EPRI

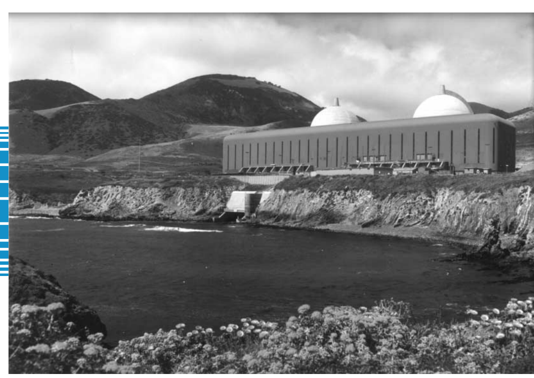
Flexible Shaft Couplings Maintenance Guide

Technical Report

Plant Maintenance Support

Reduced Cost

Equipment Reliability



NMAC

Flexible Shaft Couplings Maintenance Guide

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Final Report**,** December 2003

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REPORT SUMMARY

Rotating equipment in power plants often uses mechanical or elastomeric couplings to transmit motive force from the driver to the equipment, whether it is a pump, fan, or generator.

Background

Rotating equipment that utilizes separate driving and driven components and does not utilize a common shaft requires some method of transmitting power between the two machines. This can be a drive shaft with universal joints, such as that found in automobiles, or a coupling of a particular design. Flexible shaft couplings are used in a majority of applications for rotating equipment within the power generating station. They are often used to drive pumps with power supplied from an electric motor; however, some fans, compressors, motor generator sets, and steam turbine drives utilize flexible couplings as well.

Flexible couplings can be a source of high maintenance activity. If not the coupling itself, the machines connected by the coupling may require additional maintenance due to problems stemming from the coupling and coupling (shaft) misalignment. Fundamental maintenance activities such as alignment, balancing, and lubrication; advantages and disadvantages of different styles and designs; and age-related issues have been cited in recent NMAC Issues Surveys as areas in which guidance and usage information is needed.

Objectives

- To provide information regarding maintenance, repair/installation, and troubleshooting of couplings installed in power plants
- To provide information associated with troubleshooting, predictive and preventive maintenance, and correct maintenance practices

Approach

In cooperation with the NMAC Pump Users Group and interested NMAC members, a task group of utility engineers and industry experts was formed. This group identified key design and maintenance issues facing plant personnel and provided input used in the preparation of the guidance set forth in this document. Experience-proven practices and techniques were identified during this effort and summarized/collected herein for use by all power plant personnel.

Results

This guide provides the user with an understanding of mechanical couplings, including elemental component descriptions, common materials of construction, and typical applications. The scope of the guide includes common applications and criteria for selection; failure modes and

troubleshooting guidance, condition monitoring, and predictive maintenance techniques; preventive maintenance strategies; and good installation practices including “how to” information on important and critical steps.

EPRI Perspective

The information contained in this guide represents a significant collection of technical information, including techniques and good practices, related to the maintenance, monitoring, and troubleshooting of this important piece of plant equipment. Industry knowledge from recent experiences and improvements has been included in this report. Assemblage of this information provides a single point of reference for power plant personnel, both in the present and in the future. Through the use of this guide, EPRI members should be able to significantly improve and optimize their existing plant predictive, preventive, and corrective maintenance programs related to this equipment. This will help members achieve increased reliability and availability at a decreased cost.

Keywords

Design engineers
Plant support engineering
Plant maintenance
Plant operations
Couplings

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1 INTRODUCTION

1.1 Background

Rotating equipment that utilizes separate driving and driven components and does not utilize a common shaft requires some method of transmitting power between the two machines. This can be a drive shaft with universal joints, such as that found in automobiles, or a coupling of a particular design. Flexible shaft couplings are used in a majority of applications for rotating equipment within the power generating station. They are often used to drive pumps with power supplied from an electric motor; however, some fans, compressors, motor generator sets, and steam turbine drives utilize flexible couplings as well. Flexible couplings can be a source for high maintenance activity. If not the coupling itself, the machines connected by the coupling may require additional maintenance due to problems stemming from the coupling and coupling (shaft) misalignment.

Fundamental maintenance activities such as alignment, balancing, and lubrication; advantages and disadvantages of different styles and designs; and age-related issues have been cited in recent NMAC Issues Surveys as areas in which guidance and usage information is needed.

1.2 Purpose

This document is intended to provide power plant personnel with the means to understand the design and applications of flexible shaft couplings and the problems associated with the operational behavior of couplings and their influence on adjoining machines. Also addressed are the solutions to problems associated with troubleshooting, predictive and preventive maintenance, and correct maintenance practices.

When diagnosing problems with rotating machinery, it is often most helpful to look at problems from a system standpoint. Driving and driven machinery that is joined by a coupling enables plant personnel to evaluate problems from this perspective. Because the flexible shaft coupling joins two pieces of equipment, it may be viewed with some lack of concern when, in fact, it can be a major contributor to performance problems of the two machines or the entire train when more than two components are connected.

1.3 Scope

1.3.1 Scope of Equipment Discussed in This Report

This report discusses the types of flexible shaft couplings that are commonly installed in electric generating facilities. These couplings include mechanical, elastomeric, and metallic elements. Coupling guidance is often categorized (as it is in this report) based on the coupling falling into one or more of the following groups:

- General purpose/special purpose (high performance)
- Lubricated/non-lubricated (dry)
- Mechanical/metallic/elastomeric
- Low speed/high speed

1.3.2 Scope and Organization of the Report

This guide provides a compilation of relevant information regarding the design, operation, and maintenance of flexible shaft couplings installed at nuclear and fossil power plants. Sections 2 and 3 provide a tutorial regarding the different types of shaft couplings as well as typical configurations and operation of each type. Equipment applicability is also discussed in Sections 2 and 3 of the report. Section 4 discusses failure modes of couplings and provides the results of plant operating experience regarding coupling usage and failure history. Maintenance and replacement of couplings, including both predictive and preventive maintenance, are discussed in Sections 5, 6, and 7. Finally, Section 8 provides guidance for troubleshooting rotating equipment systems with couplings, where performance problems have been identified.

1.4 Highlighting of Key Points

Throughout this report, important information is summarized in “Key Points.” Key Points are bold-lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to take action for the benefit of their plant. The information included in these Key Points was selected by NMAC personnel, consultants, and utility personnel who prepared and reviewed this report.

The Key Points are organized according to the three categories: O&M Costs, Technical, and Human Performance. Each category has an identifying icon, as shown below, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point
Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Key Technical Point
Targets information that will lead to improved equipment reliability.

Key Human Performance Point
Denotes information that requires personnel action or consideration in order to prevent injury or damage or to ease completion of the task.

Appendix B contains a listing of all Key Points in each category. The listing restates each Key Point and provides a reference to its location in the body of the report. By reviewing this listing, users of this guide can determine if they have taken advantage of key information that the writers of this guide believe would benefit their plants.

1.5 Glossary of Terms

Coupling rating – The torque capacity at rated misalignment, axial displacement, and speed. Coupling ratings include maximum continuous rating (MCR), peak rating (PR), and maximum momentary rating (MMR).

Endurance limit – The failure strength limit of a coupling component subjected to combined constant and alternating stresses. Beyond this limit, the material can be expected to fail after some finite number of cyclic loads. Below this limit, the material can be expected to have infinite life (or a factor of safety of greater than 1.0).

Maximum continuous rating (MCR) – This is determined by the manufacturer to be the torque capacity that a coupling can safely run continuously and has an acceptable design factor of safety.

Maximum momentary rating (MMR) – This is determined by the manufacturer to be the torque capacity that a coupling can experience without ultimate failure, where localized yielding (damage) of one of its components may occur. A coupling can withstand this occurrence for one brief duration. After that, the coupling should be inspected and possibly replaced. This is sometimes referred to as the short circuit torque rating.

Peak rating (PR) – This is determined by the manufacturer to be the torque capacity that a coupling can experience without having localized yielding of any of its components. Additionally, a coupling should be able to handle this torque condition for 5,000–10,000 cycles without failing.

Service factor (SF) – Service factor (also known as the application or experience factor) is a torque multiplier, normally specified by the purchaser. It is applied to the operating torque (referred to as the normal operating point in API Standard 671, *Centrifugal Pumps for General Refinery Service*) of the connected equipment. The service factor multiplier is used to account for torque loads that are beyond the normal conditions and are of a recurring nature. Couplings are generally selected by comparing the selection torque (SF x normal operating torque) to the coupling's maximum continuous rating. Service factors account for conditions such as a compressor fouling, changes of the pumped fluid (for example, molecular weight, temperature, pressure), or any other repetitive loading conditions that may occur over 10^6 revolutions of the coupling.

Yield limit (YL) – This is determined by the manufacturer to be the failure strength limit of a coupling component that will cause damage. If this limit is exceeded, the coupling should be replaced.

1.6 Acronyms

AGMA – American Gear Manufacturers Association

ANSI – American National Standards Institute

API – American Petroleum Institute

ASME – American Society of Mechanical Engineers

ASTM – American Society for Testing and Materials

DBE – Distance between shaft ends

HP – Horsepower

LEF – Limited end float

MCR – Maximum continuous rating

MMR – Maximum momentary rating

O&M – Operation and maintenance

PD – Pitch diameter

PR – Peak rating

RPM – Revolutions per minute

SF – Service factor

TIR – Total indicator reading or total indicated runout

YL – Yield limit

2
MECHANICAL/METALLIC FLEXIBLE SHAFT COUPLINGS

If a small piece of equipment (a pump, for example) shuts down, plant operation is usually unaffected. This equipment uses a coupling type in which the flexible element, often considered a “throwaway” part, can be easily inspected and replaced. The couplings are very flexible and require very simple alignment techniques: calipers, scales, and perhaps, if one gets sophisticated, a dial indicator. A failure from over-torque or over-misalignment is usually of the flex element, and usually, little or no damage occurs to other components. A few examples of these coupling types on the market are grid, disc, and elastomeric. Small gear couplings are also found on this equipment. Some will have a nylon or plastic outer sleeve and, therefore, require no lubrication.

A flexible coupling is designed with three purposes in mind. One is to transmit torque from a driving machine to a driven machine. Second is to accommodate some misalignment. Third, the coupling must provide for axial movement of the connected machine rotors and move axially to compensate for the misalignment between shafts. Couplings with two flex planes are used to accommodate offset and angular misalignment. A single flex plane coupling can only accommodate angular misalignment. Generally, for the purposes of this document, only two flex plane couplings will be discussed. These are couplings most commonly used in power generation stations to drive a variety of machinery, such as pumps, compressors, and fans. (Some elastomeric couplings (see Section 3) are essentially single plane couplings.)

Depending upon the design, shaft couplings can isolate the transmission of vibrations from one machine to another and provide for damping of vibration and torsional changes.

Flexible couplings must have an added benefit of providing for axial movement of the coupling. This allows for movement of two shafts in relation to each other and provides for movement due to misalignment. Some couplings, by design, can provide damping between the two machines.

Key Technical Point

All flexible couplings will resist being misaligned and exhibiting axial displacement. As a result, forces are imparted back onto the coupled equipment.

Flexible shaft couplings are classified in a number of ways, often depending on the manufacturer and on the plant application. Further, manufacturers and designers often categorize flexible couplings by their design characteristics. Some of the categories most often used by manufacturers, several governing bodies, and industry associations are:

- General purpose/special purpose (high performance)
- Lubricated/non-lubricated (dry)
- Mechanical/metallic/elastomeric
- Low speed/high speed

For the purposes of this report, the primary categorization of couplings will be the differentiation of mechanical and metallic couplings from elastomeric couplings. Mechanical and metallic couplings are discussed in this section; elastomeric couplings are discussed in Section 3.

2.1 Overview of Metallic Flexible Shaft Couplings

Table 2-1 illustrates a number of distinguishing design features for metallic flexible shaft couplings.

Table 2-1
Overview of Metallic Flexible Shaft Couplings

Differentiating Criteria	General-Purpose Couplings	High-Performance Couplings
Types of Designs	Gear, grid, disc, and diaphragm	Gear, disc, and diaphragm
Metallurgy	AISI 1045	AISI 4140
Heat Treatment	Flame-hardened gears	Nitrite-hardened gears
Coupling Size (See note)	1 1/2 to 5	3 to 6
Horsepower (HP) @ rpm Ranges	0–1000 HP @ 3000 rpm >1000 HP @ 1800 rpm	>1000 HP @ 3600 + rpm
Balancing	Not balanced	Balanced
Configuration	Sometimes with spacers	Always with spacers
Lubrication	Gear – lubricated Grid – lubricated Disc – non-lubricated Diaphragm – non-lubricated	Gear – lubricated Disc – non-lubricated Diaphragm – non-lubricated
Limited End Float	Gear and grid types	Gear type only
Types of Shaft Fit	Gear – interference Grid – clearance Disc – interference Diaphragm – interference	Gear – interference Disc – interference Diaphragm – interference
Type of Movement to Accommodate Misalignment	Gear – slides Grid – slides Disc – bends/flexes Diaphragm – bends/flexes	Gear – slides Disc – bends/flexes Diaphragm – bends/flexes

Note: Users should coordinate with the coupling manufacturer on a case-by-case basis to ensure that the coupling size specified is bored to either U.S. or metric requirements as needed.

Metallic flexible shaft couplings can be sorted into two primary categories: general purpose and special purpose, as shown in Table 2-1. Note that the grid coupling type is not available for high-performance applications.

2.1.1 General-Purpose Couplings

General-purpose couplings can generally be classified according to size and speed. A coupling connected to a rotating machine operating under 100 HP is classified as small and is sometimes referred to as “low.” Between 100 and 1000 HP is characterized as medium. Usually, HP over 1000 is considered critical and, therefore, the couplings are often considered to be special purpose or high performance.

