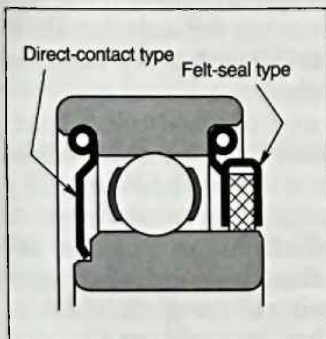


Fig. 2-19 — Typical contact-type bearing seals.

## Mounted Bearings

Most types of plain and rolling-element bearings are available as mounted units, eliminating the need to select and assemble components. Installed in a sturdy housing, each bearing provides shaft support for radial, thrust, or combination loads. They also reduce friction in applications where machined bearing seats in the equipment frame are undesirable or impractical. Mounted bearing types include pillow blocks (both solid and split-housing), flanged cartridges, cylindrical cartridges, and take-up units. Pillow blocks, the most common type of mounted unit, have the plane of the mounting base parallel to the shaft, Fig. 2-20. They are used on vertical or horizontal surfaces or on an inclined plane. Regardless of the mounting position, forces should be in the direction perpendicular to the base. Split bearings are suitable where dismantling of equipment is a problem. Depending on the required base rigidity and available space, pillow blocks are available in two and four-bolt mountings.

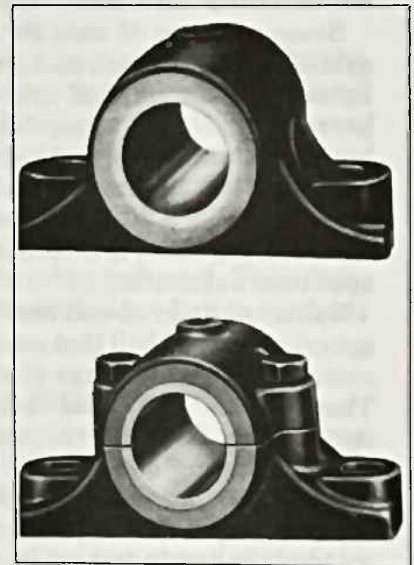


Fig. 2-20 — Solid and split-type pillow-block plain bearings.

Flanged cartridge blocks, Fig. 2-21, are usually mounted on vertical surfaces

where a shaft passes through a machine frame at a right angle. A piloted, flanged cartridge-type bearing is also available that provides better mounting accuracy and more support than a basic unit. Cylindrical cartridges, like

flanged cartridges, provide shaft support where the shaft axis is perpendicular to, and passes through, a machined housing.

Take-up units, Fig. 2-22, are used to adjust the center distance between shafts or where belt-tightening is required, such as in conveyor applications. Com-



Fig. 2-21 — Flanged cartridge block.



## Bearings — Mounted

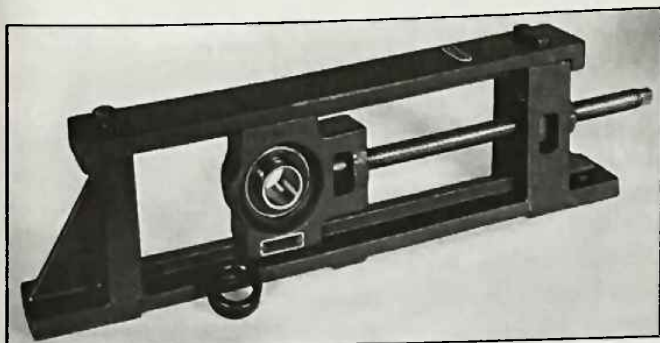


Fig. 2-22 — Ball-bearing take-up frame assembly.

plete take-up units with frames are available for both horizontal and vertical adjustments and top or side mounting.

### Mounted Plain Bearings

Several types of mounted plain bearings are available: plain-bored, cast-iron, solid pillow blocks; babbitt-lined, solid, and split pillow blocks; flanged bearings and takeups; solid-film and self-lubricated bushed pillow blocks; and hydrodynamic and hydrostatic pillow blocks. A plain (journal) bearing mounting, Fig. 2-20, may consist of a bored housing with bearing liner, or a split housing with a solid or split internal bearing.

Spherical and rod-end bearings, Fig. 2-23, have a spherical-shaped ball that rotates within a race to accommodate a wide range of angular misalignment. They are commonly used in linkages and low-speed applications. Where low friction is required, a rolling-element bearing can be used.

Hydrodynamic sleeve-bearing pillow blocks operate at low speeds in a similar way to grease-lubricated plain bearings, that is, with a boundary film. As speed increases, however, these units establish a full lubricant film, eliminating metal-to-metal con-

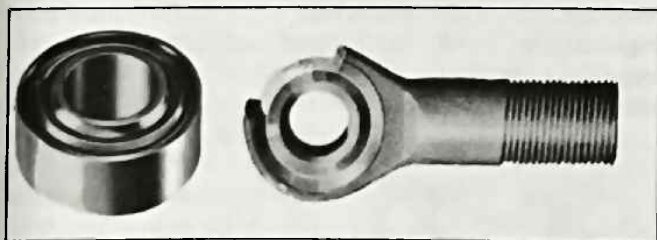


Fig. 2-23 — Spherical (a) and rod-end (b) plain bearings.

tact. Typical applications include heavy-duty fans, turbines, and diesel generators.

### Mounted Rolling-Element Bearings

Most ball bearings used with housing units incorporate a wide inner ring with an integral locking collar device. There are two common locking types: the setscrew collar and the eccentric or cam locking

collar, Fig. 2-24. Both types enable a slip fit over commercially ground shafting.

The setscrew locking device has two setscrews threaded into holes in an extension of the bearing's inner ring. An alternate design has a concentric collar that slips over the ring extension. The setscrews are threaded into the collar, and they contact the shaft through untapped holes in the collar extension.

The eccentric locking collar uses an extended inner ring of the bearing that contains a channel eccentric to the shaft, and a matching channel in a collar that fits over the inner ring extension. The unit is secured to the shaft by rotating the collar relative to the inner ring, which produces a holding force perpendicular to the shaft. A setscrew prevents loosening of the collar during reverse ro-

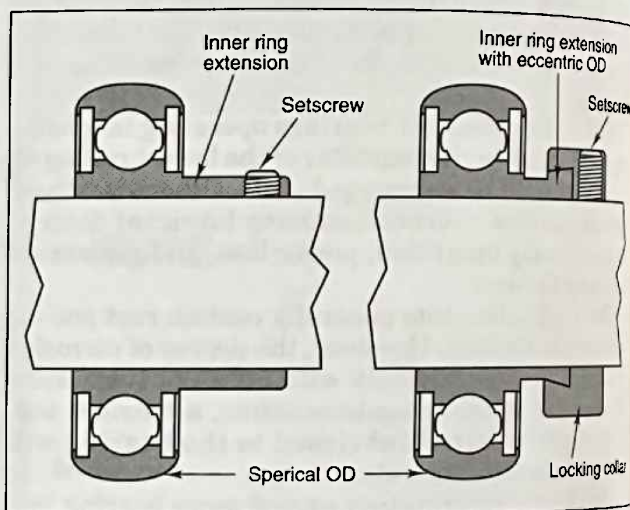


Fig. 2-24 — The setscrew locking collar, left, and eccentric collar, right, are commonly used to secure a mounted ball bearing to a shaft.

tation. This is a precaution, and does not compensate for frequent reverse rotation. *Eccentric locking collars should not be used for bidirectional applications.*

Mounted ball bearings typically have spherical outer surfaces that compensate for angular shaft misalignment. A cylindrical OD with a slip-fit in the mounting allows axial freedom.

Cylindrical, spherical, and tapered roller bearings are also available as mounted units. Because roller bearings are often used for heavier-duty applications than ball bearings, they may require more rigid locking to the shaft. Roller bearings are mounted to shafts by several methods including some that require special machining of the shaft (threads, key seat, tapers, or multiple diameters), and locking collars, which require no special machining. The simplest types mount with a slip-fit collar and setscrew



and, thus, are easy to assemble on site.

Many large bearings are mounted and dismounted with hydraulic pressure between the inner ring and the shaft. Others are applied by thermal shrink-fitting onto the shaft.

Split roller-bearing assemblies, Fig. 2-25, are available for applications where replacement is difficult, such as with long shafts or shafts with tight-fitting components outside the bearing. The bearing components are split into two halves so they can be removed and assembled without disturbing other components on the shaft.



Fig. 2-25 — Split spherical roller bearing enables easy replacement without disturbing other components.

## Bearing Standards

A large number of standards and recommended practices for ball and roller bearing usage have been developed in the U.S. by the American Bearing Manufacturers Association (ABMA), formerly known as the Anti-Friction Bearing Manufacturers Association (AFBMA). These standards were subsequently adopted by the American National Standards Institute (ANSI). In general, corresponding standards are published by the International Organization for Standardization (ISO).

ABMA standards cover various types of bearings (both inch and metric), plus terminology, tolerances and gaging, shaft and housing fits, mounting accessories, load ratings, metal balls, and roller bearing vibration and noise. The ABMA also works with ANSI and the ISO in developing national and international bearing standards. Excerpts of many standards are included in bearing catalogs.

### Load and Life Ratings

The ABMA has two standardized load ratings for rolling-element bearings: the basic load rating and the static load rating. (Bearing catalogs often include details on how bearings are rated.)

The basic load rating, used for bearings that rotate, defines the load that a group of bearings can endure for one million revolutions. The static load, used for bearings that rotate only occasionally or

not at all, is the load that corresponds to a total permanent deformation of rolling element and raceway of 0.0001 of the rolling-element diameter. Experience has shown that deformations up to this value have little effect on bearing operation. Load ratings for ball and roller bearings are given in ABMA standards No. 9 and No. 11, respectively.

The rating life,  $L_{10}$ , of a bearing is normally expressed as the life, in millions of revolutions, that 90% of a group of bearings will complete at a given load and speed before fatigue failure occurs. This life can also be given in hours of operation. The basic load rating can be used to predict the  $L_{10}$  life of a bearing under specific load and speed conditions.

Bearing life is usually inversely proportional to bearing load and speed. Thus, reducing the load or speed, or increasing the bearing size can substantially increase the bearing life.

Because it is virtually impossible to predict the exact life of a bearing, a safety factor should be used to minimize the possibility of premature or unexpected failure. Bearing replacement and machine downtime may cost far more than that for installing a larger bearing.

New philosophies of bearing fatigue are being evaluated within the bearing industry. Therefore, the industry may adopt new life-prediction methods in the future.

### Shaft and Housing Fits

To fully utilize the capacity of a bearing, the inner ring (ID) must properly fit the shaft and the outer ring (OD) must properly fit the housing bore. Fit selection depends on the load characteristics, bearing dimensions, temperature, heat expansion of the shaft, and other factors.

The ABMA and ANSI have adopted a system that provides a choice of shaft and housing tolerances, which, when used with standard ball and roller bearings, provides a range of shaft and housing fits for light, normal, and heavy loads. The standard (ABMA No. 7) covers *metric* radial ball and roller bearings, except tapered roller bearings. In general, the ISO has published corresponding standards.

## Application and Selection

Bearing selection is based on three major factors: load, speed, and life. But consideration must also be given to other operating and environmental conditions, as well as installation and operating costs. Here are some factors to consider:

- Load: Is it radial, thrust, or a combination of both? What is its magnitude? Is it, by nature, uni-



form, light shock, or heavy shock?

- **Speed:** What is its magnitude? Is it constant or variable? Bearing speeds are limited by tolerance grade, lubricant used, retainer design, and type of bearing seal.

- **Required life:** How long must the bearing operate? This is usually expressed as the number of hours of operation required at a given load and speed.

- **Noise and vibration:** Will the bearing operate where noise is undesirable or in high-speed equipment where balance is essential to prevent vibration?

- **Misalignment:** Is it present? To what degree?

- **Temperature:** What are the ambient and operating temperatures? Speed, load, and external heat affect operating temperature.

- **Environmental conditions:** Are contaminants or corrosives present? To what degree and what types?

Once you have identified and evaluated these application constraints, compare the capabilities of various bearing types with the application requirements. Consider both operating and maintenance requirements, as well as cost.

Plain bearings are most often used where speed and load requirements are low and precision is not a concern. Benefits include low first cost and low assembly cost.

Rolling-element bearings handle heavier loads and higher speeds. They have the lowest friction and require the least energy to turn. Load requirements usually determine the type of rolling-element bearing to use for a specific application. For example, thrust loading requires either thrust, angular contact, or tapered roller bearings. Heavy radial loads call for roller bearings.

Ball bearings are typically applied in high-speed applications, whereas roller bearings are best suited for high loads. Tapered or spherical types offer similar features. However, spherical bearings have a dynamic alignment capability not present in tapered bearings, and a higher-speed capability. But tapered bearings have better thrust capacity.

To select mounted bearings, consider shaft size, radial and thrust load, load characteristics, speed, mounting limitations, and environment.

The first step in selecting a mounted bearing is to determine shaft size based on the bending and torsional loads. However, overhung loads or loads between widely spaced centers may call for large shaft diameters, even when bearing loads are light. If so, consider light-duty bearings or machining the shaft

ends for smaller bearings. However, shafting is not always chosen on an optimum engineering basis. Design standardization, available stock sizes, and similar factors may dictate size.

The method of securing the bearing to the shaft is determined by considering cost vs. performance. Ease of installation is important to the builder and the maintainer. Sometimes, machine maintenance requires frequent bearing disassembly. In such cases, bearing assemblies that can be easily installed and disassembled should be used.

Choose the mounting unit with regard to its support structure and surroundings as well as its strength requirements. Also, consider installation factors such as clearance and structural members required for mounting. In most cases, housings transfer load to the structure by surface support and contact, while mounting bolts simply locate and secure. When housings are applied so mounting bolts supply support, carefully consider bolt size, bolt-hole fit, mounting procedure, ability of the housing to support a "pull-off" load, or any other factor that may affect capacity.

Also consider housing material strength and configuration. A gray-iron pillow block with a thick cross section and reinforcing web may be stronger than a thinner, steel housing, though the tensile strength of steel is greater.

## Additional Information

(Addresses and phone numbers for associations are given in the Associations section.)

Tedric A. Harris, *Rolling Bearing Analysis*, 3rd Edition, John Wiley & Sons, New York, 1991.

ANSI/ABMA Standard 7-1988, "Shaft and Housing Fits for Metric Radial Ball and Roller Bearings (Except Tapered Roller Bearings) Conforming to Basic Boundary Plans," American Bearing Manufacturers Association, Washington, D.C.

ANSI/ABMA Standard 9-1990, "Load Ratings and Fatigue Life for Ball Bearings," American Bearing Manufacturers Association, Washington, D.C.

ANSI/ABMA Standard 11-1990, "Load Ratings and Fatigue Life for Roller Bearings," American Bearing Manufacturers Association, Washington, D.C.

American National Standards Institute, New York.

Bearings Specialists Association, Glen Ellyn, Ill.



**B**elts are used with pulleys or sheaves in drives for high-volume products, such as home appliances and automobile engines, as well as machines built in small numbers, such as heating, ventilating, and air-conditioning systems, and pumps.

A wide variety of standard sizes and types of industrial belts, pulleys, and sheaves is available from power-transmission distributors. Representative types include classical V, narrow V, and double V, plus V-ribbed, joined V, synchronous, and flat.

Advantages of belt drives include:

- No lubrication required.
- Low maintenance.
- Shock load dampening.
- Quiet, smooth operation.
- Less expensive pulleys and sheaves, compared to chain sprockets.

- Long pulley and sheave life.

Some of the drawbacks of belts are:

- Endless belts usually can't be repaired. And, their length can't be adjusted.
- Slippage occurs if operated with improper belt tension.
- Adverse environmental conditions (extreme temperatures, high moisture, and chemicals) damage belts.

## V-Belts

**W**idely available from distributors, V-belts are often used in industrial and commercial applications because of their low cost and wide range of sizes. These belts are easy to install and they operate quietly and smoothly. Most V-belts are manufactured "endless" (in a closed loop).

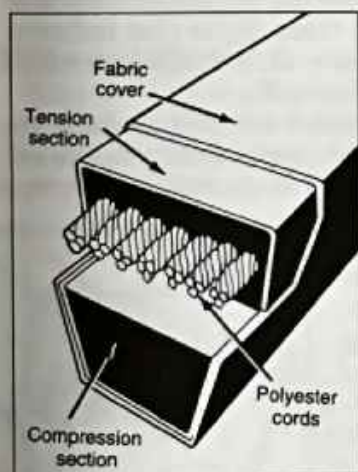


Fig. 3-1 — Construction of a wrapped V-belt.

Suitable both for transmitting power and conveying materials, V-belts operate over a wide horsepower range and at speeds up to 6,500 feet per minute (fpm) or more.

Components of a typical V-belt cross section are shown in Fig. 3-1. The tension section carries the load and contains synthetic fiber cords, typically polyester or aramid. Surrounding

rubber is bonded to these cords, which helps to cushion shock loads.

The compression section, made of rubber or rubberized fabric, supports the tensile member and exerts a wedging force against the sheave groove.

The cover is a rubber-impregnated cotton or cotton-synthetic blend fabric.

### Principles of Operation

A V-belt wedges into a sheave groove under tension, Fig. 3-2, which increases the friction force be-

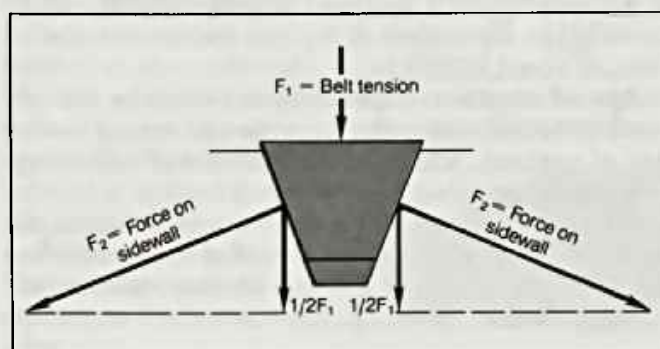


Fig. 3-2 — Wedging action of a V-belt increases force between belt and sheave groove and prevents slip.

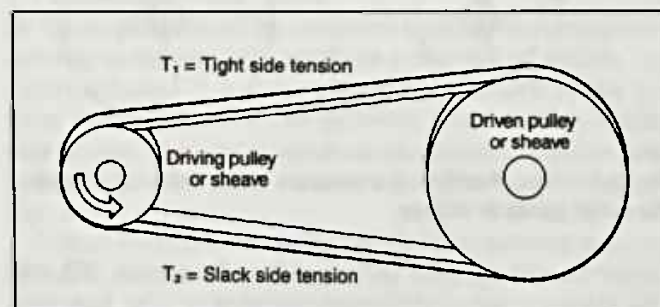


Fig. 3-3 — Effective tension is the difference between tight-side and slack-side tensions.

tween belt and sheave and, in turn, reduces the tension required to transmit torque. The V shape also tends to keep a moving belt in the sheave groove.

The motor that drives a belt is usually mounted on a movable base, which is adjusted to apply suitable tension to the belt. Belts elongate slightly in use, so the movable motor base, or alternately, an idler, is used to take up the slack and maintain proper tension. Belt-drive tensioning devices are described in Chapter 14.

The tension in a belt, Fig. 3-3, is referred to as tight-side tension,  $T_1$ . Some tension must be maintained on the other side to keep the belt from slipping, and this is known as slack-side tension,  $T_2$ . The difference between tight-side and slack-side tension is called net pull or effective tension,  $T_e$ .



