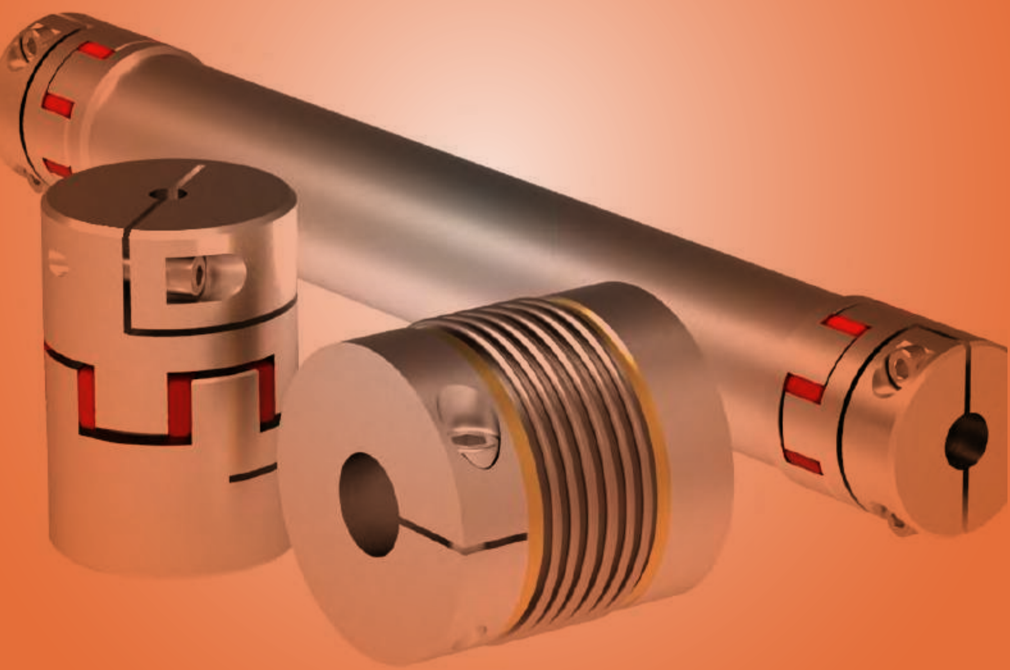

DESIGN GUIDE ON

COUPLINGS

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MOTION CONTROL TIPS

A Design World Resource

COUPLINGS DESIGN GUIDE

Mechanical connections for machine designs include couplings, shafts, and keyless locking devices. Parameters employed to select a coupling for a given application include speed, torque, service factors, predicted assembly misalignment, and bore size. However, these can sometimes conflict with pressures to keep overall machine-build costs down, delivery times short, and installation simple.

In this Design Guide, the editors of Design World detail the most common coupling types for motion control and power transmission as well best practices for sizing, selection, and installation.

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Associate editor

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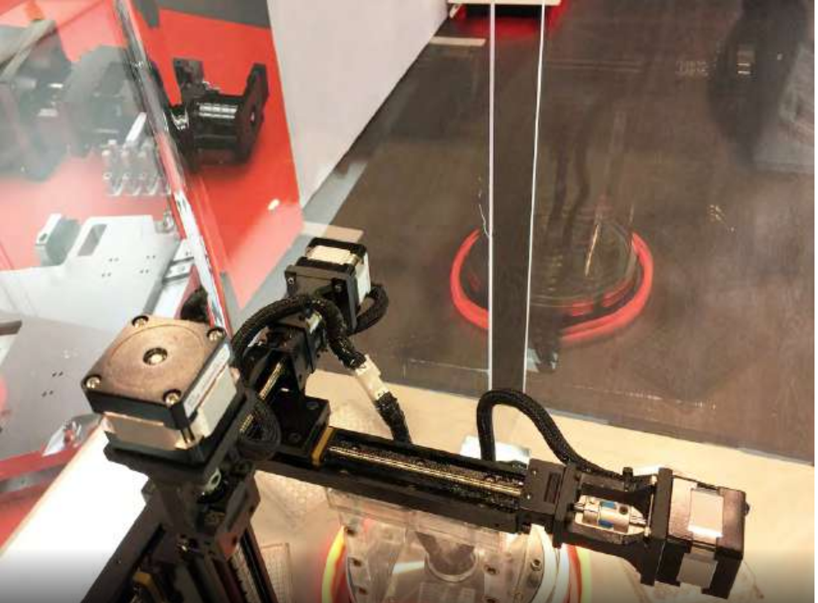


Shown here is a jaw coupling with a blue spider insert on a small Cartesian robot.

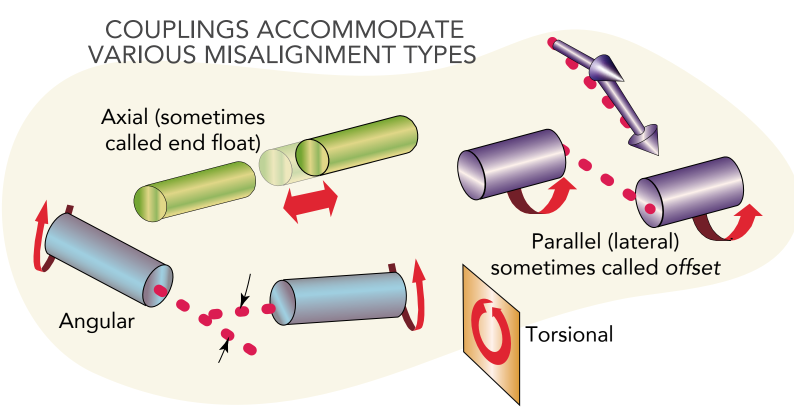
FLEXIBLE SERVO COUPLINGS AND OTHER COUPLINGS FOR MOTION DESIGNS

Couplings connect rotating shafts in equipment powered by electric motors and other drives. All transmit torque and angular velocity. Flexible variations compensate for misalignment. Many of the latter even address vibration and improve system dynamics.

Design considerations include machine or installation construction and backlash, torsional stiffness, damping, inertia, torque ratings, maximum rpm, size, misalignments, ease of installation, robustness, and cost.

For power transmission (as in motors for pumps and large material-handling setups) common choices are gear, disc, elastomeric tire, grid, jaw, and Oldham couplings because of their ruggedness and ability to transmit very large torques.

Motion-control applications (as for axes employed in precise positioning of loads, for example) typically employ couplings capable of oft-more modest but far more precise torque transmission. These include curved-jaw, beam (slit), bellows, disc, and other zero-backlash couplings.



Any misalignment that couplings accommodate should be what's otherwise unavoidable even after proper machine-axis squaring and installation adjustments. That's because misalignment (manifest as parallel, axial, and angular misalignment) degrades efficiency, induces bearing wear, and excites machine natural frequencies.

To review, the maximum amount of ***angular misalignment*** for which a coupling can compensate is expressed in degrees.

Parallel misalignment between the shafts a coupling connects is expressed in inches or millimeters.

Axial misalignment is also a length value; it's the maximum permissible spread between coupled shafts — and in fact, a misalignment permutation often most affected by thermal effects.

