

WHAT ARE THE DIFFERENCES IN HIGH PERFORMANCE FLEXIBLE COUPLINGS FOR TURBOMACHINERY?

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ABSTRACT

There are many types of couplings used on high performance turbomachinery. Explained are the differences in the various styles

and configurations, and when one is preferable to another in certain applications.

INTRODUCTION

There are three main types of high performance couplings: high performance gear, disc, and diaphragm. There are also high performance quill shaft and elastomeric designs. Furthermore, these can be in various combinations, especially an elastomeric on one machine shaft and a gear, disc, or diaphragm on the connected machine shaft, or even a gear type on one shaft and a flexible element disc on the other.

So, what is a high performance coupling? What is the difference between a high performance coupling (also called special purpose) and a general purpose coupling? Once a train designer knows that he needs a high performance coupling, which type of high performance coupling should be selected? An improper selection can mean years of troublesome operation. These topics are discussed in this tutorial, along with design details and failure modes.

OVERVIEW OF FLEXIBLE COUPLINGS

Historically, rotating equipment was first connected by means of rigid flanges (Figure 1). Experience indicates that this method did not accommodate the motions and excursions (that is, misalignment) experienced by the equipment. Shaft and flange fatigue failures were frequent. Then flanges were made thinner, which allowed them to flex. From this start, the design of couplings has evolved to the many types and styles of today, all used to transmit the maximum amount of power while accepting the required amount of misalignment. (Note that nowadays, rigid flange couplings are still used to connect equipment that experiences very small shaft excursions.)

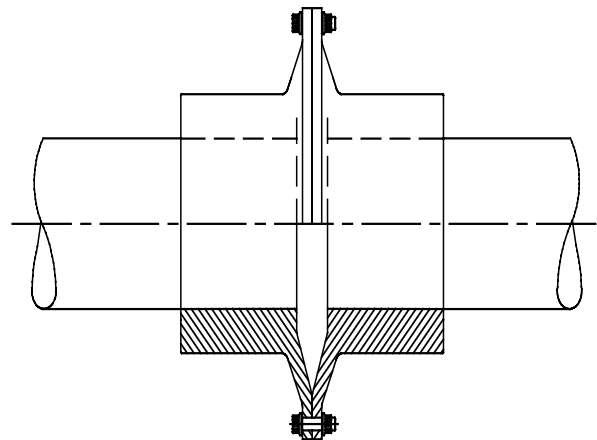


Figure 1. Rigid Coupling.

Functions of Flexible Couplings

Flexible couplings join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both. The three basic functions of a flexible coupling are to:

- Transmit power (Figure 2A)
- Accommodate misalignment (Figure 2B)
- Compensate for end movement (Figure 2C)

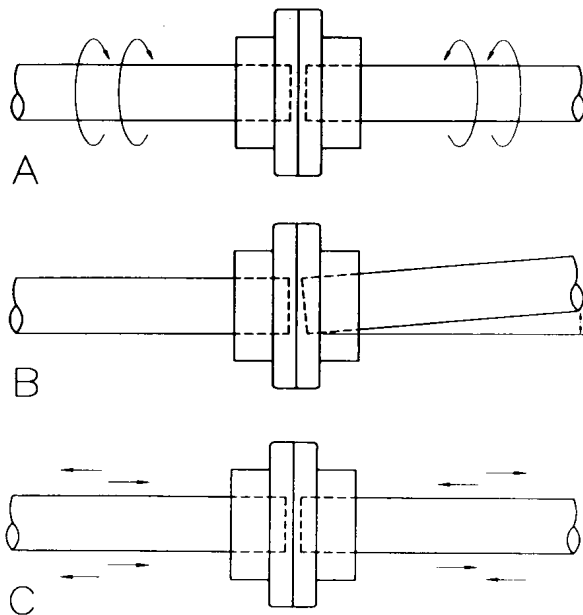


Figure 2. Functions of Flexible Coupling.

Transmit Power

Couplings are primarily used to transmit mechanical power from one machine to another. The power is in the form of mechanical torque at some speed or work per unit of time. In general, the power lost by a flexible coupling is small, although some couplings are more efficient than others.

Accommodate Misalignment

There are two types of misalignment—shaft misalignment and coupling misalignment:

- *Shaft misalignment* is the relationship between the driver and driven shafts. This can be broken down into parallel offset—the axes of the connected shafts are parallel, but not in the same straight line (Figure 3A) or angular misalignment—the axes of the shafts intersect at the center (Figure 3B). A more common misalignment is a combination of shaft parallel offset and shaft angular (Figure 3C).
- *Coupling misalignment* comes into play when you look at how the coupling accommodates for shaft misalignment. Shaft parallel misalignment (offset misalignment) and shaft angular alignment are accommodated in the coupling by the flex elements operating at an angle (Figure 3D). There are two general approaches.

One is when using a double-flex coupling such as a gear, disc, or diaphragm. These couplings can only accept angular misalignment at each flexing plane. This means there must be two flex elements in order to accept shaft parallel offset misalignment.

The second approach is used primarily for elastomeric couplings where the parallel offset and angular and axial shaft misalignments are accommodated through the deformation of one elastomeric flex element, the elastomer being synthetic or natural rubber, urethane, or some other polymer.

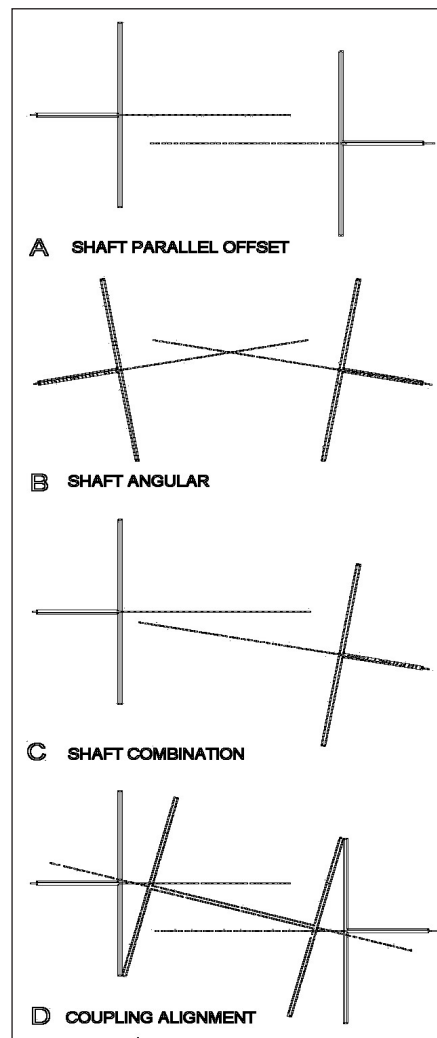


Figure 3. Misalignment.

Compensate for End Movement

Most flexible couplings are designed to accommodate axial movement of the connected equipment or shaft ends. In gear type couplings, lots of axial capacity is easy to accommodate because the gear teeth can slide relative to each other. One or both sets of teeth can be made longer to accommodate this movement. Flexible element couplings, on the other hand, depend on the flexure of metal to accommodate axial movements and so are more limited in this regard.

Other Functions of Flexible Couplings

Besides these basic functions, flexible couplings “sometimes” are required to do the following:

- Dampen vibration and reduce peak or shock loads.
- Protect equipment from overload.
- Measure output torque of driven equipment.
- Electrically insulate the driver from the driven equipment.
- Position a rotor of a motor or generator.
- Be used to tune a system out of a torsional critical.

Accommodation of misalignment and end movement must be done without inducing abnormal loads in the equipment. Generally, machines are set up at installation quite accurately, with laser and reverse dial indicator methods, but there are many things that force equipment to run out of alignment.

The thermal effects of handling hot and cold fluids cause some movement in the vertical and axial direction. There are differentials of temperature in driver media such as gas and steam. Vertical motions could be a result of support structure expansions due to temperature differences, distortion due to solar heating, axial growth, or a combination of these. Horizontal motions are usually caused by piping forces caused by poor installation practices and expansions or contractions caused by changes in temperature or pressure differential of the media in the system.

It is a fact of life that machinery appears to live and breathe, and will move, grow, and change form and position; this is one of the basic reasons for using flexible couplings. A flexible coupling is not the solution to all movement problems that can or could exist in a sloppy system. Using a flexible coupling in the hope that it will compensate for any and all motions is naïve. Flexible couplings have their limitations. The equipment or system designer must make calculations that will give a reasonable estimate of the outer boundaries of the anticipated gyrations. Unless those boundaries are defined, the equipment or system designer may just be transferring equipment failure into a coupling failure (Figure 4).

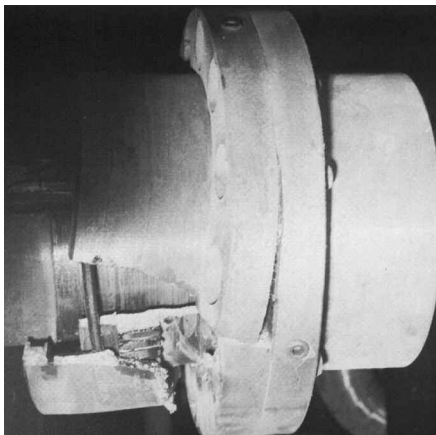


Figure 4. Failed Gear Coupling.

One thing to remember is that when subjected to torque and misalignment, “all” couplings react on the connected equipment components. Some produce greater reactionary forces than others, and, if overlooked, can cause vibration, shaft failures, bearing failures, and other operational and early failure of other components of the drive train (Figures 5 and 6).



Figure 5. Equipment Failure.

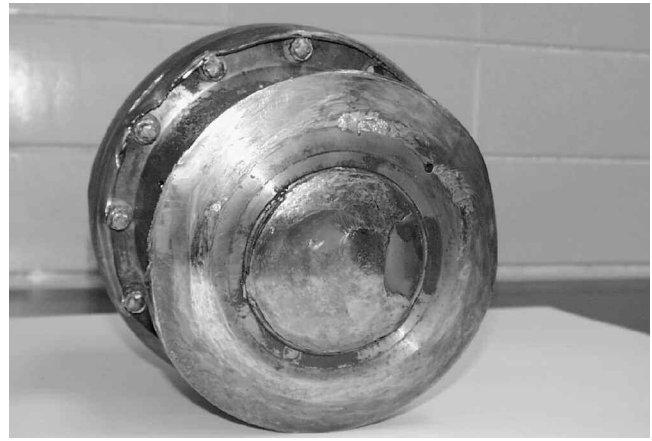


Figure 6. Equipment Failure—Broken Shaft with Coupling Hub.

It is important for the equipment or system designer not to confuse the term “coupling misalignment” capacity versus “equipment misalignment tolerance.” The capability of a coupling is usually substantially higher than the equipment can accept.

Types of Couplings

Flexible couplings can usually be classified two ways. They can be classified by how they function or their usage. As to how they function they can be classified into three basic functional types of flexible couplings:

- Mechanical element
- Elastomeric element
- Metallic element

The mechanical element type generally obtain their flexibility from loose-fitting parts or rolling or sliding of mating parts or from both. The most common types are the gear coupling and the grid coupling. They usually require lubrication unless one moving part is made of a material that supplies its own lubrication need (e.g., a nylon gear coupling). The elastomeric element types obtain their flexibility from stretching or compressing a resilient material (rubber, plastic, etc.). There are two basic types: the shear type and the compression type. The metallic element types obtain their flexibility from the flexing of thin metallic, disc, or diaphragms.

