COUPLINGS & U-JOINTS

FLEXIBLE COUPLINGS A177
UNIVERSAL-JOINTS A182
FLEXIBLE SHAFTS A183
FLUID COUPLINGS A184
COUPLINGS AND U-JOINTS ADVERTISING A187

To transmit rotary power from one shaft to another, where both shafts turn about the same nominal centerline, you need positive coupling of the shafts. The coupling device can be a rigid assembly such as two matching shaft-mounted flanges bolted together, or a long rigid metal or nonmetal sleeve fitted over and locked to both mating shaft ends. Many rigid coupling designs are available.

The first part of this product department focuses on various types of flexible couplings, which are more popular than rigid couplings in power transmission applications. Some flexible couplings can accommodate up to about 3 deg of angular misalignment as well as limited lateral displacement between two shafts. Though not covered here, composite shafts are becoming popular for connecting machinery and motors that are separated by large distances. Cooling tower drive shafts are a typical use.

Universal joints, which are covered in the second part, are a common solution to misalignment where the centerline of one shaft relative to another is expected to vary more than 3 deg. U-joints can transmit power through angles as high as 30 or 40 deg even at high speed.

Flexible shafts are commonly used to transmit rotary motion and light loads around obstacles. Covered in the third part, these shafts can make up to 90 or 180-degree turns to connect components that are not aligned.

Another type of device used to connect a driving shaft to a driven shaft is a fluid coupling, discussed in the fourth part. It must be used in combination with flexible couplings or U-joints to handle any anticipated axial alignment variations or misalignment problems. Though they do couple shafts, their main functions are to provide low starting load (soft start) and torque limitation (overload protection) through slippage. In effect, fluid couplings are slip clutches.

FLEXIBLE COUPLINGS

An obvious function of a flexible coupling is connection of a driving shaft or flange element with an adjacent in-line driven member. The selected coupling must transmit rated power efficiently and meet torque, speed, acceleration-deceleration loading, and other duty-cycle requirements. It must flex enough while rotating to accommodate, within limits, undesirable effects caused by axial misalignment, shaft end movement, and vibration between connected members. Also, sound absorption between driving and driven elements is essential in many applications, such as home appliances, office machines, and computer systems.

Function and design checklists

Before selecting a coupling type, tabulate desired coupling functions using the following checklist:

- Transmit power through mechanical shaft joining.
- Permit angular, axial, parallel, or combination misalignment.
- Permit rapid original and subsequent alignment checks.
- Permit spacer-type or radial-type disengagement (preferably without disturbing shafts).
- Provide failure warning.
- Operate in severe environments (such as oil, heat, or vibration).
- Provide torsional vibration isolation and damping.
- Permit adjustment of torsional stiffness.
- Endure momentary overload, overspeed, or high vibration level.
- Allow lateral shaft support.
- Limit load and vibration produced by misalignment.
- Provide torque limiting.

Key design criteria for flexible couplings can be established with this checklist:

- Coupling functions from preceding list.
- Safety in operation and failure.
- Weight and space.
- Ease of maintenance.
- Aesthetic appearance.
- Near constant velocity operation.
- Vibration and noise isolation and damping.

More than 80 companies manufacture one or more types of flexible couplings. They can be classified under one of the following four categories:

Mechanically flexible — Couplings in this category obtain their operating flexibility from the rolling or sliding of mating parts, which usually require lubrication. Basic types include spindle, gear, chain and sprocket, grid, disc, metallic beam, and bellows (Figures 1 to 7), plus uni-

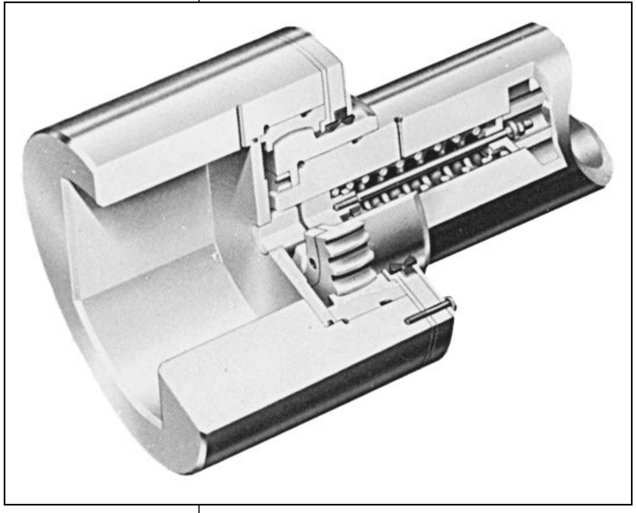

Figure 1 — Mechanically flexible spindle coupling.

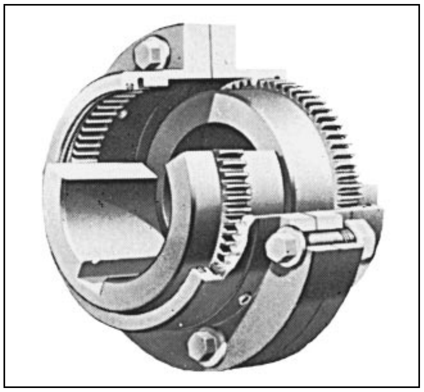

Figure 2 — Gear-type, double-engagement, manually lubricated coupling.

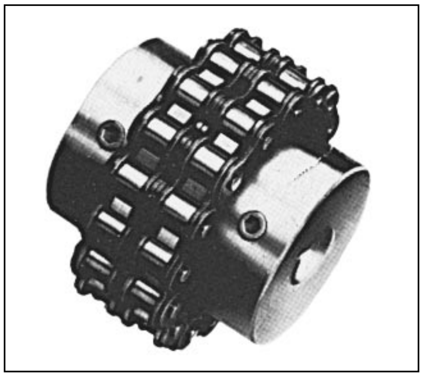

Figure 3 — Roller-chain-and-sprocket type flexible coupling.

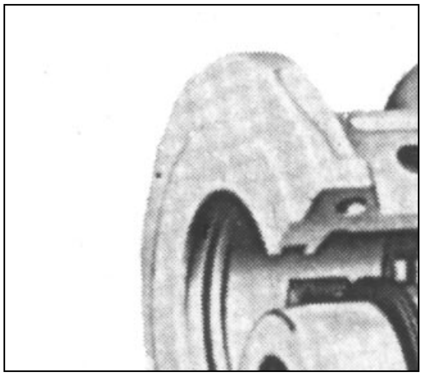

Figure 4 — Metallic grid coupling.

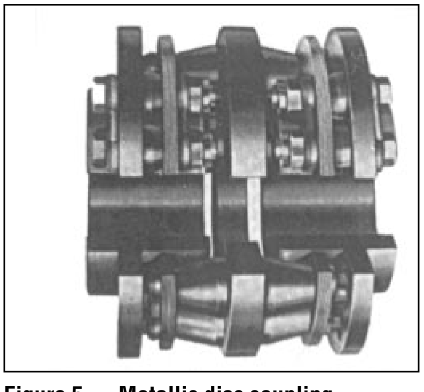

Figure 5 — Metallic disc coupling.

versal (U-joints), covered in a separate section.