## Stress and Power Ratings

The horsepower transmitted by a V-belt is:

$$hp = T_e V / 33,000$$

where:

$T_e$  = Effective tension, lb

$V$  = Belt velocity, fpm =  $0.262DN$

$D$  = Pulley diameter, in.

$N$  = Pulley speed, rpm

The usable strength of a belt is the tensile stress it withstands for a specified number of load cycles, usually the equivalent of 3 years continuous operation, or about 25,000 hr.

**Arc of contact.** Another factor must be considered in establishing the horsepower rating — the arc of contact, which is the amount of belt wrap around the smallest sheave in a drive.

Where two sheaves in a drive are of the same diameter, a belt wraps around half of the circumference of each sheave, or 180 deg. The horsepower rat-

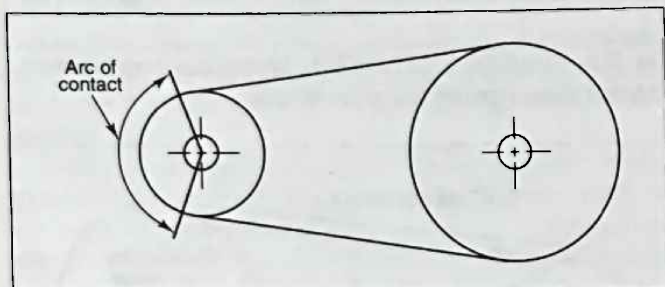


Fig. 3-4 — Arc of contact is a measure of the belt wrap around the small pulley or sheave.

ing is based on this 180-deg arc of contact. Where the sheaves are of different diameters, Fig. 3-4, the arc of contact on the smaller sheave is less than 180-deg, thus, the horsepower rating must be adjusted to a lower value.

V-belt drives generally can be selected from tables published by V-belt and sheave manufacturers. These tables include compensation factors for arc of contact, speed ratio, sheave sizes, center distance, and speed.

## Classical V-Belts

One of the first V-belts to become an industry standard is the heavy-duty classical multiple V-belt. The term "multiple" originated from the use of several belts to replace a single wide flat belt on a pair of shafts.

Classical belts are made in four cross sections, designated A through D, Fig. 3-5, where the letters indicate the nominal top width of the cross section. Belts are identified by one of these letters followed by up to three digits, which indicate the approxi-

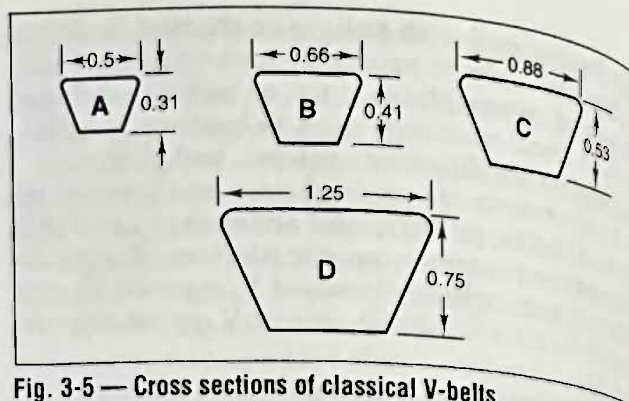


Fig. 3-5 — Cross sections of classical V-belts.

mate inside length. For example, A42 indicates a belt that is 1/2 in. wide and 42 in. long.

Years after this identification system was established, belt length was re-specified in terms of pitch length, which is measured at the neutral axis of the belt. The original length designation was kept in the identification system to avoid the confusion of a nomenclature change.

Where two or more classical belts are used in a drive, they must share the load equally. This occurs only when lengths of all the belts are within a tolerance specified by the Rubber Manufacturers Association (RMA). For matching purposes, these lengths are measured under tension and the belts are marked with appropriate code numbers. Some belt types exceed this requirement and no longer require code numbers to ensure matching.

**Single V-belts.** A special category, called single V-belts, has evolved for light-duty applications such as fractional-horsepower (fhp — less than 1 hp) motors. Typical applications are appliances and small machines used in industry and business.

Single V-belts come in four standard cross sections: 2L, 3L, 4L, and 5L where the number indicates the nominal top width in 1/8-in. increments. Belt identification numbers include the above cross-section code followed by three digits that indicate outside length. For example, 3L380 indicates a 3/8-in.-wide belt with a 38-in. length.

**Double V-belts.** The drive and driven shafts on most machines rotate in the same direction. But on some equipment, particularly in the textile industry, driven shafts rotate in a direction opposite to that of the driving shaft. This is accomplished by a double V-belt, which drives from either its top or bottom surface, Fig. 3-6. Drives of this type with

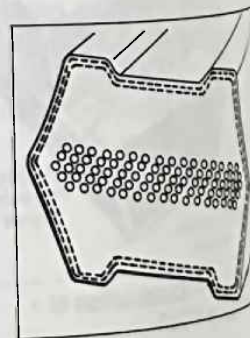


Fig. 3-6 — Double V-belt has driving surfaces on both sides.



several sheaves are called serpentine drives.

Standard double V-belts are identified by duplicate letters in the belt code: AA, BB, or CC.

**Open-end V-belts.** In some situations, an endless V-belt can't be used. For example, the drive and related equipment may be situated such as to prevent a belt from being slipped over a sheave, or emergency replacement of a V-belt precludes normal installation. For such cases, open-end belting is often used. Available in classical A through D cross sections, this belting is cut to length and the

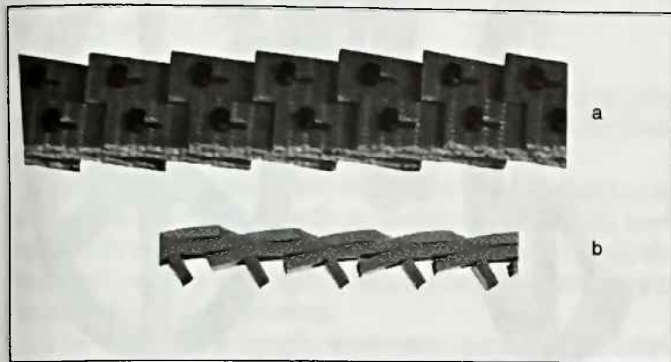


Fig. 3-7 — Link-type belts are joined by metal studs (a), or T-shaped tabs (b).

ends are spliced with fasteners to make the belt endless.

**Link-type V-belts.** Adjustable-link V-belts consist of removable links that are joined by T-shaped rivets or interlocking tabs, Fig. 3-7. These belts can be installed without dismantling drive components. Other advantages include chemical and abrasion resistance, and reduced inventory (different lengths are obtained by adding or removing links).

Made of polyester fabric and polyurethane elastomer, these belts are available in 3/8- to 7/8-in. widths that encompass both fhp (3L to 5L) and classical (A to C) cross sections.

### Narrow V-Belts

Narrow V-belts offer higher power ratings than conventional belts for a given width. Hence, they do more work in less space, which translates into low-cost, small sheaves and low "overhung" load on

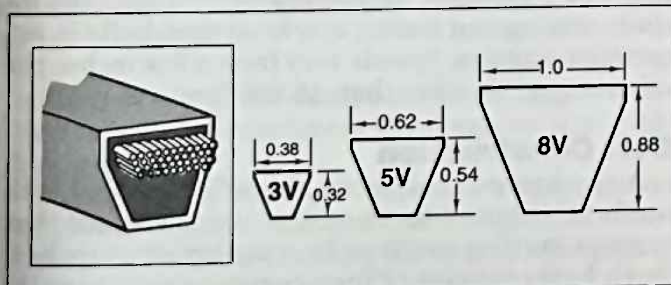


Fig. 3-8 — Narrow V-belt sections.

bearings. Standard cross sections are 3V, 5V, and 8V, the numerals indicating nominal top width in 1/8-in. increments, Fig. 3-8. A typical belt designation is 3V450 (3/8-in. width, 45-in. outside length).

### Cogged, Raw-Edge V-Belts

Belts molded with notches in the underside, Fig. 3-9, are called cogged belts. The notches relieve some of the bending stress induced in belts when they flex, enabling them to operate on smaller sheaves. These belts have no covers: hence the name, raw-edge.

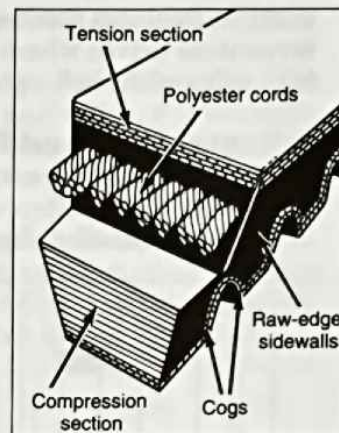


Fig. 3-9 — Cogged, raw-edge belt with stress-relieving notches.

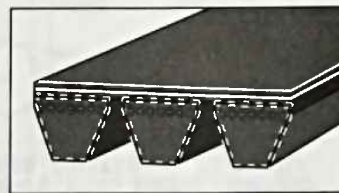


Fig. 3-10 — Joined belts have more lateral stability.

### Joined Belts

Pulsating loads, such as those generated by internal combustion engines driving compressors, produce a whipping action in conventional V-belts, which may cause them to turn over in the sheave grooves. To stabilize such drives and prevent turnover, two or more belts are joined at the top by a layer of rubber and fabric, Fig. 3-10.

Joined V-belts fit classical (B, C, D) or narrow groove (3V, 5V, 8V) sheaves. The joined configuration avoids the need to obtain belts as matched sets. Joined 5V and 8V belts with aramid fiber reinforcement offer increased capacity for high-power applications.

### V-Ribbed Belts

Another member of the "V" family, the V-ribbed belt resembles a flat belt, but with V-shaped ribs along the inside surface, Fig. 3-11. These ribs operate in grooved pulleys, making the belt more stable than a flat belt. Five cross sections are designated H, J, K, L, and M when working with English units. Comparable metric (SI) designations are preceded by the letter "P." The M section is capable of transmitting up to 1,000 hp.

The thin sections of V-ribbed belts enable them to operate with small pulley diameters, as found in

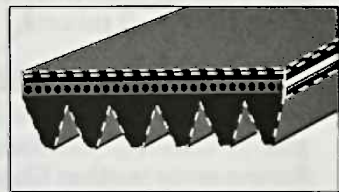


Fig. 3-11 — Multiple ribs on the underside of a V-ribbed belt engage a grooved sheave for stability.



many automotive accessory drives. Some operate in serpentine drives where they transmit power from both sides of the belt to multiple pulleys.

### Adjustable-Speed Belts

By contrast to conventional drives, an adjustable-speed belt drive (often called variable-speed) has one or more grooved sheaves with flanges that can

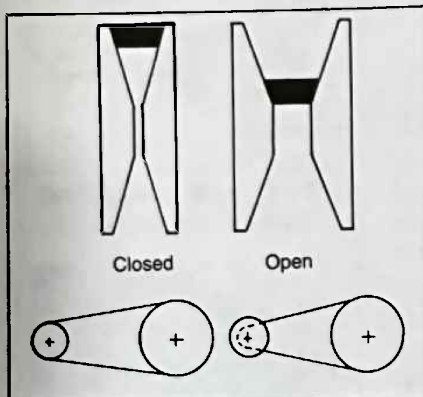


Fig. 3-12 — Spacing between adjustable sheave halves controls the belt position in the groove and the pitch diameter, which establishes the speed ratio.

be adjusted in width so the belt moves radially within the groove, Fig. 3-12. The pitch diameter changes with the belt location in the sheave groove, thereby providing a speed-ratio change.

There are 12 V-belt sections for these drives, each identified by a four-digit number, indicating nominal top width and sheave-groove angle, followed by the letter V

and three to four additional digits that indicate pitch length.

Belts for fixed-pitch drives, in which speed ratios are changed only while the drive is stationary, are offered in 3L through 5L light-duty, A through D classical, and 5V and 8V narrow versions.

For drives that are adjustable while running, 4L, 5L, A, and B belts are used for power requirements less than 2 hp and speed ratios up to 4.5:1.

Adjustable-speed drives, discussed in Chapter 12, are used in machine tools, pumps, fans, blowers, conveyors, and mixers.

### Endless Round Belts

Light-duty power transmission and conveying applications often call for endless round belts, which have a cross section like an O-ring and are available in diameters from 1/4 through 9/16 in. The elasticity of these belts simplifies design problems and reduces costs. However, they are limited to sub-hp applications such as recorders, projectors, and business machines.

### Heat-Welded Belting

Open-end round belts and V-belts accommodate hp conveying and power transmission applications. These belts are cut to length and made endless by heating and joining the ends, allowing the material to bond together. Round types are made in all in-

dustry diameters, and the V type is available in sections O, A, B, and C.

### V-Belt Sheaves

Sheaves for V-belts are usually made from cast iron, ductile iron, or steel. Light-duty versions are made of pressed steel or plastic. Standard identification systems for sheaves include the belt cross-



Fig. 3-13 — Typical sheaves for use with V-belts.

section, number of grooves, and diameter.

Sheaves are either bored to size (fixed bore) or they accept tapered bushings, Fig. 3-13. A fixed bore sheave can be installed (via setscrew and key) only on one size of shaft. A bushed sheave, because it accepts different sized bushings, can be mounted on a range of shaft diameters.

## Synchronous Belts

Used primarily where the motion of input and output shafts must be precisely matched, synchronous belts were originally known as timing belts. Synchronous belt drives are used where backlash of chain or gear drives would be undesirable.

These belts are found in a wide variety of precision drive applications including robots, machine tools, and plotters. High-volume applications include driving and timing overhead camshafts in automotive engines. Speeds vary from a few inches per minute (ipm) to more than 16,000 fpm.

### Belt Construction

A synchronous belt resembles a flat belt, but with uniformly spaced teeth on the inside surface that engage mating grooves in a pulley or sprocket. Such belts consist of four components: tensile member, backing, teeth, and facing, Fig. 3-14.



The tensile member, consisting of fiberglass, steel, or aramid cords, carries the load. These cords provide strength, excellent flex life, and resistance to elongation. Fiberglass reinforcement is the most widely used, but aramid-based belts have the highest ratings.

The backing, made of strong, wear-resistant neoprene (or polyurethane), protects the cords from dirt, oil, and moisture.

Made of shear-resistant neoprene (or polyurethane), the precisely spaced teeth smoothly engage with mating pulleys. Shear strength of the teeth exceeds the tensile-member strength when six or more teeth are in mesh with pulley grooves.

The facing is a tough, wear-resistant, nylon fabric that protects the tooth surfaces.

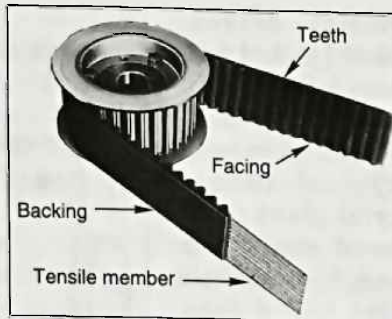


Fig. 3-14 — Four principal parts of a synchronous belt.

### Trapezoidal-Tooth Belts

Conventional synchronous belts have trapezoidal-shaped teeth, Fig. 3-15, that engage mating teeth on pulleys to maintain a constant speed ratio between driving and driven shafts. Major belt parameters are pitch line, pitch, and pitch length. The pitch line, located midway between the areas of tension and compression, coincides with the pulley pitch circle. For this reason, the pulley pitch diameter is greater than its outside diameter.

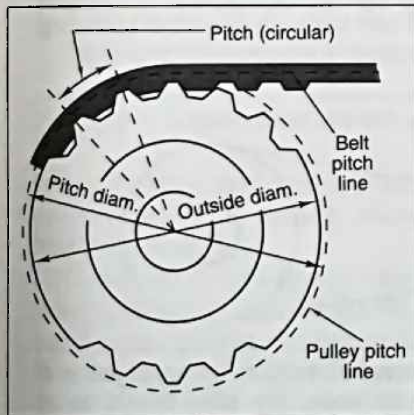


Fig. 3-15 — Conventional synchronous belt (and pulley) with trapezoidal-shaped teeth.

Pitch is the distance between centers of two adjacent teeth as measured along the pitch line. Pitch length is the belt length (circumference) measured along the belt pitch line.

There are six standard sections for conventional synchronous belts: MXL (mini extra light), XL (extra light), L (light), H (heavy), XH (extra heavy), and XXH (double extra heavy). Drive applications range from sub-hp for the MXL section (0.080-in. pitch) to

more than 100 hp for the XXH section (1-1/4-in. pitch).

The standard belt designation identifies the length (to 1/10 in.), pitch, and width. For example, 630XH200 indicates a belt with 63-in. length, 7/8-in. pitch, and 2.00-in. width.

### Dual-Sided Synchronous Belts

Some synchronous belts, called dual-sided, have teeth on both sides that enable one-belt reversed-motion drives and serpentine drives, Fig. 3-16.

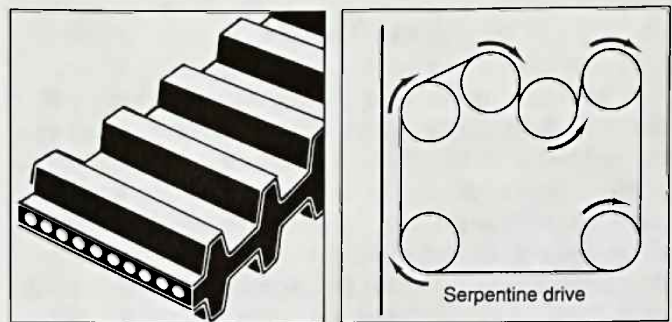


Fig. 3-16 — Dual-sided synchronous belt can drive pulleys from either side.

Dual-sided belts have similar dimensions to conventional synchronous belts and use the same code except with the prefix "D."

### Curvilinear-Tooth Belts

Newer type synchronous belts incorporate curvilinear tooth forms, Fig. 3-17, rather than the conventional trapezoidal tooth profile. These rounded forms offer more uniform load distribution, in-

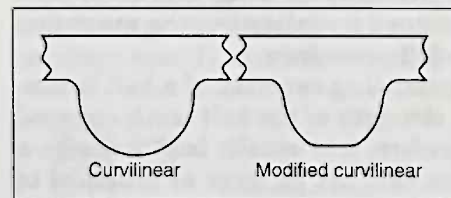


Fig. 3-17 — Newer curvilinear tooth designs give synchronous belts more capacity and smoother action.

creased capacity, and smoother, quieter action. They also handle high-torque loads that normally call for chain drives. Curvilinear-tooth belt drives are dimensioned in metric units. Commonly available pitches are 5, 8, 14, and 20 mm.

### Pulleys

Synchronous-belt pulleys are supplied with detachable hubs or are bored-to-size. The detachable hubs are available with a broad range of bore sizes, minimizing the need for a large pulley inventory.

Pulleys generally are made of cast iron for rim speeds up to 6,500 fpm. Higher speeds typically require either dynamic balancing or pulleys made of



ductile iron, steel, or aluminum to minimize vibration and noise.

Avoiding belt-tracking problems often calls for at least one flanged pulley in a drive. When the drive center distance exceeds eight times the diameter of the small pulley, both pulleys should be flanged. In either case, pulley diameter should at least equal the belt width so that side thrust does not cause the belt to ride over the flange.

Pulley numbers identify the number of grooves,

### Belt Tension

A common misconception about synchronous belts is that they require little or no tension because they operate via tooth engagement with the pulley. However, these belts rely on tension like V-belts, although to a lesser degree. Therefore, they should be installed and tensioned in accordance with manufacturer's specifications. Properly tensioning a synchronous belt increases life, reduces bearing wear, and minimizes noise.

pitch, and belt width. Because curvilinear-tooth belt drives are designed to replace chain drives in some applications, some manufacturers use the term sprocket.