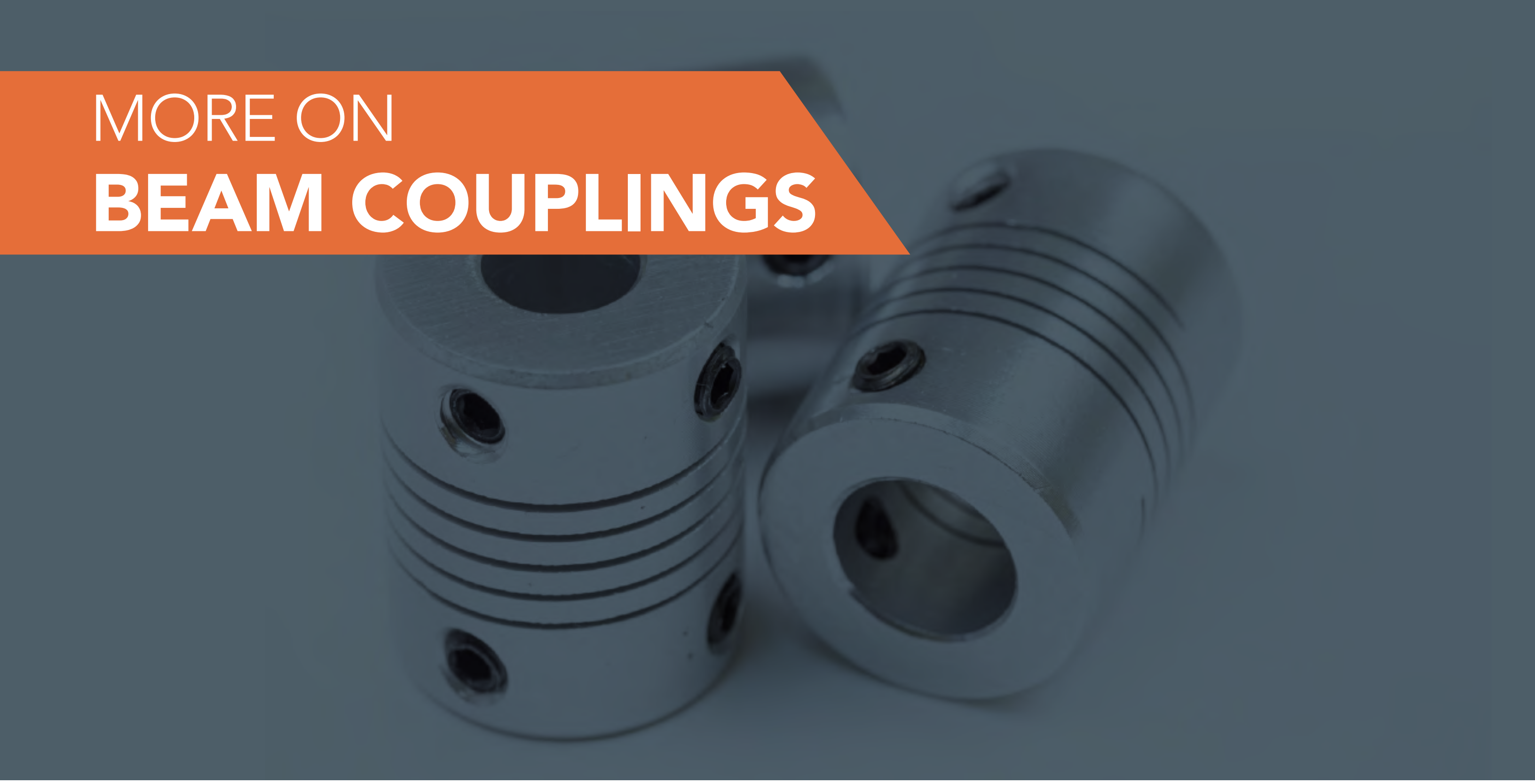
Flexible couplings for motion control are often less forgiving of misalignment than those for more straightforward power transmission and resolve it with specialty design features.

A related phenomenon and a coupling consideration specific to motion-control installations is backlash. In applications for strict power transmission, backlash is far less of a concern than that of efficient torque transmission — and actually a characteristic that (in normal moderate quantities) helps make some couplings in these settings more efficient and forgiving of misalignment.

In contrast, couplings on the outputs of steppers and servomotors are designed to prevent the lost motion that can degrade output-product quality or overall machine throughput.

Note there's a difference between backlash (which is true mechanical clearance) and the torsional deflection or windup that all loaded rotary components exhibit. Most couplings for motion applications are inherently backlash free or preloaded to eliminate backlash — but they all have different torsional stiffnesses, which is sometimes a tradeoff for lateral flexibility.

MORE ON **BEAM COUPLINGS**



Beam couplings are very forgiving of large angular and parallel misalignments — especially compared to other servo-grade couplings. Installation of this type of coupling with a straightedge is typically sufficient. That said, beam couplings will fail quite suddenly if subject to excessive misalignment.

A real strength of beam couplings is that they have multiple coils or convolutions, so work as flexible shafts that sweep through complementary bows as the mode of misalignment compensation. Torque transmission is through members in shear, so convolutions can be thin and minimize radial forces while maximizing torsional stiffness … though beam couplings have torsional stiffness that's relatively low compared to other coupling types. Beam couplings also induce loading on adjacent bearings as they force through misalignment conditions.

If a beam coupling unwinds and fails, it won't resume its original form. In addition, some tensioned or angularly misaligned conditions can allow for excitation of coupling resonances, especially at high rpm. That's the most likely to happen in stepper or servo systems that haven't been tuned properly. Because beam couplings exhibit a lot of windup (and unwinding) exceeding their typically modest torque capacity will result in positioning errors. Stainless-steel beam couplings can be costly and heavy but a suitable option where an axis would benefit from a beam coupling type … but torque requirements aren't met by a standard aluminum variation.

Wherever a motion axis fails to properly position the load and the behavior leads the OEM or end user to suspect the coupling is slipping on the shaft, it could be that design is using an over-torqued beam coupling that's winding and unwinding enough to cause positional errors.

Some newer beam couplings have speed capabilities to 25,000 rpm — which is in contrast with standard beam couplings rated to 6,000 rpm. What's more, some of these couplings come in very squat variations … useful where engineers aim to keep the shaft assembly compact as one strategy to minimize the effects of catenary and more. Of course, the design process always necessitates balancing objectives: Especially on high-rpm axes, short flexible couplings require exceptional alignment to prevent detrimental loading of adjacent components.

A related design is ***slit couplings*** — close cousins of beam couplings that have intermittent cuts that are radiused to minimize stress buildup under misalignment and heavier torque loading. These newer slit couplings have moderate torque and high misalignment capabilities. No other standard coupling satisfies applications with parameters between those suggesting use of bellows or disc couplings and those suggesting beam couplings with low inertia. After all, bellows and disc couplings are performance couplings with limited misalignment capabilities. Aluminum beam couplings have limited torque and high misalignment capabilities … and stainless-steel beam couplings have high inertia that's a detriment to most motion control systems.

Some double-slit flexible couplings can accommodate eccentricity and declination as well as axial misalignment between shafts. Such slit couplings have torque capabilities comparable to those of stainless-steel beam couplings but with better overall misalignment capabilities. Slit couplings can also fit in confined spaces and accommodate all misalignment forms. The only comparable option for high torque in tight envelopes is a single-disc coupling … but many of these allow no parallel misalignment — which is a problem if it's unavoidable.

PITFALLS TO AVOID DURING SELECTION OF COUPLINGS FOR MOTION

Design engineers often run into trouble when they neglect to account for environmental effects on couplings — particularly flexible couplings installed in gritty or caustic areas, vacuum environments, or places that are extremely hot or cold.

Beyond that and the common design considerations already listed, designers must account for dynamic forces to which a coupling will be subject. Steer clear of using published an axis' gearset or motor peak-torque values for setting its coupling's nominal torque rating. That's because this approach usually makes for an assembly with an oversized coupling and an unnecessary inertial increase.

Designers should also avoid the application of a coupling type simply because it's a familiar technology.

For example, beam couplings are extremely well known in industry, and they excel on axes transmitting moderate to light torque — as on leadscrew-driven motorized axes or where there's a need for attachment of a precision encoder, for example.

Installation tip: With beam couplings, tighten one hub first and then (before tightening additional screws) rotate the coupling by hand to let it reach free length. Setting a beam couplings while it's compressed or extended with shorten its life.