Elastomeric — These types, Figures 8 through 12, obtain their flexibility from stretching or compressing a resilient material (rubber, plastic, etc.). Although some sliding or rolling action takes place, it is minimal. This coupling type requires no lubrication.

Metallic membrane — Figure 13 shows a metallic membrane coupling that uses metallic discs or diaphragms to provide flexibility. These types do not require lubrication.

Miscellaneous types — Flexibility characteristics of this group are derived from a combination of previously listed mechanisms that include pin-and-bushing, slider-block, and spring types. Many of these designs require lubrication.

Design details

Specific design and operating characteristics of the more popular mechanically flexible and elastomeric couplings are as follows:

Gear-type, double-engagement, unlubricated and lubricated — This coupling has two hubs with external teeth joined by an outer member with internal teeth Figure 2. Initial cost can be higher for this type of coupling compared with others, and lubrication affects life span, but if properly cared for, this coupling will produce a good return on investment. Tooth profile generation produces good misalignment characteristics if the applied service factor includes the known misalignment. This coupling can operate at high speed.

Roller chain and sprocket — The two sprockets and a length of double-strand roller chain that compose this type of flexible coupling, Figure 3, all mate and provide overall flexibility. The sprocket teeth and chain rollers are hardened to give high torque-carrying capacity vs. overall size.

Metallic grid — Multigrooved flanges accept a steel grid that weaves in and out through grooves in such couplings, Figure 4. The grooves are machined to form axially tapered teeth that allow room for the grid to bend during starting or peak load conditions. In comparison to elastomeric types these couplings have higher torque-carrying capacities for their size and generally higher stiffness.

Metallic disc coupling — This is one of the few all-metallic couplings that requires no lubrication. The inherent design, Figure 5, permits high-speed operation with good balance characteristics. Torsional characteristics are extremely stiff and allow this coupling to be used where backlash cannot be tolerated. Medium lateral and axial stiffness rates are obtained with two sets of discs, one at each end of the coupling, making it a true double-engagement coupling.

Metallic beam coupling — A helically curved beam is cut into a single, homogenous piece of metal in this type coupling, Figure 6. Two basic designs prevail: the first accommodates axial movement with angular and lateral flexibility, and the second provides for maximum torsional capacity where axial movement is not a requirement. Both designs are classified as torsionally rigid.

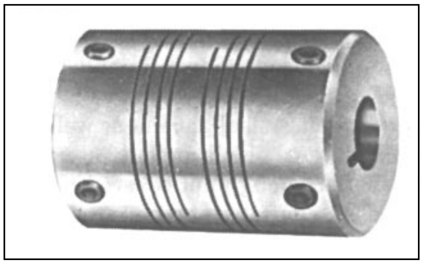

Figure 6 — Metallic beam coupling.

Bellows couplings — This coupling consists of a one-piece flexing element with end hubs, Figure 7, which provides both low windup and low side thrust. Bellows couplings typically provide torque capacities from 2 oz-in. to 20 lb-ft. Low-torque versions handle angular misalignment to 31 deg or parallel misalignment to 0.076 in.

Uses of bellows couplings range from light industrial power transmission applications to instrumentation. Precision motion control applications often use these couplings because they are both torsionally rigid, to accurately transmit rotational position,

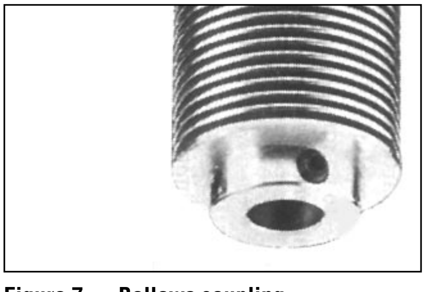

Figure 7 — Bellows coupling.

and laterally flexible, to accommodate shaft misalignment. In light industrial applications, for example, bellows couplings connect step motors and servomotors to encoders, resolvers, and tachometers.

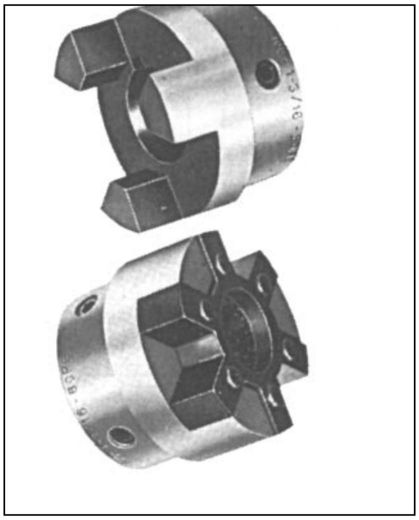

Figure 8 — Jaw-type elastomeric coupling with spider.

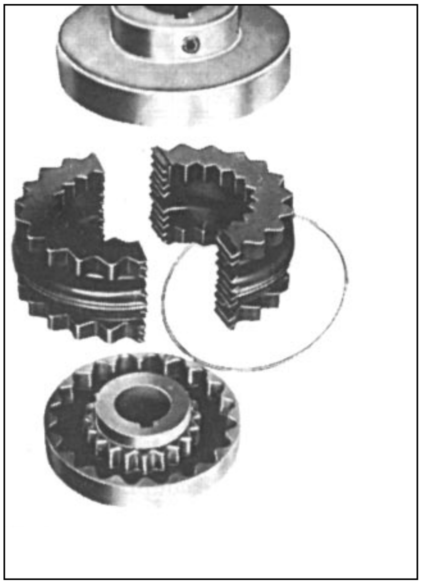

Figure 9 — Elastomeric donut-type coupling, unclamped.

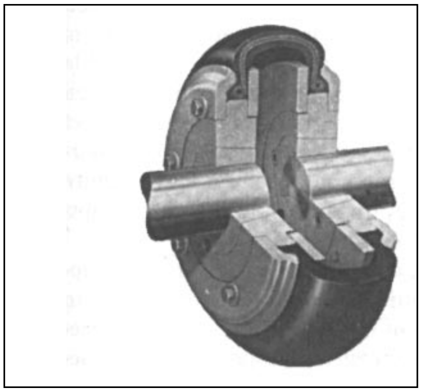

Figure 10 — Elastomeric tire coupling, clamped.

Peripheral coil spring couplings — Couplings of this type are designed to control torsional vibration. They have coil springs around the periphery of the coupling. They feature constant torsional stiffness controlled for precise torsional tuning and no stiffness variation with loading. The springs are always under compression and there is a wide selection of torque and stiffness ratings. Axial stiffness of the couplings is low and no lubrication is required.

Jaw-type elastomeric — Couplings of this type, Figure 8, have elastomers in flexing compression. The flexing elements can be a one-piece design for lower power applications, or there can be individual load cushions for medium and higher power applications. Elastomeric elements are made of many types of rubber and to varying degrees of hardness to suit load carrying capacities or system torsional characteristics. Torsional stiffness, torque capacity, and overall major dimensions can be further altered by increasing or decreasing the number of jaws, jaw width, or jaw diameters to suit the application.