There are over 100 variations of these types of couplings. The three basic types serve two basic types of applications. These can be broken into two categories:

- General purpose couplings
- Special purpose (high performance) couplings

THE DIFFERENCE BETWEEN GENERAL PURPOSE COUPLINGS AND SPECIAL PURPOSE COUPLINGS

General Purpose Couplings

General purpose couplings are used on pumps and other equipment that if shut down will not shut down the plant or the process. They are mainly low speed, generally motor speed designs. Like any other coupling, these will transmit torque from one shaft to another while allowing misalignment and axial motion between the ends of the coupled shafts.

General purpose types are more standardized and less sophisticated in design and are substantially cheaper and are used in quantities substantially greater than special purpose types.

General purpose equipment uses couplings where the flexible element can be easily inspected and replaced, sometimes considered “throw away parts.” These types of couplings are usually very flexible and require simple alignment techniques. It is usually sufficient to align equipment with these couplings to within 0.001

in/in of shaft separation. Therefore, a coupling with 10 inch shaft separation should be aligned to be within 0.010 inches. A failure for this type of coupling occurs at the flex element, and little or no damage usually occurs to other components.

A few examples of general purpose couplings are the gear, grid, elastomeric, and the disc. The gear and the grid are the most common types of mechanical element coupling.

Gear couplings consist of two hubs with external teeth that engage internal teeth on a two- or one-piece sleeve. Gear couplings are used for medium-large applications generally over 100 hp. They have torque capacities up to 54,000,000 lb-in and bore capacities to 45 inches. The gear teeth *must* be lubricated to minimize wear.

Grid couplings are similar to gear couplings. Usually composed of all metal, they have some degree of resilience. They have two hubs with serrations (grooves) rather than teeth. The grooves are connected by a steel grid. A cover keeps the required lubrication in. Grid couplings are generally used for applications under 1000 hp. They have torque capacities up to 4,000,000 lb-in and bore capacities to 20 inches.

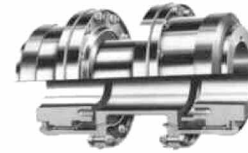
Elastomeric element couplings come in two basic types: shear type and compression type.

The shear types are generally found on applications under 100 hp. They have torque capacities up to 450,000 lb-in and bore capacities to 11 inches. The elastomer (polymer, plastic, or synthetic or natural rubber) transmits torque through shear.

The compression type is usually used on applications over 100 hp. They have torque capacities up to 20,000,000 lb-in and bore capacities to 34 inches. In Figures 7 and 8 are examples of compression type elastomeric couplings.



Figure 7. General Purpose Couplings.



Mechanical Element Type - Gear Coupling



Elastomeric Element Type
Block Coupling



Metallic Element Type
Diaphragm Coupling

Figure 8. Special Purpose Couplings.

The metallic element coupling comes in two basic types, the disc and the diaphragm.

The diaphragm coupling is *usually not used in general purpose applications* because it tends to be more costly than the other types.

The disc coupling transmits torque by a simple tensile force in disc elements between alternating driving and driven bolts on a common bolt circle. These couplings are generally used on applications over 100 hp. They have continuous torque capacities up to 4,000,000 lb-in and bore capacities to 15.5 inches.

Special Purpose Couplings

A coupling moves from the general purpose to the special purpose category once it is applied to very critical equipment within the production or process system (Figure 9). Thus a pump coupling on a spared, redundant system, in almost any process plant from refinery to ammonia plant, is likely not a special purpose unit. On the other hand, a 67,000 horsepower unspared boiler feed pump in a base station or the 12,000 rpm compressor train in the same ammonia plant is certainly special purpose and critical to trouble-free operation. A turbine generator set of 40,200 hp at 3600 rpm (606,615 in-lb) is also critical.



Figure 9. Special Purpose Disc Coupling.

Most gas turbine driven generators on peaking or cogen systems are special purpose machines that require special purpose couplings. In general, special purpose machines can be identified as expensive, high powered, and high speed. They are driven by various types of

motors, especially synchronous ones, and also gas or steam turbines at 3600 rpm or more. The horsepower is usually in excess of 1000. Usually, for the reason of expense, they are not spared. Another point is that although these machines are high powered, they are also sensitive to almost everything in their environment. That is forces or moments that would seem insignificant to high powered mill machinery become life threatening to sensitive machines. As a result of that sensitivity and the speed and the power, coupling criteria for the machines take on an entirely different perspective.

When the critical application is found in a refinery or refinery related setting, the coupling comes under the API 671(1998, Third Edition, as of March 2003) specification. That specification has definite requirements for coupling construction as well as coupling selection. For example, the specification calls out certain service factors and certain torque selection variables. A disc or diaphragm coupling selected for the continuous operating torque might have a service factor as high as 1.5. If selected by motor size rather than driven equipment output it could be as low as 1.2. Transitory torque may also be used for coupling selection.

Note that a service factor is defined in API 671 (1998) as the factor applied to the normal operating equipment torque to account for variations and unknowns in the machine torque loading on the coupling. It is not to be used to adjust the coupling manufacturer's coupling ratings, which are covered by design factors of safety.

This is not intended to be inconsistent, but to encourage a dialog between the equipment designer and the coupling manufacturer. That dialog is necessary. Too much coupling can cause operational problems and high cost, just as too little coupling could result in a failure (Figures 10 and 11). Paragraph 2.1.1 of API 671, Third Edition (1998), lists all the specific selection criteria and which are used under what circumstances.

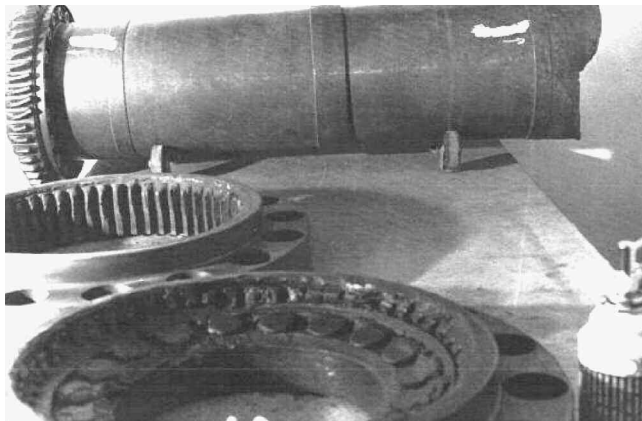


Figure 10. Gear Coupling Failure.

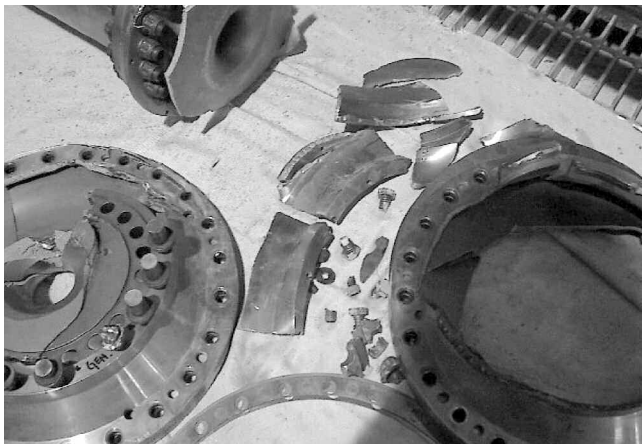


Figure 11. Diaphragm Coupling Failure.

Whether the coupling is a gear type or a flexible element type, the method of attaching to the machinery on either end can be flanged or a hub mounted on the shaft (Figure 12). API 671 (1998) allows either method by specifying the responsibility for flange dimensions and by specifying fits on hub type mounting. American Gear Manufacturers Association (AGMA) standards such as AGMA 9002 (1986), "Bores and Keyways for Flexible Couplings," and AGMA 9003 (1991), "Flexible Couplings—Keyless Fits," cover hub fits, as do particular equipment purchaser or end user specifications.

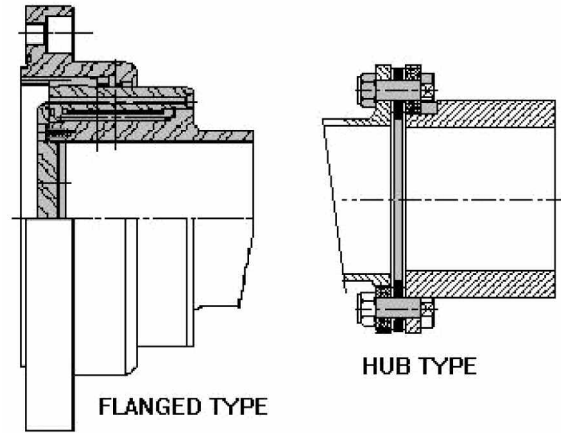


Figure 12. Flanged Connection and Shaft Mounted.

THE QUILL SHAFT COUPLING

If it were not for the misalignment inherent in the machine installation and the movement resulting from thermals and process changes, we would bolt the two machines together and be done with it. The next simplest coupling to use would be the quill shaft. While it is simple, lightweight, requires no lubrication, and is inherently balanced, the quill shaft has some limitations that are difficult to overcome.

The quill shaft design is commonly used on large industrial type gas turbine-generator applications (Figure 13). It consists of a high strength cylindrical cross section piece with flanged ends (Figure 14). The shaft is sometimes connected to the flanged ends by a spline connection. That type of coupling would not meet API 671 (1998). The narrow cylindrical section is flexible enough to handle some radial and angular misalignment. The length of the shaft determines the amount of misalignment.

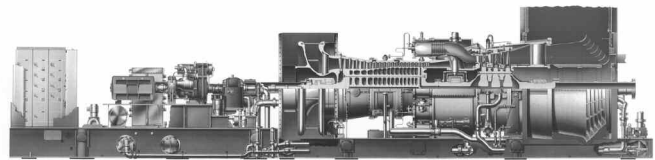


Figure 13. Gas Turbine That Typically Uses Quill Shaft Coupling.

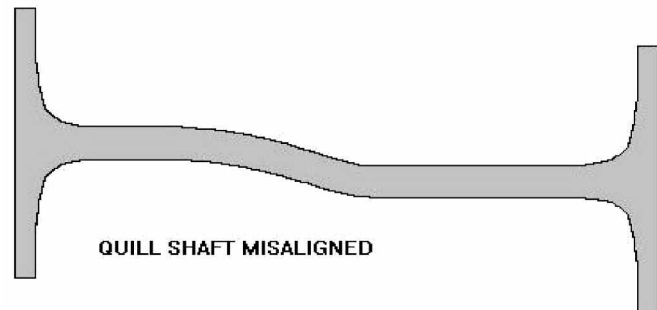


Figure 14. Quill Shaft Coupling.

Design criteria for the quill shaft includes some high stresses and super smooth surfaces as we are dealing with a fatigue life (reversed bending of a rotating cylindrical beam). As easily observed, a solid piece like this does not accept axial misalignment or movement, and it is installed between two thrust bearings. It would also not take too much radial displacement and is susceptible to having a wildly gyrating shaft under high speed operation.

This lateral critical speed concern is important with this coupling. Longer couplings mean lower critical speeds, but it takes a longer and longer coupling as the radial misalignment specification is increased. On the other hand, no maintenance or lubrication are required with this device. It is simple and relatively inexpensive, infinite life, but designed to fit each application if indeed it is suitable for the service.