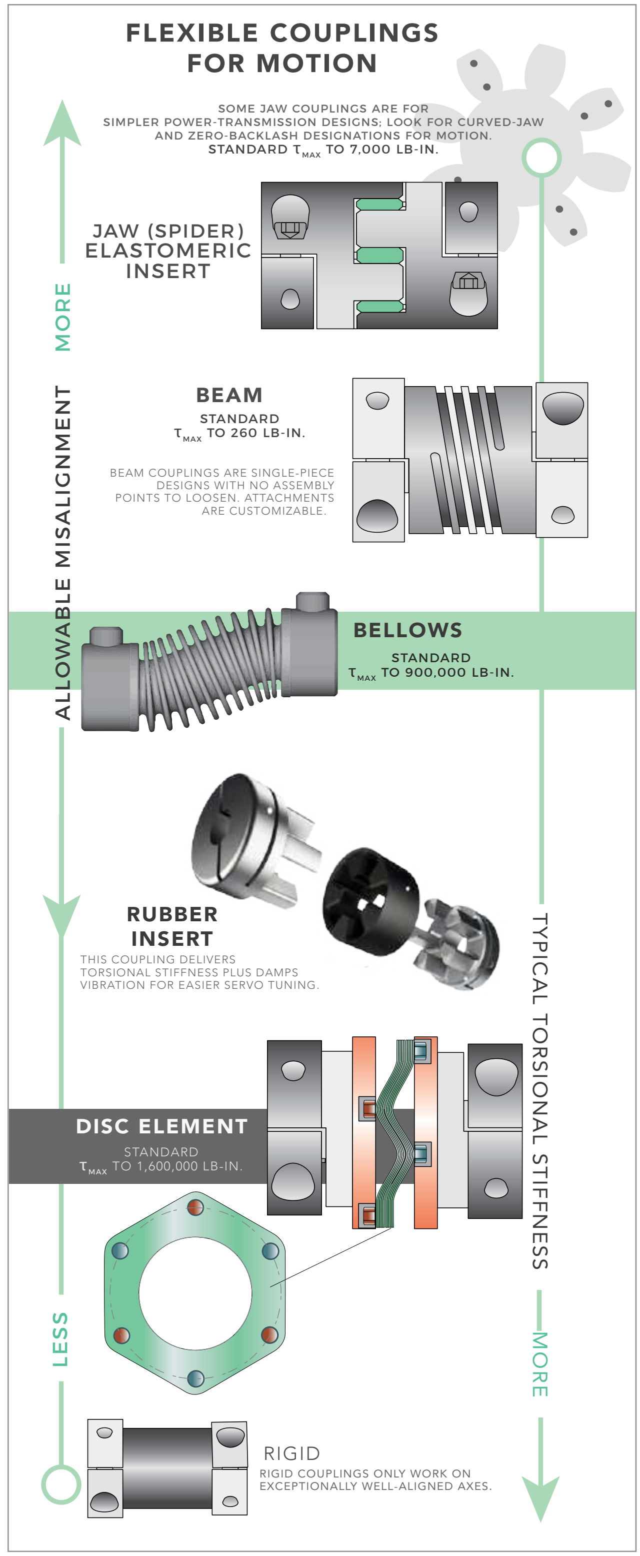
Some particularly demanding designs may necessitate a flexible coupling type that maintains higher torsional stiffness.

On the other hand, it's also inadvisable to simply pick a coupling based on high torsional stiffness. Many flexible couplings have an inherent stiffness that exceeds application requirements for servo tuning and motion accuracy.

Specification tip: On any axis subject to jams, crashes, or emergency stops, safety couplings (though initially more expensive) are a better choice than standard servo couplings. The former can disengage to prevent damage and downtime.

Even in motion designs requiring high stiffness for the shortest possible response time (as in equipment for electronics manufacturing, for example) couplings with good damping characteristics often offer more effective optimization than more torsional stiffness. That's because overly stiff couplings of many designs pose an unnecessary risk of fatigue.

Manage expectations: Not all servo couplings are meant to last as long as the machine. Where significant cyclical flexing to accommodate axis misalignment limits service life, couplings should be considered a wear item necessitating regularly scheduled replacement.



These are some of the most common zero-backlash coupling options.

NINE PARAMETERS THAT DICTATE COUPLING CHOICES FOR SERVO APPLICATIONS

Couplings for servo applications usually connect precision drives to sensitive loads, so they cannot induce any error. That's why servo couplings should be zero backlash — to prevent issues with timing and predictability (not to mention failures due to hammering on reversing axes). Couplings for servo applications must also have high torsional stiffness while imparting slight forgiveness of misalignment (within specifications) of rotating shafts … even while holding transmitted rpm steady to motor output rpm.

But these are just a couple servo coupling considerations. Consider a typical application for servo couplings — to connect a servomotor to a ballscrew. Here, couplings with low inertia let the axis deliver faster acceleration and deceleration without unnecessarily degrading overall system efficiency.

In fact, couplings for servo designs must often compensate for subtle power-transmission issues to minimize errors down to 1 arc-min. or lower. That's especially true where servo systems take the form of exacting positioning axes.

Here's a more complete list of parameters to conside for proper coupling operation in such designs.

1. Coupling type: Couplings shouldn't be the last motion component specified because proper servo-machine function relies on having a suitable coupling in place. Torsionally rigid options (ideal for motion designs) include specialty bellows couplings, rubber-jaw couplings, and disc couplings. Curved-jaw couplings have good damping characteristics to optimize performance of axes with quick acceleration and deceleration. Elsewhere, both disc-type couplings and certain bellows couplings excel on high-speed axes. Other offerings abound to serve other design objectives. One caveat on coupling type though: Never use rigid couplings to replace flexible servo couplings on axes where the latter seem to fail frequently.

Here, this issue is most likely insufficient alignment between the motor-output shaft and next component in the powertrain.

There's sometimes a misconception that rigid couplings are exceptionally strong, so can address issues in such situations. The fact is that rigid couplings only work when shafts are perfectly aligned, because these couplings transmit to connected motion components (potentially extreme) forces that arise from misalignment.

(continued)

NINE PARAMETERS THAT DICTATE COUPLING CHOICES FOR SERVO APPLICATIONS

2. Sizing for torque and speed: After specifying the coupling type, the design engineer must select a coupling size. This is heavily dependent on axis speed (rpm) as well as the levels of torque the axis must transmit and the service factor the application requires. Axes that transmit steady torque are simpler to specify; in contrast, axes that transmit variable torque need additional consideration. Here, define the application's average operating torque and the peak torque. Also consider the parameters listed in "Ability to handle reversals" below.

One tip to avoid servo coupling oversizing: Quantify actual system requirements and base coupling selection on those values — and avoid defining a whole axis by the connected gearmotor's peak torque output.

3. Stiffness: Along with exacting control of position, force, or output velocity, it's often essential to maintain high efficiency. Couplings that exhibit windup or backlash degrade this efficiency because they must overcome load inertia every move cycle. This can be a significant drawback in some setups ... which is why (especially on axes employing rigid variations) couplings should be prevented from inadvertently functioning as flywheels.

Note that if a coupling's torsional stiffness is insufficient, other system functions must compensate. One standard solution is to adjust PID controls and reduce servo gain, though that degrades system response and performance. In contrast, excessive torsional stiffness compromises the ability of an axis to withstand quickly reversing loads. That's because servo couplings with excessive stiffness can be brittle and prone to failure on demanding axes that must make frequent and sudden directional reversals.

Servo-application tip: Balance coupling characteristics for stiffness. Excessive torsional stiffness may induce premature failure. On the other hand, axes that must hold timing (as for positioning commands) benefit from incorporation of torsionally stiff couplings.

4. Inertia: As mentioned, this is an important parameter for a few reasons. Applications with particularly aggressive motion profiles rely on low servo coupling inertia most of all.

5. Damping capabilities: Disc couplings, certain bellows couplings, and high-gain rubber-type couplings are all options for coupling-based damping in servo applications. In fact, the most demanding servo applications have in recent years spurred improved response frequencies ... but vibration (and hunting) arise with high gain settings on assemblies using torsionally stiff couplings. Visit couplingtips.com and search on ***damping*** for more on this issue and some solutions.

6. Shaft connections: Most servo couplings connect shafts with clamping or locking mechanisms (and not keyways). Though keyways are often offered as an option to prevent shaft slippage, the truth is that they can be a liability — adding concentrations of stresses in shaft connections, unnecessary cost, risk of imbalance, and other potential drawbacks.