Elastomeric donut-type, unclamped — These couplings transmit torque through shear loading of the element, Figure 9. With a rubber element, the coupling provides low torsional stiffness and low lateral force caused by misalignment. Torsional and lateral stiffnesses for a given coupling size generally increase as load capacity increases.

Elastomeric tire, clamped — Couplings of this type, Figure 10, have reinforced flexing elements at the outermost radii, permitting a small ratio of overall length to torque capacity. Internal reinforcement and external clamping of the tire increases the torque capacity and overall stiffness over that of a comparable unclamped and unreinforced shear unit of the same package size.

Elastomeric donut, clamped or restrained — Such couplings, Figure 11, have elastomeric donuts that are in a precompressed state because of the dimensional tolerance of the mating components. Cap screws force the donut to a smaller diameter. All legs of the donut are in compression before the load is applied. Low torsional and lateral stiffness are inherent in this design.

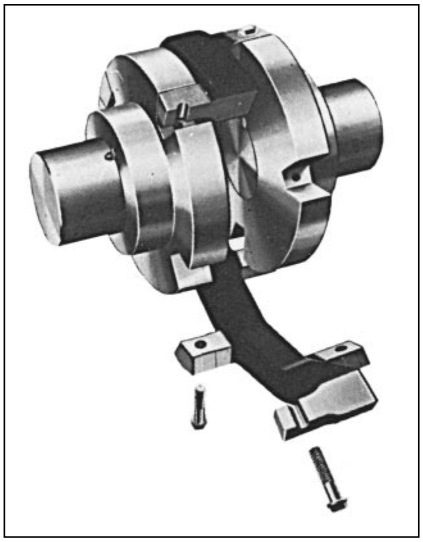

Figure 11 — Elastomeric donut-type coupling, clamped or restrained.

Elastomeric bushed type — These couplings were designed for connecting high inertia drives to low inertia driven members, such as

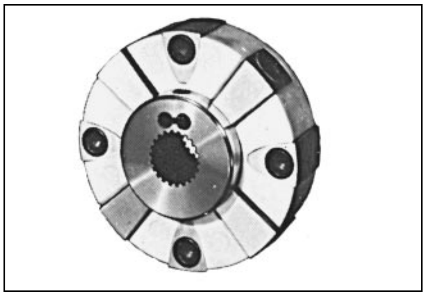

Figure 12 — Elastomeric bushed coupling.

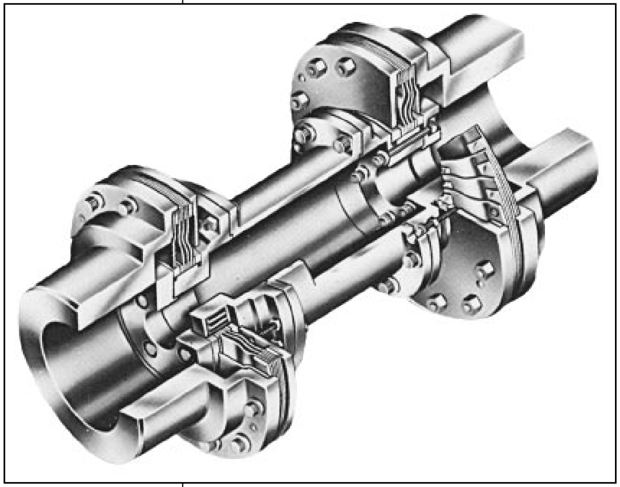

Figure 13 — Metallic membrane coupling.

diesel engines to hydrostatic pumps. The material of the elastomeric element, Figure 12, is selected to produce a torsionally stiff coupling with good thermal stability. High permissible rotational speeds are attained and minor misalignments can be accommodated. The hardware design allows a building block approach to coupling application.

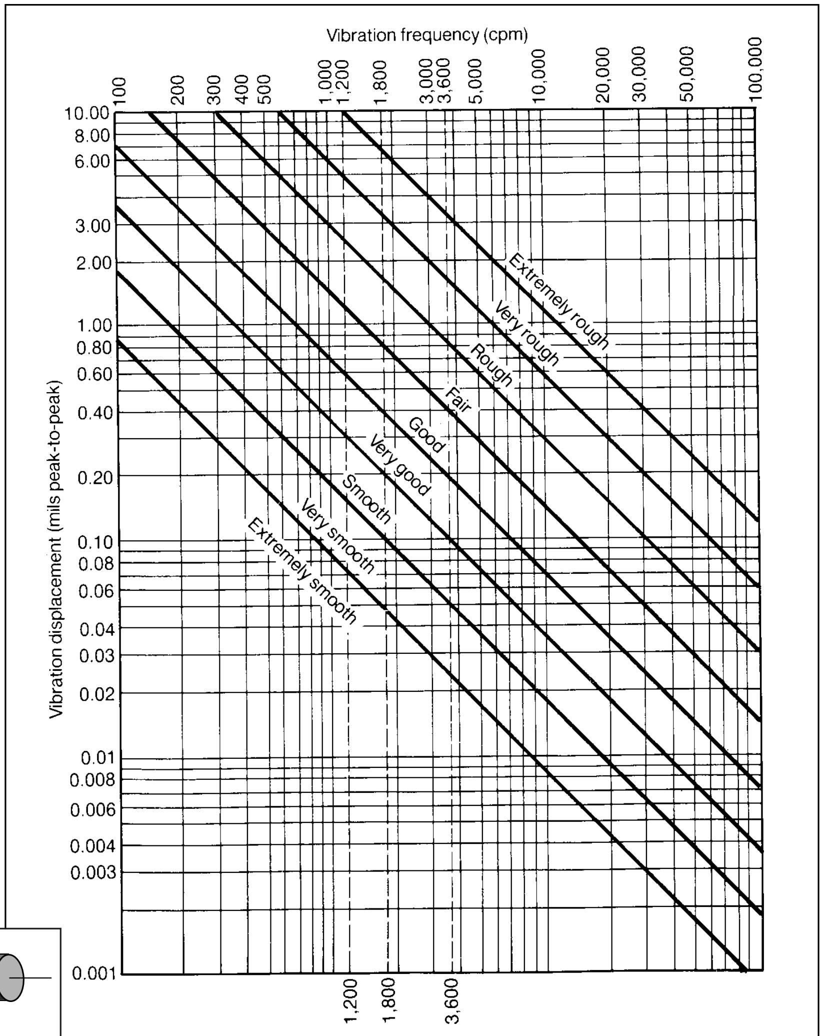

Figure 16 — General machinery vibration severity chart.

Selection factors

An engineering analysis of three key design factors should be done before making a final selection of a flexible coupling to connect a driving shaft to a driven shaft. Those factors are:

- Lateral load caused by coupling misalignment (lateral displacement).
- Cyclic variations with lateral load (lateral vibration).
- Limits of system imbalance.

Lateral loading — As the lateral load imposed by lateral displacement (parallel offset or angular misalignment, Figure 14) of the flexible coupling increases, the stiffness of metallic flexing members can cause a sharp rise in the force required to maintain the induced misalignment. Test measurements should be taken, if possible, with several representative couplings, Figure 15.