THE GEAR TYPE MECHANICALLY FLEXIBLE COUPLING

Operating Principles

One of the first choices, from a historical perspective, to couple critical equipment was the gear coupling. Some existing critical equipment will still use gear couplings, and certainly there are many of them in service right now on critical applications. The gear coupling was chosen for its high power density. It provides more horsepower capability per pound of weight and cubic inch of space than any other coupling. The gear coupling is also very rugged, which means it can take the type of beating that might come from torque spikes or starts and stops. If kept well lubricated these couplings can be very reliable for many years.

However, the gear coupling transmits torque and accepts misalignment by the meshing and movement of gear teeth. This movement, though, leads to wear on the mating surfaces. With wear comes the question of when is the part worn out? Can it be predicted? Extended? Known? The measure of reliability is knowing when an event will happen or knowing that it will never happen. With that in mind the gear coupling had to evolve into a very special purpose device when it came to critical applications.

The gear coupling as we know it consists of two sets of meshing gear teeth (Figure 15). Each set becomes a flexible point or pivot point. It is known as a double engagement type, and double engagement is a requirement of API 671 (1998). The farther apart the two flexible points, the more shaft parallel offset alignment can be accommodated in the device. API 671 (1998) requires a spacer piece between the flex planes. That spacing is to allow maintenance of machine and coupling. It is specified as 18 inches minimum.

In effect each set of gear teeth provides an angular pivot. The amount of permissible angle is a function of backlash and tooth form. The power is transmitted from tooth to tooth at the pitch line. Larger pitch diameters are necessary for higher power transmission.

The most common mode of failure for a gear coupling is wear. Due to the number of variables that can affect its successful operation it can be difficult to design and evaluate. Some of the variables affecting its design and characteristics are:

- Tooth design
 - Straight or the type and amount of crown
 - Pressure angle of tooth
 - Amount of backlash
 - Accuracy of tooth spacing
- Material
 - Type of material(s)
 - Type of core heat treatment
 - Surface hardening
- Lubrication
 - Oil
 - Grease
 - Sealed lubrication
 - Continuous lubrication

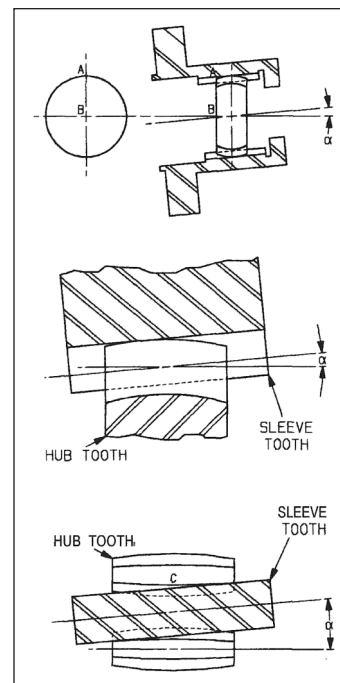


Figure 15. One Set of Flexing Gear Teeth.

A gear coupling has its most significant effect not only on itself but on the system components from the forces and moments generated when it slides and/or misaligns. When a gear coupling accommodates the shaft float from thermal growth, foundation deflection, etc., axial forces react back onto the thrust bearings and other equipment. When misaligned a gear coupling will produce a bending moment that will load equipment shafts, bearings, and other system components. Both the axial forces and bending moment are significantly affected by the lubrication and the coefficient of friction between the mating members.

Types, Styles, and Applications— Marine and Reduced Moment

The gear coupling comes in several configurations. These couplings are usually made from alloy steels and operate at speeds often in excess of normal motor speeds. These couplings are available in sealed lubrication and continuous lubrication types. There are four basic styles. Most of these couplings conform to the requirements of API 671 (1998) (Figures 16, 17, 18, and 19).

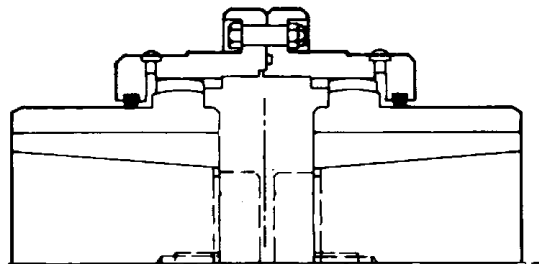


Figure 16. Close Coupled Used in Packed Lubed and Continuous Lube.

A marine style coupling has the flexing elements attached to both ends of a spacer or spool piece (Figure 17). This one-piece center assembly is then mounted to a machine flange or to a shaft mounted rigid coupling hub flange. The idea behind this design is speed and ease of change-out if the flexible elements fail or need to be replaced. The spool piece can be quickly unbolted from the



Figure 17. Marine Style Gear Coupling Generally Continuous Lube but Also Used in Pack Lubed Configurations (Accessory Drives for Gas Turbines).

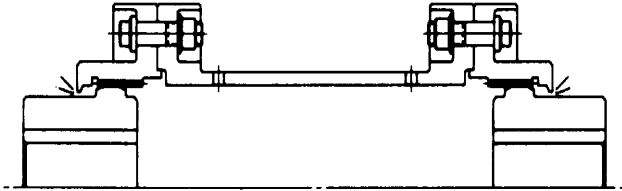


Figure 18. Spacer Coupling Generally Used in Continuous Lube Configuration.

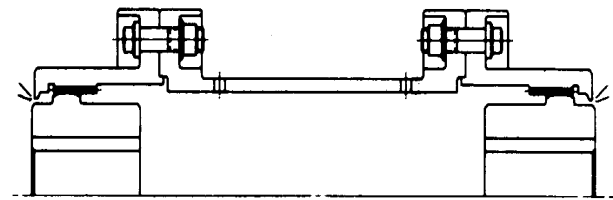


Figure 19. Spacer Coupling (Continuous Lube) with Reduced Overhung Moment on Connected Shafts, Most Common High Performance Gear Coupling in Use.

flanges at either end and a new one installed, and it is especially applicable for shipboard (marine) applications where the drive train cannot be down for any significant length of time. The removed center spool can then be repaired at a more convenient time, once the train is up and running.

A reduced moment style coupling has the flexing elements—gear teeth—mounted on the shaft hubs, with the flexing elements located as close to the equipment bearing as is practical (Figure 19). In this configuration, the effective center of gravity of the coupling is moved closer to the bearing, resulting in a decreased overhung moment. The amount of this moment directly affects the lateral critical speed of the equipment rotor, and therefore affects the sensitivity of the machine to unbalance. The larger the overhung moment, the lower the critical speed. Since many high performance compressors operate between the first and second critical, too large an overhung moment could place the rotor second critical near running speed, and without adequate damping, vibration problems could result.

An example of a high performance gear coupling application is the Frame 5002 gas turbine (Figure 20). A gear coupling is typically used between this turbine and whatever it drives: gear box, compressor, generator, or pump.

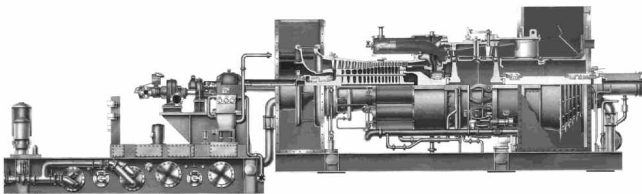


Figure 20. Typical Gear Coupling Application.

This gas turbine has a 30 year history. During that time, the horsepower of the turbine has almost doubled. The gear coupling

for this application has been changed to keep up, through design improvements, without changing its size (Figure 21). Higher strength materials are one change. The geometry of the crowned tooth was improved, for another. The tooth spacing and profile were also improved by lapping the sets together.

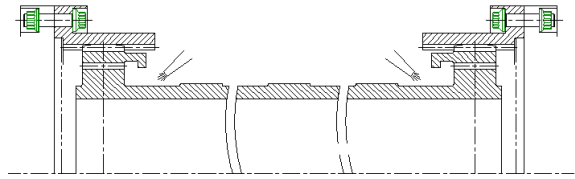


Figure 21. Typical Gas Turbine Load Coupling.

These gas turbines also use gear couplings for starting and driving the accessories (Figure 22). In that application the couplings are required to take high loads at start up and must accommodate large axial movements ($\frac{1}{2}$ inch to 1 inch), while having very low axial reactionary loads.

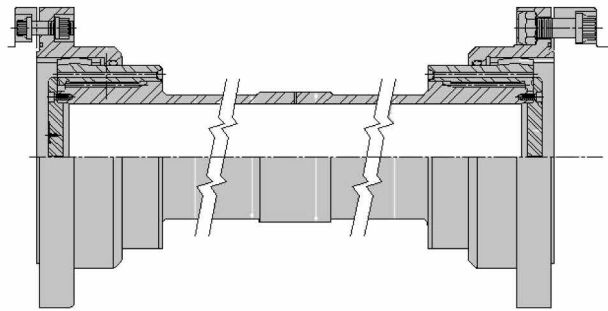


Figure 22. Typical Accessory Coupling.

It is important to note that gear couplings can be configured to meet many specification requirements beyond the usual torque and misalignment. The spacer piece can be modified to achieve various torsional stiffness requirements by changing the diameter and length. The coupling can be built using lightweight strong materials like titanium alloys to reduce weight. When built with the external gear teeth on the spacer piece, a marine style, the replacement of wear pieces is easier. It is not unusual for the coupling to be built with external gear teeth on the outer sleeve to accommodate a slow speed turning device. Gear couplings have been made with attachments such as torque measuring devices.

Design Considerations

Criterion number one under high speed applications and high power considerations is to improve the life of the coupling torque transmission surfaces. For gear couplings, that is the gear teeth. Tooth shape and involute angle have evolved into the optimal 20 degree tooth angle. The geometry of the crowned tooth has improved, as has the tooth spacing and profile by lapping the sets together.

Also required are the best, most wear resistant materials. That choice meant strength and hardness. Hard smooth surfaces also reduce friction, but lubrication is important too. Alloy steel that can be hardened to Rockwell C 45 minimum (required by API 671, 1998) or even higher is sometimes required. This is usually accomplished by nitriding the tooth surfaces (Figure 23). The harder the surface is made, the longer the life of the tooth. Under that hardness it is necessary to have a durable material (high tensile strength).

After the hardness, the most important factor is the lubrication of the mating or sliding parts. Low friction means less heat build up at the surface, and therefore less chance for the surface to breakdown or weld together. API 671 (1998) shows a preference for continuous lubrication (Figure 24). That is accomplished by

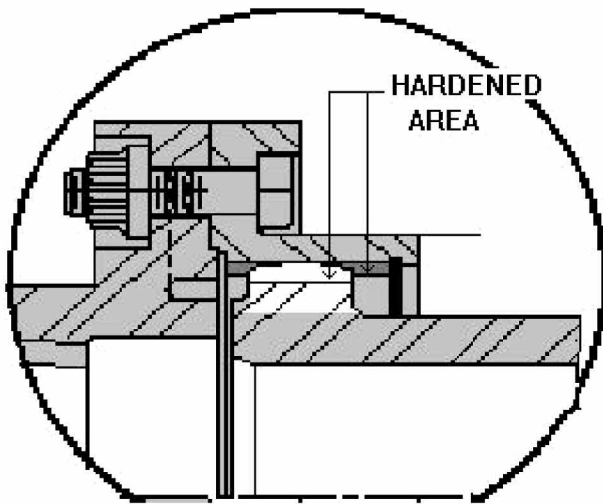


Figure 23. Tooth Hardening.

drawing the lubricant from the bearing lubrication system. The circulating oil lubricant is filtered and cooled. Even with the filtered circulating oil, sludge can still build up in the coupling. At the teeth, where the lubricant is needed, the centrifugal forces are large enough to cause solids in the oil to separate from liquids. Those solids can build up in the cavities and eventually block the oil passage or the movement of the teeth within the mesh, that same movement needed for the coupling to accommodate misalignment.