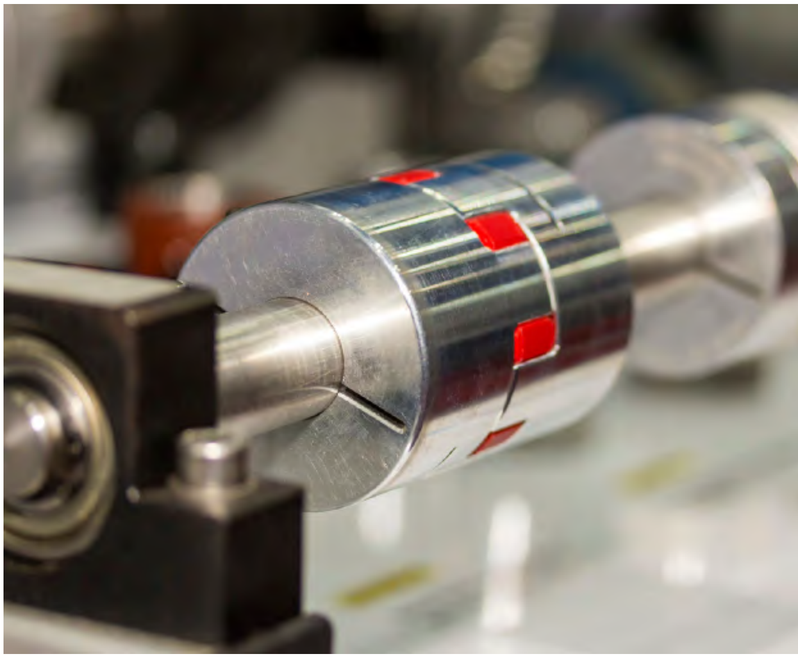
7. Ability to handle reversals: Servo applications that must make quick directional changes require special consideration. Here, consider torque associated with system inertia starting and stopping. Service factors can often quantify the effect this value will have on assembly dynamics. Another aspect of reversing loads to consider is coupling-material fatigue. Keep in mind that some servo couplings that perform for years in regular applications with fail within weeks or sooner when forced to transmit power under reversing conditions.

8. Function to protect more expensive subcomponents: Though system failures are best avoided, couplings can be designed to protect the axis actuator or motor and gearbox by breaking if there is a machine crash or catastrophic overload. That's especially useful in high-speed servo applications where drive-based current limits aren't fast enough to address existing kinetic energy associated with the drivetrain and load upon a jam or sudden impact.

9. A realistic understanding of allowable misalignment: Flexible couplings for servo applications do accommodate misalignment. However, OEMs must be realistic about the level of permissible misalignment for a given axis — and specify assembly techniques and mounting that ensure levels that ever exceed the rating of the coupling. Otherwise, coupling or another component failure may occur.

MORE ON JAW COUPLINGS

Jaw couplings are suitable for an array of applications — and are one coupling type that (depending on the subtype) is suitable for either power transmission or servo designs. They come in an array of sizes to accommodate shaft diameters of 3 to 150 mm and beyond.

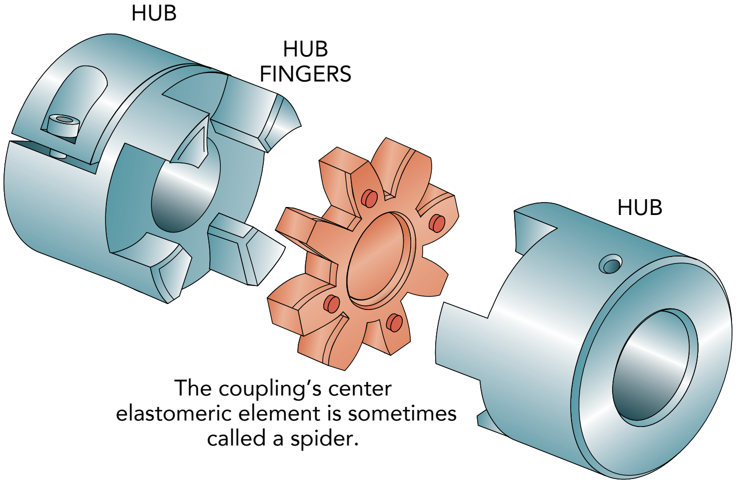


There are two main types of jaw couplings:

• Standard industrial jaw couplings have spiders with straight spider arms. Such geometry introduces an often-negligible amount of play to make assembly easier. These jaw couplings excel in many applications — though not on axes involving highly precise positioning of loads. Some manufacturers refer to these standard couplings as ***L-jaw*** couplings.

Such couplings are common in process applications employing electric motors (the primary application focus of this Design Guide) as well as hydraulic motors and turbines and even gasoline and diesel engines.

• In contrast, zero-backlash jaw couplings include spider arms with a profile ... necessitating a press fit so there's no clearance between the spider arms and jaws. Some manufacturers refer to these curved-arm couplings as ***C-jaw*** couplings.



The coupling's center elastomeric element is sometimes called a spider.

One representative use of these jaw couplings is on belt-drive linear actuators (tangential belt slides) for the positioning of loads. Such step and servomotor-driven actuators can join the belt pulley and motor ... but where the use of servo controllers excite resonances (and other design changes are prohibited) a jaw couplings excel. Their ability to damp axes and move axis operating frequencies away from the assembly resonant frequency is indispensable.

In fact, some of the largest zero-backlash jaw couplings maintain zero backlash with a heavy press fit ... sometimes requiring assembly with precision press equipment. Despite more challenging assembly, large zero-backlash jaw couplings benefit assemblies by preventing any lost motion in the coupling.

Many smaller zero-backlash jaw couplings go together by hand pretty easily.

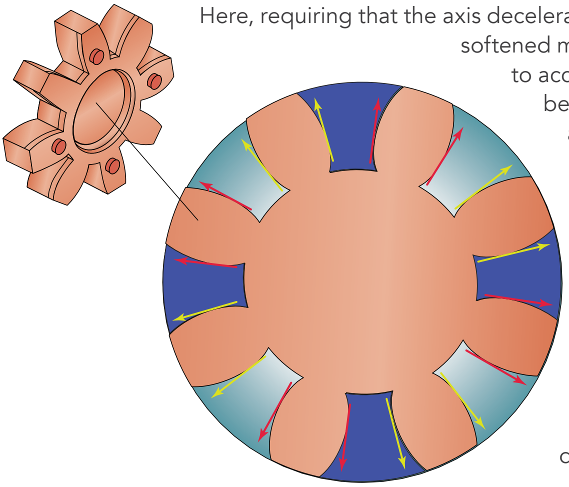
(continued)

MORE ON JAW COUPLINGS

Have quick reversals? No worries. There are multiple spider materials to match jaw couplings to application needs.

Consider how standard jaw couplings deftly handle shock loads. If the application at hand requires the coupled axis to quickly start and stop, a rigid coupling (or one without cushioning or damping characteristics — such as a zero-backlash jaw coupling) will transmit that shock and can actually accelerate the destruction of the assembly's bearings on the ballscrew input or motor. In contrast, compliant jaw couplings handle shock loads quite well — even on axes with frequent stops and starts to maintain high throughput.

Here, requiring that the axis decelerate more gently or run softened move profiles just to accommodate a bellows coupling or a rigid coupling is unacceptable. Jaw couplings here impart excellent protection for the life of the design's motor or actuator — and lets the axis run aggressive move profiles without sustaining damage.



The geometry of jaw couplings (including the radii of their jaw fingers) is engineered to ensure a balanced and torsionally rigid design that resolves tangential forces. Some versions can work on axes running many thousands of rpm.

Spider materials and spider hardnesses abound. For example, there's 98 Shore A, 92 Shore A, and 85 Shore A — sometimes more casually expressed as just 85 durometer. Depending on the amount of cushioning or damping the axis needs, design engineers can fine tune the coupling behavior to suit by strategically choosing from these different spider materials.

Bonus: The three-piece design of jaw couplings affords OEMs and other design engineers a highly customizable option.

Jaw couplings are an inherently fail-safe design: If the jaw coupling's spider is catastrophically damaged, its arms tear off ... and the coupling will go metal-to-metal and still drive. This is useful on applications where it's important to have a fail-safe design or positive drive. Even zero-backlash jaw couplings work in this manner.