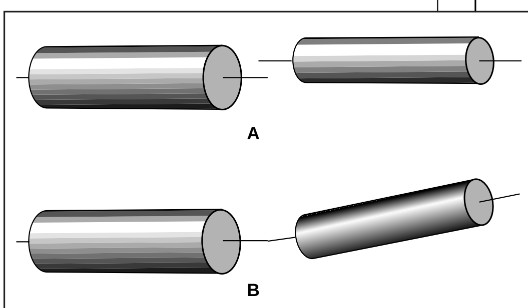

Figure 14 — Types of shaft misalignment include parallel offset, A, and angular, B.

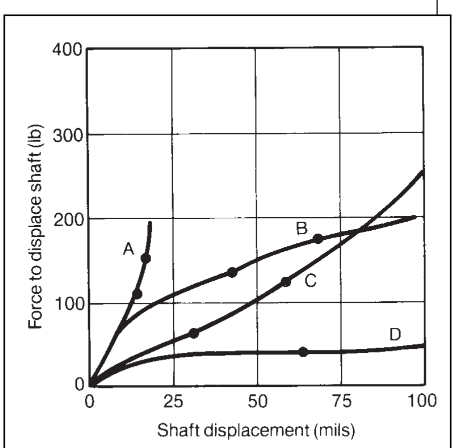

Figure 15 — Forces caused by coupling misalignment.

Because adjacent bearings of the driving and driven members are fixed, they must bear the full load forces developed by misalignment. Obviously, couplings that require the least force to misalign will impose the least radial bearing loading when shaft misalignment conditions are encountered.

Lateral vibration — Cyclic variation in lateral loading of flexible couplings is better known as lateral vibration. To evaluate this parameter, measurements must be made of peak-to-peak lateral vibration at the bearings of driving and driven shafts caused by various amounts of misalignment. A vibration severity chart, such as shown in Figure 16, can determine allowable values of misalignment based on a given lateral vibration criterion. Vibration measurements of several couplings can determine which one suffers the least increased vibration with increased misalignment.

Inherent balance — The third important flexible coupling parameter deals with inherent balance in the system and the amount of permissible imbalance. The designer must determine exactly how much imbalance a given machine system can tolerate. Plots of vibration displacement for flexible couplings under consideration, such as those in Figure 17, can help select one that is acceptable in this important system balance region. In Figure 17, Couplings B, C, and D are acceptable; Coupling A is not.

The designer must specify what upper limits of imbalance (measured in terms of unbalanced mass, eccentricity, or vibration response) will be acceptable. Charts involving a measure of mass unbalance as a function of rotational speed for the entire system

Table 1 — Physical properties and relative performance of elastomers. (Controlled Rubber Products, Inc., South Haven, Mich.)

Elastomer (in order of relative cost from low to high)	Resilience	Compression set	Abrasion resistance	Impact resistance	Electrical resistance	Impermeability, gas	Aliphatic (gasoline, kerosene, etc.)	Silicates (hydraulic fluids)	Phosphates (hydraulic fluids)	Aromatic hydrocarbons (benzol, toluol, etc.)	Ozone resistance	General weathering	Recommended high-temperature service range, F	Recommended low-temperature service range, F	Water resistance	Flame resistance
SBR (styrene butadiene)	A	A	E	E	E	A	NR	NR	NR	NR	NR	NR	180	−60	E	NR
IR (synthetic polyisoprene)	E	A	E	E	E	A	NR	NR	NR	NR	NR	NR	180	−60	A	NR
EPDM (ethylene propylene)	A	A	A	A	E	A	NR	A	E	NR	E	E	>300	−60	E	NR
NR (tree-grown rubber)	E	A	E	E	E	A	NR	NR	NR	NR	NR	NR	180	−60	A	NR
BR(polybutadiene)	E	A	E	A	E	A	NR	NR	NR	NR	NR	NR	200	> −100	E	NR
IIR (isobutylene isoprene)	NR	A	A	A	E	E	NR	NR	A	NR	A	E	300	−50	A	NR
CR(chloroprene)	E	A	E	A	A	A	NR	A	NR	NR	A	E	240	−40	NR	A
NBR (nitrile butadiene)	A	A	E	A	NR	A	A	NR	NR	A	NR	NR	250	−60	E	NR
Chlorosulfonated polyethylene	A	A	A	A	A	E	NR	A	NR	NR	E	E	>300	−40	A	A
Polysulfide	NR	NR	NR	NR	A	E	E	NR	NR	E	E	A	250	−60	E	NR
Polyacrylic	A	A	A	NR	A	A	A	A	NR	A	E	E	350	−20	NR	NR
Epichlorehydrin	A	A	A	A	A	A	A	A	A	A	E	E	300	−60	A	A
Urethane	E	E	E	E	A	A	E	NR	NR	E	E	E	240	−60	E	A
Silicone	A	E	NR	NR	E	A	NR	NR	A	NR	E	E	500	> −100	E	A
Fluorosilicone	A	A	NR	NR	A	A	E	E	E	E	E	E	400	< −100	E	E
Fluorocarbons	NR	E	A	NR	A	E	E	A	NR	E	E	E	>400	−10	A	E

E = excellent A = acceptable NR = not recommended

can be made. But system balance specifications must be established before individual component balance specifications (that could lead to great increases in component part costs) are set.

Torsional system compatibility must be considered by the designer who works with a high-volume production product. In reality, coupling selection for a power transmission system involves analysis of its dynamic torque capacity. Dynamic torque (stress reversal) and torsional critical speeds must be considered along with the apparent static load carrying ability. Because torsional stiffness can be adjusted by selection, the coupling is usually the link that ensures the dynamically compatible system. Such systems operate at speeds that do not induce resonance, or they have enough damping capacity at critical speed to control vibration response. In short, systems that are dynamically compatible need low service factors, tend to be trouble-free, and have long service life.

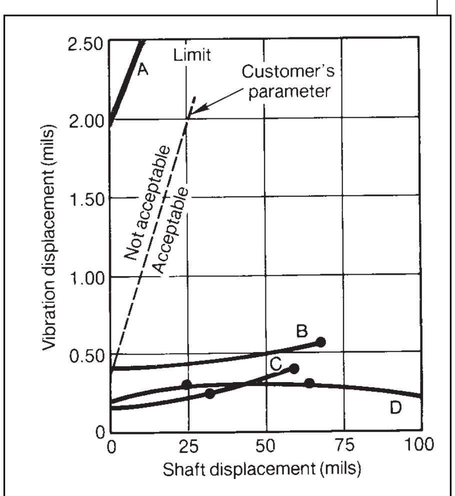

Figure 17 — Vibration displacement caused by coupling.

Why couplings fail

Excessive misalignment can destroy flexible couplings too soon. Although all rotating drive shafts operate better when they are well aligned, misalignment data on each specific coupling are most useful when something goes wrong. Substitution of a very flexible mechanical coupling for sloppy drive shaft assembly procedures is usually false economy in the long run.

