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

by
Jon Mancuso
Director of Engineering
and
Joe Corcoran
Manager, High Performance Engineering
Kop-Flex, Emerson Power Transmission Corporation
Baltimore, Maryland

Jon R. Mancuso is Director of Engineering with Kop-Flex Inc., Emerson Power Transmission Corporation, in Baltimore, Maryland. He has more than 30 years' experience in the coupling field and is author of many papers on couplings for various publications, societies, and symposia. Mr. Mancuso is also author of a book on couplings, Coupling and Joints: Design, Selection, and Application, *and editor and author of several chapters in* Mechanical Power Transmission Components Handbook. *He has been involved with many design, research projects relating to couplings, and is coinventor of several patents with couplings and clutches.*

Mr. Mancuso graduated from Gannon University with a B.S. degree (Mechanical Engineering), and has an M.S. degree (Engineering Science) from Pennsylvania State University. He is chairing the ASME Committee on Couplings and Clutches. In addition, he is a member of the AGMA Coupling Committee and also serves on the API Committee on Couplings for Special Purpose Applications.

Joseph P. (Joe) Corcoran is Manager of High Performance Engineering for Kop-Flex, Inc., a division of Emerson Power Transmission (EPT), in Baltimore, Maryland. He is responsible for an engineering group that selects and designs couplings and processes orders and inquiries for high performance couplings, mainly for turbomachinery. In addition, Mr. Corcoran has marketing and field service responsibilities. Previous to his 18 years at Kop-Flex, he was an operations engineer responsible for two 80 ton per day Union Carbide-Linde oxygen plants for the City of Baltimore. He has authored and coauthored many articles and papers dealing with high performance coupling and torquemeter applications.

Mr. Corcoran has a B.S. degree (Mechanical Engineering) from the University of Maryland. He is a member of ASME, the Vibration Institute, the Third and Fourth Edition Task Forces for API 671, and the Work Group responsible for the corresponding ISO 10441 coupling specification.

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.)

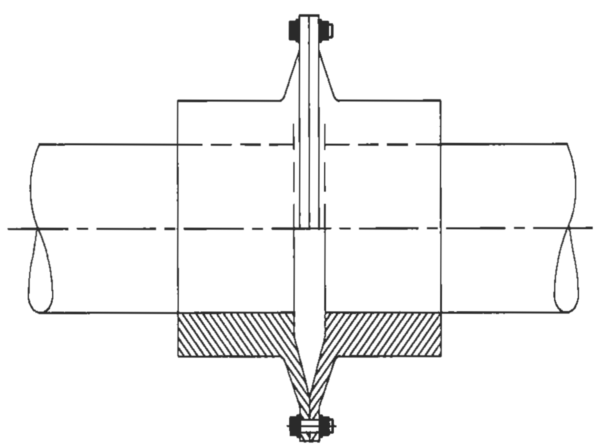


Figure 1. Rigid Coupling.

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).

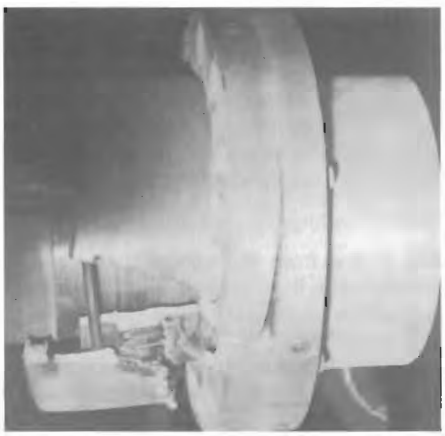


Figure 4. Failed Gear Coupling.

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.

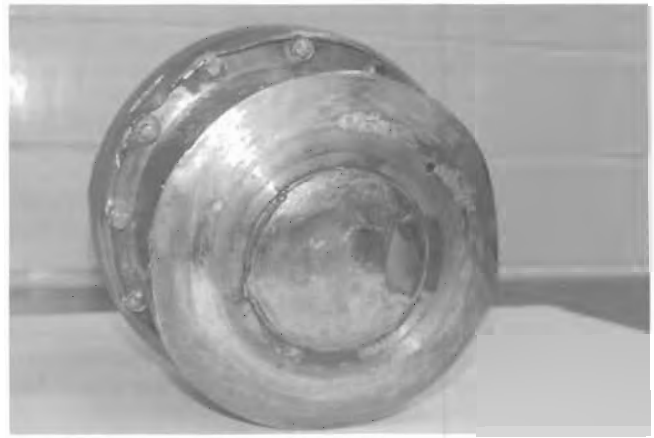


Figure 6. Equipment Failure—Broken Shaft with Coupling Hub.