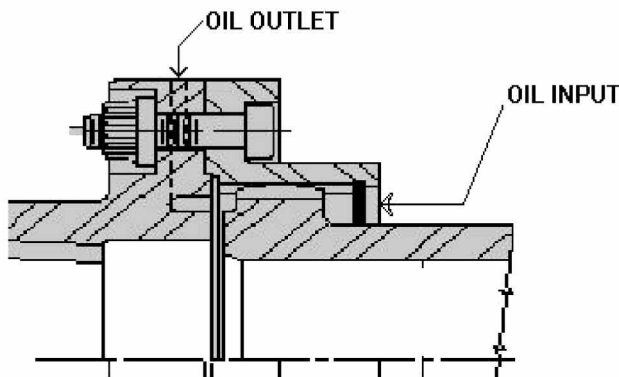


Figure 24. Continuously Lubed Gear Coupling.

Balancing of the gear coupling involves some special considerations. In order for the gear coupling to work as it was intended there must be some looseness to the assembly. That looseness is the backlash in the teeth and the major diameter fit allowance. That looseness means the coupling assembly cannot be as well balanced as a dry type, which has no clearances. The gear coupling is a major diameter fit on the teeth, to locate the center section or sleeve and spacer, but the coupling centers on the pitch line when operational. In effect the sleeve, or internal teeth, are changing position. That would change the center of gravity versus the center of rotation, thereby causing unbalance.

As with all balanced couplings, the process starts with the making of the components to very tight tolerances on concentricity and squareness. That is not always easy when part of the component is a clearanced gear tooth. Component balance is common, but to achieve assembly balance or to do an assembly check balance, the gear hub is specially made so that the fit at the major diameter is tight rather than loose for the balance operation. After balance, the coupling is disassembled and the tips are relieved (reduced) to allow for flexure and assembly. Size to size fit gear coupling teeth will limit the misalignment capability, if allowed to remain.

API 671 (1998) devotes several paragraphs to machining and tolerance specifics. That is because the first step to balance is the dimensional integrity of the coupling. The concentricity and the pilot fits and the squareness of the parallel planes will determine in a large degree the balance and the repeatability of the balance. That applies to both gear and flexible element couplings.

The work done to improve gear couplings was done to keep using a device that was rugged, inexpensive, and space saving. It was not an infinite life device, and it was not a maintenance-free device as it does require lubrication. In the final consideration even though the life has been extended to reasonable values and the lubrication is already available on the machinery, the device is being replaced by a more expensive metallic flexible element (disc and diaphragm) coupling that has infinite life and therefore more reliability. The cost tradeoff eventually favored the higher first cost flexible element device, which can be installed and forgotten.

Failure Modes

The most common gear coupling failures involve a lubrication problem. As mentioned before, foreign materials such as dust and metal particles can mix with the intended lubricant, or worse, separate from the lubricant and centrifuge out to the tooth area and form sludge (Figure 25). In the extreme case this sludge can lockup the coupling and prevent the movement necessary to accommodate misalignment.



Figure 25. Sludged-Up Continuous Lubed Coupling.

Another lubrication problem is an inadequate supply. This could lead to heavy pitting and spalling (Figures 26 and 27) and/or excessive wear (Figure 28). Excessive misalignment will also lead to heavy spalling, also called worm-tracking.

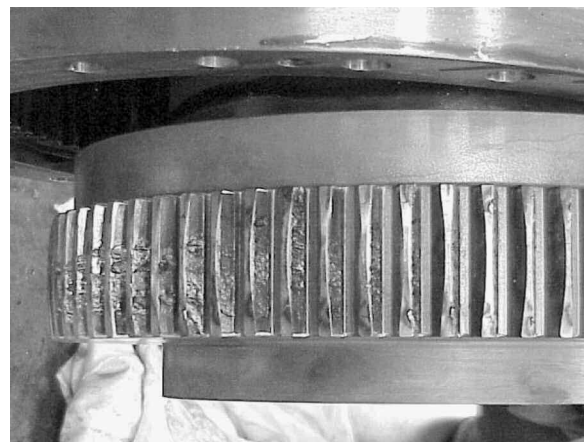


Figure 26. Heavy Pitting and Spalling of Teeth.

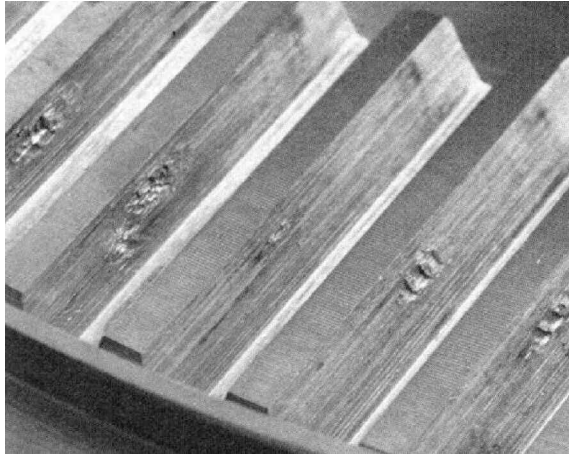


Figure 27. Start of Tooth Spalling.

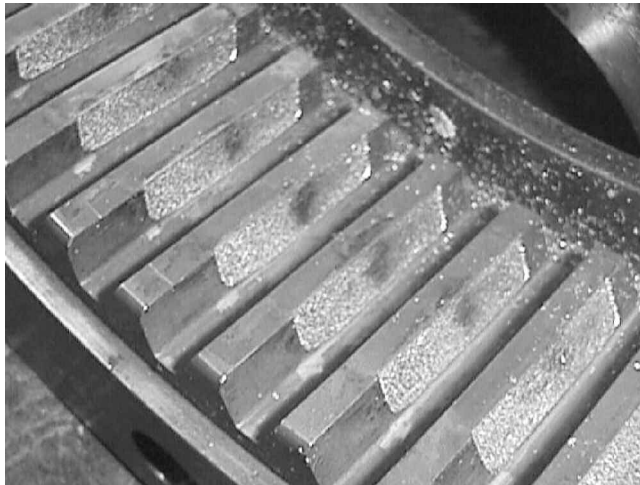


Figure 28. Excessive Wear from Lack of Lubrication.

Under extremely high misalignment, tremendous forces are transmitted to the connected shafts and bearings through the couplings. This is especially true for a gear coupling, which has up to 10 times the bending moment under misaligned conditions compared to a metallic flexible element coupling. Serious damage can result if the situation is not rectified (Figure 29).

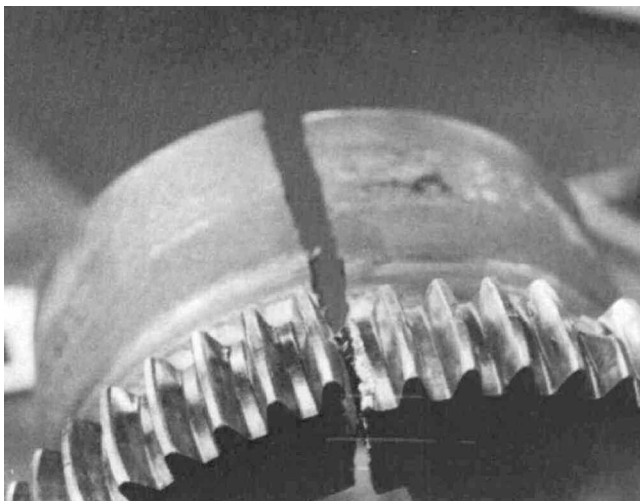


Figure 29. Broken Hub Through Keyway.

THE METALLIC FLEXIBLE ELEMENT COUPLING—DISC

There are thousands of high performance gear couplings in use today, but newer applications use disc or diaphragm. Although similar, diaphragm and disc couplings are not the same. Both types of couplings can do the job in most cases, but there are some instances where one is technically preferred over the other.

Metallic flexible element couplings, that is, diaphragm or disc couplings, rely on the flexure of metallic material to accommodate misalignment and axial displacement of shaft ends. They accommodate this flexure differently, however. The diaphragm couplings accommodate flexure from the metal between its outside diameter (OD) and inside diameter (ID) (the flex element, shown in Figure 43). Disc couplings accommodate flexure from the metal between adjacent bolts—the flex elements—that are attached to opposite flanges (Figure 30). Optimization of the flex elements can produce drastically different capacities and characteristics between diaphragm and disc couplings of the same OD.



Figure 30. Disc Coupling—Note Alternating Attachment Fasteners.

Operating Principles

The disc coupling is one style of coupling used to replace gear couplings on special purpose machinery. The principle of operation is that torque is transmitted through a flexible element by tensile loading between alternate bolts that are on a common bolt circle. One of the alternate bolts is the load transmitter, and the other the load receiver. They are fastened to opposite sides of the torque path.

The misalignment is accommodated by the flexing of the elements between adjacent bolts (Figures 30 and 31). The element must be thin to be flexible. Stacks of elements provide parallel load paths, and the diameter of the bolt circle is an indicator of the amount of torque to be carried. The amount of misalignment is related to the chord length between bolts and the thickness of the discs and disc packs.

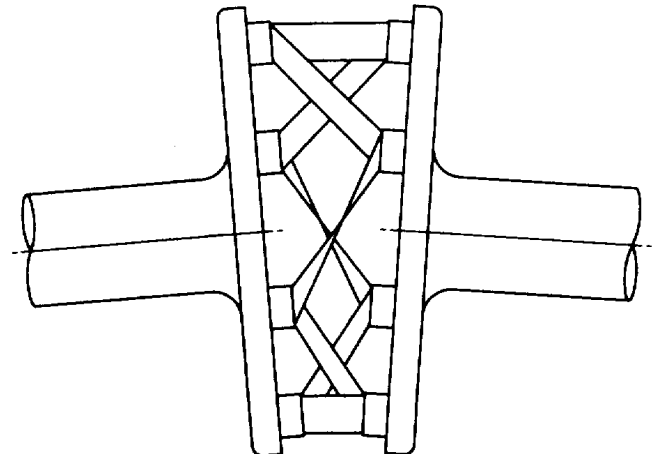


Figure 31. Disc Coupling.

Since the discs are almost always put together into packs, one of the benefits of the design is multiplicity. If one or more discs fail, the rest can still carry the load until the equipment is shut down.

The thin element has both tensile stresses and cyclic bending stresses imposed on the element so that a fatigue life analysis is required. Once the fatigue life is determined, an infinite life coupling can be designed to keep loading below that fatigue limit. It took some time to develop high fatigue strength materials. Also, advances in material load analysis, such as finite element analysis, were necessary to speed the development of reliable couplings.

The modern high performance disc coupling is nonlubricated and designed for infinite life. The amount of misalignment available is a function of the bending that can be accommodated while under tension. The unit will allow axial movement such as seen with thermal growth. However, that is not unlimited. Also, axial capability and angular capability are interrelated.