A number of telltale marks can be found in detailed fault diagnosis of coupling failures. Check the hardware and the flexing member carefully. Whether the flexing member is metallic or nonmetallic, study hubs closely. Here are some symptoms along with possible causes:

1. Does the bore of a fractured hub show galling marks?

- The bore was undersized for the shaft and was forced on. If so, look for force marks on exterior surfaces.
- The hub was cocked when positioned. If so, look for rolled-up metal flakes in the bore, and exterior hammer marks.

2. Does the hub keyway show deformation?

- If the keyway is extended radially in only one direction of rotation, consider overload or frequent high starting torque.
- If the keyway is extended in both directions of rotation, consider a bad key fit for a reversing load.
- If the keyway is deformed for only a portion of its length, consider a

short key or a slipped key.

3. Do bore internal markings indicate that the hub was not engaged with the shaft over its full length?

● When a hub is not fully on the shaft through the length of the bore, there is inevitably a telltale ring mark of grease, dirt, rust, or fret.

4. Do the bore, keyway, or connecting bolt holes have a rippled-sand appearance?

● If so, there was torsional vibration.

5. Do the outer peripheral jaws, bolt holes, and point of engagement show elongation or wear?

● There is probably excessive misalignment or torsional vibration.

If none of those tips offer a clue, the flexing member must by analyzed. For metallic members, the typical S/N (stress vs. number of flexures) curve applies. The nature of a flexible coupling subjects it to the rules of reverse bending fatigue. If ten million equivalent and continuous cycles can be obtained, prolonged life is insured. If ten million cycles have not been reached for the failed coupling, it would be safe to assume that coupling overload, excessive misalignment, or torsional vibration caused failure.

Metal necking down indicates that excessive misalignment has taken its toll. If fasteners that are part of the peripheral anchoring system of the flexing element are bent, it would indicate overload or misalignment. Torsional vibration can still be the culprit even if there are no telltale marks or neckdowns, and misalignment and apparent overload are ruled out.

For elastomeric flexing member failures, the investigative procedure gets more complex. There are many types of elastomers used in the various elastomeric couplings. Table 1 lists some of the most common, along with the relative performance data for each. Knowing exactly what material was used is important to determine the cause of failure.

There are many more indicators that can determine the cause of coupling failure, but they are best discovered by returning the broken coupling to the manufacturer with as much performance history as possible.

In reality, the flexible coupling is a mechanical fuse. Failure of that fuse (which is usually the cheapest component in the driveline) should be welcomed, since it indicates trouble in the drive system and averts major component failure. However, if coupling failure presents a potential hazard, as it could on a man lift or an overhead crane, be certain this aspect is discussed with the coupling manufacturer.

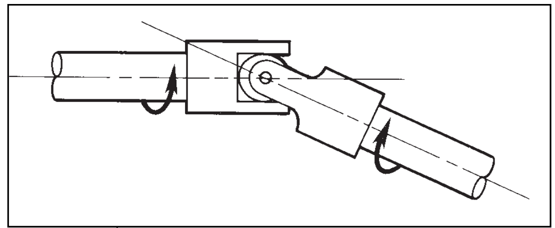

Figure 18 — Block-and-pin Cardan type universal joint.

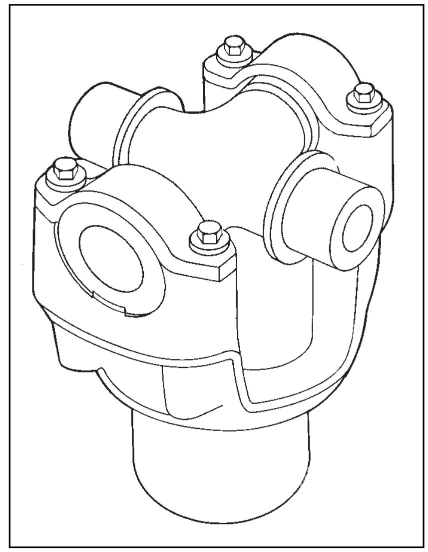

Figure 19 — Typical cross-and-bearing Cardan U-joint used widely in vehicles.

UNIVERSAL JOINTS

Universal joints, more commonly known as U-joints, allow positive transmission of rotating power at a much larger angle than is permissible with a flexible coupling. Millions of U-joints are installed each year in all types of power transmission systems. Thousands more are used to connect power take-off drive shafts in off-highway tractors that operate drawn machinery, such as rotary grass mowers, grain wagons with unloaders, feed grinders, etc. Likewise, U-joints are widely used in industrial applications.

Types of U-joints

Although many different mechanical arrangements for universal joints have been developed to transmit torque through an angle, they can be assigned to one of three categories: nonconstant velocity, near-constant velocity, or constant velocity.

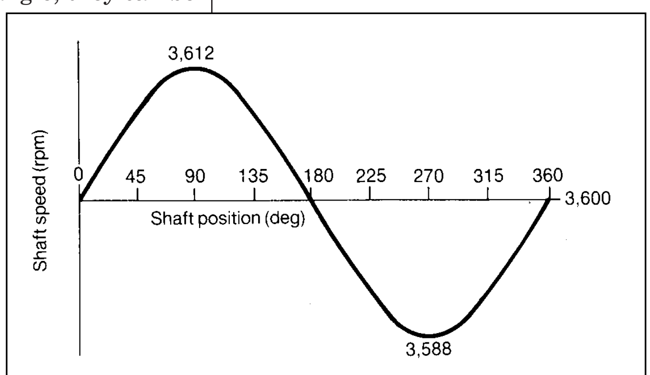

Figure 20 — Output speed fluctuation per revolution of Cardan U-joints with constant 3,600-rpm input speed and constant angular misalignment of 4½ deg.

Nonconstant velocity U-joints — This category of U-joints offers the simplest and least complex units. Originally called Hooke and later Cardan type universal joints, the units are either block-and-pin joints, Figure 18, or cross-and-bearing joints, Figure 19. The latter unit consists of two U-shaped yoke hubs joined by a cross-shaped piece with four trunnion bearings, each one fitting in each yoke arm. The main drawback of Cardan U-joints is the fluctuating output velocity produced during each cycle of revolution, Figure 20, which can cause a torsional vibration in the system. Reportedly, velocity varies 3% at 10 deg angle of input and output shafts, 13% at 20 deg, 29% at 30 deg, 55% at 40 deg, and 71% at 45 deg. Obviously, it is best to keep the input/output drive shaft angle under 15 deg unless used for manual or slow speed applications.

Typical applications are to join the drive shaft and differential in automobiles and trucks. They are also widely used in mobile equipment, farm machinery, and industrial machinery. Since the design cannot accommodate end movement, such U-joints must be mounted on a splined slip connection.

Small U-joints are available in single or double configurations with or without slip provision. Units for industrial applications are usually made of carbon steel whereas those made mainly for aircraft are fabricated of heat-treated alloy steel, bronze, or stainless steel.