### Selecting Components

The selection of synchronous-belt drives is based on horsepower requirements, speed, operating cycle (hr/day), shaft sizes and center distance, available space, and ambient conditions. With this data, most drives can be designed by following the manufacturer's recommended procedure.

The power transmitting capacity of a belt is limited by the shear strength of the belt teeth engaged in the pulley. Therefore, it is usually best to design a drive using pulleys that are as large as practical to maximize the number of teeth in mesh on the smallest pulley.

Flex life of a belt is affected by pulley size. Using a belt wider than necessary can't prevent flex fatigue caused by pulleys that are too small. For high speeds, use smaller pitches even with a heavy load. This increases flex life and the number of teeth in mesh, and reduces centrifugal load and noise.

## Flat Belts

One of the oldest forms of power transmission, flat belts are well suited for high-speed, small-

pulley drives. Early drives used flat belts running on flat-faced wheels. A typical industrial plant powered multiple machines with flat-belt drives running from overhead line shafts, via speed-reduction stages where required.

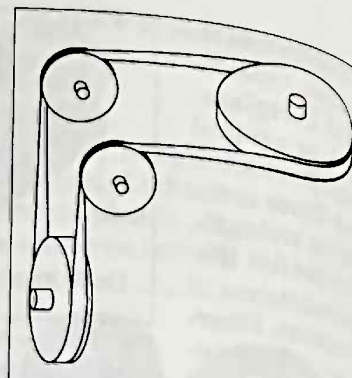


Fig. 3-18 — Flat belts have the flexibility to go around corners for special drive configurations.

Flat-belt drives generally have been replaced by other types that occupy less space and require less maintenance. But flat belts are still used in serpentine drives and in applications where belts must be twisted to achieve reverse shaft rotation or go around corners Fig. 3-18.

### Drive Characteristics

The ability of a flat belt to transmit load depends on the arc of contact, coefficient of friction, and tension, plus belt width, thickness, grade, number of plies, and type of tension member.

**Arc of contact.** As described in the V-belt section, the arc of contact is the amount of belt wrap around the smallest pulley (or sheave) in a drive. For efficient operation, the arc of contact should be 165 deg or greater.

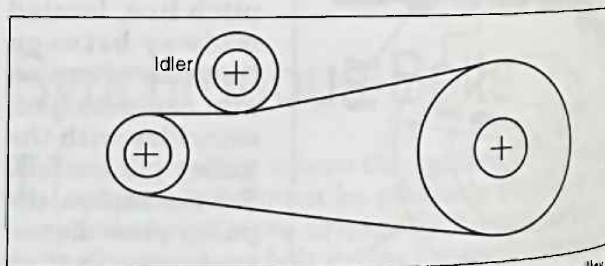


Fig. 3-19 — An idler increases belt wrap on the small pulley in a drive with short center distance. The idler should be smaller than the small pulley.

Speed ratios for flat belts generally should not exceed 6:1. Higher ratios call for longer center distances to ensure sufficient belt wrap on the driving pulley. However, higher ratios are feasible with short center distances when an idler is used to ensure sufficient belt wrap, Fig. 3-19.

**Coefficient of friction.** Factors that affect the coefficient of friction for flat belt drives include the force pulling the belt, the force between belt and pulley, and the nature of the surfaces in contact.



## Leather Belts

The earliest material used for flat belting was probably leather, a material that exhibits excellent flexibility and good service life. It also has a high coefficient of friction and good fastener-holding ability. Several manufacturers continue to supply leather belting.

Leather belts come in three "plies" or thicknesses — single, double, and triple — and in three weights — light, medium, and heavy.

## Fabric Belts

Woven cotton belts, some with multiple plies, are generally used in the textile industry and for light conveyor applications.

Woven endless belts made of cotton, nylon, or synthetic material are most often used in low-horsepower applications and at relatively high speeds. Surface grinders typically use this type of belt.

Stitched canvas belts are usually made of cotton with plies that are stitched or sewed longitudinally. Such belts are often used with farm machinery.

## Rubber Composition Belting

Rubber is the material most widely used for flat belts. Such belts have a lower coefficient of friction

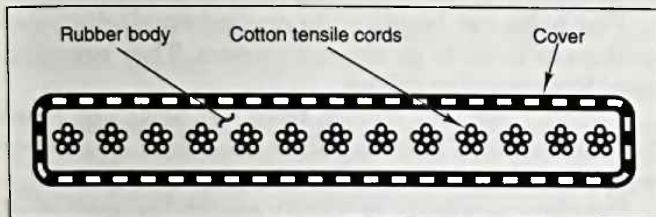


Fig. 3-20 — A covered flat belt with reinforcing cords.

than leather and are run at higher tension. They have less initial stretch, more lateral stiffness, and they track better.

Cordless types are made with rubber-impregnated cotton or canvas fabric. But those with cotton cords give better stretch resistance, Fig. 3-20. Nylon, rayon, and polyester have been used, as well as synthetic fabrics, which greatly reduce belt thickness without sacrificing strength or capacity.

Rubber flat belts are made in either raw-edge or covered configurations. Raw-edge belting is cut from a slab and the exposed edges are cemented with a rubberized compound.

## Synthetic Belting

Flat belts with nylon and polyester tension members offer high strength-to-weight ratios and negligible permanent stretch so that narrow, thin belts transmit high horsepower at high speed.

Better friction is achieved by laminating nylon or

polyester belting with a friction surface of chrome leather, polyurethane, rubber, or PVC. These belts can be installed on shorter center distances than most standard belts and in installations with reduced takeup provision. Laminated belts are used widely in industrial drives rated from fhp to more than 6,000 hp at speeds to 20,000 fpm.

## Belt Specifications

The National Industrial Belting Association (NIBA) publishes horsepower ratings for leather belts. Ratings for other flat belts are given in manufacturer's catalogs. Generally, these ratings are based on belt thickness (or number of plies) and width. Some types of belt, particularly synthetics, are specified by grade, rather than by plies or thickness.

## Flat-Belt Pulleys

Belt pulleys are made of cast iron (the most common material), steel, wood, plastic, and fiber. Both solid-hub and bushed-type pulleys are available, Fig. 3-21, the latter having bushings similar to those in V-belt sheaves.

Pulleys are normally crowned to aid belt tracking and alignment. The amount of crown is usually 1/8-in. per foot of pulley width. Some drives use a non-crowned pulley as a companion to a crowned pulley.

Rim speeds of standard pulleys should generally not exceed 6,500 fpm. For higher speeds, ductile iron and dynamically balanced pulleys are used to avoid vibration problems. The NIBA provides information on belt speeds for standard pulley sizes.

Pulleys should be large enough to avoid severe belt flexing, which shortens belt life. Manufacturer's catalogs specify minimum pulley diameters based

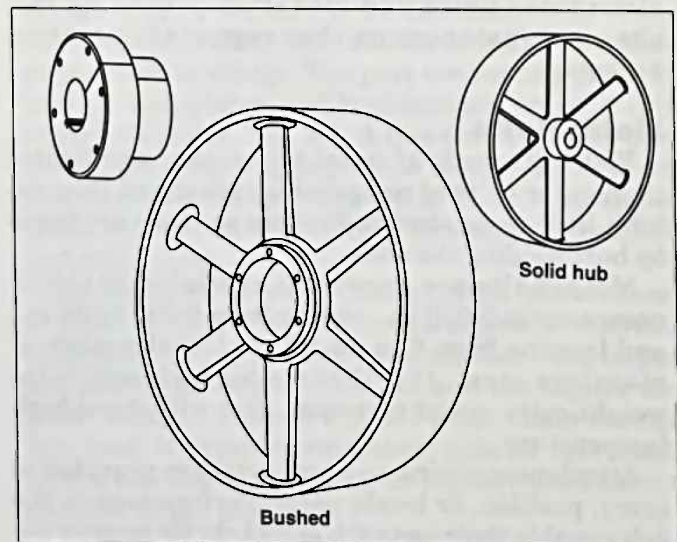


Fig. 3-21 — Standard flat-belt pulleys.



on belt type, thickness, and grade.

### Fastening and Splicing

Though endless belts ensure uniform strength, in many cases, they are impractical because of takeup, installation, and maintenance factors. Such applications call for flat belting that is cut, then spliced or joined with mechanical fasteners.

Three basic types of fasteners are used — lacing, hinges, and plates. Lacing and hinges are used for light to medium loads; plates accommodate high loads and slow speeds.

One type of lacing consists of a series of hooks, sized for different belt grades and thicknesses. These hooks, Fig. 3-22, are implanted in a belt by a machine or tool. Then, the ends are joined and a pin inserted transversely to connect them.

Flat belts are sometimes spliced by gluing tapered or scarfed ends together. This technique eliminates noise and vibration caused by mechanical fasteners as they repeatedly contact pulleys.

### Metal Belts

Flat belts made of metal are smaller and lighter than other belts of comparable rating and they exhibit little or no stretch. Endless versions are made by butt welding the ends.

Metal belts are generally available in thicknesses up to 0.030 in., widths from 0.030 to 24 in., and lengths from 6 in. to 100 ft. Usually made of stainless steel, they have a high strength-to-weight ratio, resist corrosion, and withstand high temperature.

Attachments (pins and brackets) are provided to carry, position, or locate parts. Perforations in the belts enable their use with sprockets for greater positioning accuracy.

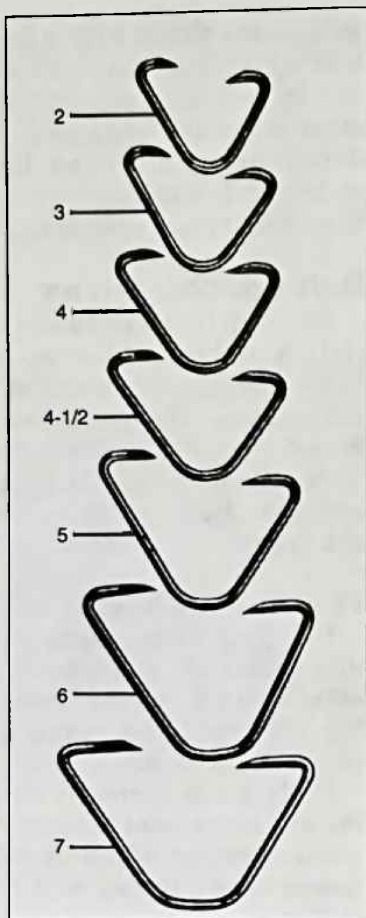


Fig. 3-22 — Hook-type belt lacing.

## Belt Standards

Through the cooperation of the Rubber Manufacturers Association (RMA) and the Mechanical Power Transmission Association (MPTA), standards have been established for all V-belts and sheaves covering nomenclature, dimensions, and tolerances. These standards also cover synchronous belts and pulleys.

Many of the standards have been revised to include both English (in.) and metric (mm) dimensions.

## Application and Selection

Belt selection is based on application requirements such as horsepower or load, speed, life, space limitations, and need for precision, plus environmental conditions and cost (both initial and operating). These and other selection factors are described in manufacturers' design manuals.

After identifying the application requirements, match them with the appropriate belt type. Consider both operating and maintenance requirements.

Flat belts can bend easily around small-diameter pulleys or twist to go around corners. They are often used in serpentine drives.

V-belts have less stretch than flat belts and more lateral stability. They are often used because of their wide availability.

Synchronous belts precisely match the motion of driving and driven shafts for indexing or positioning applications. Compared to gear or chain drives, synchronous belt drives operate with less noise and without lubrication.

## Additional Information

(Addresses and phone numbers for associations are given in the Associations section.)

*Belt Selection and Application for Engineers*, edited by Wallace D. Erickson, Marcel Dekker Inc., New York, 1987.

Rubber Manufacturers Association (RMA), Washington, D.C. (Belts).

Mechanical Power Transmission Association (MPTA), Rockville, Md. (Sheaves and sprockets).

Society of Automotive Engineers (SAE), Warrendale, Pa.  
American Society of Agricultural Engineers (ASAE), St. Joseph, Mich.

National Industrial Belting Association (NIBA), Westchester, Ill. (Conveyor & elevator belting).



Bicycles include the most recognized example of chain drives for power transmission. Even grade-school children know that the chain transmits power from the pedals to the rear wheel. This knowledge may be shallow, but they know that if the chain breaks or comes off, the bicycle cannot be ridden.

Chain drives for industrial applications employ the same principle — transmit power from one sprocket to another via a chain. But chain drives for these applications typically operate at much higher power levels than those for bicycles. And these drives are available with characteristics suitable for a wide variety of speeds, torques, and operating conditions.

Chain drives also generally reduce speed and increase torque from an input shaft to an output shaft. Some drives serve as a conveyor. The long strand of chain that pulls a roller-coaster train up the first hill is a familiar example of the latter.

## Characteristics

Chain drives operate in tension. Teeth on the driving sprocket engage with and pull chain links. Other links on the chain engage and pull teeth on the driven sprocket.

Only a few sprocket teeth are required for effective engagement, which allows higher speed ratios than are usually attainable with belt drives. Non-synchronous belts (those without teeth, such as V-belts and flat belts) require a substantial minimum arc of contact between belt and sheave to develop enough friction to avoid slippage. Loads greater than that for a single-strand chain are accommodated by multiple-strand chains.

The advantageous characteristics of chain drives include:

- No slippage between driving and driven shafts because power transmission is positive over sprocket teeth.
- Negligible stretch.
- Long operating life because flexure and frictional contact occur between long-wearing, hardened bearing surfaces separated by an oil film.
- An ability to operate in hostile environments such as high ambient temperatures and moist, oily, and corrosive atmospheres — especially where chain is made of stainless steel, bronze, or other stable materials.
- Unlimited shelf life because metal chain ordinarily does not deteriorate with age and is unaffected by the sun or reasonable ranges of heat and moisture as long as a protective factory oil coating

remains intact.

- Chain drives generally can be repaired or replaced without disturbing associated equipment.

Disadvantages of chain drives include:

- Higher operating noise than belt or gear drives.
- A potential for elongation from wearing of contact surfaces on links and sprocket teeth.
- Flexibility limited to a single plane, unlike for some belt drives.
- Lower speed limitations than those for belt and gear drives.
- A need to replace sprockets because of wear when worn chain is replaced. (V-belt sheaves undergo very low wear and usually need not be replaced when belts are replaced.)

## Types of Chain

A wide variety of standard and non-standard chain and sprocket designs are available. The American National Standards Institute (ANSI) publishes standards, prefix ANSI B29, for chains and sprockets. The standards cover transmission and conveyor chain as well as standard sprocket tooth form dimensions, pitch diameter tables, and sprocket measuring procedures.

Various types of sprockets are available including cast iron, powder metal, flame-cut steel plate, machined metal, plastic, and composite materials. To protect against shock or overload, special-purpose sprockets are available with shear pins, overload clutches, and other devices.

### Roller Chain

Standard single-strand roller chain, the best-known and first chain to be dimensionally standardized by ANSI (ANSI B29.1), contains pins that pivot inside bushings. The pins are usually press fit into pin link plates, and bushings are press fit into roller link plates, Fig. 4-1. A free-turning roller surrounds each bushing to provide rolling engagement and contact with sprocket teeth. Thus, a strand of roller chain is an assembly of alternating pin links and roller links.

The distance between flexing joints (pin centers) in roller chain is the *pitch*, a characteristic that distinguishes one chain size from another. The larger the pitch, the larger the links and the higher the load rating. Although a small-pitch chain carries less load, it provides smoother, quieter operation, and is capable of operating at higher speed than a chain of larger pitch.

A length of chain is made into a continuous strand by using a special type of pin link, called a *connect-*



## Chain Drives — Types of Chain

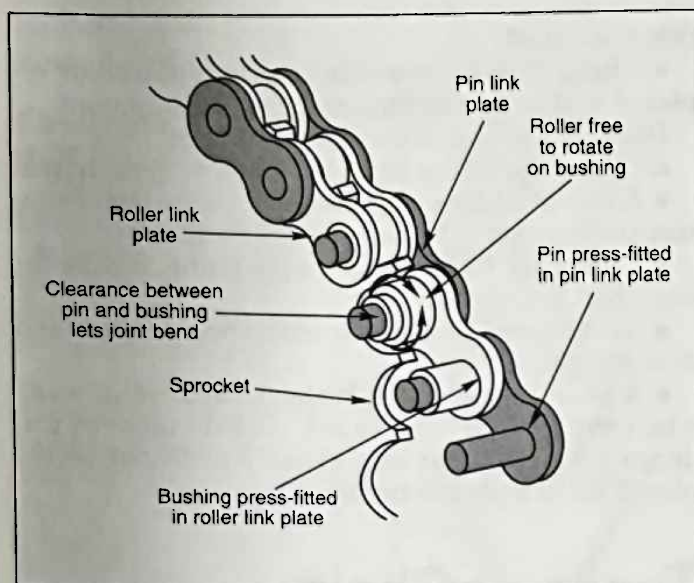


Fig. 4-1 — Single-strand standard roller chain conforms to ANSI B29.1. Pin links are shaded to differentiate them from roller links.

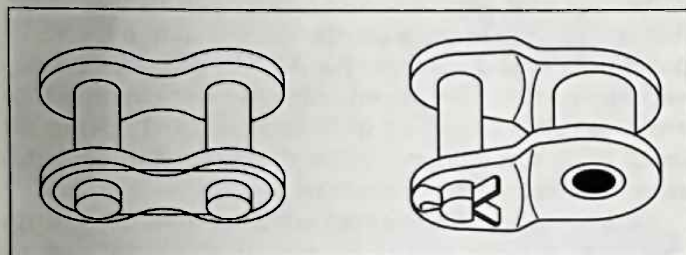


Fig. 4-2 — Connecting link, left, makes a length of chain into a continuous strand. Offset link, right, allows constructing strand of chain with odd number of pitches. One half of offset link mates with roller link, other half mates with pin link.

*ing link*, Fig. 4-2. The connecting link's pins are inserted through each exposed hole of the roller link at each end of the strand. Cotter pins or a spring clip (shown) keep the connecting link's pins from working loose. These cotter pins or clips are necessary for manual assembly and disassembly.

Because there is no way of connecting one pin link directly to another, or one roller link directly to another, standard strands of chain have an even number of pitches — an equal number of pin links and roller links. However, an *offset link*, Fig. 4-2, can be installed to produce a strand with an odd number of links. An offset link is a combination of a roller link and a pin link. When a strand of chain is taken apart, one half of the offset link attaches to the strand's pin link and the other half attaches to its roller link. So adding an offset link to a strand that has an even number of pitches produces a strand with an odd number of pitches.

Standard roller chain is available with pitches from 1/2 to 3 in. Designation numbers for chains are

obtained by multiplying pitch value by 80. Thus, 1/2-in. pitch chain is a No. 40 chain, a 5/8-in. is No. 50, etc. The zero in the designation indicates normal-weight chain. A 1 in this position indicates lightweight chain.

Chain drives are also available with 1/4-in. and 3/8-in. pitches but with a rollerless construction. With these so-called rollerless, bushed chains, the external surface of each link-bushing contacts the sprocket teeth directly. These chains carry the designations No. 25 and No. 35, respectively, the 5 in each case indicating the rollerless design.

A hyphenated 2 suffixed to a chain number denotes a double strand, 3, a triple strand, etc. For example, No. 60-2 designates two strands of No. 60 chain (normal weight 3/4-in. pitch), 60-3 indicates a triple strand, and 60-4 a quadruple strand.