An important feature of disc couplings, and couplings that work in a similar manner, is the low reactionary load that is transmitted to the machinery that it couples, compared to the relatively high load of gear couplings. Disc couplings can be more expensive in first cost compared to gear couplings.

The shape of the disc is part of the mystique of this coupling. There are circular, straight-sided, and scalloped profiles of the discs (Figure 32). The circular is the least popular as the lines of force tend to try to straighten out the curved segment resulting in excessive compressive and tensile stresses. The other shapes keep the force lines within the boundaries, so the element has mainly tensile stresses. Since the fatigue problem occurs at the bending location, the wider cross section is next to the bolts where it does the most good.

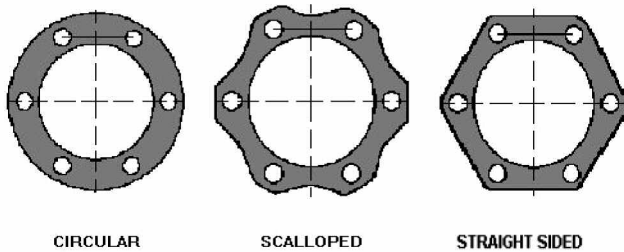


Figure 32. Disc Shapes.

Types and Styles

Similar to gear couplings, there are three basic configurations for a disc coupling: close-coupled, marine style, and reduced moment style (Figures 33, 34, and 35).

Design Considerations

When the couplings are applied to critical services, concessions and modifications have to be made to accommodate the high speed and high torque. High speed means balance, while high torque means strength. The combination of misalignment, speed, and torque means fatigue resistance.

As is the case for other types of couplings, additional considerations are needed for the special purpose application. In order to save space and reduce cost the coupling designer will select disc packs to closely match the application. In some cases a disc will be designed specifically for the equipment. That design will involve the bolt circle diameter, number of bolts, size of bolts, and the number of discs needed. Once the disc pack unit is designed and built at the factory, the pieces should not be disassembled. Piloted disc packs or factory assembled disc packs help to ensure against fatigue failure.

Balancing of the disc coupling is no different from balancing of any other rotating part. API 671 (1998) is very specific about the balance requirements of special purpose couplings. Both high speed and low speed categories are addressed. First the design is made symmetrical, then it is manufactured to a tight tolerance on concentricity and squareness. Finally, the components are

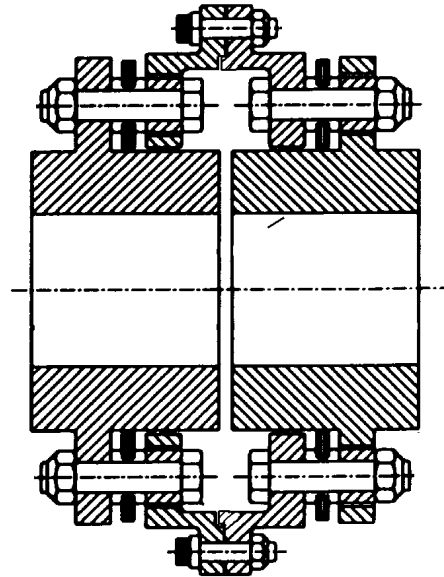


Figure 33. Close Coupled Disc Coupling.

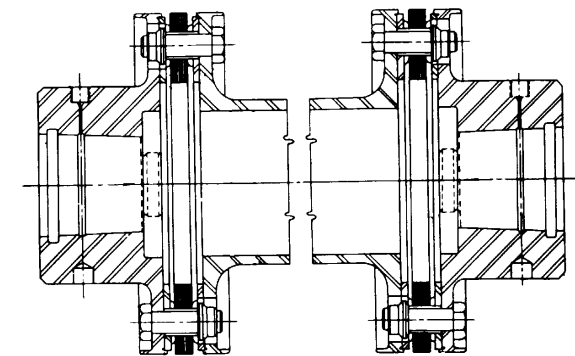
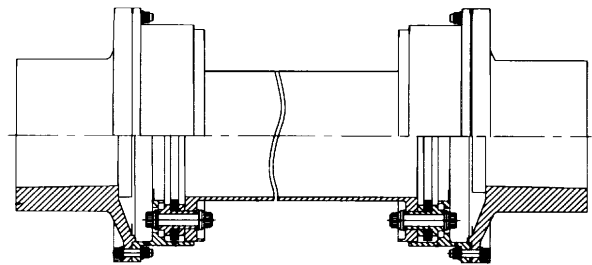


Figure 34. Marine Style Disc Coupling.

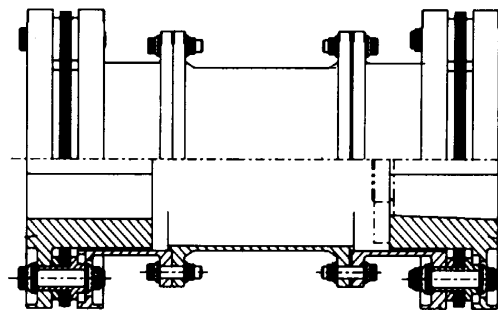


Figure 35. Reduced Moment Style Disc Coupling.

balanced. The disc coupling retains its balanced quality as an assembly since the flexing pieces are generally not a loose fit.

Designing for strength is a function of the disc pack materials and the shape of the disc at critical points such as the bolt attachments. The high performance discs are made from cold-rolled stainless steel (generally 300 series). Special discs are made of Monel®, Inconel®, PH stainless, and other special materials. Sometimes discs are coated to minimize or even eliminate the effects of fretting at high angles. Corrosion, if it is a factor, is controlled by material selection. Bending, which comes from the misalignment, is controlled by geometry, individual disc thickness, overall disc pack stiffness, the number of bolts, and the fatigue strength of the design.

API 671 (1998) covers the strength issue by specifying a fatigue factor of safety using the proportional increase method with the modified Goodman diagram or the constant life curves. Those references are used with material fatigue strength and ultimate strength. It is an issue best left to the coupling designer, but one for which the designer needs to have complete application information. Axial movement, axial thrust, and maximum allowable angular misalignment are important to know when a coupling is selected or is being designed.

The criterion for coupling selection for torque requirements versus torque capabilities is again based on paragraph 2.2.1 of API 671 (1998). For the disc coupling it is important to understand and know the misalignment requirements intermesh with the torque requirements. The angular misalignment and axial displacement both distort or bend the elements. With each revolution of the coupling the bending from misalignment is reversed or flexed. That bending is the source of the fatigue loading. The coupling manufacturer will help select the coupling so that the effects of the bending are within the coupling capabilities.

The coupling manufacturer can also provide various charts to show you the coupling capabilities. Those capabilities can include the relationship between parallel offset and/or angular coupling misalignment and axial misalignment (Figure 36). Other capabilities and restrictions would include the axial thrust versus axial displacement (Figure 37). Each of these items is needed to be sure the right size and type of coupling are selected and to be sure the designers and operators of the equipment train are aware of the coupling capabilities and limits.

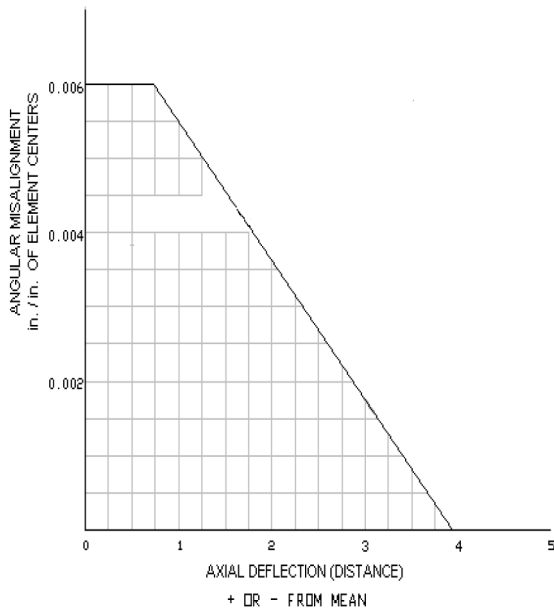
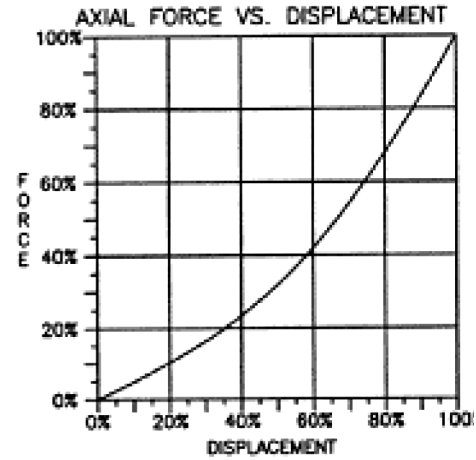


Figure 36. Coupling Angular Misalignment Versus Axial Travel.

Disc Coupling Failure Modes

Flexing metallic element couplings generally fail in either of two basic causes: overmisalignment or overtorque. Over-misalignment generally means excessive angular or parallel offset misalignment,



AXIAL DISPLACEMENT		FORCE
±(IN)	(% OF CONT.)	(LB)
0.080	100	396
0.040	50	116
0.008	10	18
0.000	0	0

Figure 37. Axial Force Versus Axial Displacement.

with or without excessive axial misalignment. There are, of course, combination failures, misalignment and torque, but there is usually only one that is primary.

An angular misalignment applies an alternating stress on the metallic flexible element or elements. The element(s) bends back and forth each revolution to accommodate the machinery angular or parallel offset misalignments. So the failure mode from these excessive misalignments is bending fatigue.

As mentioned before, one of the benefits of multiple disc pack couplings is multiplicity. If one or a few discs break, the others can still carry the load, at least for a short period of time, depending on the magnitude of the load. In a disc pack coupling, the outer discs, the ones farthest from the center of the pack, experience the highest stress from angular misalignment, as they are the farthest from the center of bending.

So, if an outer disc breaks, the load is redistributed to the inner discs, which then might have a higher torque load, but a lesser misalignment load. After enough discs break, there can be enough unbalance to cause higher machine vibrations, so that a decision can be made to shut the connected machines down and investigate the problem.

Note in Figures 38 and 39 that the outer discs have failed, from excessive misalignment, but the inner discs are still intact. The connected machines were still operating, though with higher vibration levels, and were safely shut down.



Figure 38. Outer Disc Failure.



Figure 39. Outer Disc Failure—Note Interlocking Flange Back-Up in Case of Total Failure.

The other major cause of failure is torque overload. In the case of a torque overload—for example, a compressor ingesting a liquid slug, or a generator short circuit, etc.—the major metal parts of this type coupling will yield. They will then break if the load is large enough or if the coupling is allowed to continue operating in the yielded condition.

In Figure 40, the discs are severely distorted from a torque overload. What is not readily seen is that the connecting bolts and bushings are also distorted (yielded), made more clear when the failed pack was disassembled. Note that this photo was taken with the equipment shut down and no load on the coupling.