Near-constant velocity U-joints — The most common type of joint that produces a near-constant velocity consists of two back-to-back Cardan joints, Figure 21, with the second joint compensating for the speed variations of the first. The double Cardan is made in two variations:

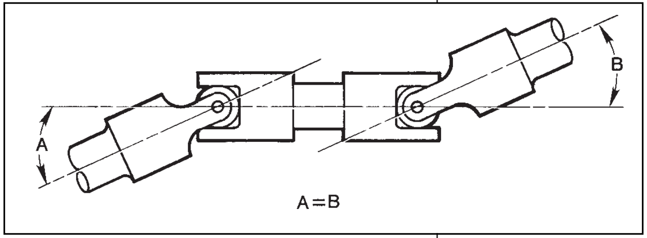

Figure 21 — Near-constant velocity double Cardan U-joint.

1. One design with an inside centering ball can handle a 15 deg shaft offset at high speed and 35 deg at low speed.

2. Another design with an outside centering ball can also handle a 15 deg shaft offset at high speed and 50 deg at low speed. Torque ratings can reach 8,000 lb-ft.

Constant velocity U-joints — Two types of these joints, which make heavy use of balls and rollers in their designs, are Rzeppa, Figure 22, and tripot, Figure 23. They are said to operate more smoothly and at higher speeds than the other two types because of their constant velocity characteristics. However, they are more complex and expensive, and do not carry loads as heavy as nonconstant-velocity types.

The Rzeppa can handle torque ratings up to 25,000 lb-ft, and the tripot, used mostly for vehicle front-wheel drives, is rated at 5,000 lb-ft.

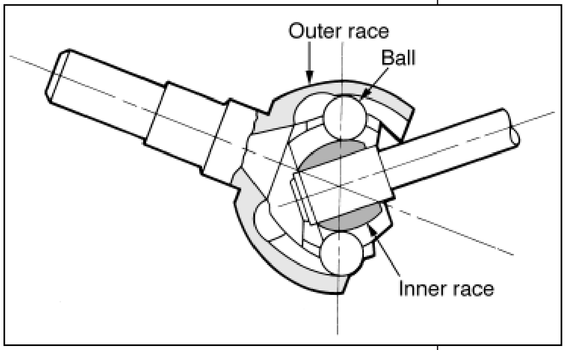

Figure 22 — Constant velocity Rzeppa U-joint.

FLEXIBLE SHAFTS

The path of the drive shaft is blocked and you need a way around the obstruction. Don't despair. Flexible shafts offer a simple and inexpensive solution to such power transmission problems.

Flexible shafts transmit rotary motion between two components that are not aligned. They are flexible enough to bend around obstacles, yet stiff enough to transmit motion and light loads. They can even make 180-degturns, Figure 24.

These shafts eliminate tight installation tolerances and difficult assembly procedures normally required with solid shafts. Typical applications include pump drives, power-seat mechanisms in automobiles, and conveyor drives.

Another common use is for machine control. In a typical application, a high-speed printing press has 12 large rollers that need on-the-fly adjustment. Originally, the roller adjustment screws were located less than 1/4 in. from fast spinning gears, and were only accessible through a maze of wires and pipes. A skilled technician made the adjustment, precariously lining up the long-bladed screwdriver with the adjustment screw.

Then the company installed flexible shafts for controlling the adjustments. Now, the process takes less time and eliminates the risk of mangling a screwdriver in the gears. It also enables more accuracy because the adjustment knob is located where the operator can better see the results as he makes the adjustment.

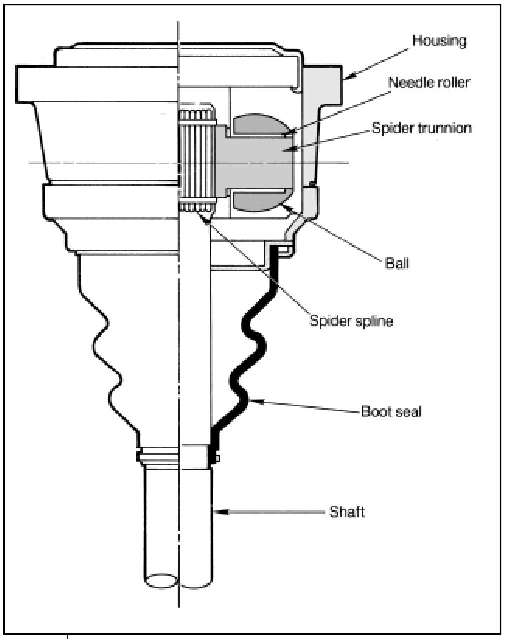

Figure 23 — Constant velocity tripot U-joint.

Figure 24 — Flexible shafts change direction and detour around obstructions in applications such as speedometers, conveyor drives, and power screw drivers.

Reasons to go flexible

A flexible shaft offers several advantages:

- Precludes the need for precision alignment that solid shafts and other drive components require. This saves machining and installation costs.
- Offers more positioning options for the motor, driving mechanism, and driven components.
- Offers more efficiency, 90 to 95%, than some traditional drive components.
- Accommodates offsets of 180 deg or more, whereas U-joints can handle about 30 deg, and flexible couplings, 5 deg.

- Offers a three-to-one weight advantage over other transmission alternatives.
- Absorbs shock and dampens vibration that could harm connected equipment.
- Enables driving and driven components to move freely relative to each other during operation. An example is a stationary motor attached to a flexible shaft and casing assembly (up to 10 ft long) that has a grinding or cutting tool attached.

Construction

A flexible shaft is built by wrapping several layers of spring-grade wire around a mandrel, Figure 25. Each successive layer is wound onto the shaft at an opposing pitch angle. End fittings are then applied for attachment to the connected machines. Engineers vary the wire diameters and the number of wires per layer to produce different bending flexibilities and torsional stiffness.

Figure 25 — A flexible shaft consists of several layers of wires wound around a mandrel in a specific sequence to obtain the desired characteristics.

Direction of rotation

Flexible shafts are classified as bidirectional and unidirectional. Bidirectional shafts transmit motion in both directions of rotation in applications such as remote valve controls, robotics, and aircraft actuators. These shafts typically have nearly comparable torsional stiffness and torsional strength in both clockwise and counterclockwise directions.

Unidirectional shafts are designed to operate in one direction of rotation only. They have bending flexibility, torsional stiffness, and ultimate torsional strength values that are generally higher than those for bidirectional shafts, but only for the direction of operation they are designed for. Common applications include motor couplings, speedometer cables, and power tools.

Making a choice

Selecting a flexible shaft is fairly easy once you understand its basic operation and performance limitations. These shafts are generally available in diameters ranging from 0.030 to 1.625 in. (excluding any outer casing). And, they sometimes offer a choice of bending flexibility and torsional stiffness for each diameter.

Before selecting a flexible shaft, answer the following questions:

- Does the application require bidirectional or unidirectional operation?
- In what direction will the shaft rotate, clockwise or counterclockwise, when viewed from the driving end? This determines the shaft construction required.
- What torque must the shaft carry? Torque capacities of flexible shafts range up to 5,000 lb-in. Shafts must be chosen for the maximum torque they will experience, which is usually the start up or stall torque rather than the running torque.
- What is the shaft speed? Those speeds under 100 rpm permit higher operating torque, usually twice the rated dynamic operating load.

Shafts up to 0.188-in. diameter operate at speeds up to 20,000 rpm, depending on the application. As a rule-of-thumb for large shafts (0.25-in. diameter and over), the surface speed should not exceed 500 fpm.

