Selecting couplings for large loads

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Engineering textbooks describe the design basics required in selecting shaft couplings. But they often overlook other important factors. This conveyor drive example gives an overview of the factors you should consider.

Selecting a coupling type for any drive application requires considering not only design concerns, but other factors related to maintenance, size, and cost. Depending on your area of concern, some of these may be easily overlooked.

Most engineers consider design parameters such as torque rating, service factors, speed, misalignment, and bore size in selecting couplings. But others who influence component selection have different priorities. Purchasing agents are concerned about price, delivery, and vendor support. Production or maintenance personnel give high priority to reliability, ease of installation, and maintenance costs.

To illustrate the many factors that a system design engineer should weigh in choosing couplings, we selected a bulk-material-handling belt conveyor application. In this example, a 150-hp motor operating at 1,750 rpm drives a double-reduction parallel-shaft gearbox with an output speed of 84 rpm. Couplings must be used to connect the shafts between motor and gearbox (high-speed section) and between gearbox and conveyor (low-speed section), Figure 1. The example considers four types of flexible couplings commonly used in conveyor applications: grid, gear, elastomeric, and disc, Figures 2 to 5.

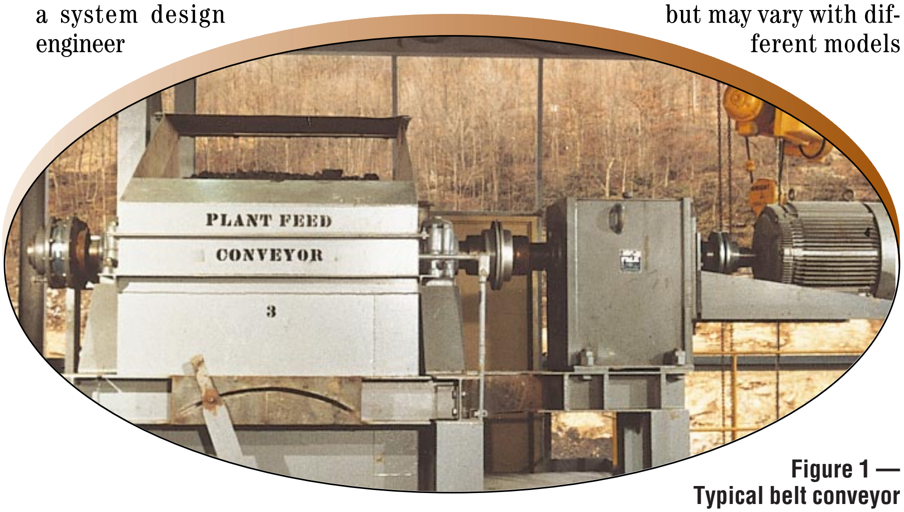

Figure 1 — Typical belt conveyor drive consists of (right to left) motor, geared speed reducer, and belt pulley (inside housing). Here, an elastomeric coupling connects motor to gearbox (high-speed shaft), while a grid coupling connects the gearbox and belt pulley (low-speed shaft).

The table lists the selection factors and coupling options, which are described in the following sections. Values shown for the different parameters (torque, service factor, etc.) are typical, but may vary with different models and manufacturers.

Though the example focuses on conveyors and specific coupling types, the same selection method applies to other high-torque applications and couplings.

Product selection simplified

Several coupling suppliers offer computerized coupling selection programs that consider many of the factors discussed here and include ratings and dimensions. A manufacturer may also have a companion program containing a library of parts drawings that can be imported into your CAD drawings.

Design considerations

This section briefly describes how each *design* factor listed in the table influences coupling selection. Cost and maintenance factors are covered later.

Torque rating. One of the key factors in selecting a coupling is its torque rating — the amount of torque that it can transmit. Another factor — also important — is the amount of torque it can transmit in a given size. This is called the torque density (sometimes called power density), which is defined as torque rating divided by OD.