### Tight and Slack Strands

The links of chain transmitting load often are said to be in the tense or tight strand. After the links rotate off the driving sprocket, they make up the slack strand because this length of chain carries no load and sags between the sprockets. In drives where a chain travels primarily in a horizontal path, the slack strand usually should be positioned under the tight strand. If the slack strand was positioned over the tight strand, excessive slack or whipping motion could cause the slack strand to contact the tight strand underneath it. This is an important consideration in applications with long center distances.

There are three situations that do not lend themselves to locating the slack strand on the bottom:

- Application parameters may dictate, for example, that the driving sprocket rotate clockwise and be positioned to the left of the driven sprocket. This arrangement requires the slack strand to lie above the tight strand.

- In bidirectional applications, the driving sprocket rotates clockwise much of the time and counterclockwise the rest of the time. Here, the tight strand alternates from top to bottom.

- In drives where sprockets are oriented vertically, strands no longer lie in a top-and-bottom orientation. For applications such as these, tensioners should be used to keep chain drives running smoothly. Tensioners and their use are described in Chapter 14 — Power Transmission Accessories.



### Double-Pitch Roller Chain

Also known as extended-pitch chain, double-pitch roller chain has dimensions listed in ANSI standard B29.3. These dimensions are the same as for standard roller chain of comparable load capacity, except the pitch is doubled, Fig. 4-3. Because a given length of double-pitch chain contains only half as many pitches, it is lighter and less expensive than standard roller chain. It is especially suitable for long-center-distance applications.

Because all dimensions are the same except pitch,

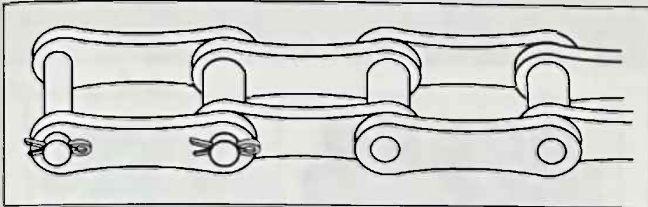


Fig. 4-3 — Double-pitch roller chain conforms to ANSI B29.3. Dimensions are identical to standard roller chain, except pitch is doubled, which reduces weight and cost.

double-pitch roller chain offers essentially the same strength characteristics as standard roller chain. Double-pitch chain is designated with a 20 preceding what would be a standard roller chain number. For example, 2050 designates 1 1/4-in. double-pitch roller chain.  $(1\frac{1}{4} \div 2) \times 80 = 50$ , preceded by 20 for the double pitch.

Sprockets for double-pitch roller chain are either single-cut (one tooth per link) or double-cut (two teeth per link). The double-cut sprocket is actually a standard roller chain sprocket. Using sprockets for standard roller chain with an odd number of teeth reduces sprocket wear, because teeth that engage rollers on one revolution lie between rollers on the next. So sprocket teeth engage chain rollers once for every two revolutions of the sprocket if the sprocket has an odd number of teeth.

When a sprocket has an even number of teeth, the same teeth will engage rollers on every revolution. Half the sprocket teeth will undergo full-time wear and half will undergo no wear. Here, once half the teeth have worn, loosening the chain allows advancing the sprocket one tooth space so the unworn teeth will engage chain rollers and the worn teeth will not.

### Silent Chain

Quieter running and more flexible than conventional roller chain, silent (inverted tooth) chain, Fig. 4-4, is available in 3/16 to 2-in. pitch sizes. The standard for inverted-tooth chain is ANSI B29.2.

The several different types of silent chain construction prohibit mixing chains in a strand, but a chain of the correct size usually will operate on

sprockets from a different manufacturer. Load capacity is increased by widening silent chain rather than using multiple strands.

For silent chain with a 3/8-in. pitch or greater, an SC prefix in the chain size designation indicates conformance to ANSI B29.2. The first one or two digits following the SC indicate pitch in 1/8-in. increments, followed by width in 1/4-in. increments as the next two digits. For example, SC1012 designates ANSI standard silent chain with a 1 1/4-in. pitch and a 3-in. width.

For silent chain with a 3/16-in. pitch, the numbers following the 03 (which identifies the chain as 3/16-in. pitch) indicate the total number of chain links wide. Width (thickness) of each link is approximately 1/32 in. Therefore, SC0314 designates a 3/16-in. pitch silent chain that is approximately 7/16-in. wide.

Two common techniques are used to keep silent chain from sliding axially off of sprockets. In one technique, center link plates ride in circumferential grooves in the sprocket. In another, side link plates hold the chain in place on the sprocket.

### Detachable-Link Chain

The ANSI standard for detachable-link chain is B29.6. The biggest advantage of chain with detachable links is that a strand can be readily separated at any joint without special tools. Before doing so,

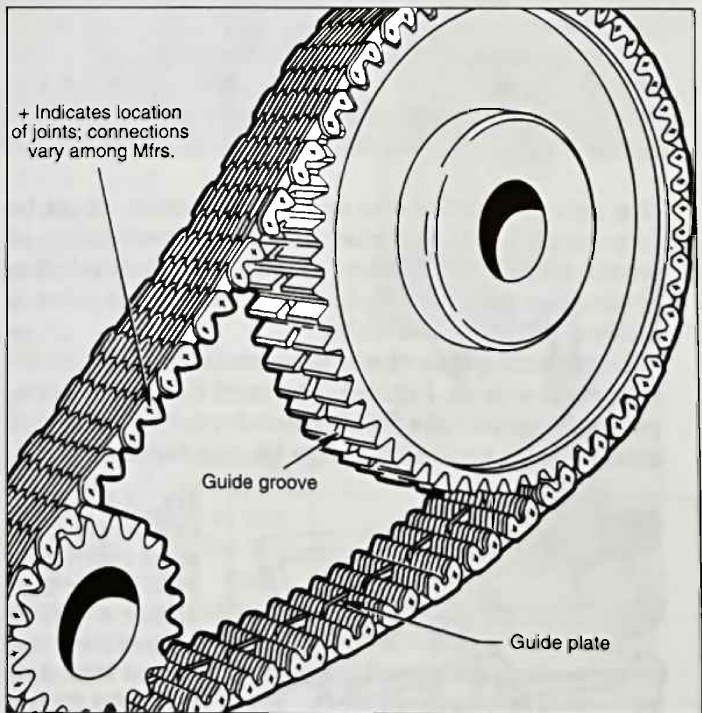


Fig. 4-4 — Silent (inverted-tooth) chain conforms to ANSI B29.2. Guide plates in this chain ride in a circumferential groove in the center of the sprocket faces.



### Standard Chain Attachments

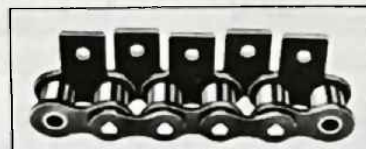
Attachments allow chain to serve as more than just a means of transmitting power from one shaft to another. Attachments allow chain to act as a conveyor to move parts or even bulk materials from one location to another. The versatility of attachments opens opportunities for chain (especially roller chain) to be used more as a conveyor than as a means of power transmission. Attachments also can play an important role in control systems.

The accompanying illustration shows just a few of the standard attachments available from chain manufacturers. Use of these attachments is limited only by the imagination. For example, if a pair of parallel chains each used straight extensions on every other link, bar stock could be carried along the path of the chain between the attachments. With a single strand, mounting the attachments upside-down would allow inserting a hook into each hole to carry small parts. A bent extension presents an ideal medium for mounting a flat surface, or even containers, for transporting bulk materials.

In control functions, an extended pin can trip an electromechanical switch, actuate a lever or cam, or even generate an electronic pulse as it passes by a magnetic pickup or proximity switch. For example, a signal may be needed to lower tooling after a feed table has rotated  $\frac{1}{4}$  turn. If the sprocket attached to the table has 48 teeth, then 12 chain links would represent  $\frac{1}{4}$  turn. Therefore, extended pin or straight extension attachments installed every 12 pitches would cause a proximity or magnetic switch to pro-

duce a signal for every  $\frac{1}{4}$  turn of the table (sprocket).

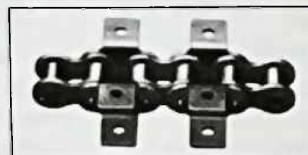
Attachments can be installed on the chain either by the manufacturer or by a distributor. Obviously, strands of chain requiring a large number of attachments are best assembled at the factory. However, if only a few attachments are needed per strand, a distributor can install the attachments. By carrying popular chain attachments in stock, a distributor can quickly come up with a wide variety of chain attachment assemblies — value-added customer service.



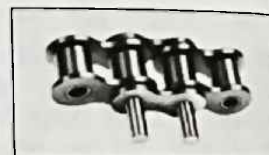
Straight extension, one side.



Pin extension, one side.



Double bent extension, both sides.



Double pin extension, one side.

A few of the many different attachments used in standard roller chain. Various configurations are available — such as single, double, one side, or both sides — that can be used at every pitch, every other pitch, or at any multiple specified by the user.

the mountings for one or both sprockets must be loosened and the sprockets moved closer together to loosen the chain. Thence, pivoting one link relative to another produces a clearance in the link joint to allow separating the links.

Detachable-link chain is manufactured from either steel or iron, Fig. 4-5. The steel designs are one-piece elements made of press-formed flat-rolled steel. Links typically range in size from approxi-

mately 0.9 to 2.3-in. pitch. Iron links for detachable chain also are one-piece elements but are made of cast malleable or ductile iron. Available sizes are approximately 0.9 to 4-in. pitch.

Detachable chain is low in cost and can transmit up to 25 hp at speeds to 350 fpm. It is not as smooth-running as precision chains, and does not require lubrication.

### Engineering Steel Chain

The transmission of high power with a single strand often calls for engineering steel drive chains. Engineering steel chains with steel rollers are widely used for industrial drives and conveyors. Engineering steel chain, for example, pulls most roller coasters to the top of the initial drop.

Standards for heavy-duty, offset sidebar engineering steel chain are defined in ANSI B29.10, and in ANSI B29.15 for heavy-duty straight sidebar chain. Examples are displayed in Fig. 4-6. Other

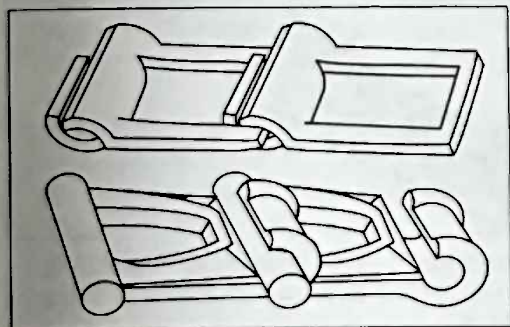
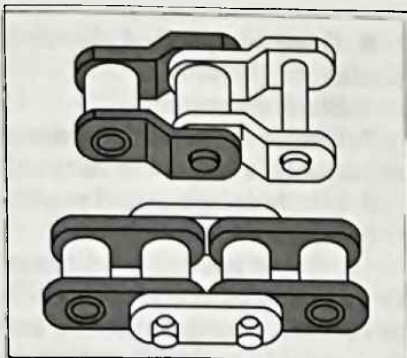


Fig. 4-5 — Detachable-link chain conforms to ANSI B29.6. One-piece elements of pressed steel, top, or cast iron, bottom, come apart to allow assembly or disassembly without special tools.



Fig. 4-6 — Two common varieties of heavy-duty, engineering steel roller chain. Offset sidebar chain, top, conforms to ANSI B29.10; straight sidebar chain, bottom, conforms to ANSI B29.15.



types of engineering steel chain include steel-bushed rollerless chain, welded steel mill chain, and drag chain.

## Lubrication

Proper lubrication is essential for a chain drive to achieve its potential design life. In fact, the type of lubrication employed may be the sole limiting factor in determining the horsepower capacity of a chain drive. Lubrication systems for chain generally fall into one of three categories: Type A — Manual or Drip, Type B — Bath or Disc, and Type C — Oil Stream.

In cases where conventional lubrication methods are impractical or uneconomical, permanently lubricated chain can be specified. Here, oil is applied to the chain during manufacture, and joints are subsequently sealed to keep the oil from leaking out. The technique increases chain cost but often is justified for drives that run intermittently, at low speed with light loads, or where manual lubrication is not possible.

### Type A

Type A lubrication involves shutting a drive down at regular intervals and manually applying oil to the chain. This method limits initial cost, but from a performance standpoint is the least desirable method of lubrication for several reasons:

- It reduces productivity because the machine must be shut down at regular intervals for lubrication.
- Workers are taken away from performing more productive tasks.
- Workers may waste lubricant by applying too much, which also creates a dirty and dangerous work environment. Others may apply too little, which minimizes the benefits of the lubricant. Or lubricant may not be applied frequently enough.

Perhaps the greatest disadvantage of manual lubrication is the "feast or famine" condition it creates. When lubricant is applied, the chain receives

more than it needs (feast). Conversely, chain operates with an inadequate supply of lubricant for a period before the next application (famine). Thus, chain drives lubricated manually operate most of the time with either too much or too little lubricant.

Drives that operate at variable speeds aggravate the problem because the chain requires more frequent lubrication at high speed than at low. Unless application schedules account for different operating speeds, the feast-or-famine condition is even more pronounced.

### Type B

Type B lubrication involves lubricating a chain (and sprocket) constantly, when operating, by routing it through a shallow pool of oil or by applying oil directly to the chain with a disc or brush.

The oil bath method, Fig. 4-7, uses an enclosure around the chain with a supply of oil that collects at the bottom. The enclosure is positioned so that the chain wrapped around the lower sprocket submerges in the pool of oil as it travels around the sprocket. The oil works into the chain and carries away heat as oil is flung off the chain and gradually works its way back down to the sump.

The chain should not submerge completely in the pool; this would needlessly hurl the oil throughout the interior of the enclosure. Ideally, the chain should submerge so that the surface of the pool intersects the center of the chain pins at their lowest point.

The disc method of lubrication, Fig. 4-8,

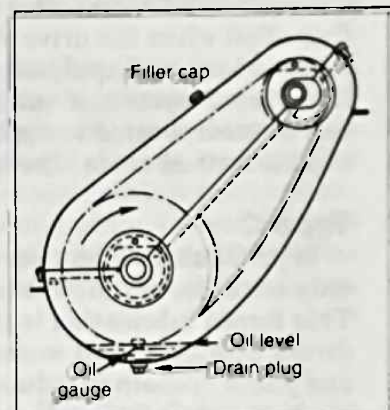


Fig. 4-7 — Oil-bath lubrication involves directing the chain into a pool of oil, which penetrates into joints of the chain to reduce friction and carry away heat.

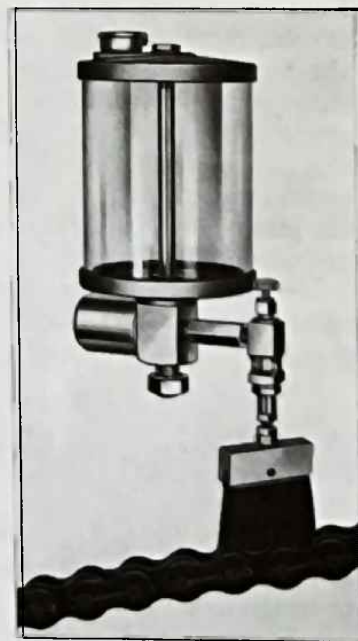


Fig. 4-8 — Disc or brush-type lubrication applies precise amounts of oil directly to the chain. This method is especially useful for lubricating chain and sprockets at several locations on large drives.



applies oil to the chain as it passes by or rubs against a disc, wheel, brush, or other implement, usually near a sprocket. While this method does not apply oil as effectively as an oil bath, it is sometimes much more practical and economical than using an enclosure. Enclosures can become increasingly expensive as drive size increases. Furthermore, lubricant can be applied with a brush at more than one critical location, a useful technique for drives with long distances between sprockets.

A variety of accessories is available to stop the flow of oil when the drive stops, signal when oil reserve is low, and apply oil at different rates along the drive. A system of valves, switches, and tubing can be incorporated to apply just the right amount of oil to critical areas of several drives.

### Type C

Type C lubrication uses a pump to force oil not only onto the chain, but into the working joints. This forced lubrication is preferred for high-speed drives because the oil works into the many crevices and joints in chain to reduce friction, thereby reducing heat generation and wear, increasing efficiency, and extending life.

In addition to lubricating chain and sprockets, oil also carries away heat. Much of the heat then transfers to a drive enclosure much like that used with oil-bath lubrication, but with tighter sealing. Heat transferred to the enclosure dissipates to the surrounding atmosphere. An oil pump mounted in the base of the chain drive enclosure forces oil through tubing that directs the jet toward critical areas of the drive. An auxiliary electric motor usually drives this pump. However, a small auxiliary chain drive connected to the main drive can drive the pump if electricity is unavailable, impractical, or undesirable.

Although this is the most costly method of lubrication, it is also the most effective for squeezing the greatest performance and life out of the chain drive.

## Application Principles

Regardless of the type or class of power transmission chain, the following information is needed to design a drive:

1. Type of input power source (electric motor, internal combustion engine, steam turbine, etc.).
2. Type of driven load (uniform load, moderate shock, heavy shock).
3. Power (hp) to be transmitted.
4. Full-load speed of fastest (usually the driving) shaft.

5. Desired speed of slower (usually the driven) shaft.

6. Shaft diameters.

7. Center distance between shafts. (If distance is adjustable, what is the range of adjustment?)

8. Limits on space and position of drive.

9. Lubrication available.

10. Other special conditions, such as more than two sprockets, use of idlers (Chapter 14), abrasive or corrosive environments, extreme temperatures (hot or cold), and wide variations in load and speed.

These data, when used with published capacity ratings, allow a designer to select the proper drive for an application. ANSI B29 standards contain capacity ratings, as do chain manufacturers' catalogs. Standards covering roller chain, silent chain, and detachable-link chain provide horsepower-capacity tabulations for a wide range of sprocket sizes and rotational speeds. Standards for steel detachable chain cover only allowable working loads. The standards and some manufacturers' literature contain both allowable working loads and horsepower tabulations for offset sidebar chain.

For most power applications, ratings for chain are

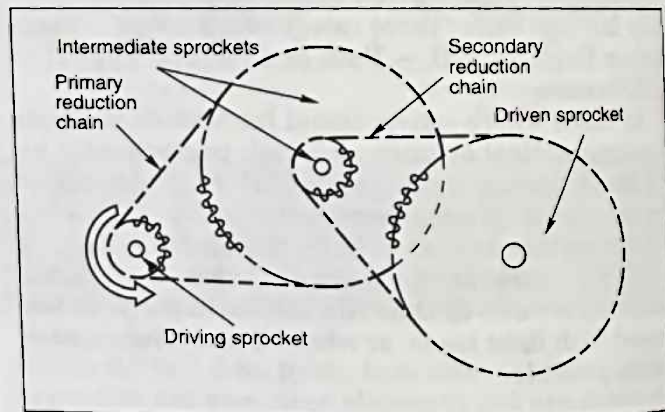


Fig. 4-9 — Double-reduction drives can be used for drives requiring 10:1 speed reduction or greater.

based on a life of 15,000 to 20,000 hr, assuming alignment, lubrication, and maintenance requirements are met. It is best to apply generous service factors, as high as 1.7, especially if heavy shock loading is anticipated.

Speed ratios should not exceed 10:1 in a single reduction for roller or silent chain or 6:1 for other types. If needed, double-reduction drives, Fig. 4-9, can be used to stay within these limits. For roller chain operating at low speed, the smaller (driving) sprocket usually can operate effectively with 12 to 17 teeth. At high speed, the smaller sprocket should have at least 25 teeth to avoid problems that can occur when a chain moving rapidly in a straight line has to suddenly wrap around a small-diameter sprocket.