Case in point: The vertical (Z axis) of a semiconductor handling machine might be responsible for lifting and lowering an expensive boat of wafers for wafer processing. Here, suddenly dropping the valuable load could be an expensive error. So to prevent dropping that load in case of failure (and having the screw back drive) a jaw coupling here will act as the positive drive.

Jaw coupling drawbacks: One drawback of jaw couplings is that they have fairly low misalignment capabilities ... so require requires precision alignment at installation. They do impart a bit of forgiveness, but nothing like beam couplings or other couplings. So if an axis' halves are misaligned beyond what the jaw coupling is capable of accommodating, that coupling's will hubs will go in shear, and the spider will degrade ... which in turn results in excessive loading on the axis' bearings.

That's especially true if the spider fails. If this occurs while the system is still running, the assembly will run though a metal-to-metal coupling engagement — potentially outputting bad product until it's discovered the coupling's spider has disintegrated.

Jaw couplings for electrical isolation: Jaw couplings do impart a modest level of electrical isolation that is sufficient for low-voltage applications. That's because spider (usually made of polyurethane or some other polymer) prevents the coupling's metal jaws from touching the face of the hub on the other side. Manufacturers don't usually recommend jaw couplings for electrically isolating high-voltage applications.

In fact, preventing low-voltage signals from jumping over the coupling (and potentially interfering with processes by traveling into other components) is possible with jaw couplings, Oldham couplings, and disc couplings with non-metallic center members.

PRIMER ON COUPLINGS FOR POWER TRANSMISSION

As mentioned, all couplings serve to transmit drive torque and angular velocity. But applications for motion control (such as axes to position loads) usually use disc, slit or beam, curved-jaw, bellows, and other zero-backlash couplings capable of precise transmission of torque.

In contrast, applications for power transmission (as in grinding machines, pumps, and material-handling machinery) commonly include disc, gear, chain, elastomer tire, grid, jaw, and Oldham couplings. Such PT couplings transmit more torque on average than couplings designed for motion control … even to millions of lb-in. Plus they're more rugged to withstand challenging environments.

These are just a few coupling types used for power transmission between shafts. Others include uni-lat, finger, K-flex, and fluid (hydraulic or hydrodynamic) couplings as well as flexible shafts and Hooke's joints, also called Cardan or universal or U joints.

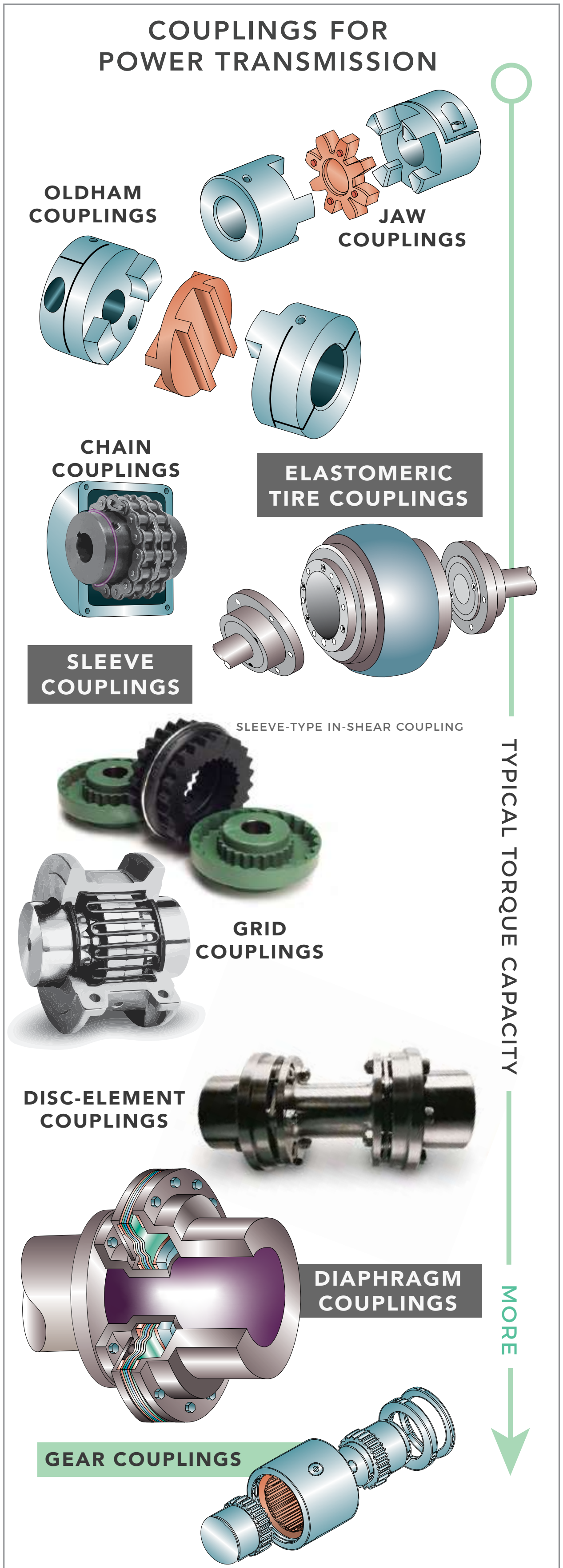
Chain couplings — with typical maximum torques to 220,000 lb-in. at their largest — wrap lengths of chain around sprockets with clearances to impart flexibility.

Certain elastomeric-tire couplings use a split natural-rubber element. This element transmits torque to 340,200 lb-in. These power-transmission couplings excel in high-horsepower applications on axes needing correction of misalignment combinations involving up to 2° and 0.01-in. angular and parallel misalignment.

Diaphragm couplings — with typical maximum torques of 500,000 lb-in. to 21,000,000 lb-in. at their largest — transmit power through a metal membrane (sometimes of varying thickness or ganged in arrays).

Though often more costly than other options, diaphragm couplings mitigate and avoid problematic transmission of forces and moments to coupled equipment such as bearings. Profiles include straight-spoked diaphragms; tapered diaphragms; and convoluted diaphragms assembled in arrays. These correct misalignment combinations involving up to 1° and 0.1-in. angular and parallel misalignment. In addition, diaphragm couplings are capable of axial travel of up to 1 in.

Elastomeric tire couplings — with typical maximum torques to 550,000 lb-in. at their largest — transmit power through a tire-shaped rubber element that bridges the coupling's two hubs. These correct misalignment combinations involving up to 4° and 0.2-in. angular and parallel misalignment.



These are just some coupling types used in power-transmission applications.

(continued)

COUPLINGS FOR POWER TRANSMISSION

This is a stainless-steel flexible disc coupling for large servo axes.

Jaw couplings — with typical maximum torques to 550,000 lb-in. at their largest — include both straight and curved variations. Spiders with straight teeth are more common for power transmission. Much like disc couplings, the design lends itself to adaptation to both power transmission and backlash-free motion control. The coupling hubs have jaws that lock into a spider made of bronze, elastomer, or other material. Power transmission is reliable even through misalignment combinations involving up to 1° and 0.01 in. angular and parallel misalignment.

Oldham couplings — with typical maximum torques to 550,000 in. at their largest — include a metal or polymer disc with slots on each face 90° offset. Usually hub fins or tenons engage a slotted disc that's free to slide even while transmitting torque.

Oldham couplings for accommodation of angular misalignment might transmit through 6° and 0.05 in. Oldham couplings to primarily address parallel misalignment might address 0.15 in. or more and 0.5° or so.

Note that the disc in an Oldham coupling actually moves up and down to accommodate parallel misalignment ... and Oldham couplings must be installed in a certain way to allow this movement. Slide the hubs onto the shaft with the tenons at 90° before inserting the center disc — and don't tighten. Place the disc on one hub and center by hand. Use a shim the thickness of the coupling's axial misalignment rating to leave a gap of proper specification.

Many installers believe it's correct to squeeze the coupling's hubs together and tighten them down. But this approach traps the Oldham disc and prevents it from moving to accommodate misalignment. Without clearance in this coupling, its disc will have limited life ... and the assembly will exhibit vibration problems as the disc is fights to move.