Gear couplings pack the most torque capability in a small size. However, the maximum bore size of gear couplings generally limits their selection. After gear couplings, other types with metallic flexible elements, such as grid or disc, offer the most torque for their size. The elastomeric couplings considered in this example are of the rubber tire type that is loaded in shear. These couplings offer

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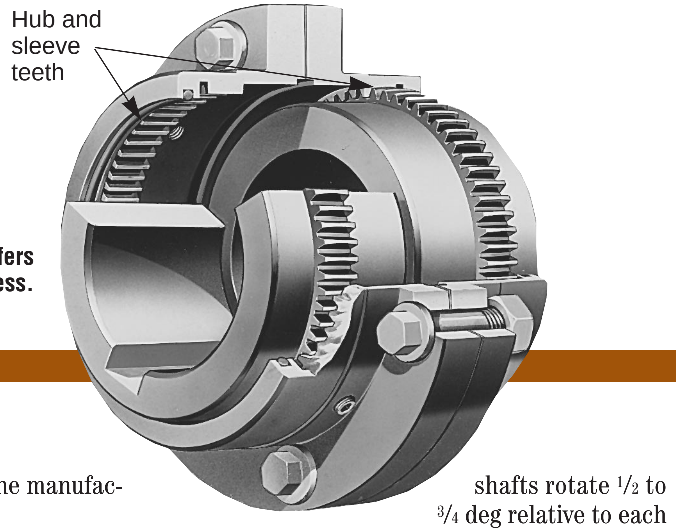

Figure 3 — Gear coupling offers highest load capacity and stiffness.

less torque capacity than the other types.

Service factor. Once the torque requirement has been determined for normal operating conditions, you need to increase the selection torque requirement to accommodate torque fluctuations in the particular application. To do this, engineers apply a service factor (SF), usually larger than 1.0, that indicates the perceived severity of the service. Higher numbers indicate more severity.

Unfortunately, coupling manufacturers don't agree on these values. Each manufacturer has developed its own SF values based on experience. The manufacturer's values also vary with the coupling materials, which range from carbon steel to elastomers and composite materials.

Almost all manufacturers rate their couplings for peak overloads of 200% of the catalog rating to accommodate motor start-up loads. But ultimate strength varies greatly among different coupling types and different brands. This variation often depends on the coupling materials.

To avoid the confusion of these different ratings, select coupling types that are field-proven in your type of service and recommended by the manufacturer.

Outside diameter. Large coupling diameters and long hub lengths often cause interference with base plates, piping, shaft fans, and coupling guards.

Below 50-hp capacity, the four coupling types have similar diameters. But, as torque and shaft size increases, couplings with metallic members (grid, gear, and disc) have smaller ODs than elastomeric types. This is particularly evident in our example, where the elastomeric coupling for the low-speed shaft is twice the diameter (24 in.) of the metallic couplings.

Weight. At 674 lb, the elastomeric coupling for the low-speed shaft weighs 500 lb more than a comparable gear or disc coupling. Such weights may induce deflections in the shafts of the connected equipment, and can cause vibration. Therefore, you should check the drive for the effect of such loading on shaft and bearings.

Moment of inertia. Where conveyor applications require controlled acceleration and deceleration, design engineers use coupling inertia values (wr^2) to properly size motors for start-ups and brakes for stopping. However, for belt conveyors that usually have long acceleration and deceleration times, the coupling inertia is seldom a problem.

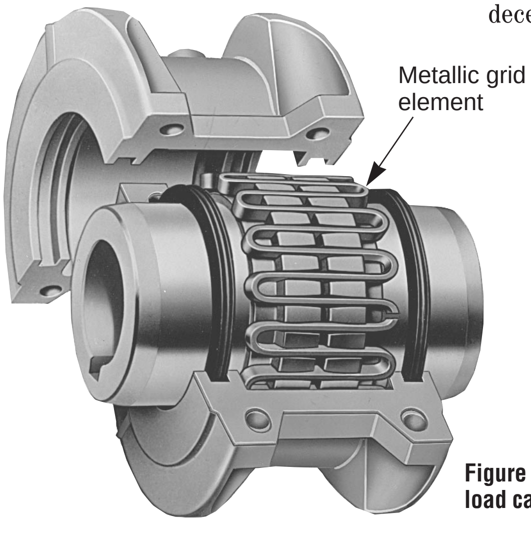

Figure 2 — Grid coupling combines high load capacity with torsional flexibility.