The majority of couplings in a power station are of the general-purpose type. These couplings can be divided into separate classes by the type of coupling: balanced or unbalanced. Materials can vary within the general-purpose category.

2.1.2 High-Performance Couplings

Special-purpose couplings are similar to general-purpose couplings. They are designed to perform the same functions as general-purpose couplings but at higher speeds and horsepower. Due to this improvement in performance, elastomer couplings do not qualify as special-purpose couplings.

For the purposes of this report, special-purpose couplings will be referred to as “high-performance” couplings. High-performance couplings may be gear, disc, or diaphragm types and usually employ a spacer between shafts. The later versions of high-performance couplings may employ reduced moment designs.

These couplings are designed to operate at high velocities at the periphery of the coupling. It is not uncommon for these couplings to operate up to and including 20,000 rpm. For a typical coupling mounted to a 4-inch (101 mm) shaft operating at these speeds, this can translate to a periphery speed or velocity of nearly 1000 ft/second (304 m/second). These couplings are typically a continuous-lubrication type, but a few are not lubricated.

Typically, there are two general categories of high-performance couplings: lubricated and non-lubricated. High-performance gear couplings (a mechanical element) usually require continuous oil lubrication. Figure 2-1 depicts a cross-sectional plan and elevation view of the cover, coupling, and associated feed system for oil on a continuous-lubricated coupling.

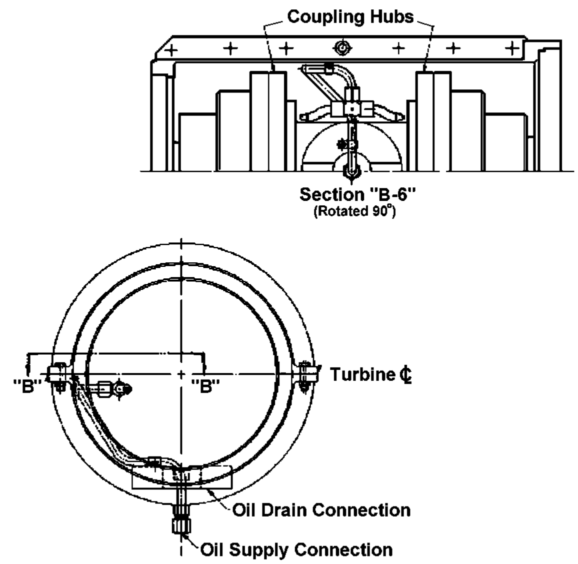


Figure 2-1
Cross-Sectional Plan and Elevation View
Courtesy Westinghouse Steam Drive Turbine Instruction Manual

Figure 2-2 illustrates a coupling cover for a continuous-lubricated coupling. Note the oil inlet and drain at the bottom center of the cover. A large number of these lubricated-gear couplings have seen over 20 years of service without any problems or visible wear effects. These couplings are generally used in power stations for high-speed turbine driven feedwater pumps.

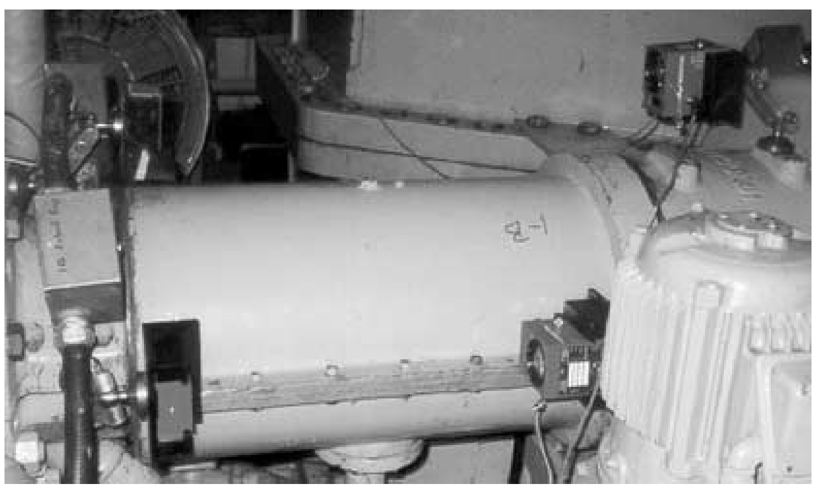


Figure 2-2
Coupling Cover for Continuous-Lubricated Coupling
Courtesy Rota-Tech Inc.

Metallic element types require no lubrication and are typically designed as the disc type or diaphragm type. These couplings may employ a secondary fail-safe system to ensure that the machine will operate at some capacity until shutdown occurs. The disc and diaphragm couplings of high-performance design may also have special guards over the flex elements to prevent personal injury or other machine damage in case of failure.

2.2 Types of Mechanical/Metallic Flexible Shaft Couplings

2.2.1 Gear Type Mechanical Coupling

2.2.1.1 General Design and Configuration

One of the most common types of couplings used over the past 100 years for transmission of power above 100 HP is the gear coupling. The gear coupling is sometimes referred to as a marine coupling, because they have been used almost exclusively on propeller shafts of vessels.

Gear couplings have been the logical choice for many years for high-horsepower or high-energy applications. For torque transmission per size and weight, the gear coupling usually has a high service factor.

Figure 2-3 illustrates an example of the standard close-coupled gear coupling.

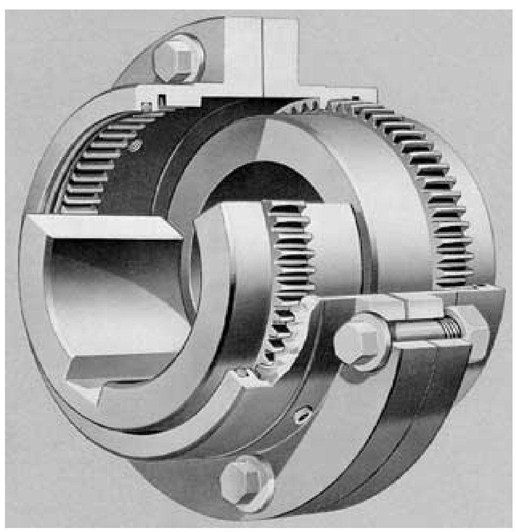


Figure 2-3
Gear Coupling of Close-Coupled Configuration
Courtesy Zurn-Ameriflex

Figure 2-4 is an exploded view of a standard general-purpose close-coupled application.

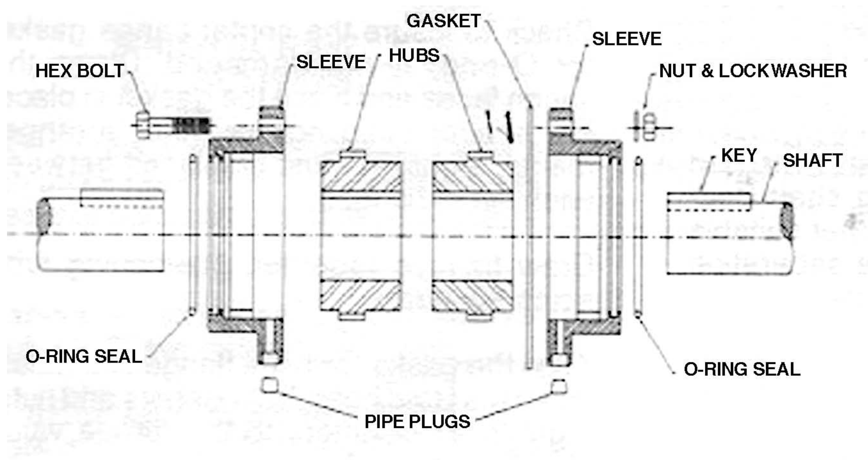


Figure 2-4
Parts of a Gear Coupling
Courtesy Kop-Flex

Due to long run periods, problems associated with lubrication, and maintenance issues, there has been a trend in recent years away from the use of gear couplings in some applications. One primary example is that of steam generator feedwater pumps or reactor feedwater pumps.

Key Human Performance Point

Care should be taken when making coupling changes on all machinery but especially high-energy machines such as steam generators or reactor feed pumps. Manufacturers should be consulted prior to making such changes.

2.2.1.2 How Gear Couplings Work

Gear type couplings consist of two hubs with external teeth that engage internal teeth on a one- or two-piece sleeve. The teeth may be straight or curved (crowned). For application requiring over 1/4 degree angular misalignment between subcomponents, curved teeth may be more appropriate. Torque is transmitted from one hub through the sleeve to the opposite hub through the meshing of the teeth.

These couplings obtain their flexibility due to the looseness (backlash) between the mating teeth. Gear couplings are used for medium and large equipment applications and are the most power dense type available. They require periodic lubrication: every one to two years, depending on duty and type of lubrication. If properly maintained (good lubrication and reasonable alignment), these couplings have a service life of 3 to 5 years and in many cases, 5 to over 10 years.

Some gear couplings have sleeves that are made of nylon or high-molecular plastic. These do not require lubrication but have much lower torque capacities than the all-steel couplings and are used mainly on small pumps.

2.2.1.3 High-Performance Gear Couplings

The sealed lubricated gear coupling was adapted and modified during the 1950s and 1960s to carry more power at higher speeds. There are several variations of designs: couplings with external teeth or with the external teeth on the spacer in the "marine" type. These designs may be used with integral flanges on the machine shafts, such as on turbines and gears. Reduced-moment versions are also readily used. If proper lubrication is maintained, these couplings will and have operated successfully for years.

2.2.2 Grid Type Mechanical Couplings

2.2.2.1 General Design and Configuration

Grid type couplings are very similar to gear couplings and have been on the market for many years. Typically composed of all metal, they have some degree of resilience. Like the gear coupling, the flex member slides in relation to the hubs. Grid couplings are used for medium and small equipment applications. The grid coupling can also handle angular misalignment better than offset misalignment due to the inherent stiffness of the grid.

Figures 2-5 and 2-6 are examples of grid couplings, one with a horizontal split cover and the other with a vertically split cover.

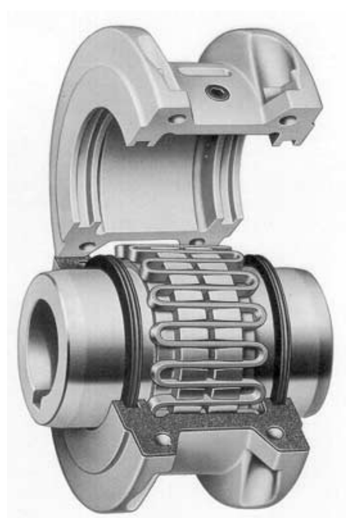


Figure 2-5
Grid Coupling with Horizontal Split Cover
Courtesy Falk Corporation

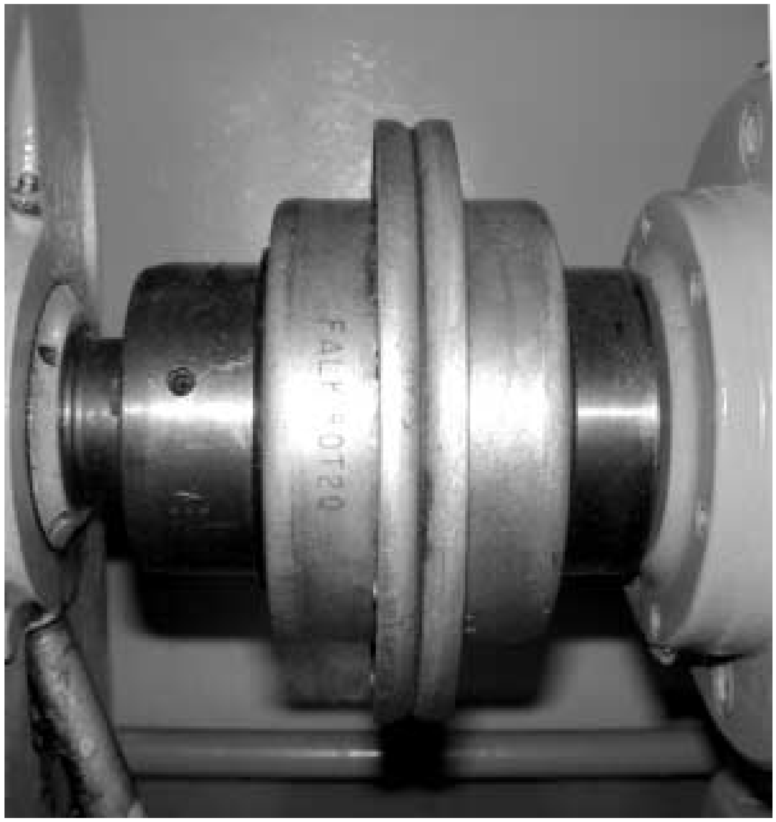


Figure 2-6
Grid Coupling with Vertically Split Cover
Courtesy Falk Corporation

2.2.2.2 How Grid Couplings Work

Grid type couplings are very similar to gear couplings. These couplings can dampen vibration and reduce peak or shock loads by 10 to 30%. They have two hubs with serrations (grooves) rather than teeth. The grooves are connected by a steel grid. A cover keeps the lubrication contained inside the housing. The covers are either vertically split or horizontally split. These couplings do not transmit as much power (per the same outside diameter) as gear couplings but are usually less costly.

Key O&M Cost Point

Grid couplings do not transmit as much power but are generally less costly than gear couplings.

2.2.3 Disc Type Metallic Couplings

2.2.3.1 General Design and Configuration

The disc coupling is available in a number of forms, all of which have driving and driven bolts on the same bolt circle. The amount of misalignment that each type can handle depends upon the length of material between bolts. Torque is transmitted by driving bolts pulling driven bolts through the disc material, which is in tension. More bolts provide greater capacity but reduce the coupling flexibility. For special-purpose applications, the discs are provided as a pack. Some disc packs are factory installed, while others are supplied with pilot rings for installation in the field. They are available in many styles, including reduced moment. Figure 2-7 illustrates a typical flexible disc coupling.