Final installation tip: Using the correct tools for coupling installation is critical. Employ a torque wrench for tightening clamp screws on precision couplings to the proper torque. Using torque wrenches during installation will save a lot of time and trouble — and in some cases, can even prevent coupling failure arising from improperly torqued screws. Shim stock, feeler gauges, and shaft-alignment measurement tools such as dial indicators or laser systems are also of great help here.

Disc couplings — with typical maximum torques to 6,000,000 lb-in. at their largest — are one of a few coupling types that come in variations to satisfy motion-control or power-transmission applications. Single or multiple packs of discs (made of metal or engineered composite) bridge the hubs. In representative *double-flex* designs, the discs impart flexibility to transmit torque even while addressing up to 2° (1° per disc pack) of misalignment. Certain *single-flex* disc couplings with specialty discs can also accommodate up to 0.05 in. of angular misalignment. Refer to a later chapter of this Design Guide for more information on single-flex and double-flex disc couplings.

(continued)

DEEP DIVE ON COUPLINGS SUITABLE FOR POWER TRANSMISSION

Caution: Typical single-flex couplings incorporating steel discs accommodate no parallel misalignment. The parallel misalignment (also called *offset*) that a double-flex disc coupling can address is defined by:

- The distance between its two flex elements
- The *tan* of the rated angle — a dimensionless value — with *tan* (1°) = 0.0175 in./in. or mm/mm.

So for a coupling 18-in. shaft to shaft and having a 1° rated angle, allowable offset = 0.3 in.

Grid couplings — with typical maximum torques to 1,500,000 lb-in. (and transmission of up to 5,000,000 lb-in. possible from specialty versions) these include a heavy spring that weaves between slots on the coupling hubs. Compliant connection damps torsional vibration and shock loading ... typically even through 0.3° and 0.30 in. angular and parallel misalignment.

Gear couplings — with typical maximum torques to 55,000,000 lb-in. at their largest — include a flexible joint on each hub. In most variations, a spindle joins the two. Each joint includes gearset that mates with a 1:1 ratio. The tooth flanks and external gearing's outer diameter are crowned to allow rotating-spline action and accommodate misalignment of 1.5° and 0.04 to 0.4 in. on average.

Gear couplings are suitable for high-torque applications.

A typical gear-coupling application is on hydraulic-fracturing pumps in the oil and gas industry. Here, some truck-mounted pumps run off electric motors instead of traditional diesel engines. Gear couplings connect the motors (which outputs many thousands of horsepower at speeds to 2,000 rpm) to the pump.

Some gear couplings in these designs allow for quick disconnections from the drive motor to prevent drivetrain damage during vehicle transport. Fully crowned gear teeth can provide maximum load-carrying capacity with minimum size and long life; separation of gear meshes in some designs permits high parallel offset capacity.

Final installation note: Some manufacturers estimate that only about 25% of coupling installations are done perfectly. Fortunately, most applications can accommodate that — or are installed well enough to avoid problems.

Sleeve couplings are heavy-duty couplings for moderate power-transmission applications ... especially pumps and similar electric-motor-driven equipment. Sometimes these are called in-shear couplings or (more ambiguously) elastomeric couplings for the way in which torque from one hub transmits through an elastomeric element via shear force (twist) to the other hub. The sandwiched element sometimes called a sleeve is made of neoprene, Hytrel, or ethylene propylene diene monomer (EPDM) material that has been engineered on a molecular level to withstand the rather unique direction of loading without heat buildup or fatigue.

BASICS OF SLEEVE COUPLINGS

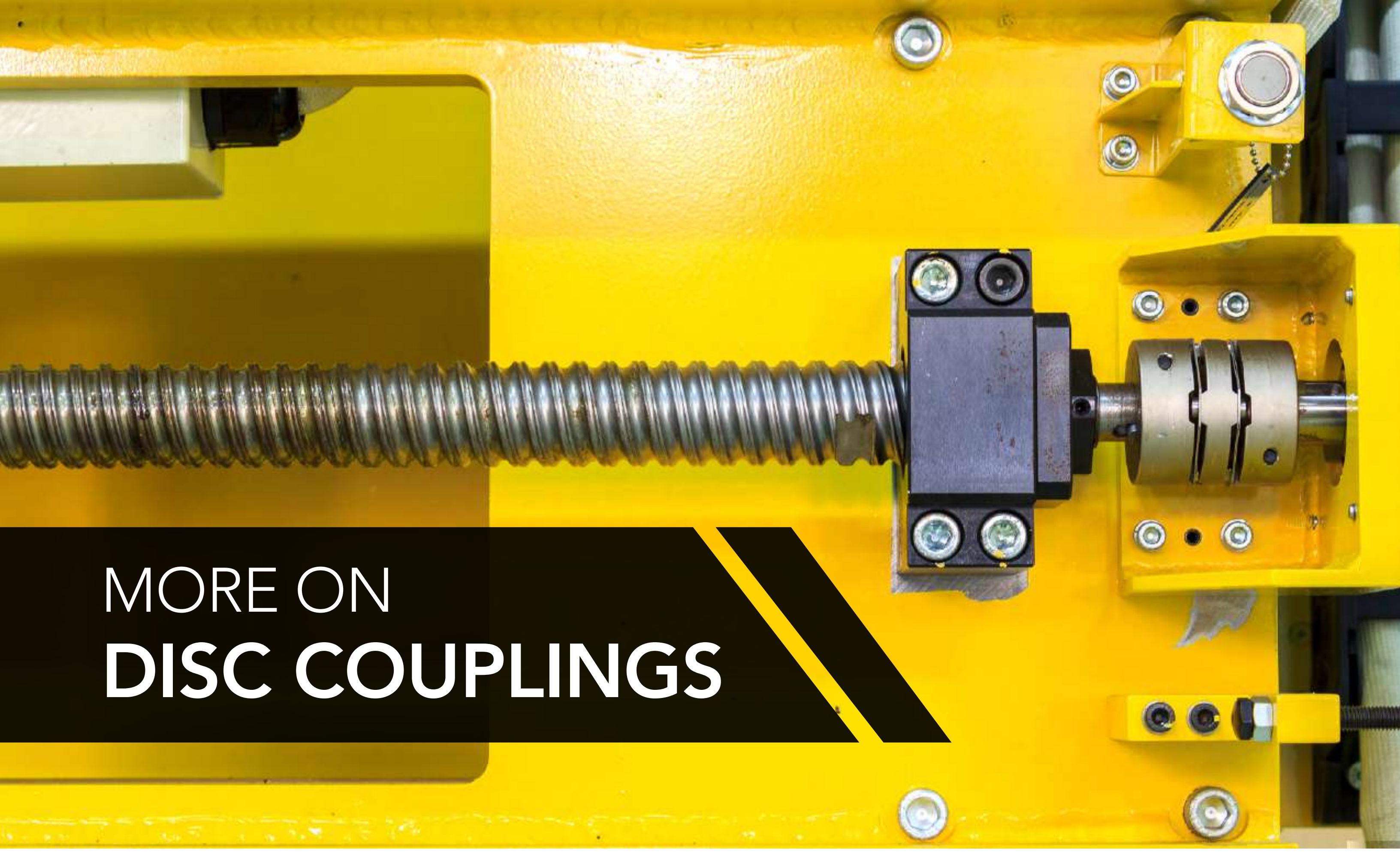
This is a very large sleeve coupling installed on a pump.

In fact, the hubs (flanges) of in-shear sleeve couplings (and the way in which their internal teeth mate with the teeth on the center element) greatly simplify installation.

Because their flexible elastomeric element deforms or stretches under load, in-shear sleeve couplings address all four types of misalignment illustrated earlier of this Design Guide. That includes some measures of torsional displacement as from shock loading.

Of course, there are limits to this action: The center element of sleeve couplings will tear loose and fail under excessive shock loading. While this can cause unexpected downtime, it also serves as a failsafe to protect attached equipment from jams.

There are other caveats: While some versions of these couplings excel in applications to about 100 rpm and 85 kW or so, sleeve couplings are not usually applied on slower or more heavily loaded axes. Most are applied on axes running at 1,800 to 3,600 rpm. But where they are appropriately specified, sleeve couplings operate to several million cycles before necessitating service.