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

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.

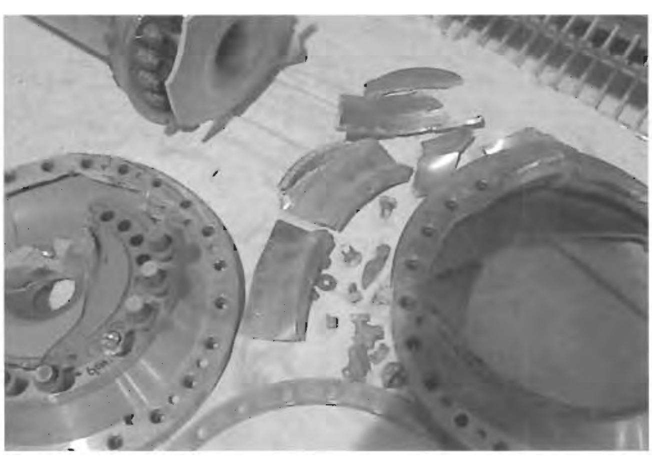


Figure 11. Diaphragm Coupling Failure.

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.

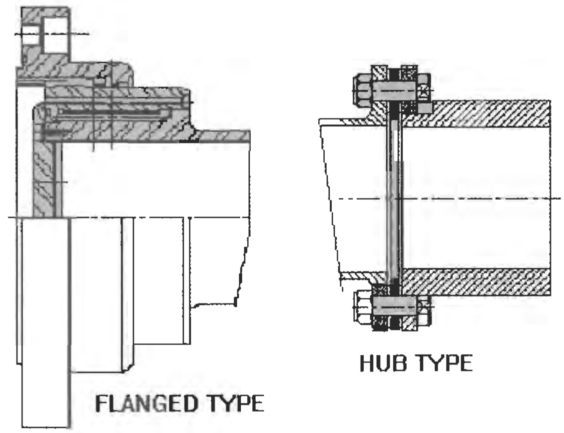


Figure 12. Flanged Connection and Shaft Mounted.

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.

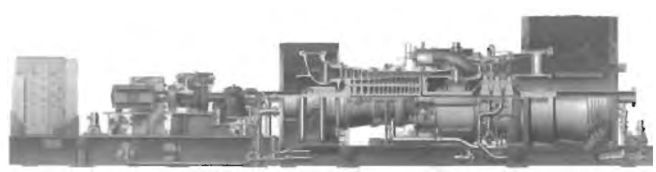


Figure 13. Gas Turbine That Typically Uses Quill Shaft Coupling.

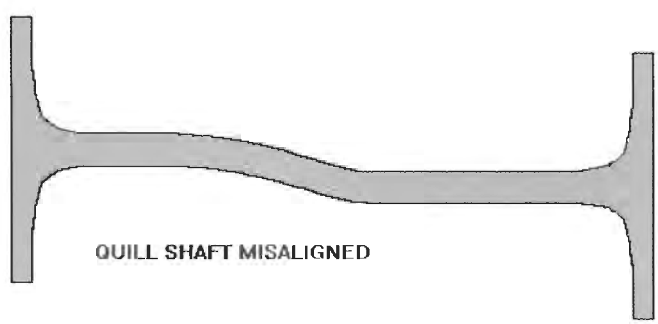


Figure 14. Quill Shaft Coupling.

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

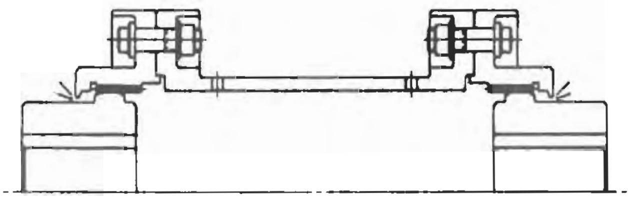


Figure 18. Spacer Coupling Generally Used in Continuous Lube Configuration.