LIFECORE EX. 1016



Clutches and brakes control and transmit torque, speed, and power in rotating drive systems. Their function is either to transfer torque from an input shaft to an output shaft (clutching) or to stop and hold a load (braking). Though offered in separate components, clutch and brake functions are often combined in a single unit called a clutch-brake. In broadest terms, the purpose of each is the same — to take two shafts independently rotating at different speeds and bring them into partial or total engagement. A brake is simply a clutch with one member held stationary.

Clutches and brakes are categorized by the technique used to engage or stop the load (friction, electromagnetic, or mechanical-lockup) and by the method used to actuate them (mechanical, electric, pneumatic, hydraulic, or self-actuating). Although different combinations of engagement technique and actuation method are often considered competitive, close examination of a specific application will usually point to one combination that offers clear advantages in terms of response, torque transmission, and overall cost of purchase, installation, and maintenance.

## Friction Types

The most common types of clutches and brakes use the friction generated between two mating surfaces to engage or stop a load. One surface is metallic, shaped into a disc, band, or drum. The other surface, usually a plate, shoe, or pad, has a facing of friction material. The stopping torque of a friction-type brake depends on the coefficient of friction and on the amount of pressure used to force the two surfaces together. The brake's capacity to absorb energy depends on the size of its frictional contact area and on the ability of all components to dissipate heat.

Because friction types sometimes spark due to metal-to-metal contact, they must not be used in explosive atmospheres.

**Friction Materials.** Friction elements normally employ a woven or molded organic material bound together with heat-cured resin. The specific material may be any of several types. Brass or aluminum chips are often included in the compound to improve heat dissipation and to extend service life.

Thanks to its excellent heat resistance, asbestos was once the main ingredient in nearly all friction materials. Environmental safety concerns (and legislation), however, led manufacturers to search for replacement materials. The ability of today's

manufacturers to tailor friction compounds to specific applications is a valuable side benefit of that search. Special formulations are designed either to meet a particular operational criterion — long wear, high temperature, or noise abatement, for instance — or to strike an economical balance of two or more characteristics. Long-wear properties are desirable in applications where working surfaces are inaccessible and maintenance is therefore difficult and costly. High-temperature materials find favor in severe, high-cycle-rate applications.

Expensive ceramic materials, once found only in aeronautical and aerospace applications, are now used for clutch and brake friction elements in mail-handling, packaging, labeling, and similar high-cycle-rate, high-acceleration equipment. Clutches and brakes using conventional friction material in these types of applications usually require high levels of maintenance and replacement.

### Disc Units

In its simplest form, a disc-type clutch or brake has one friction plate and one disc. Clutch-brake

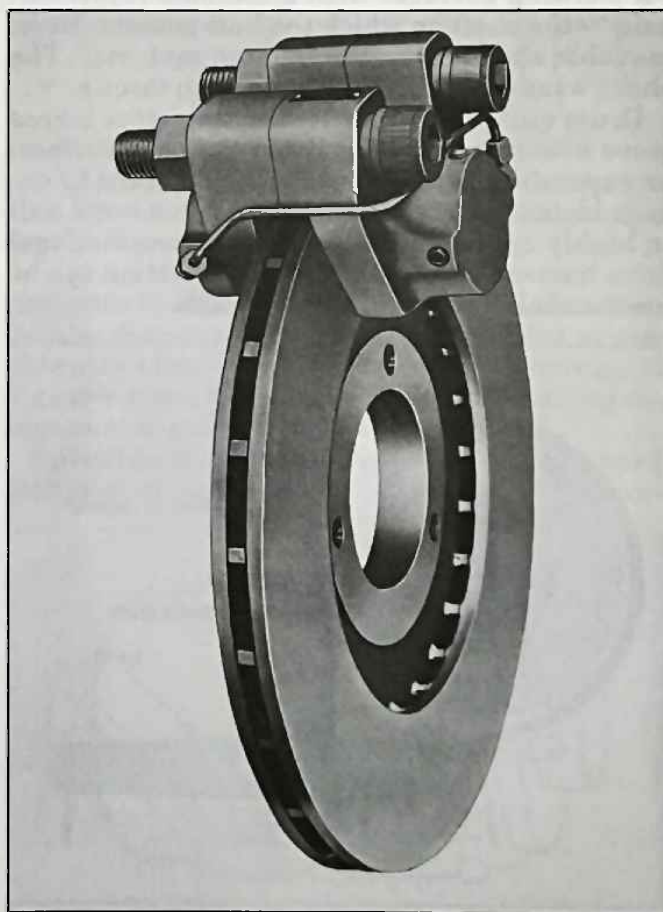


Fig. 5-1 — Caliper-type disc brake.



combination units, which use separate plates and discs for each function, are common. Various mounting arrangements and actuation methods are possible. More complex designs use multiple discs and friction plates to increase working-surface area. Heat builds quickly, however, in a multiple-disc unit. Here, the discs are often immersed in oil to aid cooling.

Some disc brakes use calipers in place of a friction plate, shown in Fig. 5-1, an arrangement that improves cooling. Friction pads are easily serviced. Also, the design usually allows room for use of multiple calipers, a technique that increases braking torque. Widely used on aircraft, automobiles, and industrial equipment, the caliper-type disc brake exhibits the best resistance to fading (a decrease in the coefficient of friction as working-surface temperatures rise). A disadvantage: the caliper-type brake requires high actuation pressure, a situation that often calls for power assist.

### Drum Units

Widely employed in industrial equipment and vehicles, drum clutches and brakes have cylindrical working surfaces with a common rotational axis — the shaft on which the unit mounts. Here, movable shoes carry the friction material. The shoes wear evenly and transmit high torque.

Drum units are either contracting types (shoes move inward against the drum's outside surface) or expanding types (shoes move outward to engage inside surface). Contracting types serve well in highly cyclic applications because centrifugal force hastens shoe withdrawal. Actuation can be mechanical, hydraulic, or pneumatic.

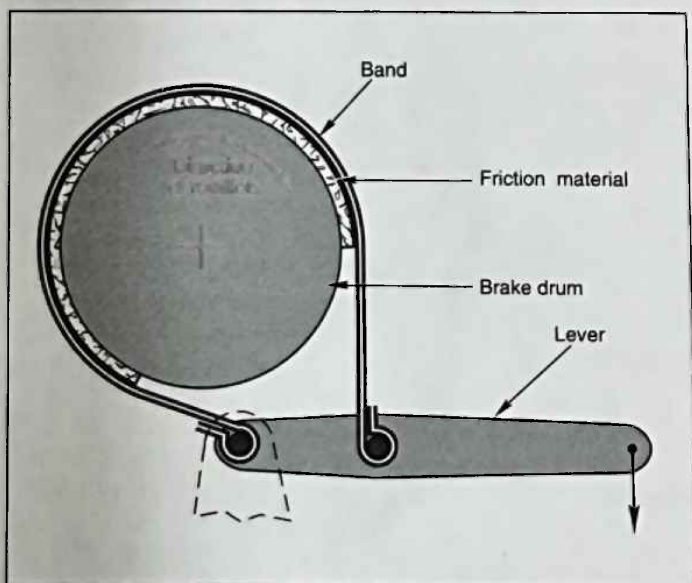


Fig. 5-2 — Simple band brake.

### Band Brakes

Simple and reliable, band brakes (also called strap brakes) comprise a rotating drum and a flexible steel band lined with friction material, shown in Fig. 5-2. A mechanical linkage tightens the band around the drum. If the pull of shaft rotation, the brake is termed self-energizing; in other words, shaft motion contributes to actuation force.

Though band brakes wear unevenly and dissipate heat slowly, they are frequently the choice in applications calling for occasional, high-energy stops. Common uses include backstops on elevators and hoists and emergency brakes on vehicles and equipment.

## Electromagnetic Types

Non-friction electric clutches and brakes (magnetic-particle, eddy-current, and hysteresis types) employ electromagnetic attraction to transfer torque. Used primarily in applications that require variable slip, electromagnetic units excel at soft starting and are well suited to remote and/or computer control. They cannot, however, be called upon to effect rapid or accurate full stops. Electromagnetic types require a source of electric power, and they are not as compact as friction clutches and brakes.

### Magnetic Particle

Fig. 5-3 illustrates the magnetic-particle clutch. The space between input and output members is filled with dry iron particles. When the coil is energized, magnetic flux lines span the space, and particles line up to form a rigid bond between input and output members. The degree of particle bonding, which is directly proportional to current, determines the level of torque transfer.

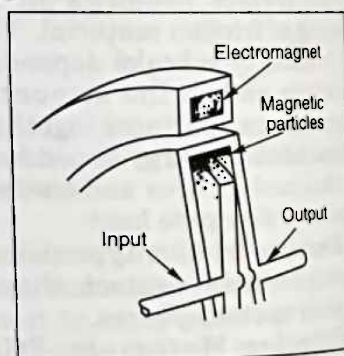


Fig. 5-3 — Magnetic-particle clutch.

Magnetic-particle clutches and brakes are useful in tensioning and positioning applications which speed continually changes (automated assembly lines, conveyors, tension controls). At zero speed, magnetic-particle brakes hold well, but



slip conditions they tend to generate considerable heat.

### Eddy Current

When the field coil of an eddy-current unit, Fig. 5-4, is energized, magnetic flux links the input drum with the output rotor. When the input drum rotates, eddy currents are generated in the rotor. The eddy currents react with the flux to produce a torque that drives the rotor. Torque is proportional to coil current.

Eddy-current clutches and brakes cannot perform at zero slip. Brakes exhibit no torque at zero slip, and therefore cannot hold a load. They tend to run hotter than other non-friction types, sometimes requiring special cooling provisions.

Applications of eddy-current units closely match those of magnetic-particle types, but they offer a broader range of torque ratings and are used primarily in adjustable-speed drives.

### Hysteresis

Hysteresis units are constant-torque devices that can provide any amount of slip, as long as their heat-dissipation capacity is not exceeded. A coil on the input rotor generates a magnetic field in the rotor and drag cup, shown in Fig. 5-5. Hysteresis losses in the drag cup set up the torque reaction as the rotor turns. Torque is proportional to coil current.

Precise control is a valuable, widely exploited feature of hysteresis brakes. Suffering very little wear and offering almost unlimited service life, they excel in fractional-horsepower applications (computer tape drives and tape recorders, for example).

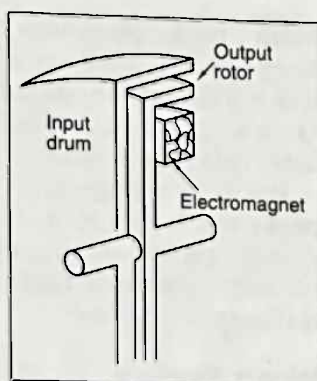


Fig. 5-4 — Eddy-current clutch.

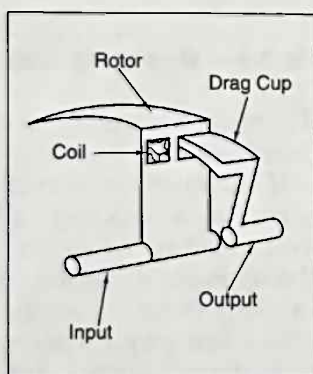


Fig. 5-5 — Hysteresis clutch.

most basic of clutching methods. In mechanical-lockup clutches, members engage by direct metal-to-metal contact (without the use of friction surfaces). Their controllability and simple design still earn application in today's market, especially where perfect, no-slip registry, or indexing is required.

Actuation can be by any conventional method, including manual or remote mechanical. Self-actuating types use centrifugal force, wrapping action, or wedging to link members. Speed, speed differential, or direction of rotation triggers engagement. One clutch in the mechanical-lockup category, the multiple-tooth unit, commonly uses electric, pneumatic, or hydraulic actuation.

### Jaw Clutches

**Square-jaw.** Using square teeth that lock into matching recesses in facing members, square-jaw clutches, Fig. 5-6, provide instant, positive en-

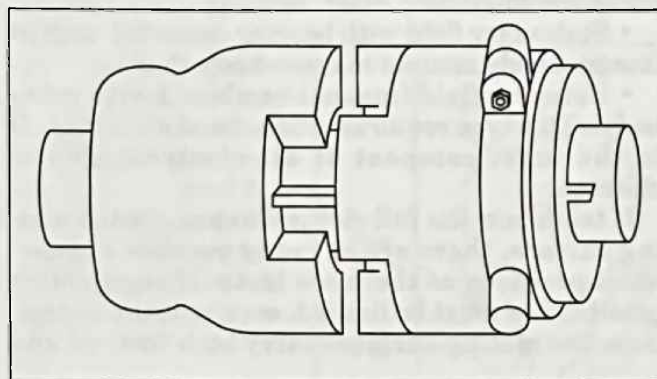


Fig. 5-6 — Square-jaw clutch.

gagement in either rotational direction. However, because they cannot slip, safe engagement is possible only when shafts are stationary or moving at the same speed in the same direction. Running engagement is possible up to about 10 rpm.

**Spiral-jaw.** Evading the engagement-speed limitation of square-jaw types by using sloped sur-

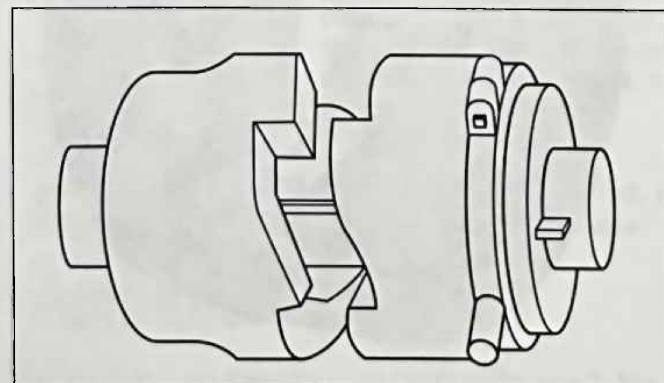


Fig. 5-7 — Spiral-jaw clutch.

## Mechanical-Lockup Clutches

Direct mechanical connection between input and output members is one of the oldest and



faces on one side of the teeth, (see Fig. 5-7), spiral-jaw clutches allow smooth, ramped engagement at speeds to 150 rpm, but only in one direction.

## Multiple Tooth

A refinement of the locking-jaw principle, multiple-tooth clutches combine the advantages of mechanical lockup with those of electric, pneumatic, or hydraulic actuation. Small size gives them a big advantage over friction types in certain applications. For any given size, they offer higher torque-carrying capacities. Engagement is between large numbers of tapered, gearlike teeth, Fig. 5-8. Some models permit engagement speeds to 400 rpm; but, as with jaw clutches, optimal input-output speed differential is zero.

Actuation of multiple-tooth clutches is usually accomplished by an on-board electromagnet. Electromagnetic units can be any of three types:

- Stationary field with wall-mounted magnet (most common).
- Stationary field with bearing-mounted magnet (magnet body mounts to inner-body shaft).
- Rotating field (magnet combined with inner body). This type requires brushes and slip rings. It is the most compact of all electromagnetic clutches.

If teeth run the full circumference of each mating surface, there are as many possible engagement positions as there are teeth. If engagement possibilities must be limited, even to just one position, the mating surfaces carry both toothed and



Fig. 5-8 — Multiple-tooth clutch (stationary field).

solid areas. Members ride upon each other until they reach a position where toothed and solid areas match, at which point engagement can occur. On a single-position multiple-tooth clutch, no two intervals of toothed and solid area are the same.

Positive engagement and positioning accuracy make multiple-tooth clutches a popular choice for printing and labeling equipment, packaging machinery, machine tools, medical equipment, and military hardware.

## Wrap Spring

Wrap-spring clutches link input and output shafts with a coiled spring whose inside diameter is smaller than either shaft diameter, Fig. 5-9. Rotation in one direction tightens the spring and transmits torque; rotation in the opposite

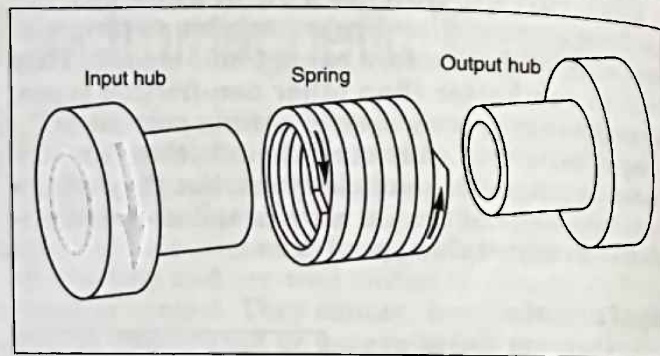


Fig. 5-9 — Wrap-spring clutch.

direction expands the spring and disengages the members.

If one member is anchored, a wrap-spring clutch serves as a backstop, allowing free rotation in the overrunning direction but preventing rotation in the opposite direction. This arrangement is useful in many indexing applications.

For some applications, the self-energizing nature of wrap-spring clutches can be externally controlled to engage or disengage very rapidly after a specified number of revolutions.

Though the spring clutch is not suited for high-speed applications, it serves well in such equipment as copy machines, packaging machines, conveyors, and paper feeders and collators. Its indexing precision is unrivaled.

## Sprag

Another overrunning (one-direction) clutch, the sprag type, uses cylindrical inner and outer races, with sprags filling the space between. Sprags are sized, shaped, and mounted in a manner that causes them to wedge between, and thereby link, the two races when rotation occurs in the proper direction, Fig. 5-10. No outside control is neces-



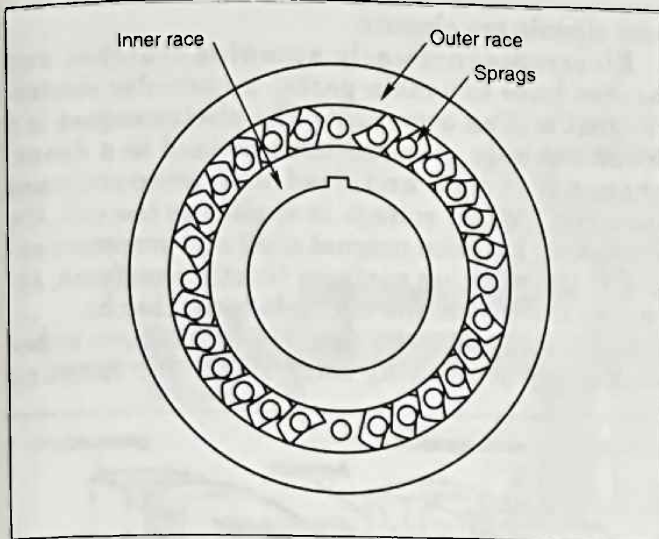


Fig. 5-10 — Sprag clutch.

sary. When rotation is reversed, or when output overruns input in the driven direction, the sprags fall out of engagement. Sprags can be designed to lift from either the inner or the outer race at specific shaft speeds.

Among sprag-clutch overrunning, indexing, and backstopping applications are conveyors, automatic transmissions, helicopter rotor blades, turbine starters, dispensers, and feed mechanisms.

Closely related to the sprag clutch is the **cam clutch**, which uses spring-loaded cams positioned between inner and outer races. The center of gravity of each cam is such that it causes it to lift off of the inner race at a specific speed.

### Roller Ramp

The roller-ramp clutch, Fig. 5-11, transmits torque through rollers that move on ramped-surface portions of a hub. A roll cage forces engagement or disengagement by positioning the rolls at the tops or bottoms of their ramps, respectively.