- How will the shaft ends be connected? There are many standard end fittings, including the often-used squared end, where shaft ends are formed into square fittings that mate with square-shaped receptacles.
- What is the minimum bend radius the shaft must meet? Torque-carrying ability is reduced as the bend radius gets smaller.
- If torsional deflection is a concern, how much angular deflection can be tolerated? This deflection is expressed as the twist per unit shaft length divided by the torque (deg/ft/lb-in.). Torsional stiffness and bending flexibility are inversely related. Therefore, achieving more torsional stiffness usually requires giving up some bending flexibility.
- How long is the shaft? An overly long shaft can cause excessive torsional deflection and decreased torque capacity.
- What are the environmental conditions? A hostile environment may require special shaft materials, such as stainless steel for corrosion resistance and temperatures to 600 F.
- Is a casing required? There are three reasons for placing a shaft inside a casing. First, a casing limits the tendency of the shaft to helix or corkscrew, particularly when length exceeds 12 to 14 in.

Second, the casing retains the lubricant that coats the shaft while protecting the shaft from dirt, corrosive chemicals, or impacts.

Finally, it shields the user from contact with a potentially dangerous high-speed shaft.

Excerpted from an article by S.S. White Technologies Inc. in the July 1993 issue of PTD.

FLUID COUPLINGS

As a method of transmitting rotational mechanical drive power. a fluid coupling, Figure 26, offers the advantages of soft starting of the load, torque limitation, and mechanical shock absorption — all with minimal energy loss. These drive function and design features are particularly important with hard-to-start loads, such as belt conveyors used to transport heavy bulk materials (ores, crushed stone, sand, coal, fertilizer, or grain) over long distances. Control of the conveyor is difficult because bulk materials present extremely heavy loads to a power transmission system driving motor, or motors. Fluid couplings allow the

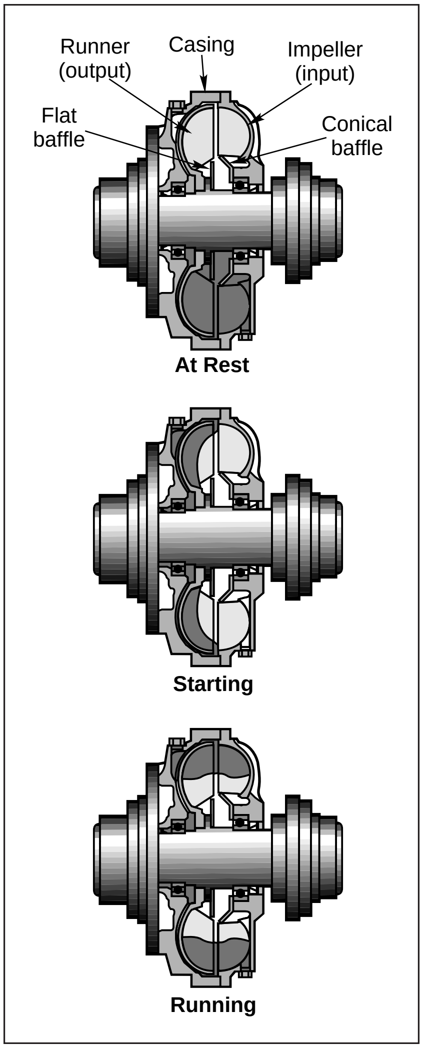

Figure 26 — Typical constant-fill fluid coupling operation.

motor or motors to come up to speed rapidly while gradually bringing the conveyor up to speed.

Couplings with a soft-cushioned start up, Figure 27, offer several beneficial effects to conveyor system designers.

First, because the motor can come up to full normal running speed quickly, the motor current draw peaks almost immediately and then rapidly tapers off to a much lower running current, Figure 28. As a result, the power factor is maximized and electrical energy to the motor is saved. With a non-slip type of coupling, current draw would remain high over a much longer period of time.

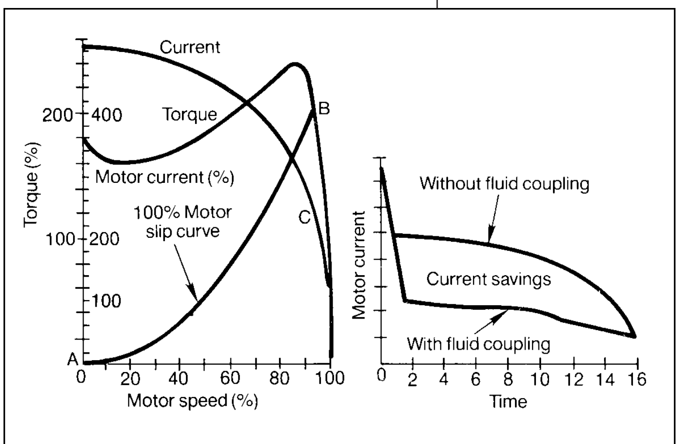

Figure 28 — Motor current draw at start up is reduced with a fluid coupling.

Second, the electric motor size can be precisely selected to carry the anticipated maximum conveyor load at peak motor operating efficiency. That means the motor can be sized to carry the load efficiently at running speed rather than being oversized to handle high-er, longer duration load current start-up demands.

Third, once the motor reaches running speed, the coupling characteristics of the fluid allow the conveyor to come up to speed slowly and smoothly without any unusual mechanical shock to the drive system. This soft start characteristic can be enhanced with fluid couplings designed with delayed filling chambers, which will be described later.

Principles of operation

In its simplest form, a fluid coupling consists of two hollow bowls with radial vanes, Figures 26 and 29. Note that one bowl is connected to the input shaft and the other to the output shaft of the coupling. When the input bowl is filled with fluid and rotated by the prime mover, centrifugal force causes the fluid to be flung outwards. This high velocity fluid impinges on the vanes of the output bowl, transferring torque to rotate the bowl and output shaft. One bowl, in effect, acts like a centrifugal pump or impeller, and the other acts like a turbine or runner. Rotating drive power is transmitted by the continuously circulating vortex of fluid — a kinetic type of rotary force. Because the motor at start-up needs to drive only the fluid within

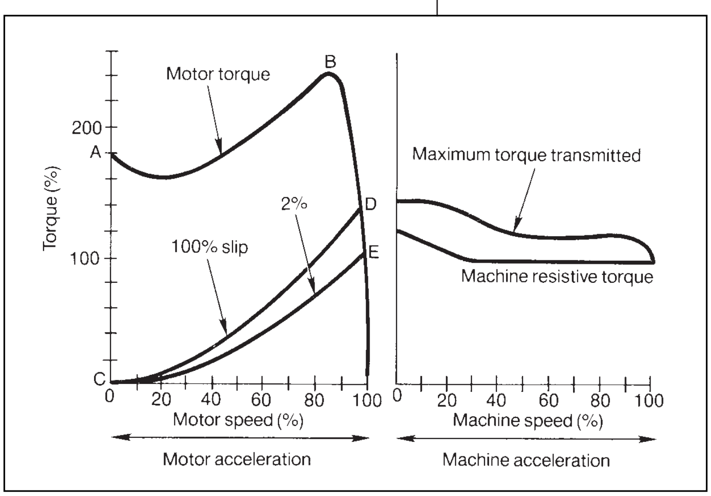

Figure 27 — Motor and fluid coupling speed/torque relationships showing soft-cushioned start up.