Torsional deflection. As torque is transmitted through a coupling, its flexible element rotates slightly, a condition known as torsional deflection or windup. Some torsional deflection is normally desirable, as it cushions uneven torque loads, thereby saving wear and tear of the connected equipment.

Torsional deflection in the grid coupling of our example lets the shafts rotate ½ to ¾ deg relative to each other, whereas the torsionally soft elastomeric couplings allow 5½ to 6 deg. Gear and disc couplings have negligible windup.

Torsional stiffness. The resistance of a coupling to torsional deflection, called torsional stiffness, affects the critical speed of the system. Designers often overlook this factor for conveyor applications. But they should evaluate the effect of torsional stiffness values on critical speeds and vibration.

Gear couplings offer the highest torsional stiffness, and elastomeric couplings the lowest. Grid and elastomeric couplings get progressively stiffer as the applied torque increases in a given size coupling.

Backlash. Rotational clearances between coupling parts allow another type of rotation, called backlash. Gear couplings contain a small amount of this clearance between hub teeth and sleeve teeth. In grid couplings, the clearance occurs between the grid member and hub slots. This clearance accommodates misalignment and provides space for a lubrication film.

A disc coupling has no backlash because its components are tightly held together. Elastomeric couplings don't have backlash either but they deflect torsionally under changing loads or starts and stops, giving an effect similar to backlash.

Misalignment capacity. Coupling manufacturers offer widely varying recommendations on allowable shaft misalignment. The suggested operating limits in the table allow for simultaneous extremes of offset and angular misalignment. Our experience shows that exceeding these limits increases loads on both the coupling and its connected equipment and can reduce their service lives. Some coupling manufacturers publish

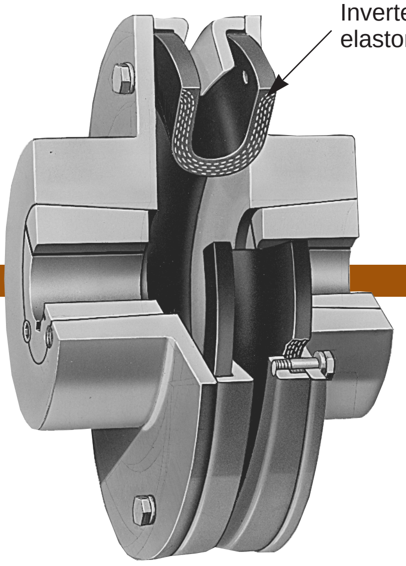

Figure 4 — Elastomeric coupling (shear type) gives torsional flexibility and requires no lubrication.

higher values that allow more angular misalignment if there is no offset misalignment and vice versa.

Manufacturers also give suggested installation and static limits. Installation limits are smaller than operating limits to allow for dynamic movement of equipment and settling of foundations. Static limits apply to nonrotational conditions. For example, removing paper rolls from a paper machine (static condition) may require more angular misalignment than operating conditions.

Be sure you know whether the coupling manufacturer is giving you installation, operating, or static design limits. Often, these three sets of values are poorly labeled in sales literature, leading to reader confusion.

The four coupling types vary in their ability to accommodate shaft misalignment. Shear type elastomeric couplings typically handle the most misalignment.

Within the metallic coupling types, gear couplings have the most misalignment capability, followed by disc and grid couplings.

Shaft gaps. Grid and gear couplings let you assemble equipment with the smallest shaft gaps (distance between shaft ends), an important factor where space is limited. Close-coupled disc couplings are not available for high-torque, low-speed applications. However, a recently developed disc coupling, Figure 5, offers the same gap as grid and gear types for most motor shaft (high-speed) applications (listed in table).

A shear-type elastomeric coupling requires larger shaft separation to accommodate its flexing element. This gap typically ranges from 1 in. on a small coupling to over 5 in. on a large one.

Balance. Coupling unbalance can cause vibration in the connected equipment. The amount of coupling unbalance is expressed by its AGMA balance class, where higher numbers indicate better balance and smoother operation. Most gear and disc couplings can be balanced by the manufacturer to improve their balance class rating and operating speed range.