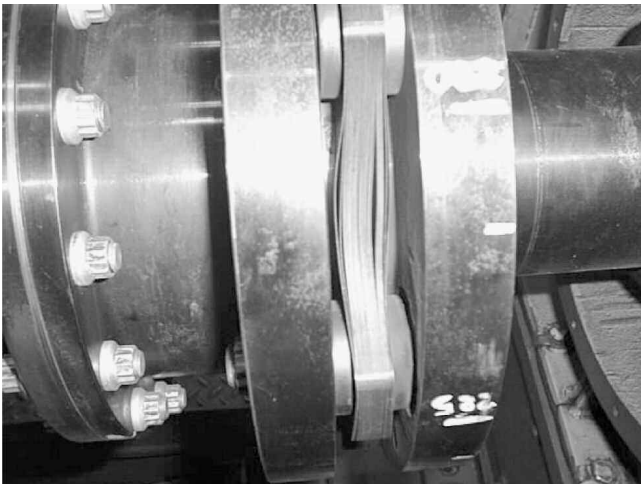


Figure 40. Torque Overload.

Under load, with a strobe, one could see a similar condition on the unloaded links in the coupling. Some gaps in the links are entirely normal for many types of disc couplings. The key to determine an overload is the condition of the disc packs with no load, or obviously damaged or bent discs and bolts under a strobe light. It goes without saying that extreme caution should be used when investigating a rotating coupling under a strobe light. It is not recommended without adequate personnel protection. Please consult your coupling vendor about what to look for.

THE METALLIC FLEXIBLE ELEMENT COUPLING—DIAPHRAGM

The other major metallic flexible element coupling is the diaphragm type. It can come as a single element, or be put together into packs, for multiplicity. There are various styles and diaphragm profiles.

Operating Principles

Diaphragm types can be classified as couplings that utilize a single or a series of “plates,” or “diaphragms,” for the flexible members. The torque transmission path through the diaphragm members is in the radial direction, from the outer diameter to the inner diameter or vice-versa. Load from operating torque is seen as a shear stress on the diaphragm member(s). There are basically two types of diaphragm couplings:

- Single (Figure 41)
- Multiple (Figure 42)

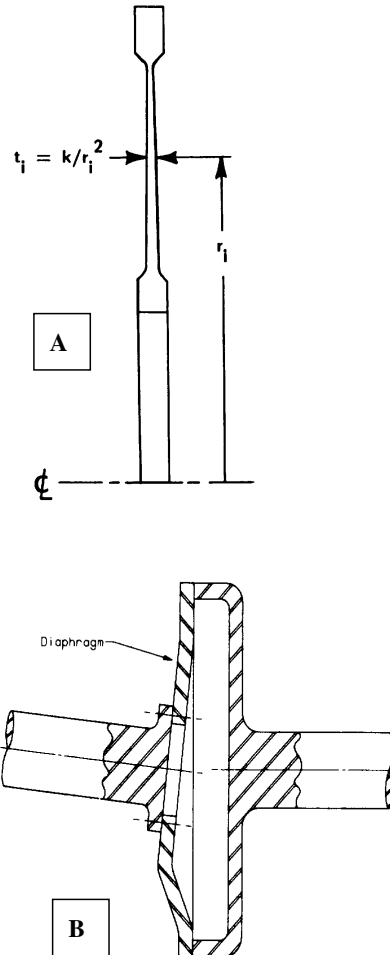


Figure 41. A, B Single Straight Contoured Diaphragm Profiles.

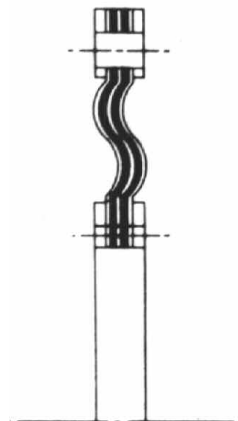


Figure 42. Multiple Convoluted Contoured Diaphragms.

They come in various profile shapes:

- Contoured or tapered (Figure 43 A)
- Convolved or wavy (Figure 43 B)
- Flat-profile, spokes (Figure 43 C), or cutout (Figure 43 D)

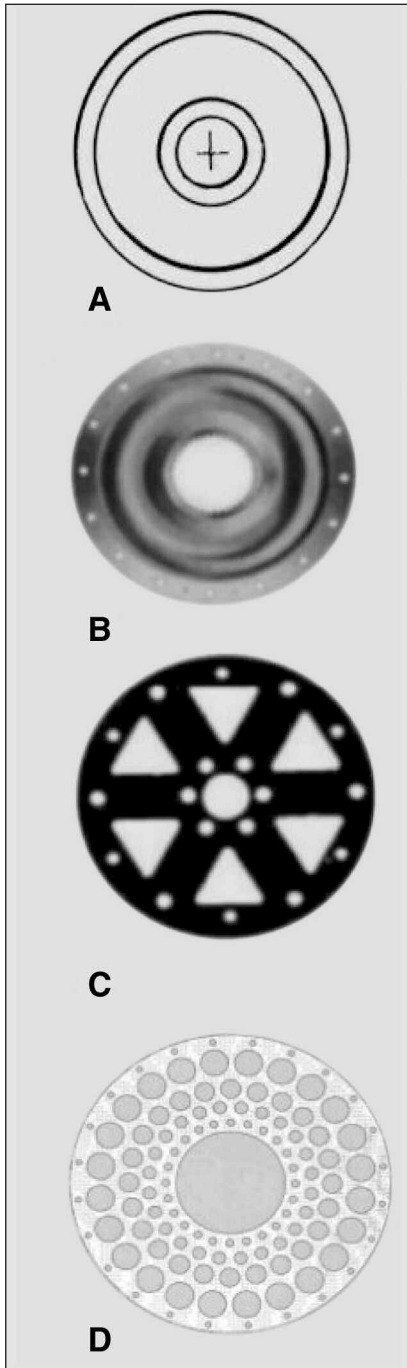


Figure 43. A, B, C, D Diaphragm Profiles.

All shapes have some type of profile modification that helps reduce size, increase flexibility, and control stress concentrations. A contoured diaphragm coupling typically uses a single diaphragm “plate” for the flexible member; the plate has a contoured or a wavy profile, which usually has a variable thickness from OD to ID to provide an optimum stress condition.

A convoluted and flat-profile diaphragm coupling typically uses multiple diaphragm “plates” that have a “wavy” profile or other

modified profile. All types of diaphragm couplings attach the flexible member to other components with bolts, splines, or welds, and both transmit torque in the same manner.

Diaphragms are made of high strength materials. Some are corrosion resistant (15-5/17-4 PH), others use high quality 4300 steel or other alloys and coat the diaphragms for corrosion protection. Some diaphragm couplings are shot-peened to reduce the residual stresses that are imposed during the manufacturing process and to prevent the development of surface crack initiation points.

Diaphragm couplings use a single “plate” for the flexing members; the plate is relatively thin and called a diaphragm. Each diaphragm can be deformed much like an automobile axle rubber boot. This deflection of the outer diameter relative to the inner diameter is what occurs when the diaphragm is subject to angular and axial misalignment.

Angular misalignment twists the outer diameter, relative to the inner diameter, and produces a complex shape on the diaphragm where it must stretch one way at one point and then stretch the other way at 180 degrees. In between these points, the diaphragm is subject to a combination of stretching and twisting. Axial displacement attempts to stretch the diaphragm, which results in a combination of elongation and bending of the diaphragm profile.

Convoluted diaphragms accommodate misalignment somewhat differently. They use multiple thin “plates” that are made to be wavy from OD to ID. They react similarly to the contoured diaphragm under misalignment except that they “unfold” the wavy profile of the plates instead of stretching the diaphragm.

Types, Styles, and Design

The contoured diaphragm coupling has as its flexible element a thin profiled diaphragm machined from a solid disc of heat-treated alloy. This diaphragm is contoured so that it has a nearly uniform torsional shear stress throughout the profile, which is therefore thicker at the hub, or ID, and thinner near the rim, or OD (Figure 41). The purpose of contouring the profile is to keep the diaphragm as thin as possible consistent with the transmitted torque. This keeps the misalignment bending and axial bending stresses as low as possible for a given torque capacity.

The thickness of a diaphragm can be changed to permit a tradeoff between torque capacity and flexibility. A thicker diaphragm has greater torque capacity, but is not as flexible and vice versa. Smooth fillet junctions are provided between the flexing portion and the rigid integral rims and hubs, which connect to the rest of the coupling, to reduce stress concentration.

In one configuration, the diaphragm hub is electron beam welded to the spacer tube in a permanent connection (Figure 44). In another configuration the diaphragm incorporates an integrally machined flange (Figure 45).

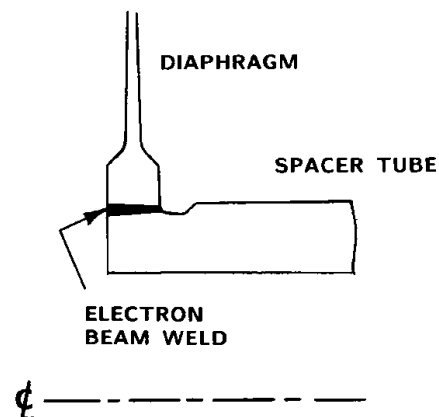


Figure 44. Welded Design.

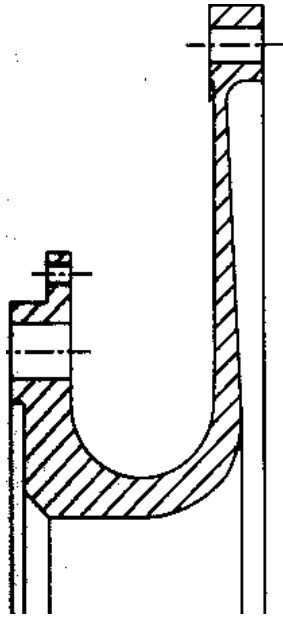


Figure 45. Integral Flanged Diaphragm Coupling.

Whereas one design minimizes the number of mechanical connections in the coupling, the other allows for flex element replacement.

The most often used diaphragm style is the marine style coupling configuration, which allows the mounting hub bore to vary considerably without affecting the diaphragm diameter (Figures 46 and 47). Thus, the size of the coupling is being chosen to fit the torque and misalignment requirements rather than be dictated by the connected machine shaft size.

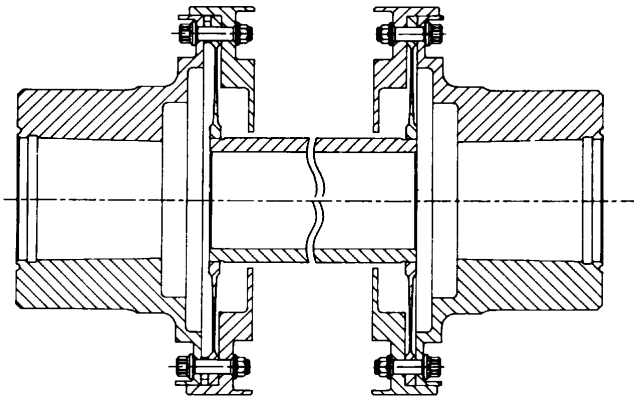


Figure 46. Marine Style Diaphragm Coupling Welded Design.

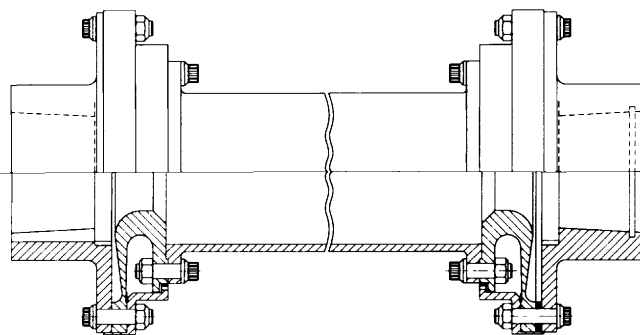


Figure 47. Marine Style Diaphragm Coupling Machined Design.