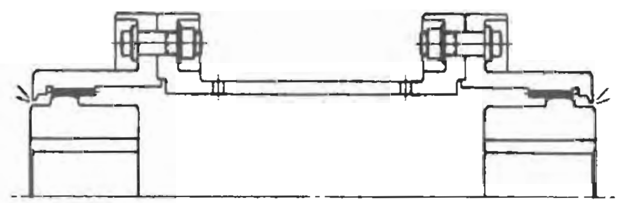


Figure 19. Spacer Coupling (Continuous Lube) with Reduced Overhung Moment on Connected Shafts. Most Common High Performance Gear Coupling in Use.

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.

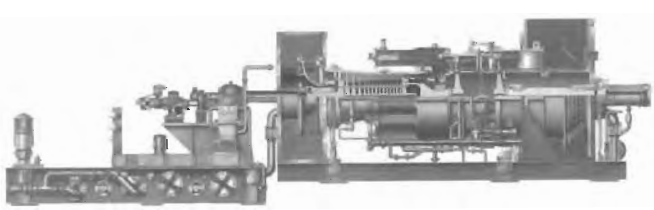


Figure 20. Typical Gear Coupling Application.

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.

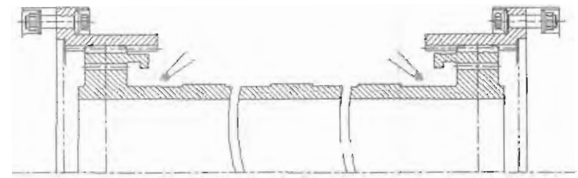


Figure 21. Typical Gas Turbine Load Coupling.

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 (1/2 inch to 1 inch), while having very low axial reactionary loads.

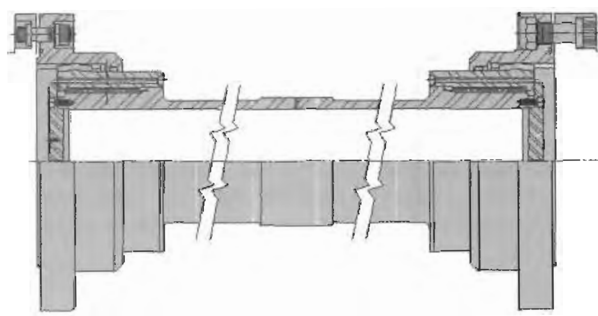


Figure 22. Typical Accessory Coupling.

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

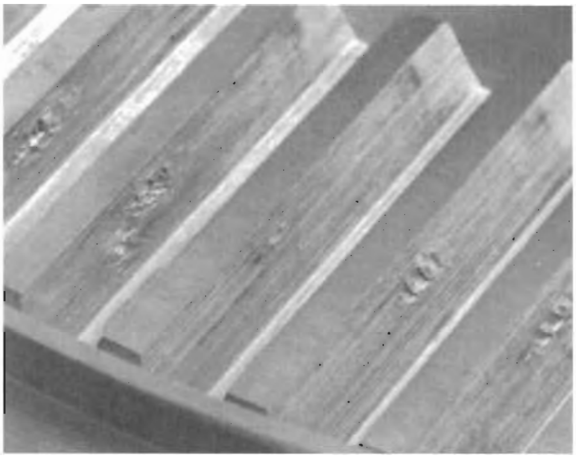


Figure 27. Start of Tooth Spalling.

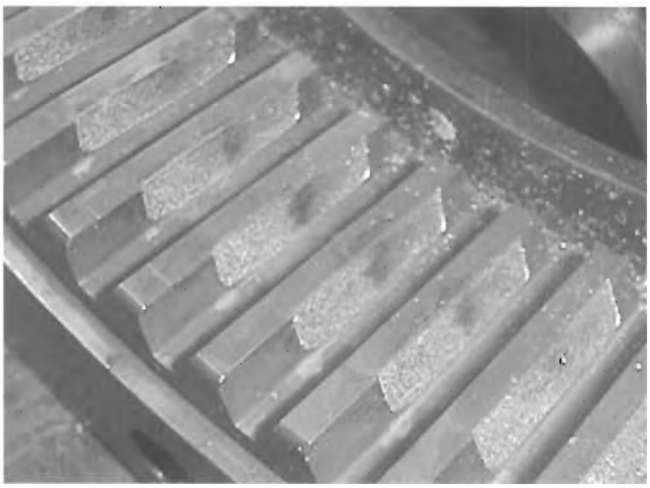


Figure 28. Excessive Wear from Lack of Lubrication.

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).