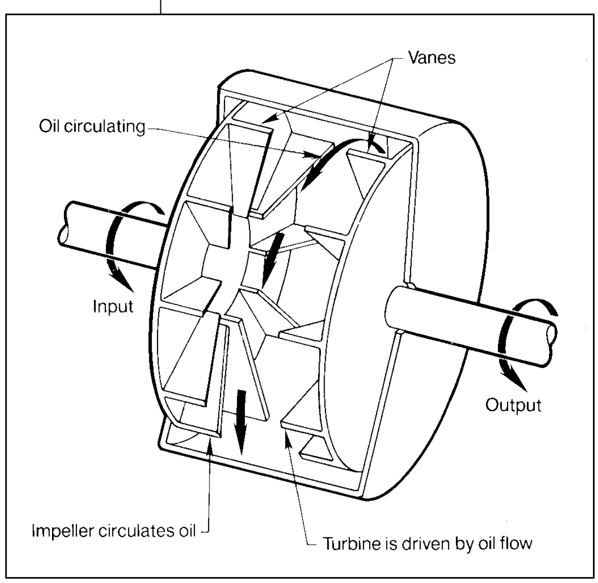

Figure 29— Simplified diagram showing fluid coupling principles of operation.

the impeller, the initial loading is light.

When fluid couplings are used on conveyor drives, the maximum torque applied can be limited to 150 to 250% of full load torque to help reduce the danger of belt "stretch." The same torque limitation benefits apply to other equipment prone to stalling or jamming, such as a rock crusher.

Fluid couplings make it easy to balance loads on multiple drive systems, as shown in Figure 30. Note that a small amount of oil can be added from one coupling or withdrawn from the other to decrease or increase in small amounts the relative slip and transmitted torque. Also, motors on multiple drive systems can be started individually because non-driven couplings can operate temporarily at 100% slip. The advantage of starting one motor at a time is the decrease in start-up current draw, which reduces the size and cost of switchgear needed.

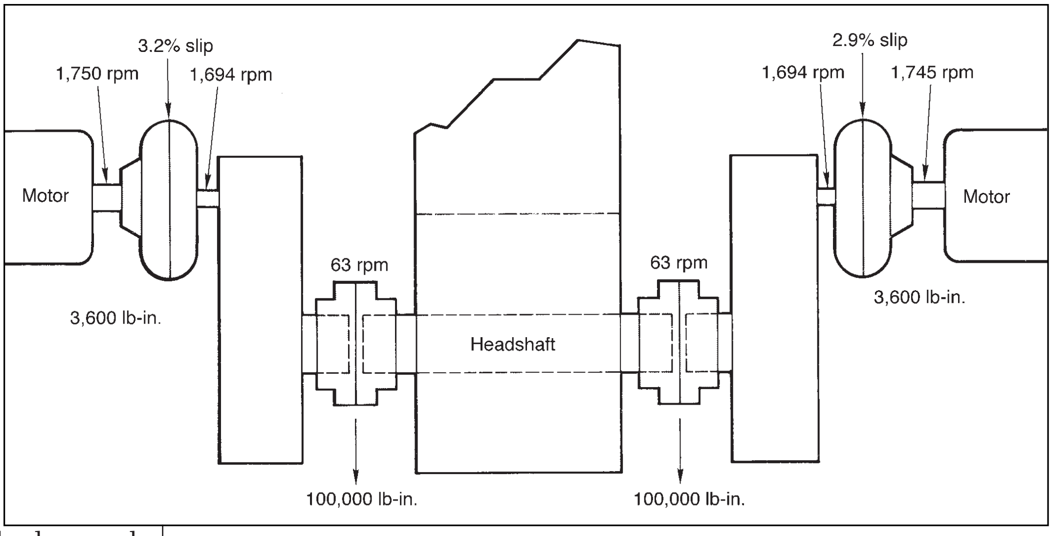

Figure 30 — Load balancing with fluid couplings on two separate drive motors.

Coupling Types

Constant-fill couplings — Torque development in a coupling is a function of the amount of fluid available in the working section of the coupling described previously and the speed of rotation. Most fluid couplings are constant-fill types, which have been described in detail.

Delayed-fill couplings — An interesting type of fluid coupling is a delayed-fill type. It is designed with a delayed filling chamber, where a portion of the total fluid in the coupling is stored in a reservoir while the motor is starting. Because less torque is developed in the coupling and transmitted to the load, a slower start of the load with a lower current draw can be achieved. As motor output shaft speed increases, centrifugal force gradually expels the fluid from the reservoir. The fluid travels through orifices between the outer diameter of the delay chamber and the primary wheel, which allows the coupling to eventually develop full torque when the entire volume of fluid is spun into action. This type of coupling offers excellent overload protection should a conveyor belt jam for a short period of time.

Variable-fill couplings — With variable-fill fluid couplings, the drive motor can be started and run without any load until fluid is introduced to the coupling by the operation of an external lever. This feature allows the coupling to operate like a frictionless clutch and an adjustable-speed drive with a smooth, radial acceleration or deceleration. The external lever can be operated manually or by automatic control devices. Output speeds can be adjusted over a 5:1 range for centrifugal equipment, such as industrial pumps, fans, and blowers, or a 3:1 range for constant torque equipment, such as crushers or positive displacement pumps.

Centrifugal lockup couplings — One drawback of a fluid coupling is the heat generated during operation because of the required slip between the input impeller and output turbine, which is necessary to make the coupling operate. High efficiency fluid couplings slip 2 to 4%, less efficient types as much as 7 or 8% . The slippage loss is only in the speed of rotation, not in output torque which is always approximately equal to input torque. However, it does create heat in the coupling and wastes a certain amount of energy.

A solution to these drawbacks, though not commonly used, is a combination fluid coupling with an internal, centrifugal-force-operated clutch. Lockup occurs at about 850 rpm and a l:l mechanical link between input and output takes effect.

Triangular shaped wedges operate three weights in the clutch that press against a friction lockup ring. If the load exceeds the lockup rating of the unit, rollers on the weights roll on the lockup ring, the turbine speed drops, and the unit operates like a fluid coupling. In the lockup mode of operation, it carries a higher load than a conventional fluid coupling of the same size.

Dry-fluid couplings — In application, a dry-fluid coupling, which consists of a metal housing that is keyed to a motor drive shaft and a belt drive sheave, is connected to the interior rotor member.

A measured flow charge of "dry fluid," consisting of heat-treated metal shot, is introduced into the housing chamber. When the motor is started, centrifugal force throws the flow charge to the perimeter of the housing, packing it between the housing and the rotor to eventually provide lockup to transmit rotating power to the load with no slippage. Like other fluid couplings, the motor accelerates under relatively light load, and gradually accepts full load without straining the motor, belts, bearings, shafts, or drive components. ■