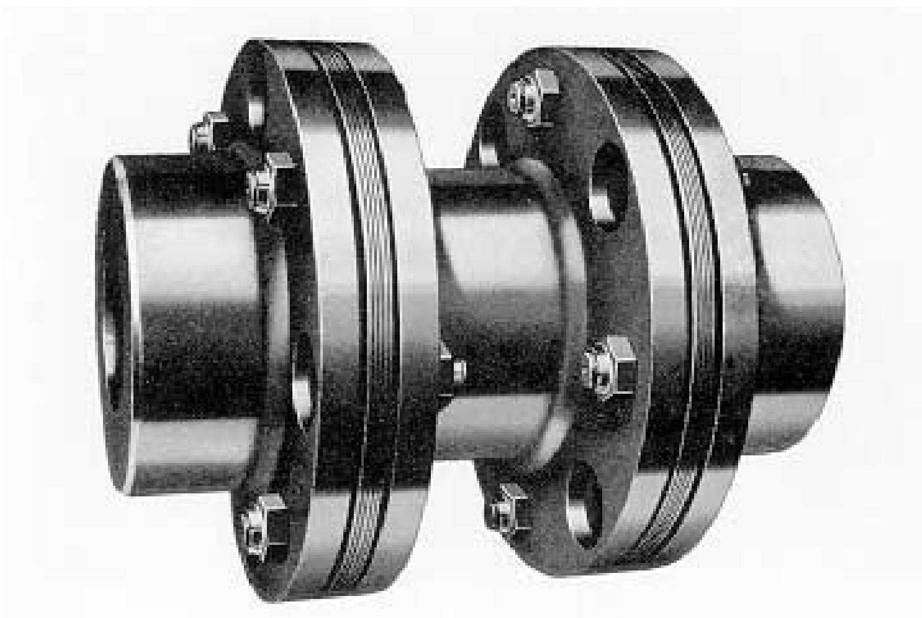


Figure 2-7
Flexible Disc Coupling
Courtesy Kop-Flex

The disc pack coupling flexing elements are made up of two sections of discs. Each section (flex plane) is made up of a given number of discs based on the design and application. These are thin, flexible discs that are stacked together and are shown in Figure 2-8.

Figure 2-8
Disc Pack Coupling Discs
Courtesy Kop-Flex

Disc couplings are also provided for close-couple applications. The discs are mounted to the hub and the hub to the shaft. (There is not enough room between shafts for the disc.) This coupling utilizes an axially-split spacer to connect the two shafts. Figure 2-9 illustrates a typical close-coupled disc coupling.

Figure 2-9
Close-Coupled Disc Coupling
Courtesy Kop-Flex

2.2.3.2 How Disc Couplings Work

Disc couplings transmit torque by a simple tensile force between alternating driving and driven bolts on a common bolt circle. Misalignment is accommodated by the flexibility that comes from the length of material between the bolts. Disc couplings have been employed for many years, but with the use of finite element analysis, this type can and has been optimized for performance. These couplings are composed of all metal and do not require lubrication. The discs are usually continuous but can be individual links. Most disc couplings use multiple thin discs, rather than one thick disc/link, because stresses from misalignment are proportional. These couplings are used in medium-size equipment applications. If the misalignment is beyond 1/2 to 3/4 degree during operation, then the flexible element will probably fail in fatigue.

Key Technical Point

In a disc coupling, if the misalignment is beyond 1/2 to 3/4 degree during operation, then the flexible element will probably fail in fatigue.

2.2.4 Diaphragm Type Metallic Couplings

The diaphragm coupling comes in two basic forms: a singe tapered profile or multiple modified profile (contoured or cut-out). Both forms have profile modification that reduce size, increase flexibility, and control stress concentration. The torque path is through the diaphragm member in the radial direction, from the outer diameter to the inner diameter. They are used in most special-purpose applications and are available in many shapes and styles, including marine and reduced moment. The diaphragm coupling is well suited for high-performance coupling applications. Figures 2-10 and 2-11 illustrate the convoluted diaphragm and the single profiled diaphragm couplings, respectively.

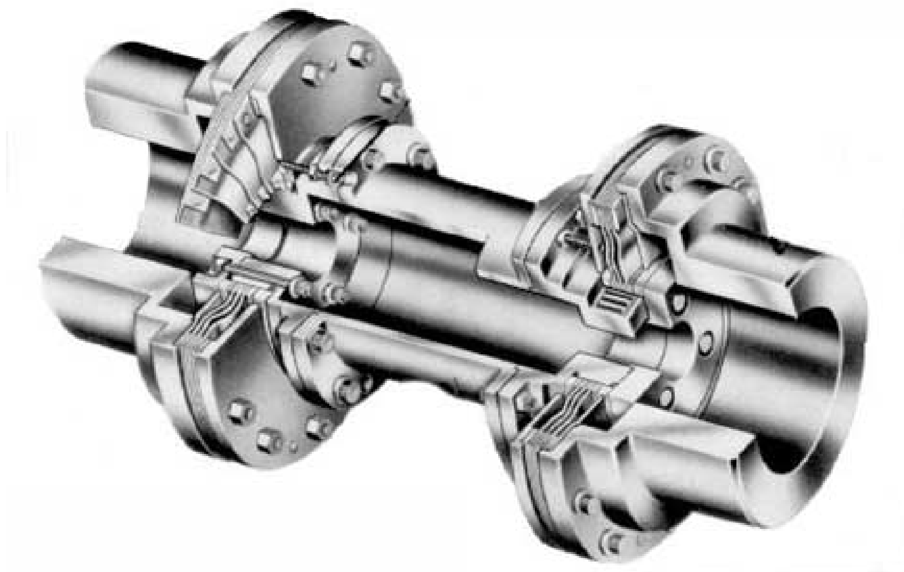


Figure 2-10
Convoluted Diaphragm Coupling
Courtesy Zurn-Ameriflex

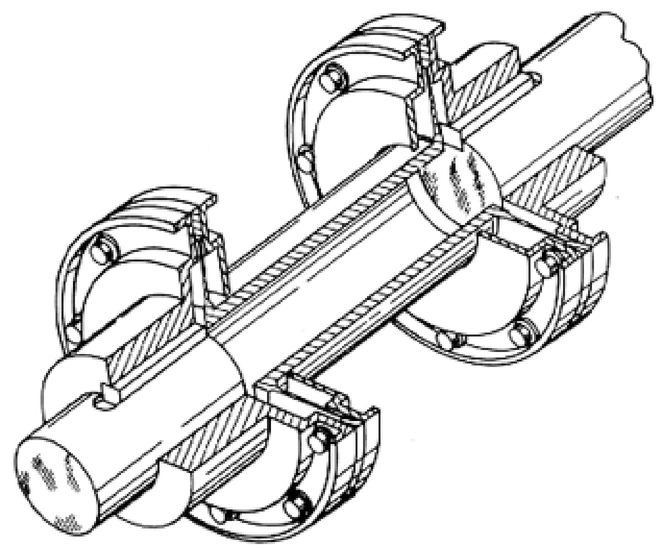


Figure 2-11
Single Profiled Diaphragm Coupling
Courtesy Machinery Failure Analysis and Troubleshooting

2.3 Metallurgy and Heat Treatment

Typically, general-purpose couplings are made from AISI 1045 steel, whereas high-performance couplings are typically made from AISI 4140 steel. The AISI 4140 provides the stronger grade necessary to accommodate the higher speed and horsepower of high-performance applications.

General-purpose couplings are typically provided with flame-hardened gears. For high-performance applications, nitrite-hardened gears are needed to accommodate the higher speed and horsepower.

2.4 Coupling Sizes, Horsepower Ratings, and Speeds

General-purpose couplings are typically limited in size, ranging from 1 1/2–5 inches (38–127 mm). High-performance couplings range in size from 3–6 inches (76–153 mm).

Metallic flexible couplings can be classified according to the horsepower and speed of the driving machine. Couplings that connect a rotating machine operating under 100 HP are classified as small and are sometimes referred to as "low." Between 100 and 1000 HP is characterized as medium. Usually, HP over 1000 is considered critical and, therefore, couplings designed for this horsepower are often considered to be high-performance couplings.

Medium sizes (100 to 1000 HP) are not normally critical to the operation of the plant but are problematic and costly if constant maintenance and downtime is required. Grid, gear, disc, and diaphragm type couplings can all be used in medium-sized applications.

2.5 Balancing and Spacer Configurations

2.5.1 Balancing

Typically, only high-performance couplings require dynamic balancing due to the higher horsepower and speeds that these couplings endure. General-purpose couplings are typically not balanced in most plant applications. Balancing of high-performance metallic flexible shaft couplings is discussed in Section 5.

2.5.2 Spacer Configurations

2.5.2.1 Gear Couplings with Spacers

Spacers are sometimes installed in general-purpose couplings but are almost always installed in high-performance couplings. The trend over the past four decades is to try to supply rotating equipment with spacer type couplings. The spacer performs two beneficial functions: First, it allows for easy removal of parts such as bearings and mechanical seals without having to remove the rotor or move the driving machine to obtain the necessary clearance. Figure 2-12 illustrates an example of a spacer type gear coupling.

Figure 2-12
Spacer Type Gear Coupling
Courtesy Lovejoy, Inc.

Second, it allows for more shaft-to-shaft misalignment. Shaft misalignment is based on the speed of the machine and the distance between coupling flex points. When measuring acceptable misalignment between shafts, the amount of offset or angularity, or both, is usually described in inches per inch of shaft spacing or the distance between flex planes. An example would be to compare a close-coupled machine with a spacer machine operating at the same speed.

2.5.2.2 Floating Shaft Gear Couplings

Floating shaft couplings are spacer couplings with the flex elements on the spacer. The shaft uses rigid mounted hubs such as a typical spacer. An advantage of floating shaft couplings is that the user may design the length of the spacer shaft depending on the particular plant application. This can be seen in Figure 2-13.

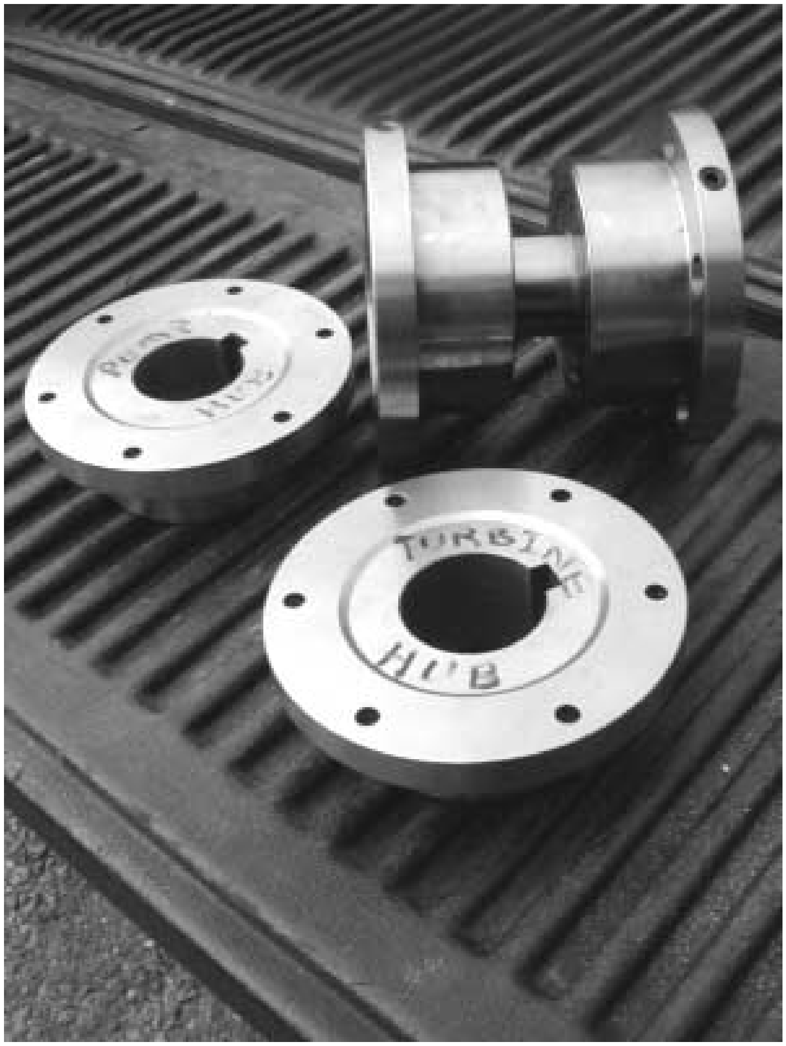


Figure 2-13
Floating Shaft Coupling Components After Assembly
Courtesy Rota-Tech Inc.

A complete set of hubs and sleeves can be ordered and bar stock of a known material such as AISI 4140 can be used to make a spacer or floating shaft of a determined or known length. This is particularly useful when a manufactured spacer cannot be obtained quickly for installation into existing equipment.

The distinct disadvantage of these couplings is a considerable increase in overhung weight as compared to a standard-gear coupling or a reduced-moment coupling.

Figure 2-14 illustrates floating shaft coupling components as received from the manufacturer and prior to boring and fabricating the floating shaft or spacer.

Figure 2-14
Floating Shaft Coupling Components Before Assembly
Courtesy Rota-Tech Inc.

Figure 2-15 illustrates a floating shaft coupling used on a steam generator feed pump at a nuclear station. This coupling uses continuous lubrication and is a balanced high-performance coupling.

Figure 2-15
Gear Coupling Spacer
Courtesy Rota-Tech Inc.