MORE ON
DISC COUPLINGS

Disc couplings include two hubs of aluminum, stainless steeel, or other grades of steel that sandwich a pack of discs. Like a deck of cards, each thin element of this disc pack (sometimes called a disc spring) is the same size. This stack of discs is pressed together by bushing-fitted bolts that induce torque-transmitting friction between the discs. In some cases, the thin discs are made of stainless steel; in other instances, they're made of engineered composite material.

Because torque transmits through the faces of the discs, there's no backlash or issues with stress concentrations that would arise in a coupling having only the bolt shanks to transmit torque. Friction operation also imparts torsional stiffness.

Like the jaw couplings profiled earlier in this Design Guide, variations of disc couplings abound … with many satisfying applications characterized as heavy industry, power transmission, and process equipment. But other variations of disc couplings are applied in high-performance motion applications that require the precision transmission of torque and speed as well at the accommodation of shaft misalignment.

Typical maximum torques for all disc couplings are 100 to 678,000 Nm. Refer to page 11 of this Design Guide for more on their ability to address combinations of angular and parallel misalignment. Maximum speeds from particularly specialized offerings are to 10,000 rpm.

DISC-COUPLING DESIGNS

Single-disc couplings should perhaps be called single disc-**pack** couplings … because they include a single disc pack having many friction discs. In industry their less ambiguous name is ***single-flex couplings***.

In contrast, double-disc couplings (in industry referred to as ***double-flex couplings***) have two disc packs — with an additional center hub between them. In some cases, this center spacer is of the same material as the two end hubs; otherwise the component supplier may offer center spacers made of something else — acetal for electrical isolation, for example.

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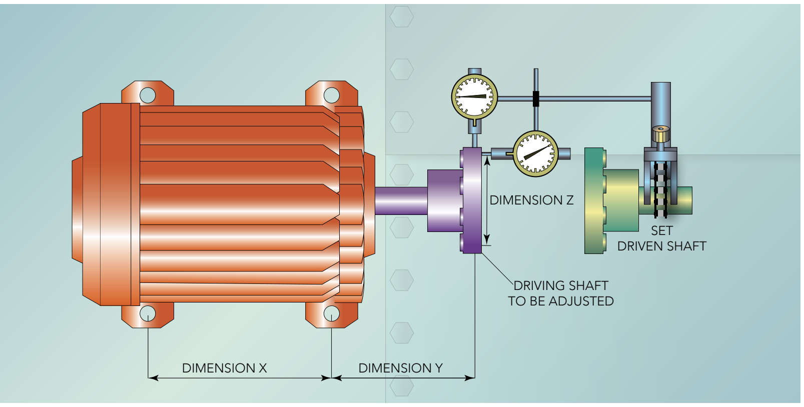
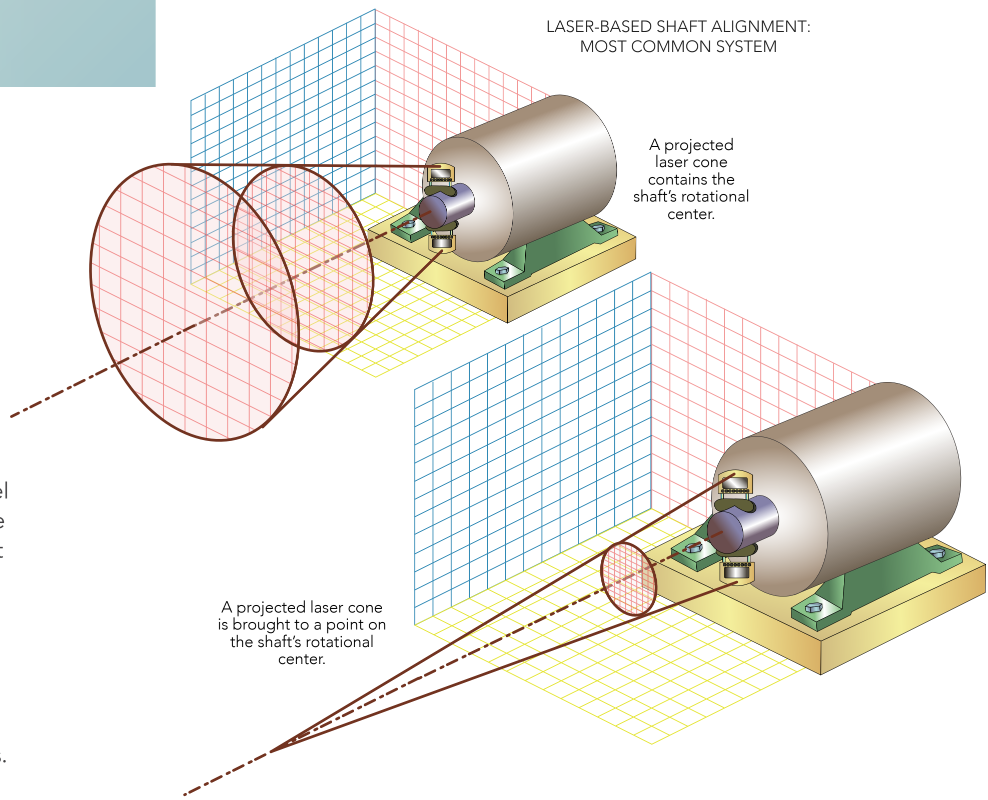
MORE ON DISC COUPLINGS



Other disc-coupling variations abound. Some include:

- Laminated discs
- Discs of circular or hexagonal or other shape
- Attachments through the disc pack
- Attachments alternating between the two hub flanges
- Features to satisfy API, ATEX, and other standards

Although typical single-flex couplings incorporating steel discs accommodate no parallel misalignment, **this limitation isn't universal**: Those with composite discs can accommodate a modest amount of parallel misalignment. That's useful in compact machine footprints that don't allow the extra length of a double-flex coupling. But where longer axes are acceptable and more dramatic parallel misalignment is unavoidable, double-flex couplings leverage the ability of two discs to flex in opposing directions for accommodating offsets.



Any misalignment that couplings accommodate should be what's otherwise unavoidable even after proper machine-axis squaring and installation adjustments. In-field aligning routines often complement the installation of couplings for power transmission. In contrast, flexible couplings for motion control are often less forgiving of misalignment … so rely more heavily on specialty brackets, housings, and design features that prevent misalignment.

DISC COUPLINGS ≠DIAPHRAGM COUPLINGS

Diaphragm couplings — a completely different design than disc couplings — are nevertheless confused with and mistakenly substituted the latter. Note that diaphragm couplings transmit torque via one or more thin diaphragms. The diaphragm or diaphragm pack attaches to one shaft hub near its inner diameter and to the other near its outer diameter. Deflection on this attachment differential's freespan accommodates both axial and angular misalignment.

TORSIONAL RIGIDITY AND REACTION FORCES

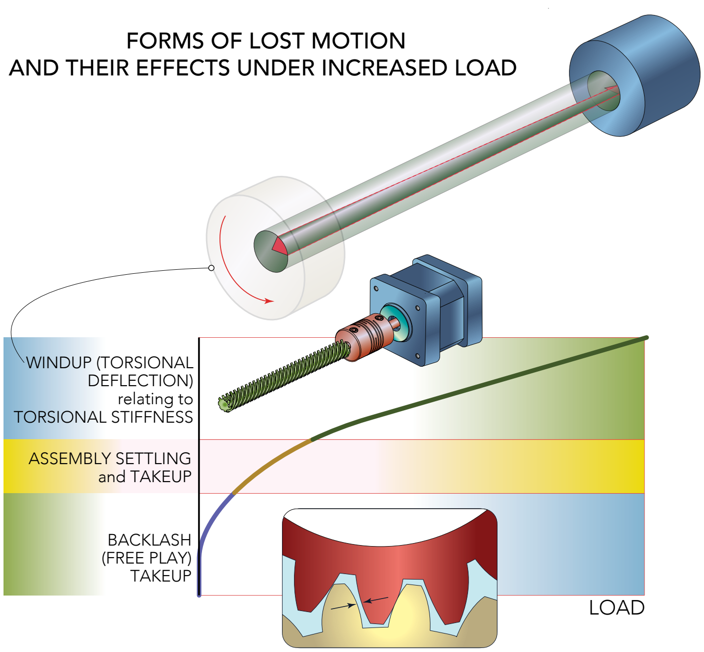
Torsional rigidity is an object's resistance to torsion or twisting under applied torque. Torsional rigidity in couplings is torque per value of angular displacement, and it's a value that affects overall machine design. Even slight variations degrade positioning accuracy and limit cycle speeds. Consider the case of bellows couplings and the specifics of how their moderately high torsional stiffness is verified and expressed:

Torsional stiffness Ct (in N·m/rad) = M/ψ — where M = Torque, N·m and ψ = Angular displacement, rad.