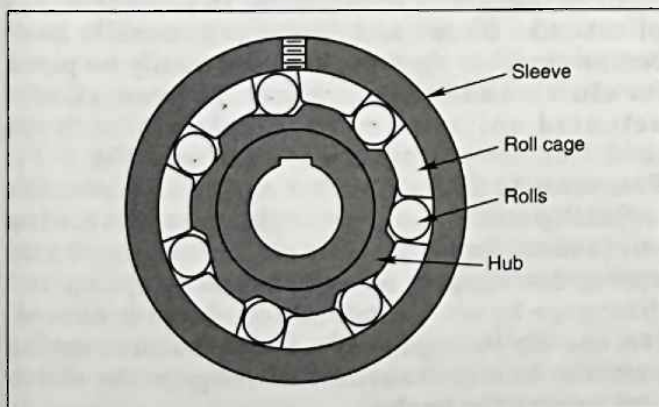


Fig. 5-11 — Roller-ramp clutch.

An external cam-and-lever assembly — actuated manually or by electric, hydraulic, or pneumatic solenoid — controls roll-cage position. Torque transfers from continuously rotating sleeve to intermittently driven hub.

Related to both the sprag and roller-ramp types is another overrunning unit, the **round-roller clutch**. It employs a round outer member, dowel-shaped rollers, and an inner member that has a flat surface for each roller. Light spring pressure keeps rollers in the chambers formed by the flat inner-member surfaces and the cylindrical surface of the outer member. Friction causes rollers to wedge tightly, locking input and output members, when input turns in the driving direction. When output is externally driven and input is slower or stationary, rollers move against spring force and the unit disengages.

Because of their overrunning characteristics, sprag- and roller-type clutches are often employed in dual-drive systems. Each motor in a dual-drive system uses an overrunning clutch. The drives are arranged so that when one motor is in service and its clutch engaged, the clutch adjacent to the other motor automatically overruns.

### Ratchet

Low-speed overrunning, indexing, and backstopping applications often employ a ratchet clutch, shown in Fig. 5-12. Here, a spring-loaded pawl engages a notched wheel or gear, permitting rotation in only one direction. The position of a control lever determines whether the clutch operates in forward, reverse, freewheeling (neutral), or locked modes.

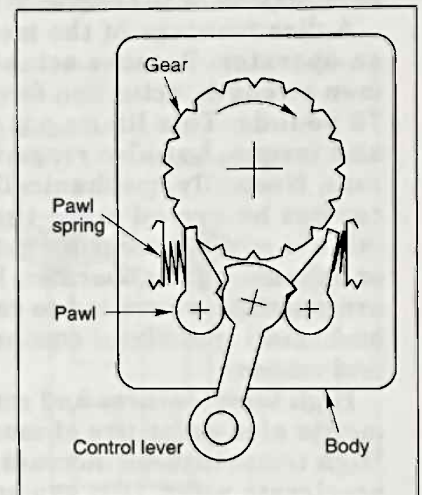


Fig. 5-12 — Ratchet clutch. Moving control lever right or left engages and disengages spring-loaded pawls. With left pawl engaged (as here), gear can be driven clockwise only; right pawl engaged, counter-clockwise only. With lever at center position, both pawls engage, and unit is locked.

## Actuation Methods

Clutches and brakes are generally available in a fairly broad range of ratings (from frac-



tional to about 50 hp is typical). But size, torque, and power requirements are not the only criteria for selecting a clutch or brake. Careful consideration must also be given to the available methods of actuation and their operational characteristics, advantages, and limitations.

### Mechanical

Mechanical actuation, the simplest and least costly method, is used where an operator can manually control engagement. Actuation, whether by hand or by foot, is accomplished by rods, cables, levers, or cams. Compound linkages serve on larger equipment. This method is usually practical only when a lever or pedal can be located near the clutch or brake. Friction forces increase with linkage and cable length.

The major operational advantage of mechanical actuation is the feel of engagement afforded the operator. Tactile feedback from a pedal or lever helps the operator gauge the amount of braking force applied or the degree of slip obtained.

A disadvantage of the method is the need for an operator. Because actuation depends on human strength, actuation force is limited to about 75 pounds. This limits not only clamping force and torque, but also response time and cycling rate. Normally, mechanically actuated clutches cannot be cycled more than a few times per minute without wearing out clutch components or exhausting the operator. For this reason, they are generally restricted to vehicular applications and small industrial equipment such as hoists and cranes.

High temperatures and contaminated environments also deter use of mechanical actuation. High temperatures increase clutch slippage and accelerate wear. Dirt can encrust linkages and wear clutch and brake elements. In some cases, special housings and oil-bath protection for friction elements can help fight contamination.

### Electric

Electrically actuated clutches and brakes offer extremely high cycle rates — up to 1,600 cycles per minute in some applications — and quick response. Some small-diameter clutches respond in 1 or 2 milliseconds. Electric types, however, provide neither the wide torque-capacity range nor the inherent feel or feedback of other types, though feedback can be improved by certain closed-loop control units.

Electric actuation is preferable where remote control is required or where special slip characteristics are needed. Electric types also predominate in automatic machinery applications, where con-

trol signals are electric.

Electromagnetically actuated clutches and brakes have two main parts: an annular electromagnet and an armature. The electromagnet is a wound-copper coil that is embedded in a donut-shaped iron shell and lined with wear-resistant material. When voltage is applied to the coil, the attraction between magnet shell and armature engages the working surfaces (friction surfaces, except in the case of the multiple-tooth clutch).

Electromagnetic clutches and brakes have either stationary or rotating coils, Fig. 5-13. Rotating

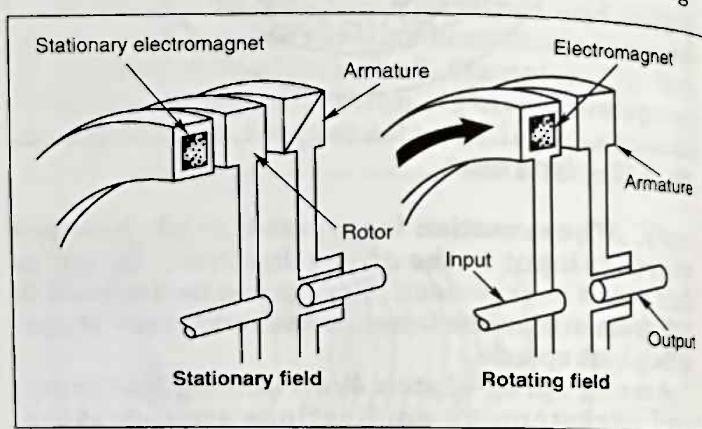


Fig. 5-13 — Electromagnetic actuation of single-disc units.

types have slip rings and brushes. The fixed magnetic coil of a stationary-field unit requires no rings.

Friction-style electric clutches and brakes sometimes employ multiple discs. Interleaving input and output discs provide greater friction area and higher torque than do single-disc units. However, multiple-disc types do not dissipate heat as readily. Thus, to improve cooling, friction elements in multiple-disc clutches and brakes are often immersed in oil.

### Pneumatic

Air actuation is widely used in industrial applications. Shops and factories generally have compressed-air systems that can easily be piped for clutch and brake service. In general, air-actuated units are mechanical friction types modified for pneumatics, shown in Fig 5-14. Pressures to 200 psi, either acting on pistons or inflating tubes, engage or disengage working surfaces. Some units are air-engaged and spring-disengaged; others engage by spring and disengage by air. Combination clutch-brakes often use air to engage the clutch but use spring pressure to simultaneously disengage the clutch and engage the brake.

Pneumatic units transmit higher torque than

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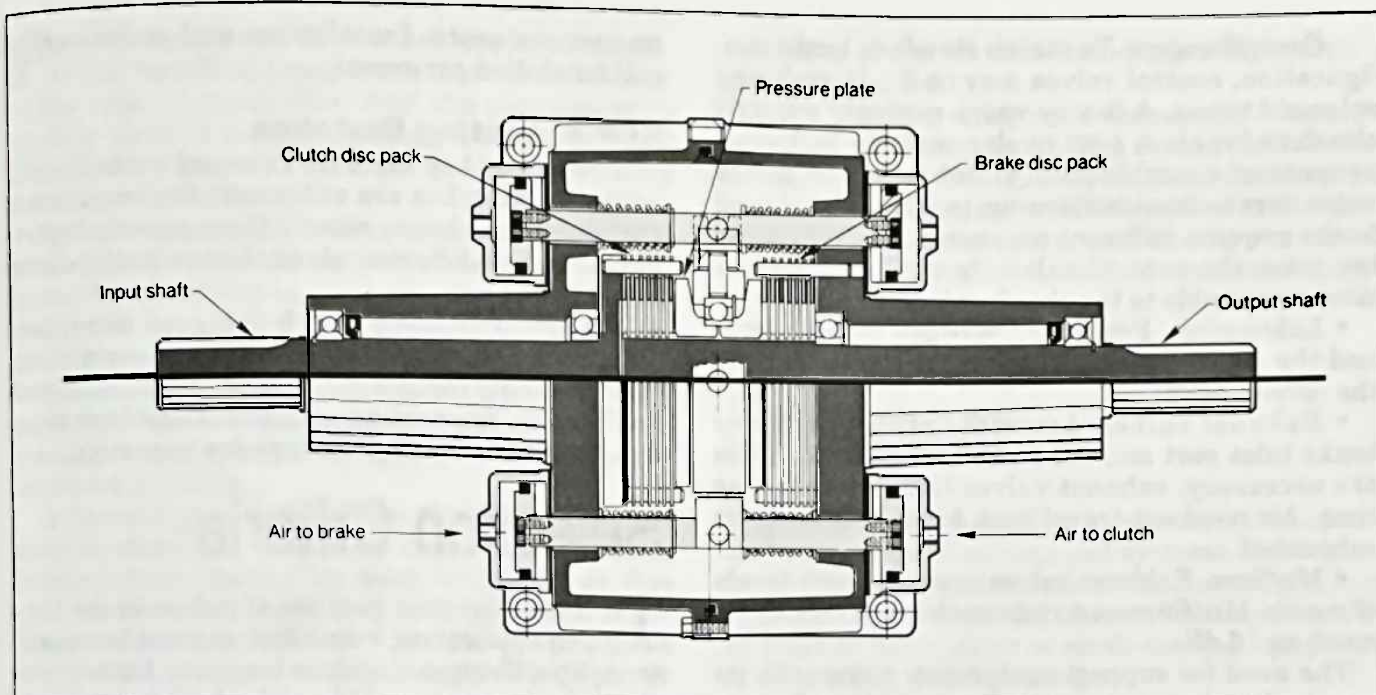


Fig. 5-14 — Multiple-disc pneumatic clutch-brake.

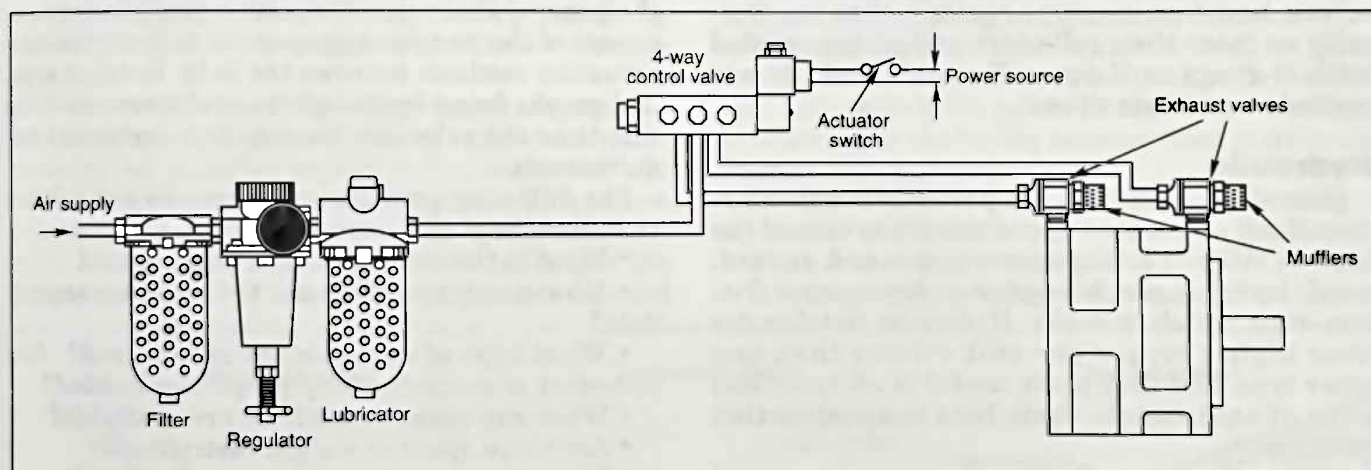


Fig. 5-15 — Typical pneumatic-clutch installation.

comparably sized mechanical units, but they fall short of the torque levels possible with hydraulic actuation. Cycle rates run as high as 80 cycles per minute, though most applications call for 20 cycles per minute or less.

Low heat generation is perhaps the most valuable benefit of air actuation. Pneumatic units add no heat during long periods of engagement. Pressure remains constant after a piston chamber fills; virtually no power is needed to sustain working torque level once it is reached.

Pneumatic actuation also offers a degree of feel for the operator — though less than that afforded by mechanical means — when pressure is channeled through hand- or foot-operated throttles.

Remote control poses no problem; air-pressure level holds well over long distances. When automatic or remote control is desired, an electrically actuated solenoid valve can be used to control pressurization. Also, flow-control valves can smooth engagement.

Air-actuated units typically require several pieces of support equipment, Fig. 5-15:

- **Pressure regulators.** Selected according to their flow capabilities, these valves set the proper air-pressure ranges for desired clutch or brake torque.
- **Filters.** Located upstream of the pressure regulator, filters must have at least a 5-micron screening capacity.



- **Control valves.** To match clutch or brake configuration, control valves may be 3-, 4-, or 5-way solenoid types. A 3-way valve controls a single clutch or brake. A 4-way valve controls both components of a combination clutch-brake. A 5-way valve serves combination units when clutch and brake require different pressures. For minimum lag time, the control valve should be located as close as possible to the clutch or brake.

- **Lubricators.** Positioned between the regulator and the control valve, a lubricator injects oil into the service air.

- **Exhaust valves.** Installed at the clutch or brake inlet port and used when long service lines are necessary, exhaust valves improve response time. Air need not travel back to the control to be exhausted.

- **Mufflers.** Exhaust valves generate high levels of noise. Mufflers can reduce those levels by as much as 16 dB.

The need for support equipment, along with its required maintenance, is a disadvantage of pneumatic actuation. The clutches and brakes themselves, however, employ actuators that are typically no more than cylinders and pistons sealed with O-rings or U-cups. No special skills are needed to maintain them.

### Hydraulic

Operationally similar to pneumatic units, hydraulically actuated types use oil pressure (as high as 500 psi) acting upon a piston and, in turn, a rod, lever, or cam to engage or disengage a friction-style clutch or brake. Hydraulic clutches deliver higher torque per unit volume than any other type, and they prove useful in all types and sizes of equipment—from fans to construction machinery.

Hydraulic units offer low response times and — thanks to pressure-control valves — very smooth engagement. Because quick response is usually the primary reason for choosing hydraulic actuation, fluid lines are kept relatively large in diameter and short in length. Remote locations or special control requirements may prescribe additional fluid-control devices to maintain pressure. As in electric types, multiple friction elements may be immersed in oil for cooling.

Support equipment for hydraulic actuation (pumps, valves, piping) is more sophisticated and more expensive than the accessories needed for

pneumatic units. Installation and maintenance call for skilled personnel.

### Self-Actuating Clutches

Insofar as they need no external control, self-actuating clutches are automatic devices. Actuation and/or release result from speed, input-output speed differential, or change in the direction of rotation.

The self-actuating clutch is a good candidate where the motor speed of a power-transmission system is fully compatible with the proposed clutch mechanism, where slip starts are desirable or tolerable, and where energy savings are important.

## Selection Criteria

To choose the best possible clutch or brake for a given application, many factors must be considered. Specifying a clutch or brake on horsepower alone, for instance, could yield a half dozen candidates, all of a different type and size. Knowledge of the general characteristics, strengths, and weaknesses of the various engagement techniques and actuation methods narrows the field. Data, charts, and graphs found in manufacturers' literature help fine-tune the selection for detailed, technical requirements.

The following questions can serve as a checklist to determine if all factors have been considered:

- What is the maximum operating speed?
- How much torque must the unit accommodate?
- What type of engagement is required? Are soft-start or controlled-slip properties needed?
- What engagement methods are available?
- Are there space or weight restrictions?
- What is the response-time requirement?
- What is the cycle-rate requirement?
- What thermal capacity (level of heat-dissipation ability) is needed?
- Does the job need to have remote or electronic control?
- What are the environmental conditions?
- What are acceptable service lives for the unit and its friction elements?
- How much routine maintenance will be required?
- What are the costs and maintenance requirements of auxiliary equipment?



# Conveyors & Components Chapter 6

Power transmission devices are employed on material handling equipment more than on any other type of apparatus. And the equipment is widely used in manufacturing and processing plants, warehouses, farms, ports, ships, and even retail establishments.

Power transmission devices used here include active elements such as motors, motor controls, adjustable-speed drives, sensors, clutches, brakes, gear reducers, bearings, rubber and fabric belts, chains, gears, and sprockets. Material handling also employs a wide variety of passive components such as motor bases, turnbuckles, torque arms, adhesives, lubricants, and auxiliary hydraulic and pneumatic components.

Attempting to define here the specific power transmission devices that are used in each instance is impractical; there is too much variety. Thus, this chapter describes the salient characteristics of the most widely used material handling equipment from which a reader can deduce the likely power transmission devices needed.

There are generally two broad categories of material handling equipment distinguished primarily by characteristics of the material handled — discrete and bulk.

Discrete item handling equipment transports individual items, large or small, as individual items usually not jumbled together. Examples include watch components, auto body parts, TV picture tubes, printed circuit boards, packaged goods, barrels, and loaded pallets. Discrete handling is the largest segment of handling equipment. A broad

sampling of the material handling components is shown in Fig. 6-1.

Bulk handling equipment transports a homogeneous stream of material. The equipment handles chemicals, ores, sand, gravel, coal, and similar products. In some cases, material is handled in the open, as on bulk belt conveyors, and in other cases enclosed, as in pneumatic tubes and screw conveyors.

## Discrete Handling Equipment

Discrete item handling equipment includes a wide range of mechanical systems and components that convey, shift, orient, lift, lower, and turn items of various sizes and shapes. The items may be as large as locomotives or earth-moving equipment or as small as watch bearings.

### Floor Conveyors

Based on mounting configuration, floor conveyors are categorized as either in-floor or on-floor types. In-floor conveyors are mounted flush with the floor and have their drive power located below the floor. On-floor types can be any conveyor that rests on the floor.

In-floor conveyors are available in a variety of styles and configurations. Some run in the floor — towline conveyors, for example.