2.6 Lubrication

Only the mechanical elements of gear and grid couplings require oil or grease lubrication; disc and diaphragm couplings do not. There are many subgroups for gear couplings; however, they are only variations of the basic design that employ alloy steel and have surface-hardened teeth.

The disc type or diaphragm type couplings are designed to operate at high velocities at the periphery of the coupling. It is not uncommon for these couplings to operate up to and including 20,000 rpm. For a typical coupling mounted to a 4-inch (101 mm) shaft operating at these speeds, this can translate to a periphery speed or velocity of nearly 1000 ft/second (304 m/second).

The major problem with gear couplings is lubrication. Grease tends to separate under centrifugal force and, over time, O-ring types of seals begin to leak. Continuously lubricated designs, using the coupled machine's bearing oil, are more common for these types of applications. If proper lubrication is maintained, these couplings will and have operated successfully for years. Lubrication, or lack of it, is the biggest cause of failure. The coupling itself tends to act as a centrifuge and separates dirt particles out of the oil. This produces sludge, which can cause the coupling to lock up or seize, which subsequently causes increased equipment vibration.

Key O&M Cost Point

Proper lubrication is important to long coupling life.

2.7 Limited End Float Couplings

Limited end float (LEF) couplings are intended to do precisely what their name suggests: they limit the end float of an electric motor rotor. They are designed and set up to prevent motor rotor axial movement that can cause damage to the motor journal bearings. Only gear and grid couplings are designed with limited end float; disc and diaphragm couplings are not. A typical LEF coupling is illustrated in Figure 2-16.

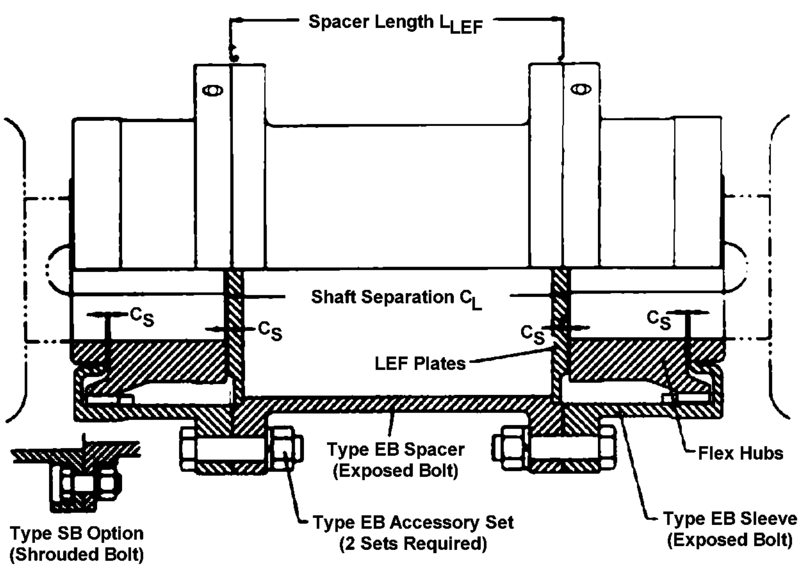


Figure 2-16
Limited End Float Coupling
Courtesy Kop-Flex

2.8 Shaft-to-Hub Fits

The type of fit between a shaft and a hub can be one of the three types listed below:

- Interference fit with key
- Clearance fit with key
- Keyless interference fit

Gear, grid, and diaphragm type couplings typically have an interference fit with the shaft. Grid type couplings typically have a clearance fit.

2.9 Type of Movement to Accommodate Misalignment

Couplings may be classified in a less descriptive manner by the method they use to accommodate misalignment. A coupling accommodates misalignment in one of two ways: it either slides or flexes. Gear and grid couplings slide across the flex planes, while disc and diaphragm couplings flex (or bend) at the flex planes.

As noted in the preceding section, couplings that slide to accommodate misalignment, such as a gear or grid couplings, are typically lubricated.

Figure 2-17 depicts a gear coupling, showing the movement of the gear teeth in relation to misalignment and how the axial position changes as the shafts rotate. Figures 2-18 and 2-19 illustrate sliding elements and elements that bend or flex, respectively.

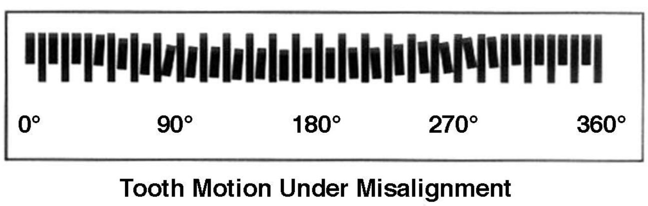


Figure 2-17
Sliding Motion of a Gear Coupling
Courtesy Kop-Flex

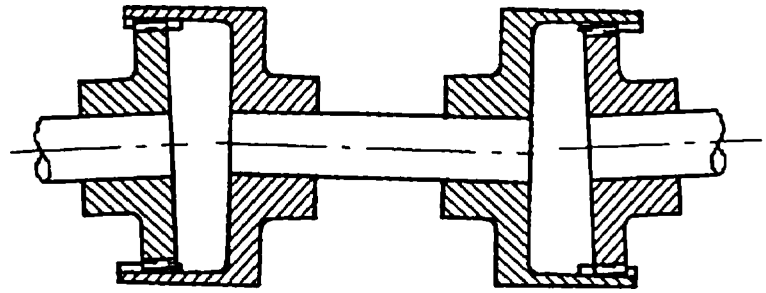


Figure 2-18
Spacer Gear Coupling Illustrating Sliding Elements
Courtesy Flexible Couplings

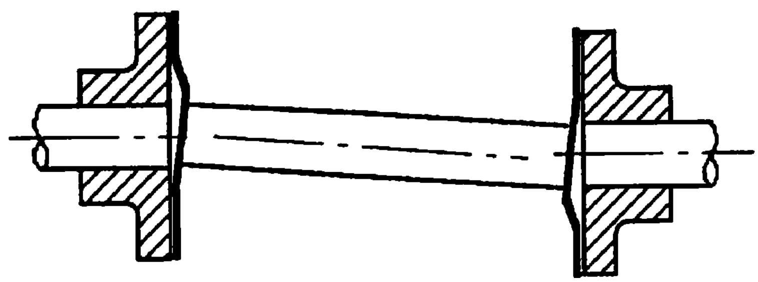


Figure 2-19
Diaphragm Coupling Illustrating Bending or Flexing
Courtesy Flexible Couplings

2.10 Plant Applications

Table 2-2 lists a number of typical plant applications for metallic flexible shaft couplings. This table is not intended to be inclusive of all plant applications and is provided for illustrative purposes only. The selection of a coupling for a particular plant application should be performed in conjunction with plant engineering personnel and the coupling manufacturer.

Table 2-2
Typical Plant Applications of Metallic Flexible Shaft Couplings

	General-Purpose Couplings	High-Performance Couplings
Plant Applications	Auxiliary boiler pump Component cooling pump Motor generator set Auxiliary feedwater pump	Feedwater pump Condensate booster pump Centrifugal charging volume control pump Safety injection charging pump High-pressure injection charging pump

Note: U-joint or cross-joint couplings would also fit into this category (metallic flexible shaft couplings). While not very common in power plant applications, there are occasional uses for these couplings.

3 ELASTOMERIC FLEXIBLE SHAFT COUPLINGS

3.1 Overview of Elastomeric Flexible Shaft Couplings

Table 3-1 illustrates a number of distinguishing design features for elastomeric flexible shaft couplings. One important feature of elastomeric flexible shaft couplings is that they are limited to general-purpose applications and typically are not available for high-performance applications. Elastomer type couplings provide for misalignment and axial motion through flexing or compression of the elastomeric elements.

Table 3-1
Overview of Elastomeric Flexible Shaft Couplings

Differentiating Criteria	General-Purpose Couplings
Types of Elastomeric Flexible Shaft Couplings	Synthetic gear, jaw/spider, tire (urethane or corded), donut
Metallurgy	Carbon steel or cast iron
Heat Treatment	Not heat treated
Coupling Size (See note)	1/2 to 2 1/2
HP @ rpm Ranges	0–1000 HP @ 3000 rpm
Balancing	Not balanced
Configuration	Sometimes with spacers
Lubrication	Non-lubricated
Limited End Float	Not applicable (except for block type)
Type of Force on Elastomeric Element	Synthetic gear – compression Jaw/spider – compression Tire (urethane or corded) – shear Donut – compression
Types of Fit	Clearance (except for block type and some synthetic gear types which may have interference fits)
Type of Movement to Accommodate Misalignment	Synthetic gear – slides Jaw/spider – slides Tire (urethane or corded) – bends/flexes Donut – bends/flexes Resilient block – slides/flexes

Note: Users should coordinate with the coupling manufacturer on a case-by-case basis to ensure that the coupling size specified is bored to either U.S. or metric requirements as needed.

3.2 Types of Elastomeric Flexible Shaft Couplings

Elastomer type couplings, whether of the sliding type or the flexing type, are torsionally soft. This means that they will deform under torque and misalignment and also provide damping to some extent. These couplings are typically used in applications below 100 HP.

3.2.1 Synthetic Gear Type

Two elastomeric type couplings that slide to accommodate misalignment are the synthetic gear coupling and jaw type coupling. The basic theory of operation for synthetic gear type couplings is similar to that of metallic gear couplings except that synthetic gear couplings cannot sustain equivalent horsepower and speed due to the lesser-strength materials of the gears.

Synthetic gear couplings are common on small equipment and have their elastomeric elements in shear. They provide low torsional stiffness and low reactionary forces. Over-sizing can lead to premature failure by wearing of the engaging teeth rather than material failure from flexing. Figure 3-1 illustrates the basic elements of a synthetic gear coupling.

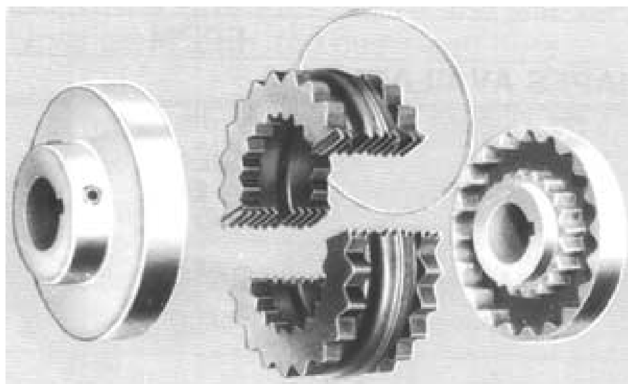


Figure 3-1
Synthetic Gear Coupling
Courtesy TB Woods, Inc.

Key Technical Point

Over-sizing of synthetic gear couplings can lead to premature failure.

3.2.2 Jaw/Spider Type Couplings

Jaw/spider couplings have their elastomers in compression. This coupling is most often referred to as a spider coupling. The flex element can be one piece or split to facilitate replacement. They also have a fail-safe feature. Flex elements are made of many types of elastomeric materials, such as rubber and urethane. The material properties (hardness and resilience, for example) can be varied to suit required loads. These couplings are used primarily to accommodate misalignment and transmit power. Small and medium-size equipment employ these types of couplings. Care should be taken when these couplings are used to absorb energy and dampen loads. Figure 3-2 illustrates the elements that comprise a jaw/spider type coupling.

Figure 3-2
Elastomeric Jaw Type (Spider) Coupling
Courtesy Lovejoy, Inc.

3.2.3 Tire Type Elastomeric Couplings

3.2.3.1 Urethane Tire Couplings

Common on small equipment, these couplings have their elastomeric element in shear and are made of urethane. The tires are split to enable easy assembly without removing the hubs. Urethane couplings offer a high degree of flexibility. When the coupling fails, usually only the elastomeric element needs to be replaced.

Figure 3-3
Synthetic Tire Coupling
Courtesy Rexnord-Thomas Couplings

The synthetic tire coupling or “orange tire,” as it is typically referenced and as shown in Figure 3-3, deforms or flexes to compensate for misalignment. This coupling also provides excellent damping between machines. One of the disadvantages of this coupling is due to centrifugal forces. At operating speed, the tire can “grow” in the radial direction, thus increasing the axial float on the connected shafts.

3.2.3.2 Corded Tire Couplings

Corded tire couplings also have their elastomeric elements in shear. They use a reinforced element (similar to belted auto tires). Because of the reinforcement in the element, the torque capacity is greater per outside diameter than the urethane tire type. Most small-size and some medium-size equipment applications use these couplings. The corded tire coupling can typically accommodate up to 4 degrees of misalignment. Figure 3-4 illustrates an example of a corded tire coupling.

Figure 3-4
Corded Tire Coupling
Courtesy Dodge-Reliance Electric

3.2.4 Compression Donut Type Elastomeric Couplings

Compression donut couplings have a pre-compressed elastic element. Screws force the donut to a smaller diameter. All legs of the donut are in compression before the load is applied. Medium and some small equipment employ this type of coupling. Figure 3-5 illustrates a typical compression donut coupling.