Based on our experience, conveyor operating speeds are generally low enough so that it is not necessary to balance the couplings.

Other considerations

Now that we've discussed the basic design considerations, let's examine the other important selection factors related to *cost, maintenance, and environmental conditions.*

Initial cost. Grid couplings generally cost the least for shafts up through 4-in. diameter. Beyond this point, the high-torque capacity per size of gear couplings makes them the least expensive.

Elastomeric couplings are inexpensive in fractional to low-horsepower sizes, but their cost grows rapidly as torque and shaft sizes increase. In our example for the high-speed shaft, elastomeric or disc couplings cost $200 more than grid or gear couplings.

For the low-speed shaft, the order of coupling cost, low to high, is gear, grid, disc, and elastomeric. Here, the elastomeric coupling costs $1,200 or more than the other types.

In addition to the purchase price, other costs are incurred for replacement parts and downtime.

Replacement costs. OEMs often supply the lowest cost couplings on their equipment to minimize total equipment cost. Unfortunately, the lowest cost coupling is often not the best choice for the application and causes more expense after installation.

This situation is evident when you consider what parts of a coupling usually wear out and how difficult it is to replace these parts. In a gear coupling, the teeth generally wear out, which requires a completely new coupling. Here, the replacement cost usually wipes out any initial cost savings.

The other three types — grid, elastomeric, and disc — require replacing the less costly flexible elements only. The cost of a replacement grid is usually well below that for an elastomeric or disc element. This makes the grid coupling a better value for the low-speed shaft even though its initial price is higher than a gear coupling.

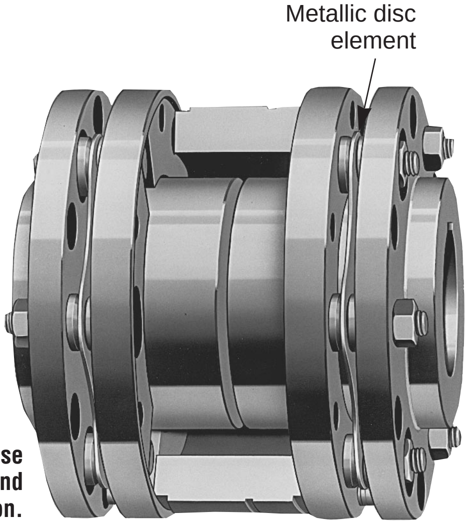

Figure 5 — Disc coupling enables close mounting of connected shafts and requires no lubrication.

Table – Coupling selection factors for belt conveyor

Torque required: 5,400 lb-in. (high-speed side), 112,500 lb-in. (low-speed side).

Shaft sizes: motor 2-⅜ in., speed reducer (high-speed side) 2-¼ in., speed reducer (low-speed side) 4-½ in., belt drive headshaft 5-7⁄16-in.

Couplings listed meet torque and shaft size requirements.