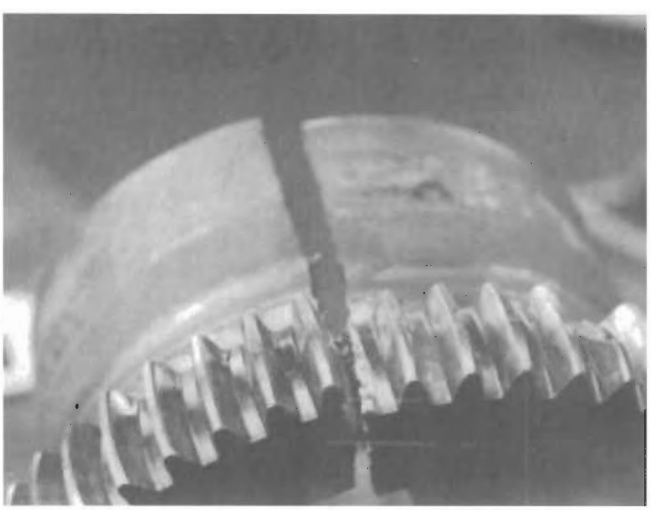


Figure 29. Broken Hub Through Keyway.

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.

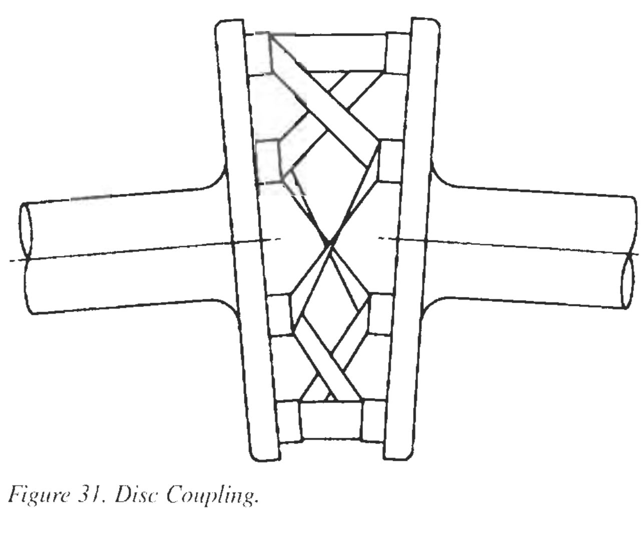


Figure 31. Disc Coupling.

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.

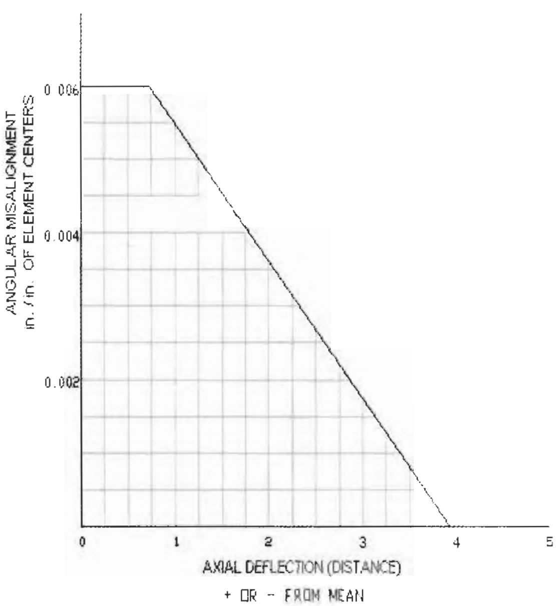
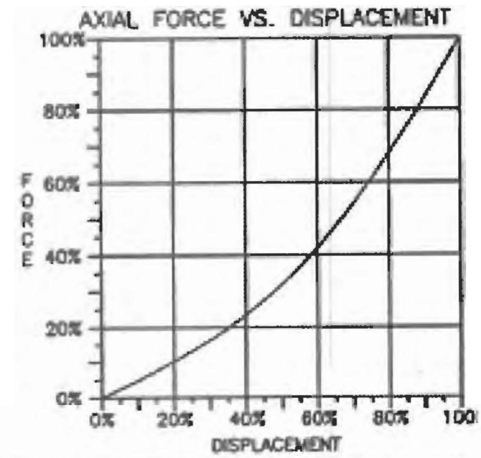


Figure 36. Coupling Angular Misalignment Versus Axial Travel.

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



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.

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.