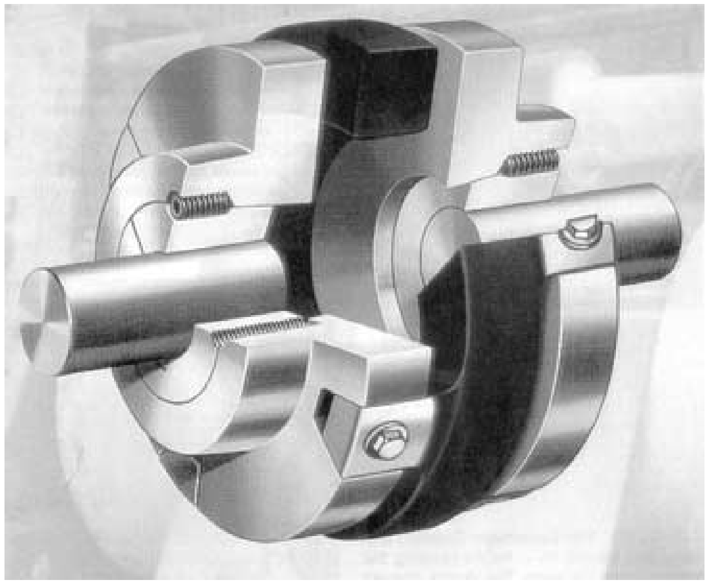


Figure 3-5
Compression Donut Coupling
Courtesy Kopflex

3.2.5 Block Type Elastomeric Couplings

The block coupling is sometimes called the Croset (after its inventor) or Holset (after the original manufacturer) coupling. Large critical equipment (such as synchronous motor driven equipment) use elastomeric block couplings in special purpose applications to reduce vibratory torque or to torsionally “tune” a system (using torsional “softness”). Block couplings use rubber in compression. The rubber blocks are installed in cavities formed by internal sleeve blades, external hub blades, and two end plates.

This type of elastomeric coupling is unique among couplings because of its fail-safe feature. If the elastomer fails, the coupling may continue to run for some time using only the metal blades. These couplings can provide up to 1/2 degree of misalignment and parallel offset capabilities of 1/64–1/4 inch (0.4–6.5 mm) using a spacer and a matched set. Sometimes medium and small equipment will employ these couplings, because if properly aligned, they require no maintenance (except for replacement of blocks every three to five years). These couplings are also supplied in large diameters for high-horsepower machines. Figure 3-6 illustrates the basic elements that comprise a typical block coupling.

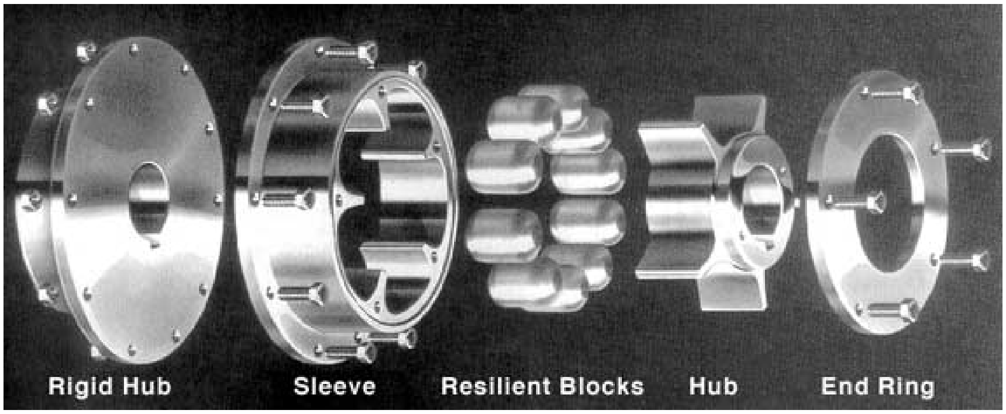


Figure 3-6
Block Coupling
Courtesy Kopflex

3.3 Metallurgy and Heat Treatment

Elastomeric flexible shaft couplings employ housings made from either carbon steel or cast iron. Because they are used only in general-purpose applications, the metallic housings of elastomeric flexible shaft couplings are typically not heat-treated.

3.4 Coupling Sizes, Horsepower Ratings, and Speeds

General-purpose elastomeric couplings typically range in size from 1/2–2 1/2 inches (13–64 mm). These couplings can accommodate drivers with horsepower up to 1000 HP and speeds up to about 3000 rpm.

3.5 Balancing and Configuration

Elastomeric flexible shaft couplings are typically not balanced, because they are not suited for high-performance applications. Some elastomeric flexible shaft couplings may be furnished with spacers.

Key Technical Point

Elastomeric flexible shaft couplings are typically not balanced, because they are not suited for high-performance applications.

3.6 Lubrication

Elastomeric flexible shaft couplings do not require lubrication. Some block couplings may use a lubricant for installation purposes.

3.7 Type of Force Exhibited on the Elastomeric Element

The elastomeric elements in the synthetic gear, jaw/spider, and donut types of flexible shaft couplings all exhibit compression when in use. The elastomeric elements in the tire types of flexible shaft couplings exhibit shear forces when in use. Elastomeric flexible shaft couplings are not designed to accommodate limited end float.

3.8 Types of Fit

Typically, all elastomeric flexible shaft couplings employ a clearance fit between the hub and the shaft.

3.9 Type of Movement to Accommodate Misalignment

The synthetic gear and jaw/spider types of elastomeric flexible shaft couplings slide to accommodate misalignment. The tire and donut types bend or flex to accommodate misalignment.

3.10 Plant Applications

The selection of a coupling for a particular plant application should be performed in conjunction with plant engineering personnel and the coupling manufacturer. The following are typical (but not all-inclusive) plant applications for elastomeric flexible shaft couplings:

- Auxiliary water treatment pumps
- Auxiliary boiler pumps
- General oil pumps
- Oil transport pumps
- Turbine vapor extraction blower/fan
- Motor-driven auxiliary oil pumps

4
FAILURE MODE ANALYSIS AND EVALUATION

4.1 Failure Mechanisms

A flexible shaft coupling is designed to transmit the rotational torque of a driver (for example, a motor or turbine) to a piece of rotating equipment (for example, a pump or fan). In doing so, some couplings are designed to accommodate some amount of misalignment and movement between the shaft of the driver and the shaft of the rotating equipment.

Given these design functions, the primary failure mechanism of a coupling is its inability to transmit the torsional forces from the driver to the equipment. The following are reasons why a coupling would not effectively transmit the torsional forces in accordance with design requirements:

- Loss of structural integrity of the coupling
- High frictional forces leading to failure of the coupling
- Loss of torque transmission of the coupling

4.2 Root Causes of Coupling Failures

The root causes of coupling failures not only pertain to the coupling but to the machines connected through the coupling. Behavior such as high vibration or excessive bearing temperatures can be traced to coupling or alignment problems.

4.2.1 Loss of Structural Integrity of the Coupling

Causes of structural integrity loss are:

- Excessive shaft misalignment leading to vibration and structural fatigue failure
- Excessive corrosion
- Physical damage

Key Technical Point

Misalignment is a leading contributor to vibration and to structural fatigue failure.

Fatigue failures occur in gear couplings due to their being operated outside of the designated misalignment parameters. This can mean that the coupling is either operated in a locked position or is jammed into a position by shaft separation distances. If the shaft separation is too close, then it is possible that the hub-to-sleeve engagement is not correct, and the hub teeth are carrying all of the load on just a portion of the length of teeth. If the shaft separation is too far apart, the coupling may be jammed against the back of the sleeve and may be prohibited from sliding or moving to accommodate misalignment. At this point, the fatigue on the teeth becomes cyclic and failure is often imminent.

Key Technical Point

Fatigue failures occur in gear couplings due to their being operated outside of the designated misalignment parameters.

Failures in disc type or diaphragm couplings are also induced by large misalignments. Although flexible metallic couplings have a theoretical infinite life, they are subjected to cyclic fatigue when over-stressed. Disc and diaphragm couplings give no warning of impending failure, whereas a gear coupling will generate noise and vibration prior to failure. High misalignment can cause a rapid increase in cycles of the flex element. Failure can occur without notice in just a few hours.

Key Technical Point

Disc and diaphragm couplings give no warning of impending failure, whereas a gear coupling will generate noise and vibration prior to failure.

Corrosion may attack not only dry type couplings but lubricated couplings as well. Air and foreign debris can enter a gear or grid coupling at any area that is not sealed tightly. These can be gasket areas or the area above the key, in the open keyway.

Dry type couplings are subjected to environmental corrosive conditions, such as salts, chlorides, dirt, or certain lubricants, which can travel from the adjoining machines.

Another cause of loss of structural integrity of a coupling is physical damage caused by inadvertent contact between the coupling and a foreign object (for example, tools or long lengths of shaft or pipe).

4.2.2 High Frictional Forces Leading to Failure of the Coupling

Causes of frictional forces leading to failure are:

- Inadequate lubrication
- Corrosion of internal coupling parts
- Improper/inadequate tolerances
- Excessive shaft misalignment leading to overheating and thermal expansion

Wear is the major problem with lubricated couplings. Most cases of wear can be traced to the lubrication or lack thereof. Dirt in the lubricant can cause disaster. If misalignment is high, the tooth velocities are also high. This means additional friction, and once wear starts, the wear particles become entrapped in the lubricant and accelerate the wear of the coupling teeth.

Improper or inadequate tolerances result from design or installation errors and can subject the coupling to seizure and, ultimately, to failure.

Elastomeric couplings are subject to heat through compression or damping. They are also subject to failure from ozone. Large amounts of misalignment can cause the elastomers to be subjected to high loads, which can tear the couplings apart.

4.2.3 Loss of Torque Transmission of the Coupling

Causes of loss of torque transmission are:

- Key failure
- Improper/inadequate tolerances
- Failure of the bolts
- Teeth failure or shear
- Diaphragm or disc breakage
- Shaft failure(s)

Proper fitting of the key, as well as its material type, is essential for proper operation of the coupling. Manufacturer's drawings or technical literature should be consulted if concerns arise regarding the suitability of the coupling keys and keyways.

Bolt failures generally occur from improper tightening, which may not be a concern on a gear coupling (other than its resulting in imbalance) but can be disastrous on metallic flexible couplings. The bolting is a primary anchor for the flex point of a coupling. The manufacturer's guidelines should be adhered to where bolting is concerned. The proper torque and lubricant for bolts should be used. Many manufacturers stipulate that no lubricant be used on coupling bolts. Also, coupling bolts typically have a specific service life and require changing after a designated number of run cycles.

Teeth often fail because of fretting, improper lubrication, or excessive exposure to heat during installation, which can adversely affect the metal's physical properties.

Fretting can also occur in dry metallic couplings such as disc-pack couplings. Disc failures typically occur near the bolted area.

Shaft failures typically occur due to misalignment or fretting and fatigue from improperly mounted coupling hubs. Careful inspection of all fits should be performed on a periodic basis.

4.3 Human Error

Couplings can fail as a result of human error, typically occurring during the design, installation, or maintenance of the item.

Selection of an unsuitable design usually results in a coupling being placed in service that is too small or is the wrong design for the application. Coupling manufacturers should be consulted when specifying coupling types and sizes to ensure their suitability for the application.

Coupling failure can result from improper installation of the coupling itself. Installation practices that, if incorrectly performed, could lead to coupling failure are improperly torqued bolts, inadequate tolerances or fits, and/or improper lubrication.

Improper maintenance can result from inadvertently extending lubrication intervals, neglecting the cleanliness of the coupling, and/or using an unsuitable type of lubrication.

Key Technical Point

Improper maintenance can lead to inadequate coupling performance and/or failure.

Key Technical Point

Installation practices that, if incorrectly performed, could lead to coupling failure are improperly torqued bolts, inadequate tolerances or fits, and/or improper lubrication.

4.4 Damage and Failure of Gear and Grid Couplings

4.4.1 Fretting and Fatigue

Fretting occurs when two surfaces move in relation to one another. The loading and heat generated by friction causes metal to be removed, to be transferred, or to crack. Fretting is actually fatigue of metal surfaces. In gear and grid couplings where flex members slide in relation to each other, the sliding velocities generate heat that exceeds the lubricant's ability to perform its function, and major fretting occurs. Figures 4-1 and 4-2 show fretting on a sleeve and hub of a gear coupling caused by an extended run period with misalignment and lubrication breakdown.

Figure 4-1
Sleeve Wear in a Gear Coupling
Courtesy Rota-Tech Inc.

Figure 4-2
Hub Showing Wear on Teeth
Courtesy Rota-Tech Inc.

Figure 4-3 depicts the loss of lubrication over a long period. As the grease began to solidify, the metal from wear combined with the dried grease at the ends of the grid. This is a case of not inspecting the coupling at a predetermined frequency as recommended by the coupling manufacturer.

Figure 4-3
Lack of Lubrication on a Grid Coupling
Courtesy Rota-Tech Inc.

4.4.2 Gear and Grid Coupling Lock-Up

The effect of coupling lock up of a gear coupling is well known. Coupling lock-up occurs because of misalignment and the associated increased friction levels in the coupling. This increased friction imposes a corresponding pre-load to the two shafts that are connected by the coupling, which prevents the coupling from moving axially to compensate for misalignment. The effects of this phenomenon are not widely understood and can lead to misinterpretation of machine condition or performance.

Unfortunately, many still hold to the misperception that a flexible coupling will compensate for a majority of shaft misalignment problems. The force, which provides for the locking of the coupling, originates with the rotational torque supplied by the driver to power the driven unit. This is a function of horsepower, rpm, and pitch diameter.

Key Technical Point

Extreme misalignment can lead to coupling lock-up and can result in a misinterpretation of machine operating conditions.

With an increase in misalignment, the sliding velocities increase and surface contact area decreases, resulting in increased loading on coupling components. This results in increased friction levels, leading to coupling lock-up. This phenomenon is illustrated in Figure 4-4.