Most diaphragm couplings have a guard to protect the diaphragm or diaphragm pack from scratches and nicks that would act as stress risers on the diaphragms. These guards also act as antifail devices, to keep the center section contained in the unlikely event of a diaphragm failure.

Furthermore, the guards can act as pilots to locate the center section to meet the API Standard 671 (1998) and enhance the balance repeatability of the coupling. This makes using the technique of only balancing the coupling components (for component interchangeability) more practical.

For those special applications requiring a reduced moment coupling, the contoured diaphragm coupling is made with the diaphragms machined from forgings with integral hubs (Figure 48), or the diaphragm is reduced in ratio and inverted so it fits over the hub (Figure 49). This configuration shifts the flexible center closer to the machinery bearings to reduce the overhung moment from the weight by moving the coupling center of gravity (CG) toward the machine bearings.

Figure 48. Reduced Moment Integral Hub.

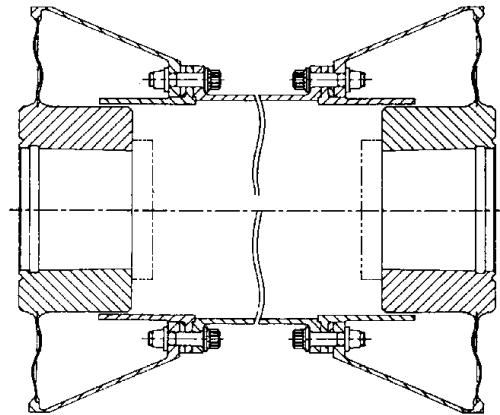


Figure 49. Reduced Moment Reduced Ratio Diaphragm.

The multiple convoluted diaphragm coupling uses a stainless steel diaphragm pack (Figure 42). The pack consists of several thin, separated, convoluted diaphragms. The design comes in two standard styles of diaphragms—a large OD/ID ratio and a reduced OD/ID ratio. The diaphragm pack consists of several thin convoluted diaphragms, separated at the OD and ID. The diaphragms are attached at the ID by a fine pitch spline to an adapter that is clamped tight by a nut.

Just like the other types of high performance couplings, there are three basic styles of multiple convoluted diaphragm couplings: marine style (Figure 50), close coupled (Figure 51), and reduced moment (Figure 52).

The multiple flat diaphragm coupling consists of a series of thin "plates" assembled as packs with welds, rivets, etc. Torque is transmitted from the hub to the pack by splines, bolts, or friction fits. Again, there are three basic styles of multiple flat diaphragm couplings (Figures 53, 54, and 55).

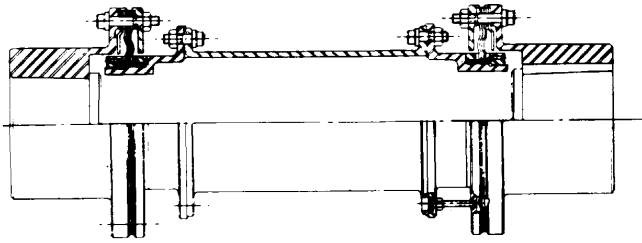


Figure 50. Marine Convoluted Style.

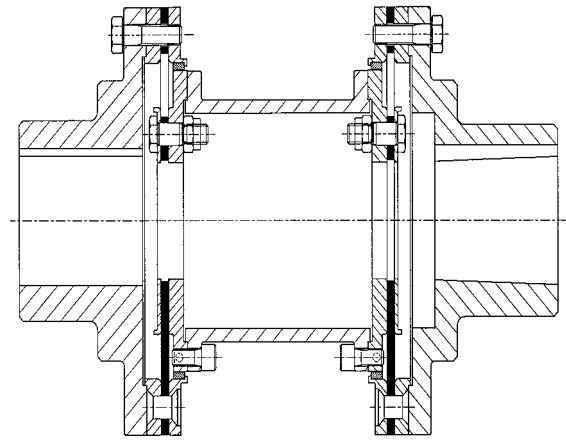


Figure 54. Marine Style Multiple Flat Diaphragm.

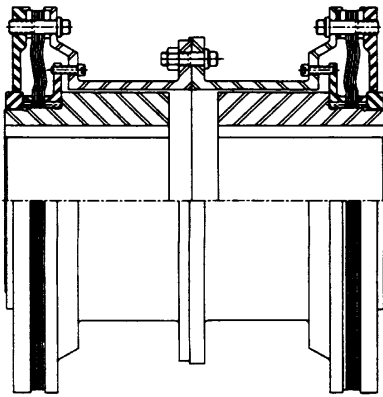


Figure 51. Close Coupled Convoluted.

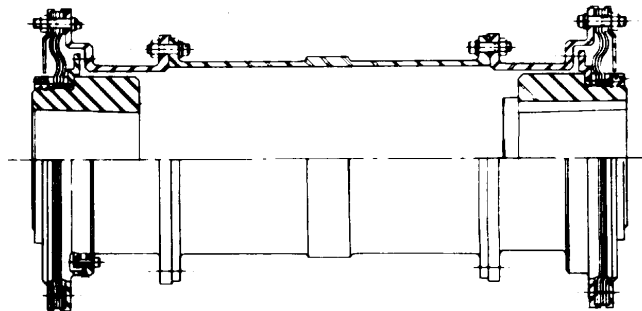


Figure 52. Reduced Moment Convoluted Style.

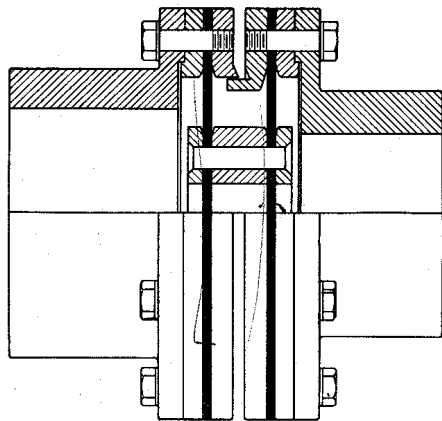


Figure 53. Close Coupled Multiple Flat Diaphragm.

Diaphragm Coupling Failure Modes

Like the disc metallic flexible element coupling, the diaphragm type will generally fail from either overmisalignment or over-torque. This type also depends on the bending of metal to accommodate angular, offset, and axial misalignment. Like the disc type, the angular and offset misalignments are seen as alternating stresses in the diaphragm.

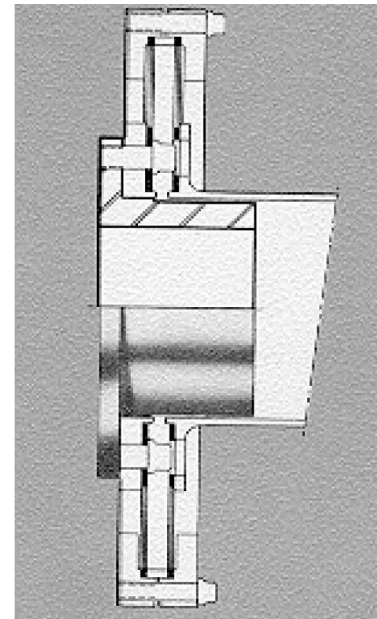


Figure 55. Reduced Moment Style Multiple Flat Diaphragm.

Failures from angular misalignment start as cracks in the diaphragm web. Axial misalignment can contribute to the stress and failure, though it does not stress the diaphragm in an alternating fashion (Figures 56, 57, and 58). Finally, torque overload will cause one or more ripples in the diaphragm (Figure 59).

APPLICATIONS AND CONSIDERATIONS

In most applications, a well-designed high performance coupling will do the job no matter which type or style it is. As long as it meets the torque and misalignment requirements, and the weight and any other mass elastic characteristic limitations, it will operate well, as long as it is not operated outside its stated limits. Cost and delivery then become significant factors. However, there are some cases where one type of coupling or the other is well suited.

Lubricated Couplings (Gear)

For many years, gear couplings have been used on steam turbines, gas turbines, compressors, and pumps. When the horsepower, speeds, and operating temperatures increased, many problems with gear couplings developed. Gear couplings are now used very rarely for new applications of special purpose applications. Where they are used is as accessory couplings for some gas turbines. They have been proven in these applications to be the most cost-effective.



Figure 56. Reduced Moment Diaphragm Failure from Angular and Axial Misalignment.



Figure 57. Marine Style Diaphragm Failure from Angular and Axial Misalignment (A).

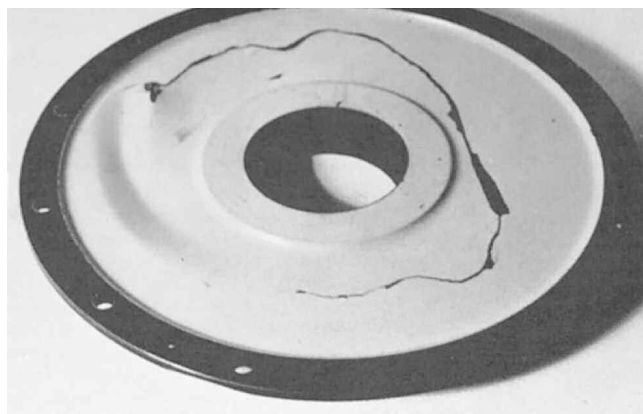


Figure 58. Marine Style Diaphragm Failure from Angular and Axial Misalignment (B).

Nonlubricated Couplings (Rigid)

Rigid couplings are used when neither angular misalignment nor axial displacement is required. They are used by a few original equipment manufacturers (OEMs) as their standard offering when



Figure 59. Diaphragm Torque Overload.

thrust bearings are not incorporating in the mating equipment allowing the rigid coupling to “float.” Presently rigid couplings are used as standard equipment for some generator set load couplings mating the turbine to the generator.

Disc Metallic Flexible Element Couplings

The flexible element disc coupling is used on a variety of applications for special purpose couplings. The multidisc reduced moment design is ideal for compressor applications where moment reduction is crucial to eliminate potential lateral system problems. Since the torque is transmitted circumferentially from bolt to bolt through the discs, the discs can slide over the hub and shaft end to where the disc pack is closer to the equipment bearings. It will generally also be smaller in diameter than a diaphragm type, which must transmit torque from OD to ID, and therefore will have less windage related problems. It will travel at less surface speed, and therefore heat up and/or shear less air in the coupling guard (Carter, et al., 1994).

Diaphragm Metallic Flexible Element Couplings

Large gas and steam turbines are ideal applications where the diaphragm coupling’s diaphragm can bolt directly to the turbine flange (e.g., Frame 6, LM 6000, TP&M FT8, etc.), thereby giving the best center of gravity location relative to the turbine bearing. Usually only a single diaphragm is used per coupling end and can handle very large amounts of axial travel. Some single diaphragms can accommodate ± 1 inch of misalignment.

Other variations include a double diaphragm, used for high axial misalignment along with high torque loads, and “J” diaphragms, which have two different profiles per end (Figure 60). There are also, of course, the multiple wavy and multiple flat configurations, which also work well in gas turbine applications.

THE BASIC DIFFERENCES

In Tables 1 and 2 are the differences and characteristics of some basic types of high performance couplings. The values in Table 1 are typical catalog numbers. Other values for each type of coupling, specific to an application, are possible. The Table 2 characteristics are relative ones based on the authors’ combined experiences. Again, different designs, specific to applications, of each type are possible.