	Coupling type							
	High-speed shaft (1,750 rpm)				Low-speed shaft (84 rpm)			
Selection factor	**Grid**	**Gear**	**Elastomeric**	**Disc**	**Grid**	**Gear**	**Elastomeric**	**Disc**
Torque rating, lb-in.	8,000	17,100	5,400	5,600	160,000	220,500	141,800	157,600
Service factor	1.48	3.17	1.0	1.04	1.42	1.96	1.26	1.40
Maximum bore, in.	2.500	2.375	3.250	2.625	6.000	5.750	8.000	5.750
Outside diam, in.	6.38	6.00	10.86	6.54	13.62	12.50	24.28	10.85
Weight (bored), lb	16	15	67	33	195	162	674	153
Moment of inertia (bored), lb-in.^{2}	58	67	803	191	3,150	2,936	38,820	2,078
Torsional deflection, deg	0.73	Negligible	6	Negligible	0.58	Negligible	5.5	Negligible
Stiffness (x10^6 lb-in./rad)	1.0	17	0.09	6.29	27	143	2.5	36
Backlash, deg	0.53	0.42	None	None	0.28	0.31	None	None
Operating misalignment capacity:								
- Offset between parallel shafts, in.	0.016	0.017	0.031	0.007	0.022	0.042	0.062	0.032
- Angularity between shafts, deg	¼	¾	0.32	¼	¼	¾	0.28	½
Shaft gap, in.	0.125	0.125	1.75	0.125	0.250	0.250	5.75	9.00
AGMA balance class	8	8	7	8	8	8	7	8
Cost, $	211	228	420	436	1,292	867	4,242	2,970
Wearing component	Grid	Hub & sleeve teeth	Flexible element	Discs	Grid	Hub & sleeve teeth	Flexible element	Discs
Replacement part cost, $	69	228	136	104	427	867	1,473	988
Downtime labor cost	Low	High	Medium	Low	Low	High	Medium	Low
Maintenance interval, yr	1 5 + with LTG*	½ 3 with LTG*	Visual insp. 1 to 2X/yr	Visual insp. 1 to 2X/yr	1 5 + with LTG*	½ 3 with LTG*	Visual insp. 1 to 2X/yr	Visual insp. 1 to 2X/yr
Temperature range, F	-40 to 200	-40 to 200	-40 to 150	-40 to 450	-40 to 200	-40 to 200	-40 to 150	-40 to 450
Grease requirement	Yes	Yes	No	No	Yes	Yes	No	No

* LTG = Long term grease

Downtime. A conveyor shutdown caused by coupling failure can easily cost thousands of dollars per hour. The problem is compounded if the failed coupling is difficult to service.

Gear couplings, which must be replaced entirely, are the worst in this regard. Replacement typically requires moving the connected equipment, then removing the hubs. New hubs are then installed, and the equipment must be repositioned and realigned. This is not an easy task, for example, when working on a confined conveyor drive platform 50 ft above ground.

When a grid coupling fails, the grid usually fails in fatigue due to excessive misalignment or it breaks due to overload. The coupling can continue operating until several segments are broken. Grids can be replaced without moving the connected equipment.

With disc couplings, the disc usually fractures due to improper bolt tightening or excessive misalignment. Unitized disc packs, wherein discs, bushings, and washers are held together in a sandwich, simplify replacement and avoid lost components.

Elastomeric flexing elements experience fatigue failures due to excessive misalignment as well as overloads and environmental deterioration. Their flexing elements are usually easy to replace.

Maintenance interval. Until recently, grid couplings had to be lubricated annually to replace grease in which oil separated from the thickeners. A new type of long-term grease (LTG) extends this interval to over 5 years.

When applied to gear couplings, LTG grease extends the interval from 6 mo to 3 yr. Gear couplings depend more on lubrication than grid couplings because of the limited tooth surface area (that transmits the torque) and resultant high tooth stresses. Up to 90% of gear coupling failures relate to lack of lubricant, leakage, contamination, or wrong grade.

Disc and elastomer couplings don't require lubrication. Moreover, disc couplings can be inspected while rotating, with a strobe light. Tiny hairline cracks in the disc assembly are an early sign of failure.

Environmental factors. Bulk material conveyors operating outdoors expose couplings to temperature extremes plus sunlight, ozone, moisture, and abrasive contaminants.

Disc couplings, which have neither seals or lubricants, offer the largest temperature range and are unaffected by most environmental conditions found in conveying.

Grid and gear couplings offer moderate temperature ranges, which are limited by the seals and grease. Grid couplings tend to be more forgiving of abuse and less sensitive to contaminants, compared to gear couplings.

Elastomeric couplings have the smallest temperature range. At temperatures approaching −40 F, they get stiff and brittle; above 150 F, the heat may degrade the elastomeric element. If either of these conditions is common in your application, it could shorten the elastomeric element fatigue life. Ozone and sunlight also may deteriorate elastomeric compounds.

Making the choice

For this particular conveyor application example, we selected grid couplings for both the high-speed and low-speed shaft connections. This coupling is the most economical choice based on total costs. It has a low initial cost and lowest replacement parts cost, and requires little maintenance. It also provides adequate misalignment capacity, gives some resilience for vibration damping, and is not limited by environmental factors. ■