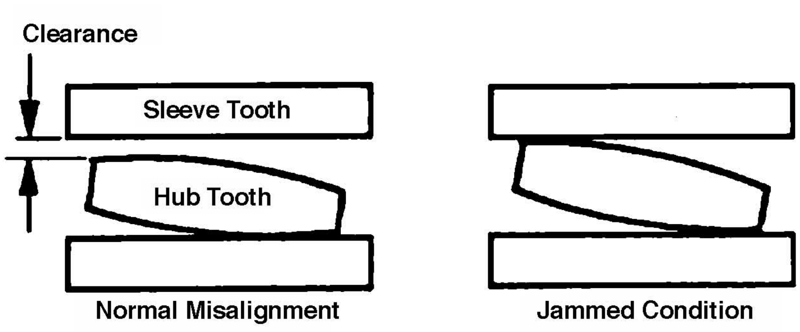


Figure 4-4
Gear Coupling Lock-Up Due to Excessive Angularity
Courtesy Flexible Couplings

4.5 Disc Coupling Failures

The disc-pack style coupling failures result from fatigue due to excessive flexure from greater than designed misalignment. Operating in an environment where corrosives are present will also cause premature failure.

Figure 4-5 illustrates how signs of fretting and corrosion can be detected on a disc coupling. A reddish-brown color will bleed out between the discs on the outside diameter. Fine line cracks will start at the outer disc, tangent to the washer's outside diameter. This is also indicative of misalignment.

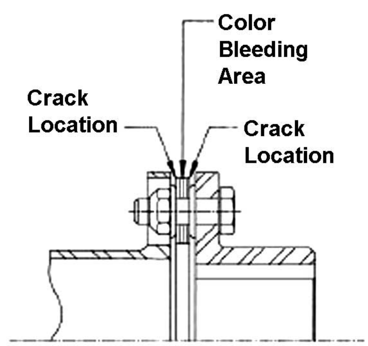


Figure 4-5
Fretting and/or Chemical Attach
Courtesy Rexnord-Thomas Couplings

Figure 4-6 illustrates a disc coupling in compression. The coupling can be inspected for this condition while operating with the use of a strobe light tuned to the running speed. If the "N" dimension is smaller than what the assembly drawing specifies, then adjustments must be made. If this phenomenon occurs during operation and not during shutdown, this is indicative of one or both machine shafts moving or thermally growing toward each other in the axial direction. If this is the case, the machines should be aligned properly in the axial direction for their respective operating conditions. If this condition is found at shutdown, the machines should be moved to compensate.

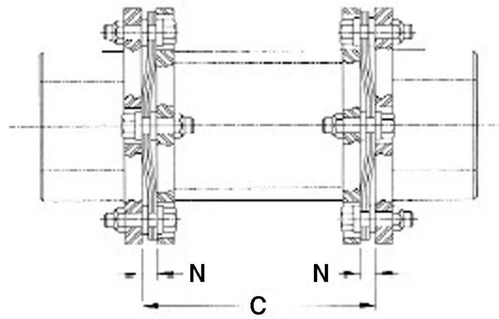


Figure 4-6
Disc Packs in Compression
Courtesy Rexnord-Thomas Couplings

Figure 4-7 depicts an elongated coupling. The "N" dimension will be wider than specified. This problem is due to either the coupling being installed with too much shaft separation or, if running in this condition, axial movements of the shafts.

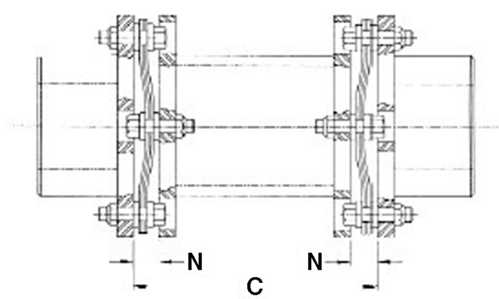


Figure 4-7
Elongated Disc Pack
Courtesy Rexnord-Thomas Couplings

Figure 4-8 illustrates the results of a coupling failure. If hole elongation and cracking is found, it is most likely due to loose bolting. The most common causes, however, are improper coupling selection, assembly, and alignment. The cracking may also be due to corrosive attack. If the hole is elongated, inspection should be made for loose bolting. The disc pack should be replaced and the bolting torqued to the proper specifications.

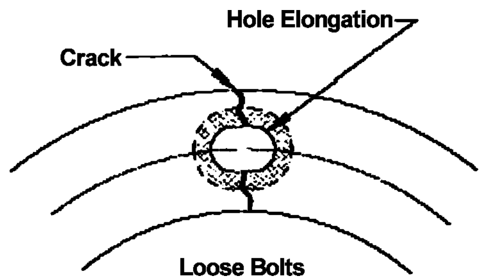


Figure 4-8
Loose Bolts
Courtesy Rexnord-Thomas Couplings

Figure 4-9 depicts how a coupling bolt would look after loose bolting. Note that the disc has tried to embed in the bolt, causing a reduction in diameter or cutting of the bolt. When this failure occurs, the bolts and disc pack should be replaced. Torque should be applied to the nut and not the bolt.

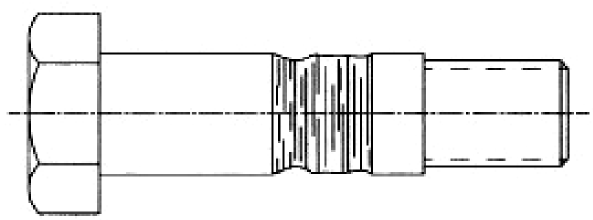


Figure 4-9
Loose Bolts
Courtesy Rexnord-Thomas Couplings

Figure 4-10 illustrates how cracks appear on discs. Cracks usually start on the outer discs and progress inward. If satisfactory cold alignment was performed, then hot alignment checks should be made, using an acceptable measuring method, while the machine is hot and running. Shutting a machine down to take hot readings (while it is cooling) is not an appropriate way to perform hot alignment.

Key Technical Point

Shutting a machine down to take hot readings (while it is cooling) is not an appropriate way to perform hot alignment.

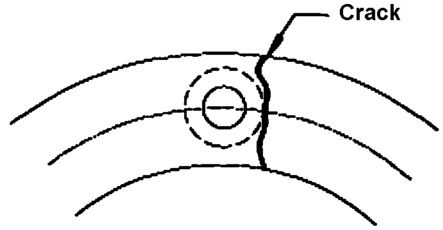


Figure 4-10
Excessive Misalignment
Courtesy Rexnord-Thomas Couplings

4.6 Diaphragm Coupling Failures

Figure 4-11 illustrates a diaphragm coupling failure due to improper installation or, possibly, excessive misalignment. This type of failure is a fatigue failure that occurs after the endurance limit of the material has been reached. Failures such as these occur almost instantaneously and without warning.

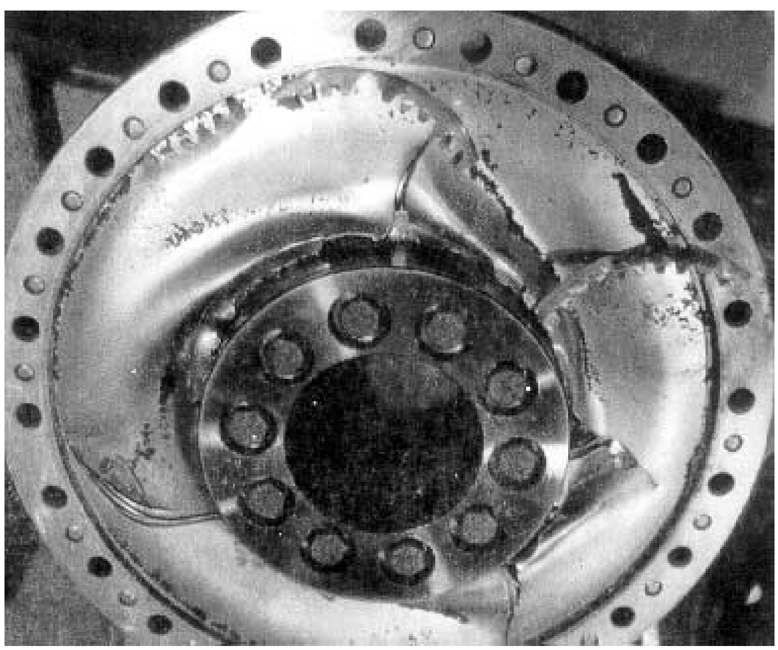


Figure 4-11
Diaphragm Coupling Failure
Courtesy Flexible Couplings

4.7 Elastomeric Coupling Failures

Coupling failures for elastomer type couplings vary; misalignment is often a major cause. Due to the damping effect of elastomeric couplings, heat is generated with the flexing or compressing of the material. If the temperature limits are in excess for the material used, the coupling will fail. The synthetic gear coupling shown in Figure 4-12 is used to illustrate the axial movement and misalignment that results from pipe strain. The suction piping on an ANSI pump was pulled into place to be “flanged up,” resulting in movement of the pump. Note the degree of misalignment that causes axial movement of the flex element halves in relation to one another.

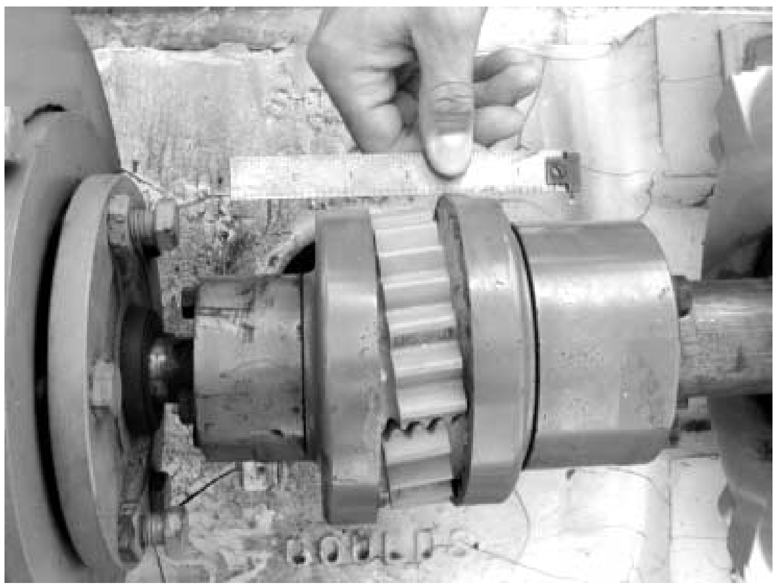


Figure 4-12
Grossly Misaligned Coupling and Shafts
Courtesy Rota-Tech Inc.

All rubbers and synthetics have a specified service life and shelf life. Exposure to chemicals and corrosives as well as ozone can precipitate a failure due to the loss of material properties. Broken pieces or dusting of material the same color as the flexing element around the coupling is an indication of material degradation.

5 MAINTENANCE, INSTALLATION, AND REPLACEMENT RECOMMENDATIONS

In many cases, the coupling is neglected during corrective maintenance activities on the adjoining machines. Once the coupling and all its parts are removed, its component parts may be placed in appropriate packaging (bag or box) and set in a corner until the machine(s) are reassembled. It may then be taken out of temporary storage, possibly cleaned without much observation of the condition, and reinstalled.

To ensure optimum performance and reliability, the coupling should be checked thoroughly during maintenance activities. Placing a worn or damaged coupling back in service leaves personnel open not only for operational problems but machine problems and the potential for catastrophic damage or personal injury.

For elastomeric and metal flexing couplings, a visual inspection should be made on a periodic basis. A strobe light is an excellent tool inspecting elastomeric and disc-pack couplings. The diaphragm coupling usually cannot be inspected without disassembly.

Key Human Performance Point

Placing a worn or damaged coupling back in service leaves personnel open not only for operational problems but machine problems and the potential for catastrophic damage or personal injury.

5.1 Proper Lubrication of Gear and Grid Type Couplings

Lubrication schedules for couplings are critically important. Most manufacturers of lubricated type couplings recommend a lubrication interval of six months. However, in today's operating environment, schedules of 18 months for fuel cycles at most nuclear facilities, and greater times in some instances at fossil stations between shutdowns, the lubrication and inspection of lubricated type couplings can inadvertently be severely extended.

This is particularly true when spare machines such as pumps are not rotated on- and off-line, which facilitates these necessary inspections.

Operating experience suggests that lubrication and related lubrication problems are the primary reason for failure or accelerated wear in gear and grid couplings. Lubrication problems result from one or several of the following causes:

- Loss of lubrication due to leakage, or over-lubrication
- Use of the improper amount of lubrication as described in manufacturer's literature
- Excessive lubrication (grease), which can hydraulically lock the coupling in position
- Excessive misalignment, which can overheat the lubricant
- Perfect or very near perfect alignment, which can prohibit pumping of lubricant through the flex elements
- Use of the improper type of lubricant

Key Technical Point

Proper lubrication and maintenance are important elements of an overall coupling maintenance program.

There are two types of lubricants used in mechanical element couplings: grease and oil. The oil lubrication of couplings can either be static oil in the coupling or continuous lubrication from an outside source, such as a pump or turbine-driven oil pump. Special coupling grease, such as Kop-Flex KHP, is formulated to prevent oil separation from the filler due to the centrifugal actions of the coupling rotation.

Today, there are a number of different types of facilities that continue to use oil lubrication inside a coupling with excellent success. This is mentioned in this report because it is considered a viable alternative to grease lubrication.

Coupling mating surfaces should be kept in good condition, along with good gaskets to ensure leak-free performance. Couplings with O-rings or sealing rings should have the rings inspected and/or replaced on a regular basis. The manufacturer of the couplings that utilize O-ring seals around the hub should be consulted about the optimum frequency of inspection or replacement of the O-rings. Gaskets should be checked for missing sections or tears.

Table 5-1 illustrates a condensed version of a manufacturer's lubrication data chart showing the capacities of lubricant for grease and oil. Note that in this example, the manufacturer chose to only show grease and oil capacities in U.S. units. In many cases, manufacturers can provide similar charts using metric units.