APPLICATION COMPARISONS

Gas Turbine Load and Accessory Couplings

In Table 3 is a comparison of the coupling characteristics for the load and accessory drive of a popular gas turbine (refer to Figures 21 and 22). Two different gear tooth designs are compared with dry

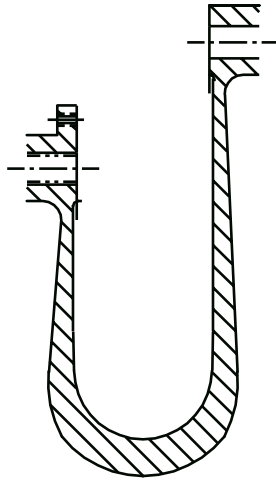


Figure 60. Two Diaphragm Profiles in Same Part.

Table 1. Differences in High Performance Couplings.

Coupling Capacities And Design Differences	RM Gear Coupling	Marine Gear Coupling	Circular Disc	Misc. Shape Disc	Multiple Diaphragm	Convolutd /wavy Diaphragm	Tapered Diaphragm
Maximum Continuous Torque (x10 ⁶ lb-in)	10	10	4	6	4	6	6
Maximum Speed (RPM)	10,000	10,000	30,000	30,000	20,000	30,000	30,000
Maximum Bores (in)	18	18	12	12	12	12	12
Maximum Acceptable Misalignment	½ degree	½ degree	¼ Degree	½ Degree	1 Degree	½ Degree	½ Degree
Maximum Allowable Axial Travel (+/- in.)	1 inch	1 inch	3/8 inch	1/2 inch	1/2 inch	1 inch	1 inch

Table 2. Characteristics of High Performance Couplings.

Coupling Characteristics	RM Gear Coupling	Marine Gear Coupling	Circular Disc	Misc. Shape Disc	Multiple Diaphragm	Convolutd /wavy Diaphragm	Tapered Diaphragm
OD/Bore Ratio	Small	Small	Small	Small	Large	Medium	Large
Overhung Moment	Low	Medium	Low	Low	Medium	Med/Low	Medium
Unbalance force	Medium	Medium	Medium	Low/Med	Low/Med	Low	Med/Low
Bending Moment	High	High	Medium	Low	Med/Low	Low	Med/Low
Axial Force	Med/High	Med/High	High	Medium	Medium	Low	Low/Med
Torsional Stiffness	High	High	High	Medium	High	Medium	High
Windage	Low	Low/Med	High	Med/Low	High/Med	Med/Low	High/Med

couplings (disc or diaphragm). As explained before, the diameters of the gear couplings are less than the flexible metallic element disc or diaphragm couplings, as are the corresponding weights. For both the accessory and the load couplings, the bending moment for the gear couplings is larger than the dry couplings. This is especially true for the load application.

Table 3. Gas Turbine Accessory and Load Coupling Comparison.

Coupling Type	Coefficient of friction	OD (in)	Weight (lbs)	Continuous Torque Condition (Lb-In)	Axial Force at continuous conditions (0.25") (lbs)	Continuous Angular Misalignment (Degrees)	Bending Moment (Lb-in/deg)
Accessory Gear Coupling I	U = 0.075	12.75	190	18,000	440	+/- 0.25	1900
Accessory Gear Coupling II	U = 0.25	12.75	190	18,000	1450	+/- 0.25	4800
Accessory Disc Coupling		12.62	220	18,000	1090	+/- 0.25	1000
Accessory Diaphragm Coupling		12.75	250	18,000	500	+/- 0.25	600
Load Gear Coupling I	U = 0.075	16.00	480	534,000	6870	+/- 0.25	56,300
Load Gear Coupling II	U = 0.25	16.00	480	534,000	22880	+/- 0.25	140,800
Disc Load Coupling		18.12	620	534,000	3000	+/- 0.25	16,000
Diaphragm Load		17	580	534,000	4000	+/- 0.25	5,600

Note that the axial force (and to a lesser extent the bending moment) of the gear couplings is dependent on the torque and coefficient of friction. Since the accessory couplings were designed for a relatively small continuous load, but a large startup load (not shown), the axial force from the gear couplings is comparable to the dry couplings. For the load couplings, with much higher continuous torque loading, the axial forces are much lower for the dry couplings.

High Speed Gear to Compressor

A comparison of various types of couplings for a 6000 hp/10,000 rpm—normal conditions—high speed gear to centrifugal compressor coupling application is in Table 4. Assumed is a typical 18 inch shaft separation, with 2.5 inch identical shafts on both ends. Also note that the service factor applied to select the dry couplings is 1.5, while for the gear is 1.75, both values per API 671 (1998). So the normal torque given is 37,800 lb-in, and the selection torque for the gear coupling is 66,180 lb-in, while for the disc it is 56,700 lb-in. The reasons for the difference in factors is complicated, but has to do with successfully used experience.

Table 4. High Speed Gear Compressor Application Comparison.

Coupling Type	OD (in)	Half Weight (lbs)	Center of Gravity (in)	Continuous Torque Rating (Lb-In)	Axial Force at continuous conditions (0.05") (lbs)	Continuous Angular Misalignment (Degrees)	Bending Moment (Lb-in) @ ¼ degree
Reduced Moment Gear	6.06	16.3	1.99	66,800	840 @ 0.25 deg.	+/- 0.25	3150
Reduced Moment Disc	6.56	18.1	2.31	75,000	166	+/- 0.25	318
Reduced Moment Multiple Diaphragm	6.94	15.8	2.13	76,700	250	+/- 0.25	240
Marine Gear Type	6.06	19.2	0.27	66,800	840 @ 0.25 deg.	+/- 0.25	3150
Marine Disc Type	7.81	20.3	-0.20	75,000	166	+/- 0.25	318
Marine Single Diaphragm	9.16	25.4	-0.09	118,000	720	+/- 0.25	388

Note the improved centers of gravity of the reduced moment couplings compared to marine styles. The centers of gravity are from the end of the shaft toward the equipment bearing. Some vendors call this minus, others plus, so be careful when comparing coupling offerings. Also note the decreased reaction forces of the dry couplings.

A similar caution applies to the use of this table as with the ones above: a good coupling designer can design couplings of lower than catalog weight with higher torque, different center of gravity, etc. In this table are typical catalog values for a specific design. If the torque requirement was slightly less or more, very different selections could have been made. For example, if the torque requirement was 10 percent less in this application, meaning a lower service factor, the marine single diaphragm could have been a smaller size.

Low Speed Synchronous Motor to Gear (Driving a Blower)

Finally, Table 5 is a comparison of two different couplings for a synchronous motor to gearbox driving a blower application—54,000 hp at 1800 rpm normal between motor and gearbox. This is a special design as synchronous motors have high amplitude torsional vibrations at startup.

Table 5. Low Speed Synchronous Motor to Gear/Blower Application Comparison.

Coupling Type	Driving OD (in)	Driving Half Weight (lbs)	Driven OD (in)	Driven Half Weight (lbs)	Max Start-Up Torque (million lb-in)	Coupling Transient Torque Capacity (million lb-in)	Axial Misalign. Capacity (in)	Angular Misalign. Capacity (deg/end)
Resilient Disc Hybrid	26.88	509	41.75	3546	4.00	4.26	+/- 0.200	0.25
Marine Style Diaphragm	27.41	610	27.41	911	5.35	6.60	+/- 0.080	0.17

One way to reduce these potentially damaging torque oscillations is to use an elastomeric damping coupling (Figures 61 and 62). The alternative is to design the coupling and equipment by rotordynamically torsionally tuning the system so that the torque loading is at its lowest possible without a damping coupling or device. Then a more conventional coupling can be used as long as it can handle the torque oscillations (Figure 63).

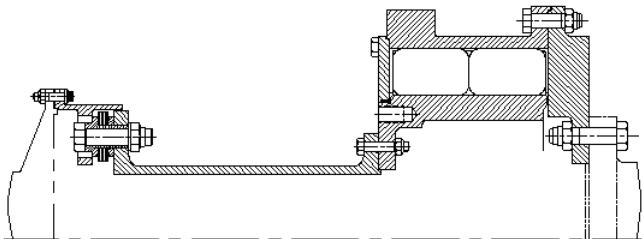


Figure 61. Disc/Resilient Coupling Hybrid for Synchronous Motor Application.

As can be seen in Table 5, the more conventional coupling weighs a lot less and will likely cost less, but is much more rigid in the axial and angular direction—not necessarily a big drawback in a motor/gear situation with little thermal movement. Also in its favor, the conventional coupling does not have wearing elements.

The resilient elastomeric coupling—actually a hybrid with a conventional style coupling on one end—is huge, and also has the disadvantage of wearable elements that need to be checked every year or so, and possibly changed every 2 to 10 years, depending on the severity of the loading. On the plus side, the startup torque loading is significantly lower.

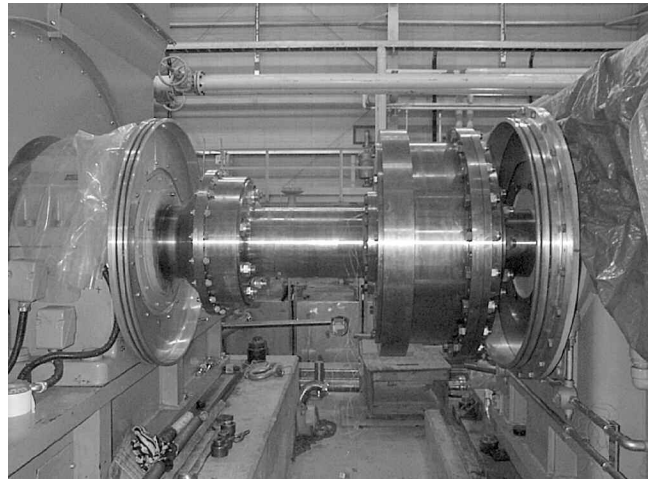


Figure 62. Disc/Resilient Coupling Hybrid for Synchronous Motor Application.

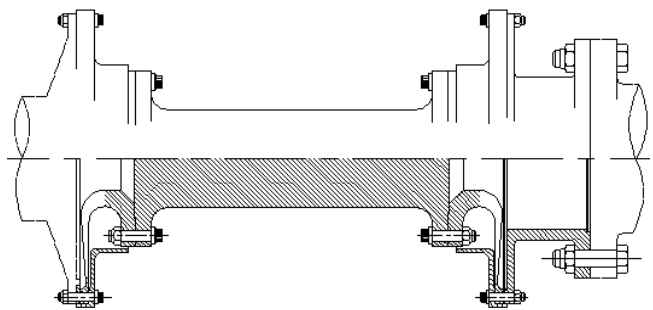


Figure 63. Marine Style Diaphragm for Same Synchronous Motor Application.

Note that Table 5 only indicates a peak magnitude of startup torque. The torque fluctuations are not indicated but are more severe with the conventional design. For that design the startup fluctuating load was calculated to be 543,000 lb-in, ± 4,790,750 lb-in. Though unknown for this application, from experience the fluctuating loads with the elastomeric coupling design are likely less in magnitude and also less in the number of cycles per startup, due to the damping.

CONCLUSION

Although any high performance special purpose coupling can be designed for most any application, there are some times that one type fits better than another. Choosing the best design can ensure more reliably operating turbomachinery.

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