Applied mass at an industry-set moment arm gives torque $M = m \cdot g \cdot R$, where m = mass, kg; R = Moment arm; g = Gravitational acceleration of 9.81 m/sec^2 and m = 0.38 m.

Angular displacement Δx from a test-setup dial indicator = Indicator reading (mm); τ = Indicator moment arm (mm); tan (ψ) = Dx/τ as noted in the illustration showing a typical fixture for measuring bellows-coupling torsional stiffness. Also ψ = arctan (Dx/τ) in degrees. So torsional stiffness in N·m/rad is Ct = M/ψ (Nm/deg) = $M \cdot 180/\pi \cdot \psi$.

It's usually unnecessary and impractical to test all components in design, which is why engineers use theoretical system-stiffness values. One caveat here related to couplings is that different manufacturers' coupling-stiffness ratings vary with measurement methods. There can also be differences between published and measured values. Two tips on this: Use caution when designing a motion machinery relying heavily on overall stiffness for good design performance. Also, look for evaluations that faithfully model performance characteristics to ensure stiffness and machine-assembly performance.



Note there's a difference between backlash (which is true mechanical clearance) and the torsional deflection or windup that loaded rotary components exhibit. Most couplings for motion applications are inherently backlash free or preloaded to eliminate backlash — but they all have different torsional stiffnesses, which is sometimes a tradeoff for lateral flexibility.

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TORSIONAL RIGIDITY AND REACTION FORCES

In fact, the most suitable coupling choice ultimately depends on application requirements and machine throughput. If improving axis positioning and cycle time is priority, focus on boosting powertrain stiffness. Selecting couplings with high torsional rigidity (among other things) can minimize lost motion from torsional windup. Shorter couplings or those with reinforced bellows can boost torsional rigidity values ... But keep in mind that while a shorter coupling has higher rigidity (to 60 to 70%) misalignment compensation capabilities also decrease with length.

Of course, no coupling — no matter how engineered — can correct for excessively misaligned shafts. The nature of flexible couplings occasionally misleads design engineers and assembly personnel (or more often, end users) into believing that they're a fix-all for compromised or less exacting machine builds. But flexible couplings put into designs with excessive misalignment exhibit material stresses and fatigue and premature failure.

Though coupling failures do occasionally originate from couplings themselves, it's far more common that coupling issues arise as a symptom of other design problems. If a motion design does exhibit coupling problems, avoid the temptation to simply upsize or upgrade that coupling. Such upgrades are often unnecessarily expensive and short-lived solutions that actually put system bearings as well as gearing and connected motors at risk of collateral damage. Instead, make a holistic analysis of the design and consult the coupling manufacturer for assistance.

When motion systems exhibit coupling issues long after a proper installation and run of service, it's sometimes a result of some other change in the drive assembly. Even small changes to the motor, drive, or programming can be to blame — especially if a new motion sequence demands higher transmission of motor torque or the elimination of a previously held electronic limitation.

WHAT ARE REACTION FORCES?

All flexible couplings compensating for misalignment cause reaction forces, and their effect is significant if misalignment is excessive. These often-overlooked reaction forces transmit to connected shafts and support bearings and can cause damage to motion axes — especially on precision designs with delicate bearings and slender shafts. Though couplings get their compliance from elastomeric deflection, sliding contact, and flexing coupling members, here we focus on the types most common for motion designs employing stepper or servomotors.

Ultimately, reaction-force magnitudes depend on the level of misalignment and the coupling type in use. Bellows couplings, so-called membrane couplings such as disc couplings, and beam couplings have thin sections of various designs capable of radial flexing. Resistance to misalignment — a spring-rate reaction defined as a force per unit of deflection — increases proportionally with shaft deflection. Because these couplings bend to accommodate misalignment, reaction force depends on the thickness of the flexible element.

But bellows and beam couplings have multiple coils or convolutions, so work as flexible shafts that sweep through complementary bows as the mode of misalignment compensation. Torque transmission is through members in shear, so the convolutions can be thin and keep radial forces low while maximizing torsional stiffness. In contrast, membrane-coupling variations transmit torque via bending members, so need thick members to get high torsional stiffness. Such couplings' bending (through complementary directions) also compensates for shaft misalignment. The catch is that these torsionally stiff couplings can induce significant radial-reaction forces if excessive misalignment is present.

Because radial-force magnitude depends on bend severity, minimizing bending angles reduces the detrimental forces on support bearings … though can reduce misalignment capacity as well. Some membrane couplings address more misalignment with a central member between the flexible members … and the added distance imparts an ability to turn while making shallower bends (and lower radial forces) for a radial shaft offset. In fact, aforementioned beam and bellows couplings with divided flex-element arrays also sometimes leverage more distance between flexure points to get shallower bends for a given radial shaft offset. Short models sometimes connect via an intermediate shaft.

In contrast, elastomeric couplings have myriad torsional-damping properties and transmit torque in shear, bending, and compression. Coupling class is key with this design: Some versions exhibit zero backlash while others rated for use in power-transmission applications can exhibit minute inter-hub rotation. Most variations transmit torque (and address misalignment) through compressible elastomeric-insert spiders trapped between jawed halves ... and induce reaction forces when connecting shafts with excessive radial shaft deflection. Jaw designs can accommodate more misalignment (and minimize detrimental forces on the shafts' support bearings) with softer elastomer spiders — though that sometimes reduces torsional stiffness.

Remember that if excessive misalignment is a concern, consult with coupling manufacturers on the design. Their engineers may suggest design improvements; offer coupling types to resolve the misalignment without inducing unacceptable reaction forces; and supply charts of reaction forces that a given coupling is projected to induce under a given set of conditions.

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TORSIONAL RIGIDITY AND REACTION FORCES

STIFFNESS — AS WELL AS DAMPING

New technological improvements in servomotors have spurred dramatic improvements in response frequencies. The catch is that vibration (and hunting) tend to arise when designers apply high gain settings to servo systems and use advanced couplings with high torsional stiffness ... such as disc or bellows-type couplings, for example.

One way to resolve hunting in setups with high gain settings is to use couplings with vibration-damping capabilities. Here, couplings with hydrogenated nitrile butyl rubber (HNBR) center elements are one option to make servo systems for precision automation tasks (as those in semiconductor manufacturing) more responsive. Sometimes called high-gain rubber couplings, these have an integrated structure that includes aluminum hubs on both ends molded with vibration-reducing HNBR to prevent backlash but stay flexible. The rubber-lined claw structure optimizes torsional rigidity as well as damping.

ONE WAY TO RESOLVE HUNTING IN SERVO SYSTEMS UNDER HIGH GAIN SETTINGS IS TO USE COUPLINGS WITH VIBRATION-DAMPING TECHNOLOGY.

Bode plots show how high-gain rubber couplings increase servomotor gain beyond the capacity of comparable couplings with high torsional stiffness. Gain width between 0 dB and the point at which there's a phase delay in the Bode plot is -180° — and this is called the gain margin. General guidelines for servo systems recommend gain margins between 10 and 20 dB. As servomotor gain rises, gain margin decreases. When the gain margin falls below 10 dB, hunting tends to occur.

Consider the limit gain (the servo gain at which hunting occurs) of assemblies using high-gain rubber-type couplings. Values exceeding 16 dB surpass that of other coupling types. Plus because the margin exceeds 10 dB, the servomotor gain of the rubber-insert couplings effectively shortens stabilization time and increasing throughput.