Table 5-1
Example of Lubrication Data Chart
Courtesy Kop-Flex

Coupling Size (See note)		**1 1/2**	**2**	**2 1/2**	**3**	**3 1/2**	**4**	**4 1/2**
Grease Capacity (lb. –oz.)	Full flex	0 – 6	0 – 7	0 – 14	1 – 6	2 – 0	3 – 6	4 – 1
	Spacer only (per in. of length)	0 – 2	0 – 2	0 – 2	0 – 3	0 – 4	0 – 6	0 – 8
Oil Capacity (U.S. Pints) SAE 140	Full flex	0.125	0.1875	0.3125	0.50	0.75	1.25	1.50
	Spacer only (per in. of length)	0.02	0.04	0.05	0.07	0.08	0.12	0.15

Note: Users should coordinate with the coupling manufacturer on a case-by-case basis to ensure that the coupling size specified is bored to either U.S. or metric requirements as needed.

Figures 5-1 and 5-2 are illustrations of the difference in styles of lubricated gear couplings. Note the difference in sealing mechanisms. The coupling shown in Figure 5-1 utilizes a labyrinth style seal at the ends of the hubs, while the coupling style shown in Figure 5-2 utilizes O-rings. The capacity of lubricant is typically less in the O-ring style coupling. The O-ring type seal is not acceptable for oil lubrication, while the labyrinth type coupling can use oil as a lubricant.

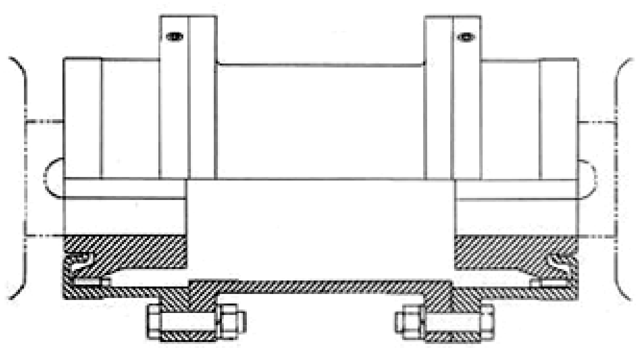


Figure 5-1
Labyrinth Seal Type Gear Coupling
Courtesy Kop-Flex

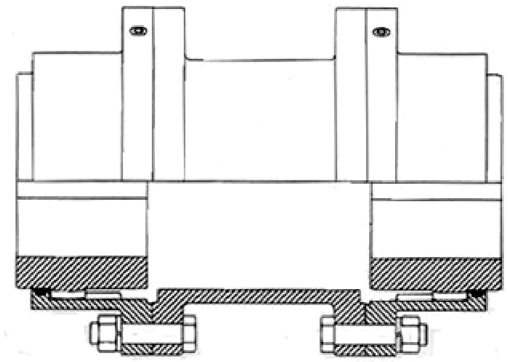


Figure 5-2
O-Ring Seal Type Gear Coupling
Courtesy Kop-Flex

The fill plugs should be used for oil lubrication and not grease lubrication. Grease should be hand-packed around the coupling teeth and should be kept clean while it is being packed. Overfilling with grease in a gear or grid coupling is a very common mistake and should be avoided because heat can build up in the coupling or cause a hydraulic lock. After packing, check that the coupling will move back and forth to ensure that the coupling is not grease-bound.

Key Technical Point

Overfilling with grease in a gear or grid coupling is a very common mistake and should be avoided, because heat can build up in the coupling or cause a hydraulic lock.

Insufficient lubrication can also cause fretting of the sleeve and hub, respectively, from the same coupling, as illustrated in Figures 5-1 and 5-2. The sleeve shows extreme wear from sliding of the hub over the sleeve without sufficient lubrication. Over a long period of time, the grease can solidify and cause damage, as illustrated in Figure 4-3.

Leakage from shaft seals or packing tends to infiltrate coupling housings; this has adverse consequences and should be avoided. The coupling shown in Figure 5-3 exhibits rust and discoloration due to infiltration of water due to improper sealing of the coupling and/or spray from leakage on the adjoining machines and the presence of condensation.

Figure 5-3
Water Infiltration into a Lubricated Coupling
Courtesy Rota-Tech Inc.

5.2 Maintenance of Limited End Float Couplings

Limited end float (LEF) couplings are intended to do precisely what their name suggests: they limit the end float of an electric motor rotor. They are designed and set up to prevent the rotor, which has no thrust bearings, from contacting the journal bearings.

5.2.1 Estimating Travel

The standard travel on most large motors is 1/2 inch (13 mm). That is 1/4 inch (6 mm) (shown as distances B and C in Figure 5-4) to either side of mechanical center. A limited end float coupling is expressed as total LEF. The LEF coupling limits the travel of the motor by using stops to prevent movement in either direction by a prescribed amount from mechanical center. If a limited end float coupling has a total limited end float of 3/16 inch (5 mm), it will restrict a motor's travel by 3/32 inch (2.5 mm) (shown as distance A in Figure 5-4) in either direction.

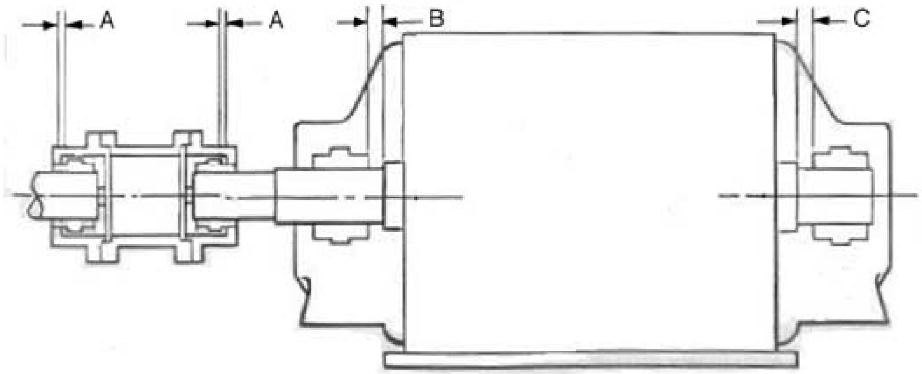


Figure 5-4
Motor and Coupling Schematic Showing Rotor Float
Courtesy Bingham Pumps, Inc.

If the motor's magnetic center is used as a reference point, it should be obtained by operating the motor in an uncoupled condition. The reference point is usually obtained by using layout dye on the shaft and scribing the shaft against the end seal cover of the motor to give a reference line to set the rotor position. After the rotor has stopped rotating and the motor is tagged out, the rotor can be moved to this position and a measurement may be taken to determine the DBE (distance between shaft ends).

Figure 5-5 illustrates the driving end of an electric motor rotor and is an example of the shaft configuration at the bearing journal. Note the step-down at the journal and the built-in discs, which provide for emergency thrust-carrying capabilities. In reality, these should never touch the edge or end of the bearings if the proper end float is limited as recommended. Figure 5-6 illustrates an outboard journal of a motor rotor that has journal sleeve bearings.

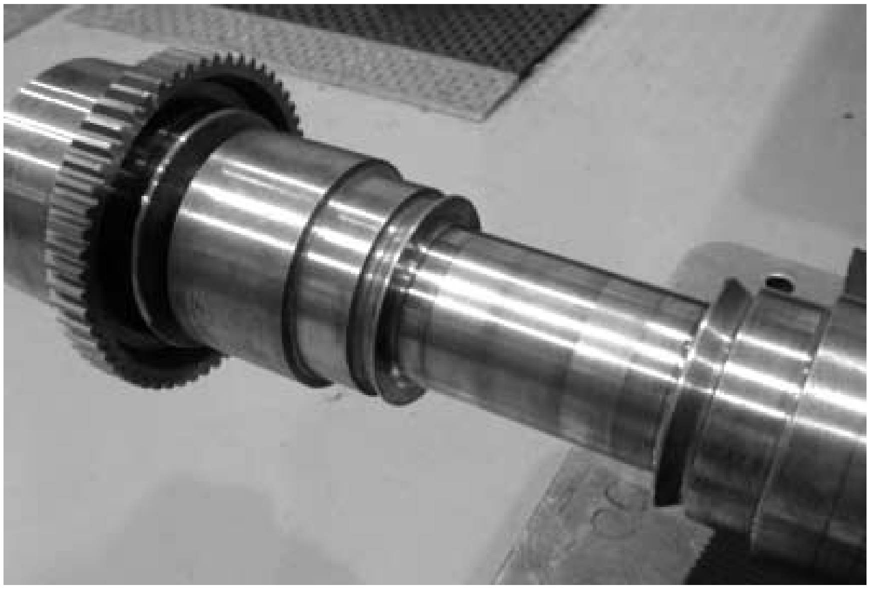


Figure 5-5
Driving End of Electric Motor Rotor
Courtesy Rota-Tech Inc.

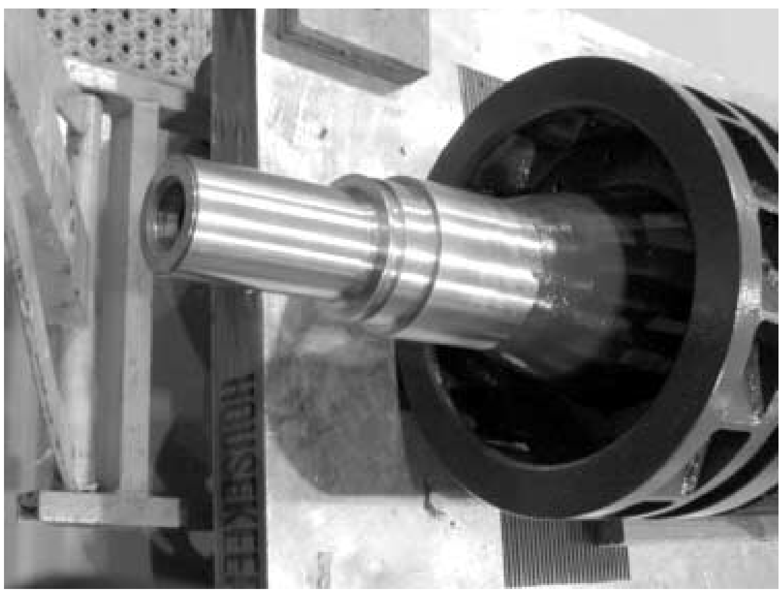


Figure 5-6
Outboard Journal of Motor Rotor with Journal Sleeve Bearings
Courtesy Rota-Tech Inc.

Figure 5-7 depicts one of the journal bearings for the rotor shown in Figures 5-5 and 5-6. Note the babbitted area on the end of the bearing. The shaft has made contact with the end of the bearing. This usually takes place on coast-down, when lack of current cannot control the position of the rotor. If the rotor stops against one or both of the bearings, then an immediate rub will occur shortly during startup. In the case above, the end float was not limited correctly because the plates in the end of the spacer were not of the correct length, and the shaft separation was incorrect.

Figure 5-7
Journal Bearing for Motor
Courtesy Rota-Tech Inc.

Gear couplings, which prohibit the movement of a shaft such as a motor shaft (which has no thrust bearing), may be considered to perform a function similar to bearings. Horizontal induction motors greater than 250 HP typically are furnished with only journal bearings and no thrust bearings. The faces or ends of the journal bearings usually have a babbitted surface for coast-down or intermittent touching of the rotor. If end float is limited properly, the shaft should never contact the bearing faces. Thus, not only does the coupling limit motor end float **toward** the pump but also **away from** the pump.

By design, disc and diaphragm couplings limit end float but are very stiff in the axial direction. It is very important to remember that shaft separation is critical, and the motor is on magnetic center when using this type of coupling. Figure 5-8 illustrates a limited end float close-coupled coupling and its accompanying data sheet.

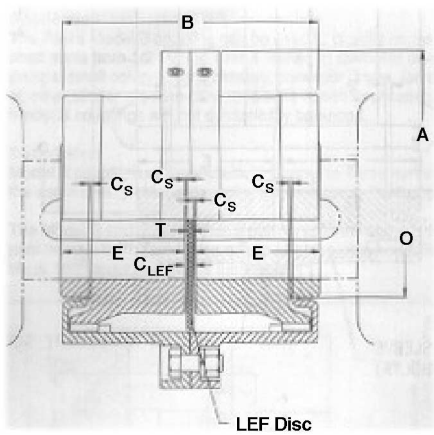
Key Technical Point

Disc and diaphragm couplings limit end float but are very stiff in the axial direction. It is very important to remember that shaft separation is critical, and the motor is on magnetic center when using this type of coupling.

For sleeve-bearing motor applications, a Fast's Model B full-flex coupling is supplied with an LEF disc to limit the axial float of the motor rotor and to protect the motor bearings at startup and shutdown. The hub separation, C_{LEF}, is larger than for a standard full-flex, and the phenolic LEF disc is placed between the hubs at assembly, limiting the float of the motor rotor to the total LEF value shown.

The equipment should be installed with the proper hub separation, C_{LEF}, when the motor rotor is located on the magnetic center.

The LEF disc part numbers are listed below.



Coupling Size	Total LEF	Maximum Bore with Standard Key	Dimensions						LEF Disc**	
			A	B	C_S	C_{LEF} (Hub Sep.)	E	T (Disc Width)	Part No.	Wt.
1	1/8	1 1/8	4	2 5/8	1/32	3/16	1 1/4	1/8	1B LEFD	1
1 1/2	1/8	1 5/8	5	3 1/2	1/32	3/16	1 11/16	1/8	1 1/2B LEFD	1
2	1/8	2 1/8	6	4 5/16	1/32	3/16	2 3/32	1/8	2B LEFD	1
2 1/2	1/8	2 3/4	7	5 1/4	1/32	3/16	2 9/16	1/8	2 1/2B LEFD	1
3	3/16	3 1/8	8 3/8	6 1/2	3/64	9/32	3 5/32	3/16	3B LEFD	1
3 1/2	3/16	3 3/4	9 7/16	7 3/4	3/64	9/32	3 25/32	3/16	3 1/2B LEFD	1

* All finish bores and keyways per AGMA 9002-A85 commercial standard tolerances. Each clearance bore includes one set screw over keyway.