They come in various profile shapes:

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

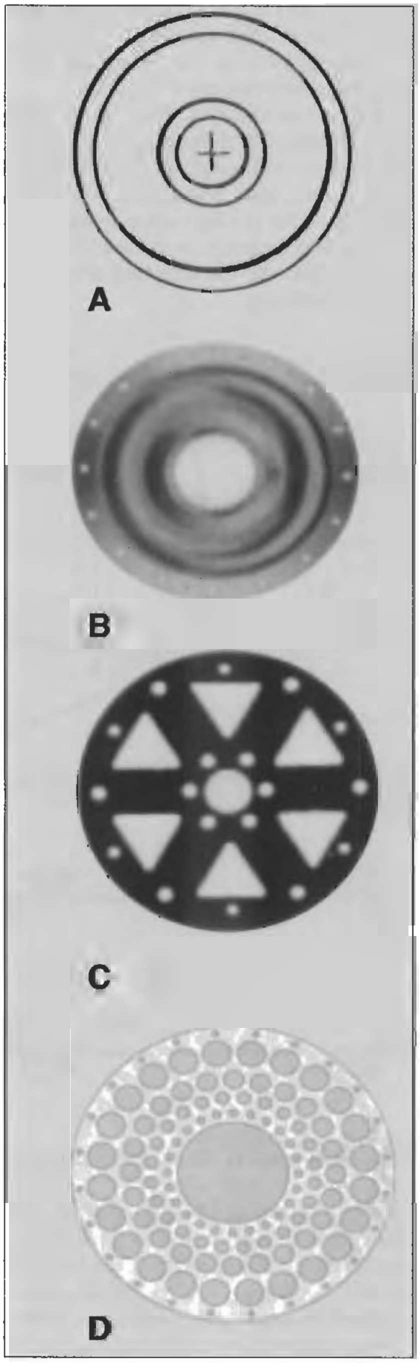


Figure 43. A, B, C, D Diaphragm Profiles.

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).

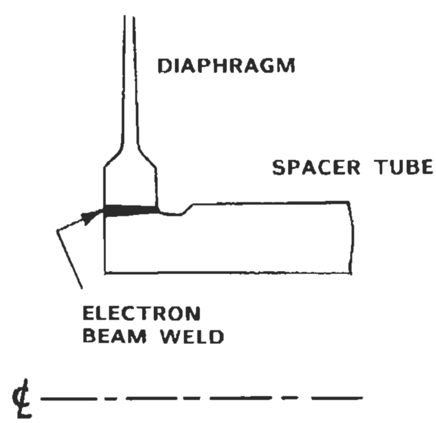


Figure 44. Welded Design.

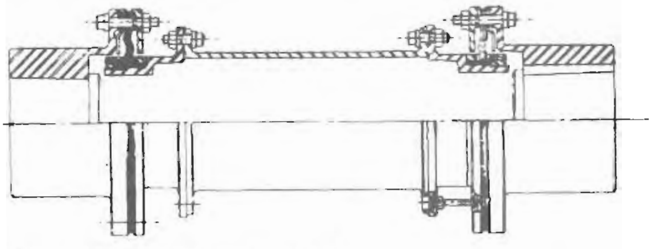


Figure 50. Marine Convoluted Style.

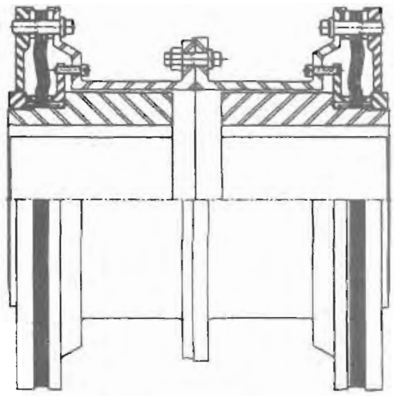


Figure 51. Close Coupled Convoluted.

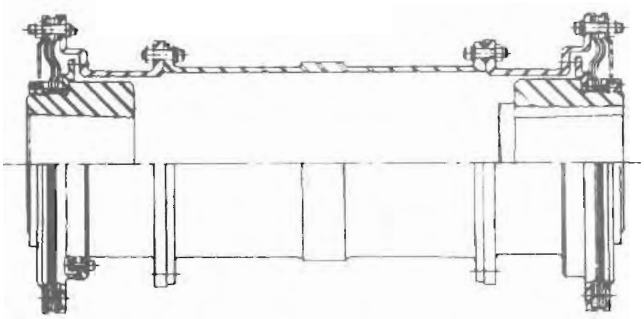


Figure 52. Reduced Moment Convoluted Style.