Towline conveyors, Fig. 6-2, consist of a channel

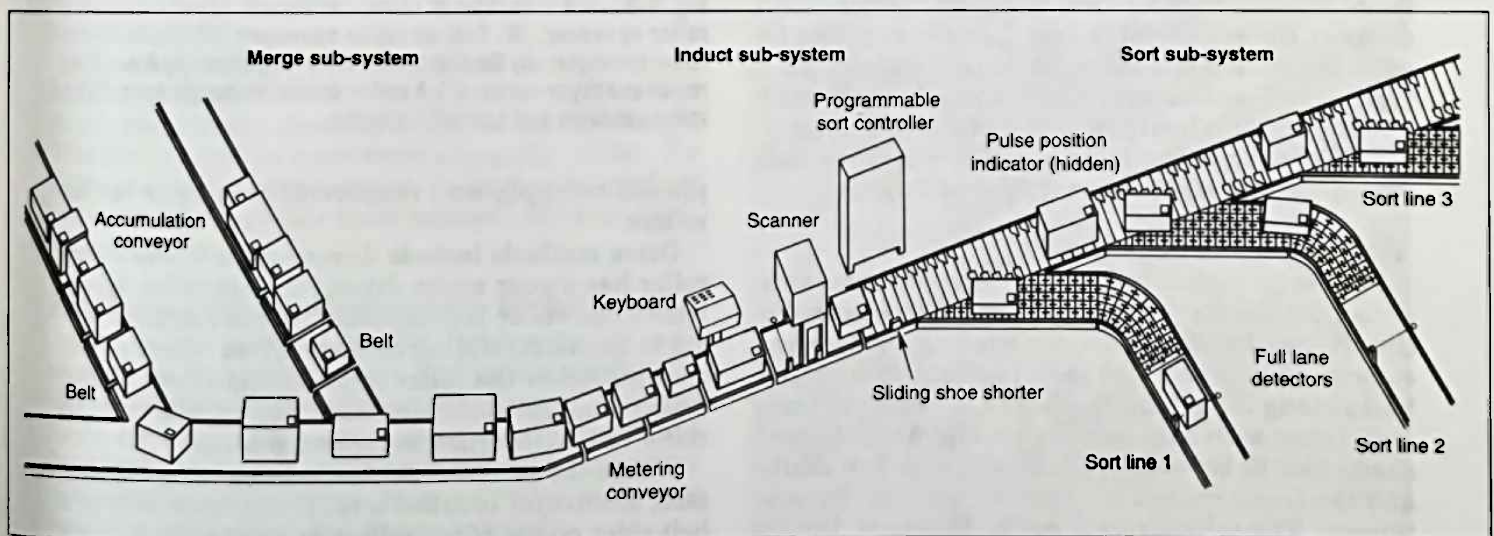


Fig. 6-1. — A group of conveyor types joined as one conveyor system. Types shown are belt, wheel conveyor, sliding shoe sorter, metering belts, and roller conveyor.

The functions performed are conveying, accumulation, metering, merging, scanning, and sorting.

This single system uses sensors for full lane detection, metering, or spacing systems, keyboard data entry, bar code scanning, position indication, and photoelectric detection. All are under the direction of a programmable sort controller.



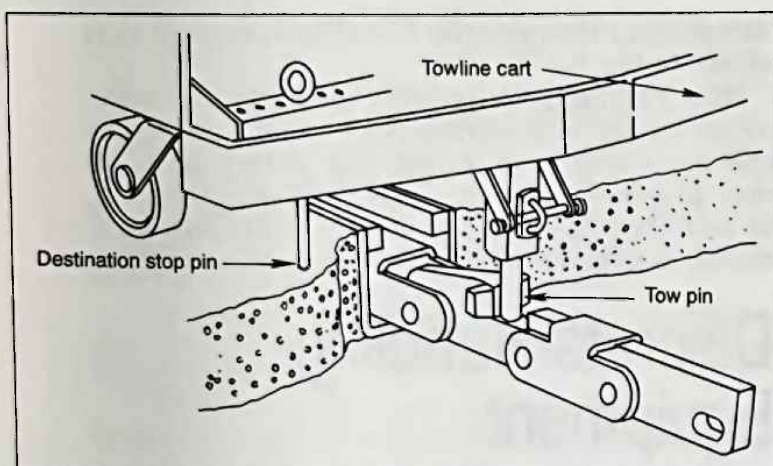


Fig. 6-2. — A low-profile or shallow in-floor towline conveyor. Stop pin selects spur, transfer, or stop point disengaging the tow pin.

recessed in the surface of the floor with a chain running in it. The chain, in some cases, is a horizontal loop powering carriers continuously, and, in others, a vertical loop powering them for a distance and then returning, unexposed, below the floor. The chain is sometimes greased to minimize friction between it and the channel or it may ride on spaced pairs of bearings that support it in the channel.

The chain-in-channel is the active part of the conveyor. It pulls wheeled trucks or rolling platforms along on the surface of the floor. A pin interconnects the trucks or platforms with the chain. The pin can generally be engaged or disengaged at will.

Other in-floor conveyor types employ various flat-top conveyor chains that ride in channels in the floor. The hinged chains can be as wide as needed to support the conveyed items. Two or more can be used in tandem spaced some distance apart. This type is used on assembly lines for mobile equipment and to transport heavy finished coils of hot metal.

On-floor conveyors include roller conveyors, belt conveyors, and many other types and varieties.

### Roller Conveyors

Falling into one of two categories, roller conveyors are either gravity powered, or motor powered roller (live roller). In either case, the basic roller conveyor structure consists of side rails, punched with spaced holes along their length. Rollers, assembled from steel tubes with bearings in each end, ride on steel shafts that fit between the rails, Fig. 6-3. The shafts and the inner race of the bearing are usually stationary. The rollers rotate on the bearings. But in some cases the rollers are fixed to the shaft and the shaft ends are mounted in flange or pillow block bearings. The rollers may be free running or driven in any of a variety of ways. Power may be applied continuously or intermittently with devices em-

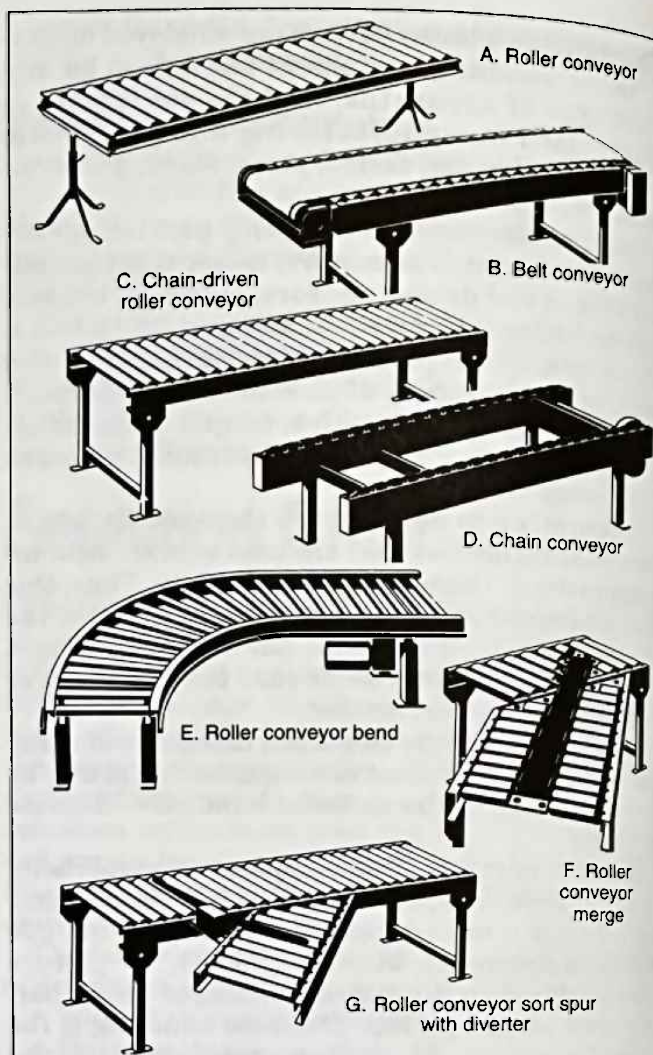


Fig. 6-3. — A selection of roller conveyors. (A) Non-powered roller conveyor; (B) Belt-on roller conveyor; (C) Chain-driven roller conveyor; (D) Double-strand roller conveyor; (E) A powered roller conveyor curve; (F) A roller conveyor merge spur; (G) A roller conveyor sort spur with diverter.

ployed to apply and remove drive power to the rollers.

Drive methods include direct drives where every roller has a gear motor drive; roller-to-roller drives where one roller is connected by chain and sprockets to the next; sliding contact drives where a belt running below the roller contacts and drives it; and self-contained motor-in-roller drives, where each roller has an internal motor and gearbox.

Where the rollers form the top or conveying surface, a conveyor is called a roller conveyor. Where a belt rides on top of the rollers and the product rides on the belt, a conveyor is called a belt conveyor, Fig. 6-3(B). Belts that slip on a solid polished surface instead of on rollers are called slider bed belt conveyors, Fig. 6-3 (B). The latter type is covered in greater depth later in this chapter.

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When a belt runs beneath the rollers and contacts them to drive or power the rollers, the conveyor is designated a belt-driven roller conveyor, Fig. 6-3 (D).

A roller conveyor may have only one drive per section. This can be a motor, speed reducer, pulleys and belts, or chains and sprockets. It may also be a gearmotor or shaft-mounted gear reducer and motor plus appropriate coupling devices.

On heavy-duty roller conveyors, such as runout conveyors used for handling coils, billets, and slabs in steel mills, there may be one drive or gearmotor per roller and these may be electronically synchronized or servo controlled.

In some cases power is selectively and intermittently applied to individual rollers or groups of rollers to stop and start the flow of product or to accumulate product close together in a line. Some of these configurations are called accumulation conveyors, Fig. 6-4. Drive methods for the action include mechanical, a combination of air and mechanical, and electrical or electronic techniques, Fig. 6-4.

Chain-driven roller conveyors typically employ a double sprocket on each roller with power transmitted between rollers by short loops of roller chain. Otherwise there may be one sprocket per roller with a continuous chain powering all.

In some light-to-medium-duty applications, such as handling boxes in a warehouse, very long conveyors are driven by a single line shaft running beneath the rollers the length of the conveyor bed, Fig. 6-4 (B). The line shaft is supported by pillow blocks. Universal joints carry the line shaft around curves, and to spur conveyors and diverters, where it powers other actions.

The line shaft powers the rollers through short belt loops. The belts run from a groove in the roller down and around plastic pulleys on the line shaft. The groove can be anywhere along the roller. To drive stub rollers or spurs, the belts may be applied between rollers rather than between the line shaft and the roller.

### PT Components Commonly Used

Live roller conveyors employ a wide range of components in a variety of sizes and layout configurations. Bearings in abundance and of every type and style are used. These range from simple unground bearings (used on inexpensive rollers) to precision double-row ball bearings, tapered roller bearings, bushings, and pillow and flange bearings.

Motors of every kind from foot-mounted to face flange types may be mounted separately or as gearmotors and gear reducers, both in-line or right-angle. The gear reducers may be connected by V-belts, timing belts, chains and sprockets, or flexible cou-

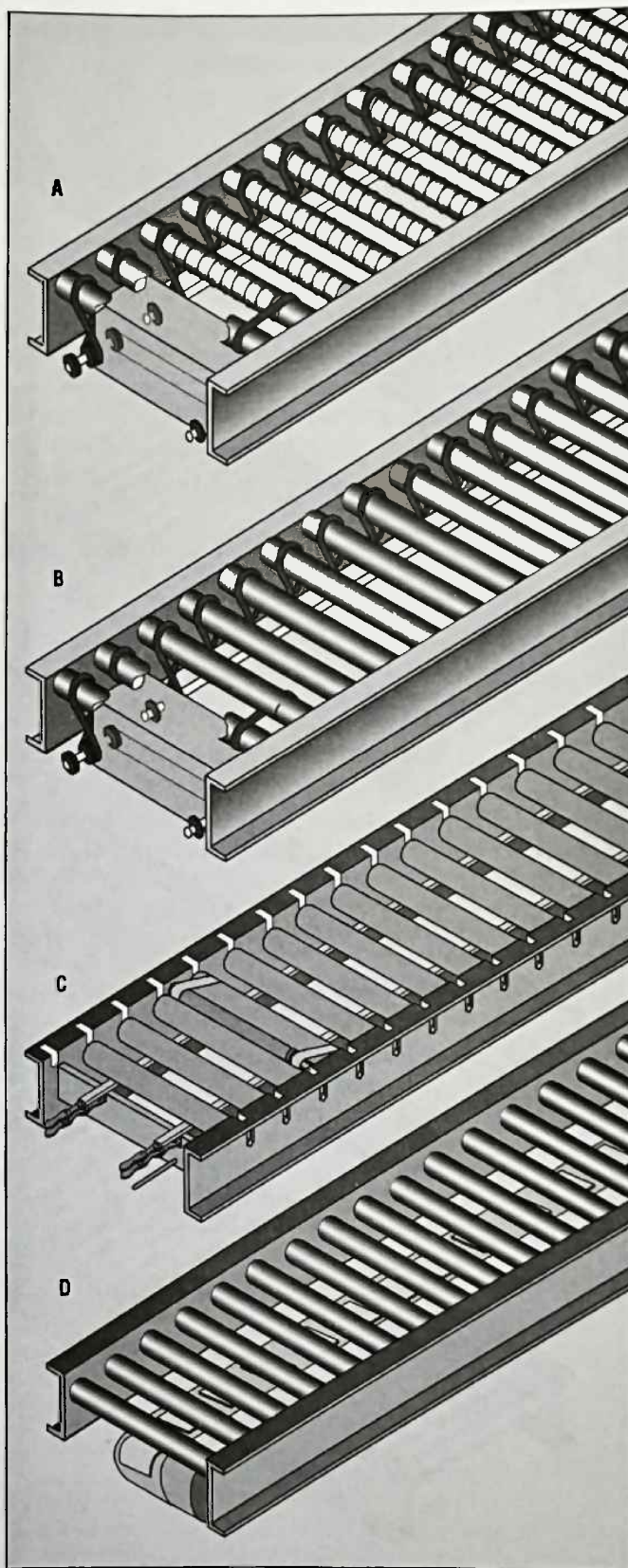


Fig. 6-4. — Methods of driving roller conveyors: (A) Free rollers on driven shafts; (B) Line shaft drive; (C) Tube-on-chain friction drive; (D) Padded or flat belt drive.



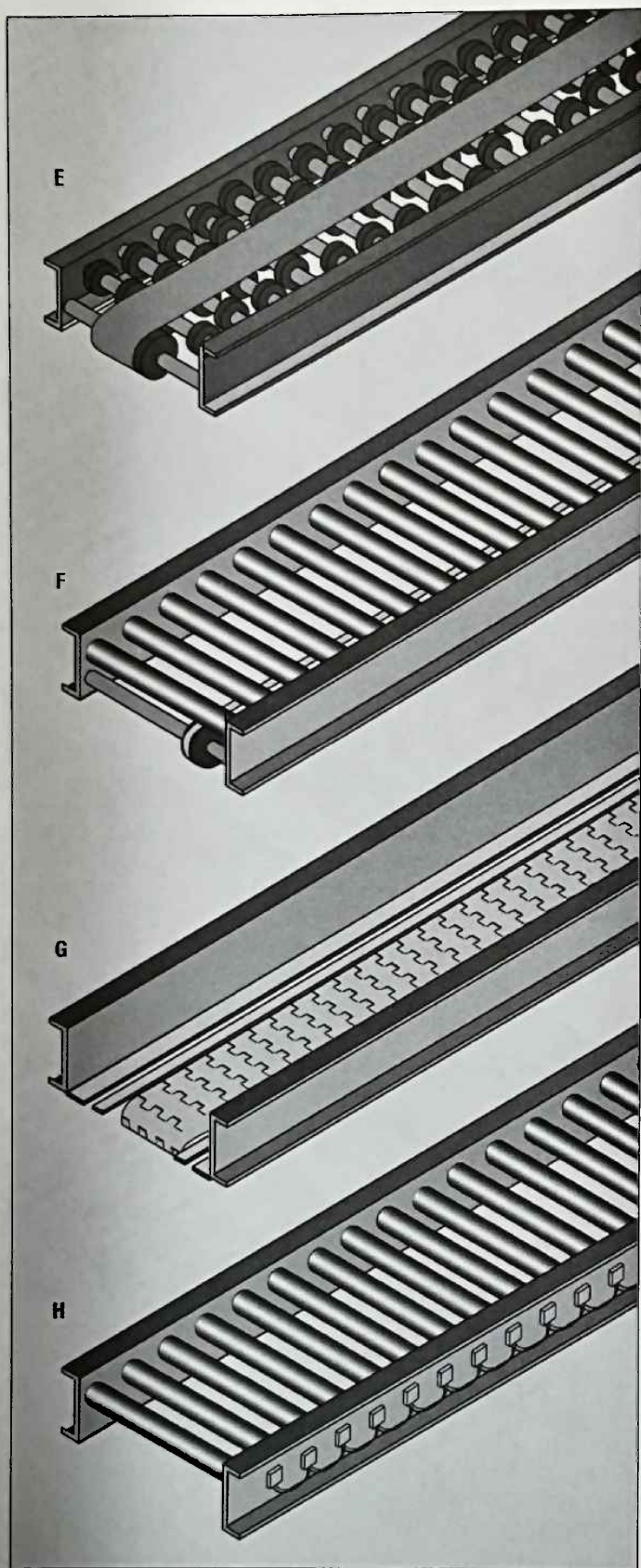


Fig. 6-4. — Methods of driving roller conveyors: (E) Flat belt between rollers; (F) Chain, cable, or V-belt drive; (G) Chain flight between rails; (H) Individual motorized rollers.

plings, and shaft mounts, Fig. 6-4 (A).

In elaborate multi-section conveyor systems, almost all drives are variable speed. They are usually electronically controlled through the motor rather than through variable transmissions or gearboxes. Variable speed overcomes drag or friction, heavy loads, and high start-up torque, or it matches the conveyor to down-line equipment.

Retarders, brakes, and clutches are also used. Pneumatic components are applied for product stops as well as starting and stopping controls for conveyor sections and for deflectors and diverters. Controls and sensors systems, used in conjunction with conveyors, are elaborate and often under computer or programmable controller direction.

## Belt Conveyors

A belt conveyor consists of a large head and tail pulley with a belt stretched between them. Between the head and tail pulleys is a bed of polished steel or of spaced free-running rollers. The belt either slides on the steel surface (slider bed) or runs on the rollers (roller bed).

A conveying surface may also be made up of various kinds of belts running side by side. These may be round elastomeric belts, V-belts, round spring steel belts, or narrow flat belts. Belt conveyors sometimes include curved sections, which can be either slider or roller bed types.

Roller-bed conveyors are more popular than slider-bed types because they can carry greater weights with less friction. Slider-bed belts tend to slow down as weight increases due to friction between the back of the belt and the bed.

Belt conveyors are most often used to move material up or down a grade. Here the friction between the product and the belt keeps material in place.

## Belts

The only significant difference between roller and belt conveyors is the belt itself. There is great variety in belting because of the range of situations encountered.

Belt material ranges from stainless steel to woven cotton or woven wire. In some cases it is thin and flexible as paper; in others, as stiff as 1/8-inch plywood. The material may have to withstand the heat of bakery ovens, the abrasive action of shot-blast tunnels, or the solvent spray of parts washers. High impact may also be encountered where material is dropped onto the belt. Belts also have to withstand continuous pull without stretching significantly.

Hinged belts consist of metal or plastic plates, hinged at the edges, to form a rigid member that will



# Bearings

As with any other power transmission system, a linear motion system must be supported and guided. Forces generated by bearings for the system to remain stable. For information on bearings for rotary systems, see Chapter 2.

Linear-motion bearings are of many types, some much like rotary bearings. Those used for linear motion applications generally are classified as either plain or rolling-element bearings. With plain bearings, surfaces slide on each other or on a lubricant film between them. With rolling-element bearings, either balls or rollers between moving surfaces provide low-resistance rolling friction instead of sliding friction.

## Plain Bearings

The simplest linear-motion plain bearing, the flat way, is perhaps the oldest device that lets one machine element, such as the bed of a planer, move easily on another. However, it is difficult to make such a bearing so that it has nearly perfect flatness over a long distance. Early machine ways were hand-scraped to remove high spots. The flat way must also have a means to keep the payload from running off the edge due to a transverse load. A common method is to provide not one flat surface, but two, butted at an angle to each other to form one V-shaped way. A companion V-shaped way mates with it. Dovetail ways are a variation of the V-shaped way.