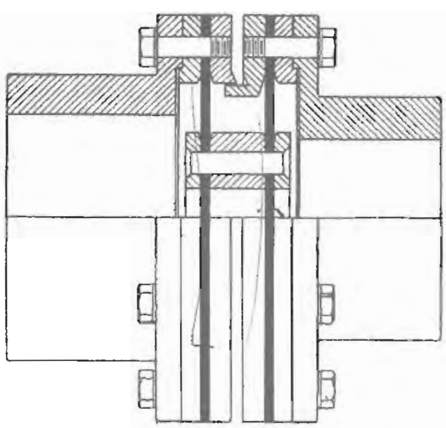


Figure 53. Close Coupled Multiple Flat Diaphragm.

Diaphragm Coupling Failure Modes

Like the disc metallic flexible element coupling, the diaphragm type will generally fail from either overmisalignment or overtorque. 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.

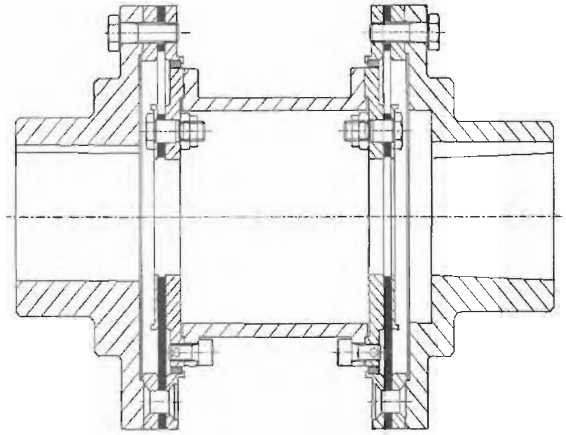


Figure 54. Marine Style Multiple Flat Diaphragm.

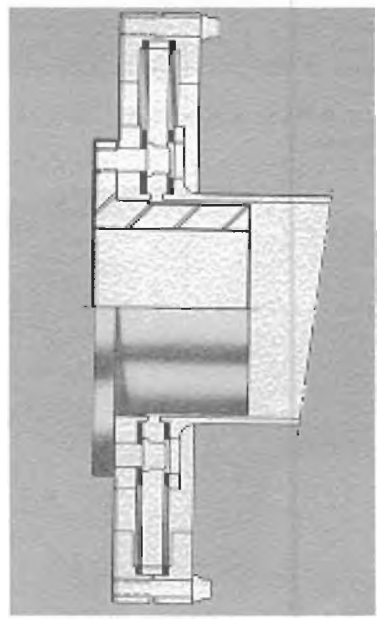


Figure 55. Reduced Moment Style Multiple Flat Diaphragm.

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.

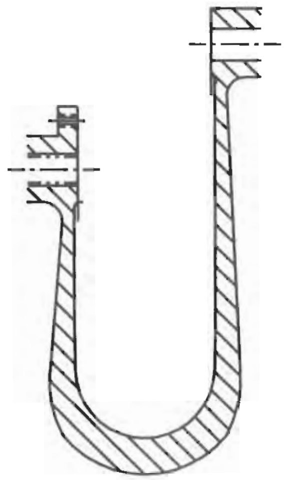


Figure 60. Two Diaphragm Profiles in Same Part.

Table 1. Differences in High Performance Couplings.

Coupling Capacities And Design Differences	RM Gear Coupling	Marine Gear Coupling	Circular Disc	Misc. Shape Disc	Multiple Diaphr.	Convoluted /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	Convoluted /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) @ ½ 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

Turbomachinery Laboratory, Texas A&M University, College Station, Texas, pp.115-123.

BIBLIOGRAPHY

Mancuso, J. R., 1999, *Couplings and Joints: Design, Selection & Application*, Second Edition, New York, New York: Marcel Dekker.

Mancuso, J. R., Cutler, D., D'Ercole, S., Findlay, R., Gibbons, B., Mahan, J., Rackham, C., O'Neil, M., Pokrandt, G., and Thompson, R., 1998, "Flexible Couplings," Short Course Notebook, Twenty-Seventh Turbomachinery Symposium and Short Courses, Turbomachinery Laboratory, Texas A&M University, College Station, Texas.