Replacing the flat way with a cylinder and making the companion moving piece a cylindrical rod results in a sleeve bearing. Now, however, short, well-aligned sleeve bearings can be used in series to support linear-motion devices.

Though such bearings look like the type used to support and guide rotary motion, they support axial motion instead. A major difference: the hydrodynamic oil film "wedge" that develops between a rotating shaft and a sleeve bearing above a certain speed isn't present when the shaft moves axially. Well-lubricated linear-motion sleeve bearings serve well at low speed.

Linear sleeve bearings differ in the type of bearing material. Common bearing bronzes and graphites are often used. So, too, are metal sleeve bearings with solid-lubricant inserts. Another type is the ceramic lin-

ear bearing — a metal sleeve coated with a hard ceramic. Solid plastic or metal-backed plastic sleeve bearings are also in common use.

## Rolling-Element Bearings

Lower friction and, thus, higher speed capacity can be achieved by substituting rolling-element linear bearings for plain linear bearings. For example, putting rolling elements between the mating surfaces of a simple flat way reduces friction. With proper restraining systems, the elements can be either balls or rollers.

Likewise, balls and rollers are used in more complex systems such as V and dovetail ways. Also, the flat way assembly can evolve into a box beam arrangement with cam-follower bearings or similar bearings on the sides to guide a carriage along the length of the beam. All these devices are used in various applications, depending on precision, complexity, and cost constraints.

**Ball bearings.** Perhaps the simplest type of rolling-element linear bearing is the linear ball bearing. Figs. 10-20 and 10-21 show a basic arrangement, with recirculating balls that travel an oblong path. A linear ball bearing has three or more oblong circuits of balls. Each circuit holds balls in one of its straight sides in rolling contact between the shaft and the bearing race. The load rolls along the balls in this part of the circuit. Balls in the rest of the circuit circulate freely within the sleeve clearance. A retainer guides the balls and keeps them from falling out if the bearing is removed from the shaft. Thus, the retainer makes the linear ball bearing as easy to handle and install as a plain bearing.

Life expectancy and shaft hardness influence the load capacity of a linear-bearing-and-shaft combination. Life expectancy is expressed as total inches of linear movement between bearing and shaft. Manufacturers' catalogs give normal and maximum rolling load ratings. Generally, they are based on a travel life of 2 million in.

In some cases, a linear ball bearing is a continuous cylinder encompassing the shaft and in others a cylinder that is split axially. The latter is preloaded on a shaft

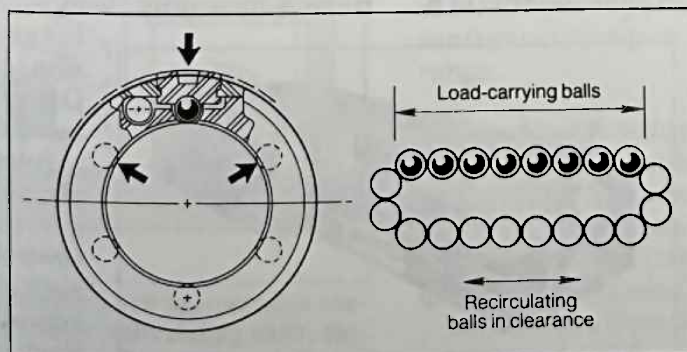


Fig. 10-20 — Ball arrangement in a recirculating linear ball bearing.

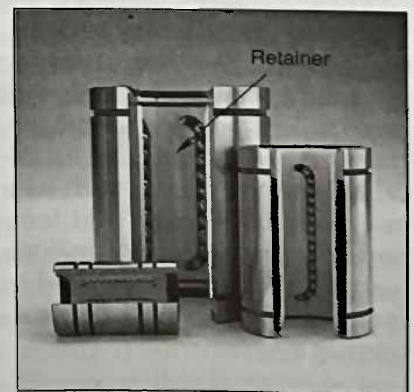


Fig. 10-21 — Typical linear ball bearings have a retainer to guide balls and keep them in place.



when the bearing is forced into an interference-fit housing. Some linear ball bearings have "rolling keyways." Balls roll in a semi-circular-cross-section axial groove that prevents the bearing unit from rotating on the shaft.

A variation of the linear ball bearing is the linear-and-rotary unit, made up of a sleeve that holds a cylindrical array of balls in contact with the shaft and housing. This construction permits individual or simultaneous linear and rotary movement — a combination needed in many applications.

**Roller bearings.** Precise, high-load, linear travel can be obtained in many applications by using linear roller bearings in place of ball bearings. Rollers pass over a flat channel, rolling in line contact between channel and load. At the end of the channel, rollers recirculate, running unloaded behind the channel to the other end where they again support the load.

Roller skewing can cause instability and high friction. To prevent it, precise roller end guides, central stabilizer bands, or similar means are provided.

Dynamic load capacity of linear roller bearings is generally quoted in terms of  $L_{10}$  life for a given travel life, such as 10 million in.

## Positioning Systems

Slides, stages, and tables are all devices for ensuring precise motion in one or more directions, and positioning of a load. Positioning systems come in two basic types, manual and motorized.

### Manual Systems

These systems are used in labor-intensive manufacturing, laboratory testing, or other applications calling for direct operator interaction. There are two primary types, slides and stages. A slide consists of a bearing system, base, and carriage. A stage includes an integral manual drive such as a micrometer or crank that temporarily positions and locks a load. Stages can be stacked to make two or three-axis positioning systems.

### Motorized Systems

Linear positioning systems that are motor-driven come in

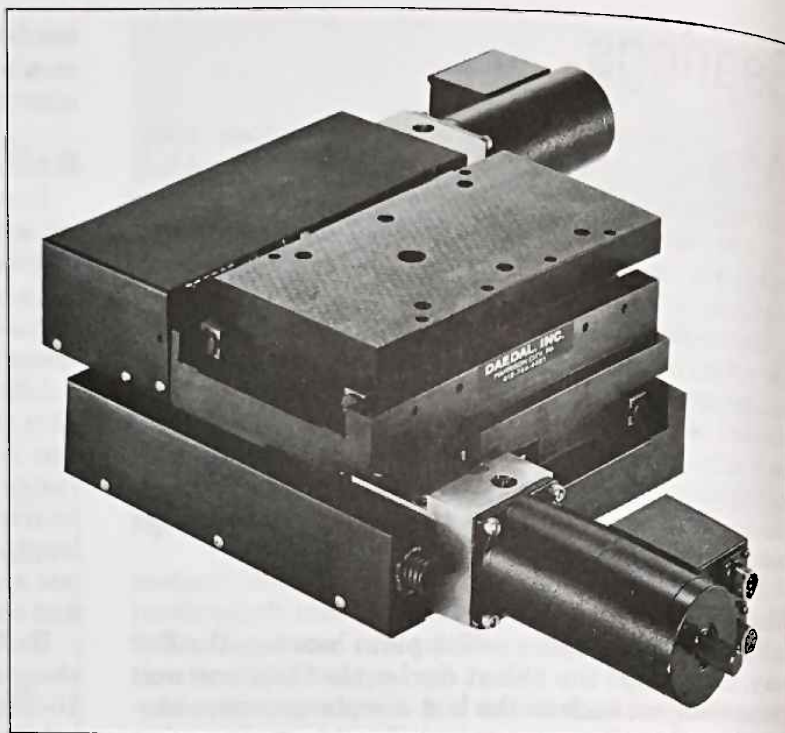


Fig. 10-22 — Two-axis cross-roller table with ground ball screw handles up to 1,200-lb payload with positioning accuracy of 0.00005 in./in. Side drive minimizes height.

four basic types: nonrecirculating ball bearing table, cross-roller table, linear ball bearing system, and linear motion guide bearing system. Each type has four basic parts — base, tabletop or carriage, bearing system, and a drive mechanism, typically a screw and nut.

There are many table configurations. The most common are multiaxis XY tables, which provide linear motion in two perpendicular directions, Fig. 10-22, and XYZ tables that move in three directions. But custom tables can have as many as 16 axes.

**Nonrecirculating ball bearing tables.** For applications that require short to medium (1 to 12 in.) travel with moderate load, a nonrecirculating ball bearing table, Fig. 10-23, is often cost-effective. Precision-grade versions have good accuracy and repeatability (typically  $\pm 0.00008$  in.) and a large carriage, which suits them well for carrying items with

large surface area such as film, circuit boards, or wafers. Other applications include laser cutting and welding.

Available in standard models, these tables have a base, movable carriage, and two rows of hardened steel balls on each side of the base to provide smooth, low-friction motion. Each row of balls is contained between four hardened and

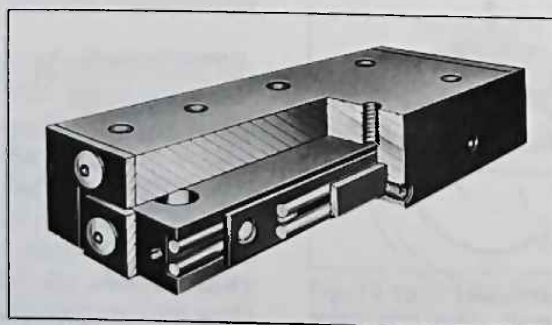


Fig. 10-23 — Nonrecirculating ball bearing table.



ground stainless steel rods — two mounted to the base, two to the tabletop. A cage or retainer holds and separates the balls. Most tables are self-cleaning and don't need lubrication.

**Cross-roller tables.** In general, cross-roller tables, Fig. 10-24, are used where loads exceed ball-bearing table capacity. Rigidity, fast settling time, and stiffness characteristics suit them well to applications with short, high-speed, repetitive contouring moves common in electron beam and laser welding. With a large footprint, the cross-roller table is used mostly for short to medium travel, typically 1 to 16 in.

Like the ball-bearing table, the cross-roller table offers smooth, low-friction motion and a large carriage. Rollers provide larger contact surface than balls, so the table is somewhat straighter and flatter and provides better load and moment capacity.

**Linear ball bearing assemblies (with bushing).** This system consists of a round, hardened steel shaft and a bushing with rows of recirculating balls. Load and travel are limited because the bushing fully encircles the shaft. Support is possi-

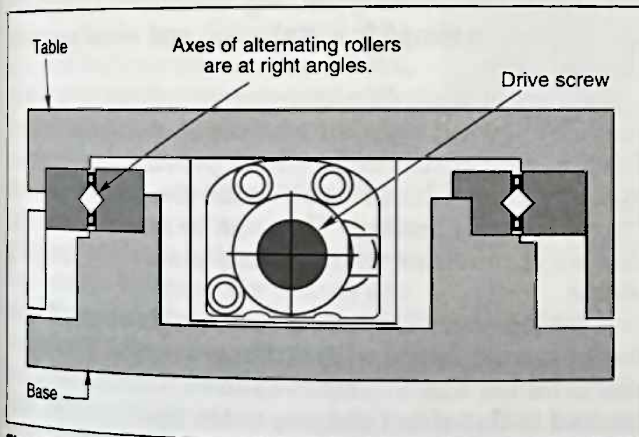


Fig. 10-24 — Cylindrical rollers in a cross-roller table provide more load capacity than balls.

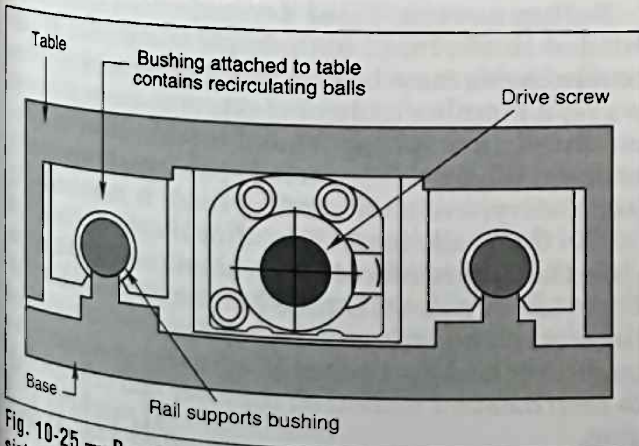


Fig. 10-25 — Bearing in a recirculating ball bearing table consists of a bushing, containing axially recirculating balls, surrounding a shaft. Partially open bushing allows bottom shaft support and full-length bushing travel.

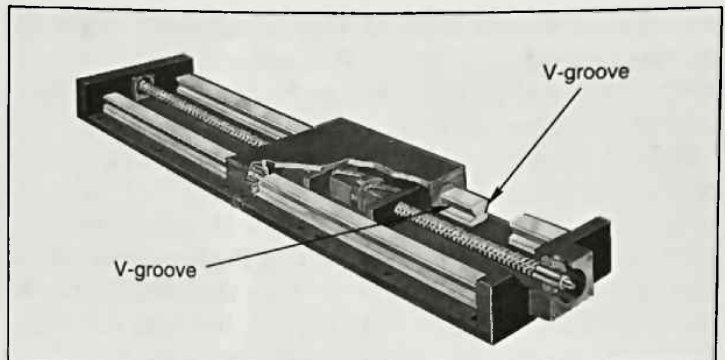


Fig. 10-26 — In a guide bearing system, V-grooves on opposite sides of rails carry recirculating balls. Arrangement allows long travel and high payload.

ble only at the ends.

A supported linear ball bearing rail table handles moderate payloads and provides moderate accuracy (0.0003 to 0.001 in./in.). Applications include: XY or XYZ systems mounted over tanks for dipping or ultrasonic testing, film-handling systems, robots that insert parts into ovens, and glass or plastics cutting.

Tables also come in a partly open bushing style, Fig. 10-25, that allows full-length shaft support, yet permits nearly unlimited travel. Such units typically achieve straight-line accuracy of 0.0002 in./in. with 100 to 200-lb payloads. Linear ball bearing systems have smooth motion, long life, and maximum speeds that can exceed 6,000 ipm.

**Linear motion guide bearing systems.** Typically, guide bearing systems handle heavy parts, such as castings and tires. The stiffness of such a system compared with that of the shaft and bushing system makes it well-suited for side drive table applications needing a large center opening — over a tank for ultrasonic testing, for example.

The linear guide bearing system, Fig. 10-26, consists of a rectangular rail with ground grooves along its length. The bearing block is filled with rows of recirculating balls that run against the rail grooves. Recirculation makes very long travel possible, with straight-line accuracy on the order of 0.00004 in./in. Payload is constantly supported, and with capacities of hundreds of pounds in all directions, multiaxis configurations position accurately over their full range.

### Drive Mechanisms

The drive mechanism for a table is typically a precision-ground ball screw, rolled-thread ball screw, or precision-ground lead screw. A precision-ground ball or lead screw positions within 0.0004 in./in.; a good quality rolled-thread ball screw, within 0.00025 in./in.

Lead screws typically come in 1 to 36-in. lengths; ball screws, up to 10 ft or more. Lead screw efficiency runs from 40 to 65%, a result of a friction-fit nut. A lead screw



## Associations that interface with the PT industry

**T**hese organizations create standards, or otherwise provide industry forums in North America for mechanical, fluid, and electronic power transmission components and systems or related materials and equipment.

**American Bearing Manufacturers Association (ABMA)**  
*formerly Anti-Friction Bearing Manufacturers Association*  
1101 Connecticut Ave., N.W.  
Suite 700, Washington DC 20036  
(202) 429-5155,  
Fax: (202) 223-4579

**American Chain Association (ACA)**  
932 Hungerford Dr., No. 36,  
Rockville, MD 20850  
(301) 738-2448,  
Fax: (301) 738-0076

**American Gear Manufacturers Association (AGMA)**  
1500 King St., Suite 201,  
Alexandria, VA 22314  
(703) 684-0211,  
Fax: (703) 684-0242

**American Institute of Motion Engineers (AIME)**  
Kohrman Hall,  
Western Michigan University,  
Kalamazoo, MI 49008-5064,  
(616) 387-6515;  
Fax: (616) 387-4024.

**American Iron & Steel Institute (AISI)**  
1101 17th St. NW, 13th Fl.,  
Washington DC 20036  
(202) 452-7100,  
Fax: (202) 463-6573

**American National Standards Institute (ANSI)**  
11 W. 42nd St., 13th Fl.,  
New York, NY 10036  
(212) 642-4900,  
Fax: (212) 302-1286

**American Society of Mechanical Engineers (ASME)**  
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New York, NY 10017  
(212) 705-7722,  
Fax: (212) 705-7674

**American Society for Testing and Materials (ASTM)**  
1916 Race St.,  
Philadelphia, PA 19103  
(215) 299-5400,  
Fax: (215) 977-9679

**American Supply & Machinery Manufacturers' Association (ASMMA)**  
1300 Sumner Ave.,  
Cleveland, OH 44115  
(216) 241-7333,  
Fax: (216) 241-0105

**Association of High Technology Distributors (AHTD)**  
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(215) 564-3484,  
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**Bearing Specialists Association (BSA)**  
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Bldg. C, Suite 20,  
Glen Ellyn, IL 60137  
(708) 858-3838,  
Fax: (708) 790-3095

**Canadian Standards Association (CSA)**  
178 Rexdale Blvd.,  
Rexdale, Ont., Canada M9W 1R3  
(416) 747-4000,  
Fax: (416) 747-4149

**Electrical Apparatus Service Association (EASA)**  
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Fax: (314) 993-1269

**Electrical and Electronics Manufacturers Association of Canada (CEEMA)**  
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Fax: (202) 457-4985

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Norwood, MA 02062  
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Fax: (617) 762-9375

**Fluid Power Distributors Association (FPDA)**  
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Cherry Hill, NJ 08034  
(609) 795-6113,  
Fax: (609) 795-6362

**Industrial Distribution Association (IDA)**  
3 Corporate Square, Suite 201,  
Atlanta, GA 30329  
(404) 325-2776,  
Fax: (404) 325-2784

**Industrial Fasteners Institute (IFI)**  
1717 E. 9th St., Suite 1105  
Cleveland, OH 44114  
(216) 241-1482,  
Fax: (216) 241-5901

**Institute of Electrical & Electronic Engineers (IEEE)**  
345 E. 47th St., New York, NY 10017  
(212) 705-7900,  
Fax: (212) 705-7182



**Instrument Society of America (ISA)**

67 Alexander Dr., P.O. Box  
12277, Research Triangle Park,  
NC 27709  
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Fax: (919) 549-8288

**International Electrotechnical Commission (IEC)**

3, rue de Varembe  
CH-1211 Geneve 20, Switzerland  
*U.S. Contact: American National Standards Institute*

**International Organization for Standardization (ISO)**

1, rue de Varembe  
Case postal 56  
CH-1211 Geneve 20, Switzerland  
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(704) 522-8644,  
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Fax: (301) 738-0076

**Metal Powder Industries Federation (MPIF)**

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**Power Transmission Representatives Association (PTRA)**

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Fax: (913) 262-0174

**Rubber Manufacturers Association (RMA)**

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Fax: (202) 682-4854

**Small Motor Manufacturers Association (SMMA)**

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Sherborn, MA 01770  
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Fax: (508) 651-3920

**Society of Automotive Engineers (SAE)**

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Warrendale, PA 15096-0001  
(412) 776-4841,  
Fax: (412) 776-5760

**Society of Manufacturing Engineers (SME)**

One SME Dr., P.O. Box 930,  
Dearborn, MI 48121  
(313) 271-1500,  
Fax: (313) 271-2861

**Society of Tribologists & Lubrication Engineers (STLE)**

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Park Ridge, IL 60068  
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