** LEF discs are used only in close-coupled applications. One disc is required per coupling.

Figure 5-8
Limited End Float Coupling and Data Sheet
Courtesy Kop-Flex

The limited end float disc on a close-coupled coupling is the same thickness as the two discs combined on a spacer coupling. In other words, the protrusion of the discs or plates from the face of the coupling equals the thickness of the disc on a close-coupled coupling.

When examining hub separation, one should remember that limited end float distance and hub (shaft) separation are not the same thing. Figure 5-9 illustrates a spacer coupling with limited end float.

LEF Spacer Couplings

Limited end float (LEF) spacer couplings are used for sleeve-bearing motor applications with extended shaft separations. LEF spacers are supplied with steel LEF plates installed in each end.

Spacer length, L_{LEF}, is calculated by subtracting the LEF full-flex, close-coupled gap, C_{LEF}, from the shaft separation, C_L.

$$L_{LEF} = C_L - C_{LEF\ (full\text{-}flex,\ close\text{-}coupled)}$$

LEF spacers are shorter than standard spacers for a given shaft separation and are manufactured to order.

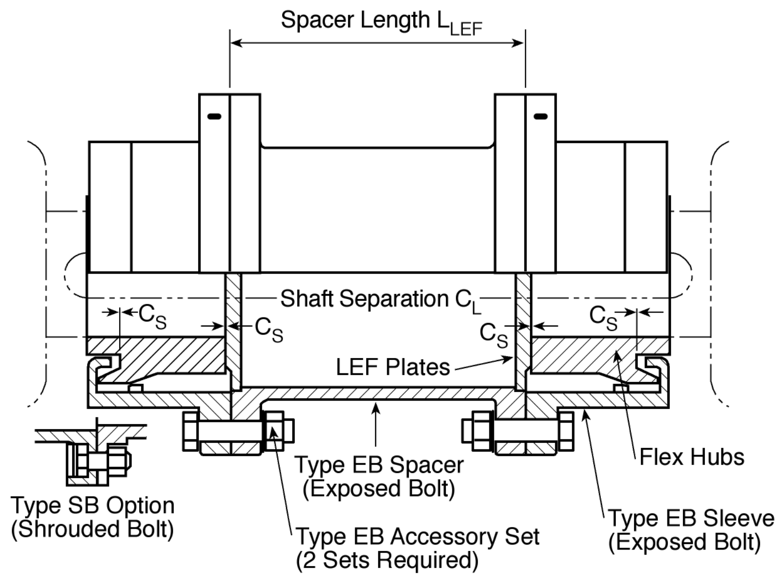


Figure 5-9
LEF Spacer Coupling
Courtesy Kop-Flex

The shaft spacing or hub separation is not the same as the limited end float. This is shown in Table 5-2. The column labeled "Total LEF" is the limited end float; the column labeled "C_{LEF}" is the actual shaft spacing or hub separation. On LEF couplings, the total limited end float is C_s multiplied by 4, as represented graphically in the example shown in Figure 5-9.

Table 5-2
Calculating Total LEF
Courtesy Kop-Flex

Coupling Size	Total LEF (in.)	Dimensions					LEF Disc**	
		A	B	C_s	C_{LEF} (Hub Sep.)	E	Part No.	Wt.
1	1/8	4 9/16	3 3/16	1/32	3/16	1 11/16	1W LEFD	1
1 1/2	1/8	6	3 7/8	1/32	3/16	2 1/16	1 1/2W LEFD	1
2	1/8	7	4 5/8	1/32	3/16	2 7/16	2W LEFD	1
2 1/2	3/16	8 3/8	5 11/16	3/64	9/32	3 1/32	2 1/2W LEFD	1
3	3/16	9 7/16	6 9/16	3/64	9/32	3 19/32	3W LEFD	1
3 1/2	3/16	11	7 5/8	3/64	13/32	4 3/16	3 1/2W LEFD	2
4	3/16	12 1/2	8 5/8	3/64	13/32	4 3/4	4W LEFD	2
4 1/2	3/16	13 5/8	9 5/8	3/64	17/32	5 3/8	4 1/2W LEFD	2
5	3/16	15 5/16	10 13/16	3/64	17/32	6 1/8	5W LEFD	2
5 1/2*	3/16	16 3/4	11 5/8	3/64	17/32	6 5/8	5 1/2W LEFD	2
6*	3/16	18	13 1/4	3/64	19/32	7 3/8	6W LEFD	2
7*	3/16	20 3/4	14 3/4	3/64	25/32	8 11/16	7W LEFD	2

* Sizes 5 1/2, 6, and 7 are only available with exposed bolts. Type EB exposed bolts are standard.
** LEF discs are used only in close-coupled applications. One disc is required per coupling.

A formula is provided in Figure 5-9 for defining shaft separation or spacer length. Another method of determining shaft separation is to measure the overall length of the spacer (including the end float discs) and add 2 times C_s (as shown on the table and figure) or half of the total end float that is specified for the particular coupling.

Key Technical Point

The shaft spacing or hub separation is not the same as the limited end float.

If using the magnetic center for your calculations, the motor rotor should be moved to the full outboard position, and the distance between shafts should then be measured. Then move the rotor to the full inboard position and take a measurement. Subtract the two distances to determine the total float of the rotor. Divide this number by two and add it back to the smaller distance. This distance is the shaft separation at magnetic center. If the shaft separation is not within 1/32 inch (0.79 mm) of the shaft spacer length plus half of the total end float, one machine or the other must be moved on its base to achieve the required distance. An example follows:

Coupling used = 3/16 total LEF ÷ 2 = 3/32 = 0.094 inch (2.4 mm)
Spacer length = 6.900 overall
Shaft separation = 6.900 + 0.094 = 6.994 = 7 inch (178 mm) shaft separation at magnetic or mechanical center

5.2.2 Electric Motor Rotor Positions

The electric motor rotor position on motors above 250 HP can be mechanical or magnetic. If a limited end float gear coupling is used, many end users opt for the mechanical position based on the light forces of electromotive force exhibited in the axial direction. However, if a non-lubricated coupling such as a disc, diaphragm, or elastomeric coupling is used, then the magnetic center position should be the motor rotor position that is used.

5.3 Maintaining Proper Fits Associated with Couplings

5.3.1 Shaft-to-Hub Fits

The type of fit between a shaft and a hub can be one of the three types listed below:

- Clearance fit with key
- Interference or shrink fit with key
- Keyless interference fit

Interference fit coupling hubs on straight shafts require a method of removal to avoid damage to the shaft or the coupling. Figure 5-10 illustrates a gear hub with the puller holes drilled and tapped. Also, note that an additional set screw has been placed at the key.

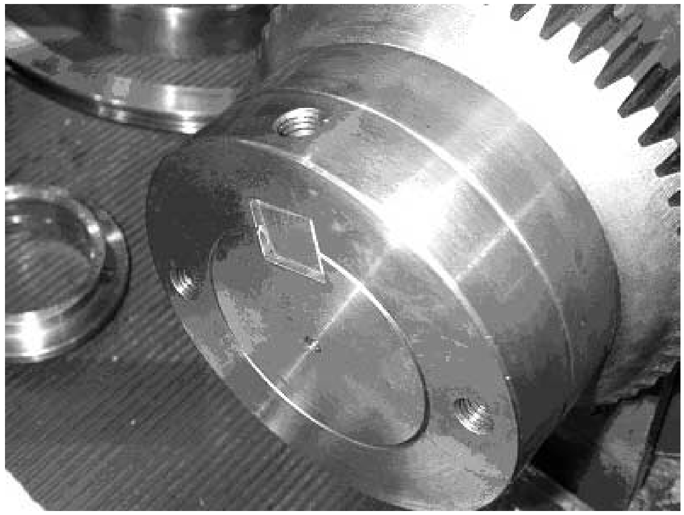


Figure 5-10
Gear Hub with Set Screw Over Key and an Interference Fit
Courtesy Jack

When coupling hubs are received, whether bored to size or rough-bored, they typically do not have holes tapped to facilitate a puller. Unless specified, the hub is often provided without puller holes. The manufacturer can usually provide guidelines for the hole size, thread, and location for layout of the holes.

High-performance couplings are sometimes furnished with two keys to distribute the shear stress on two keys instead of only one. Figure 5-11 illustrates a coupling hub that uses two keys.

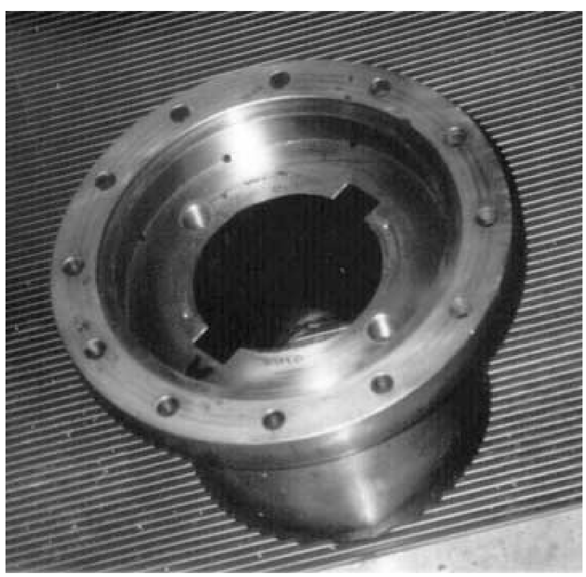


Figure 5-11
Coupling Hub Utilizing Two Keys
Courtesy Jack

Care should be taken when using a hub and shaft, which employ two keys. The coupling and the shaft should be match-marked to ensure that the coupling is returned to same orientation on the shaft each time. This is especially true when rotor balancing is to be performed. Lubrication of the key with a slight coat of "never seize" will prevent galling.

5.3.2 Clearance Fit with Key

Some coupling manufacturers recommend clearance fits that can be used on up to 4 inches (10 cm) of shaft diameter. A large shaft and a combination of large misalignment can create bending moments and, thus, flexing of the hub to the shaft. In practice, clearance fits should not be used above a diameter of 2.75 inches (70 mm). However, the manufacturer of the equipment and the coupling manufacturer should always be consulted to provide the appropriate fit for the equipment in question. Speed and torque should also be considered when determining the type of fit.

Torque is transmitted through the keys on all keyed couplings. Clearance fits should be limited to small-horsepower applications. Set screws are used to minimize play between the hub and shaft and also to limit movement of the hub and/or key in the axial direction. Clearance fits are not normally used on shafts with speeds above 1800 rpm.

Key Technical Point

Clearance fits should be limited to 0.002 inch (0.05 mm) maximum. On larger-diameter shafts, heat may be required to expand the hub.

5.3.3 Couplings with Shrink or Interference Fits

Couplings with shrink fits to shafts provide for a tight fit, resist forces and moments applied across the coupling, and prevent rocking on the shaft. This benefit subsequently prevents fretting, which can result in failure of the shaft and/or the coupling.

Care should be taken not to have too tight a fit with keyed hubs, as this induces stresses and can cause cracking of the hub. The American Gear Manufacturers Association (AGMA) and API 671 are quite explicit concerning these shrink fits. The hubs, on shrink fit shafts, are driven by the key(s). The fit is to prevent rocking and axial movement of the hubs.

5.3.3.1 Shrink Fits on Straight Shafts

Some coupling manufacturers provide a calculated interference that is based on the size of the shaft. This generally ranges from 0.00075 to 0.001 inch (0.019 to 0.0254 mm) per inch of shaft diameter. Experience has shown that, more commonly, these numbers should be reduced to around 0.0005 inch (0.0127 mm) per inch of shaft diameter. For a 3-inch shaft, a maximum of 0.002 inches (0.051 mm) is typical. For shafts larger than 3 inches, a good rule of thumb is to use 0.00025 inches (0.00635 mm) for each additional inch of shaft diameter.

Manufacturers also provide heating instructions for hubs. These recommendations usually request that a heater of some sort be used instead of an open flame from a torch. Oven heating in something similar to a welding rod oven is generally one of the better methods. Oil bath type heaters may also be considered, but care should be taken to ensure that the elevated hub temperature remains well below the flash point of the oil. Manufacturer's limits on heating should be followed and often limit heating to less than 250°F (121°C). This can be verified with a "temp stix" rated for the desired temperature.

Experience has shown that a good method for determining if the hub is hot enough to be installed is to use a measuring device. One of the preferred methods is to use a telescoping gage set slightly larger (0.0005 to 0.001 inches; 0.00127 to 0.00254 mm) than the interference fit. When the temperature is acceptable for installation, the gage should easily pass through the hub.

Key Human Performance Point

CAUTION –Care must be taken to prevent contact with the hub, which will cause severe burns. Threaded rod inserted in the puller holes works well to handle heated components during installation. The use of welder's gloves can prevent burns.

The interference fits recommended by manufacturers are generally acceptable numbers for installation of the hubs. However, the numbers recommended above give personnel the added advantage of removing the hub without problems occurring, such as galling. An important reminder is that, usually, a torch is required to remove the hub at the equipment location. If the location of the equipment is such that the environment is volatile, then the rotor should be removed and transported to an area where conditions are safer.

Large interference fits also pose problems when spacing between shafts is minimal. In some cases, the hub must be allowed to cool while a different fixture is used to continue pulling the hub. In this case, the hub must be heated a second time for removal. Figure 5-12 illustrates a case when the interference was acceptable going on the shaft but created problems upon removal.

Figure 5-12
Broken Puller Stud Due to Tight Fit on Shaft
Courtesy Jack

Figure 5-13 shows the reverse side of the item shown above.

Figure 5-13
Coupling Hub Fit Too Tight for Removal
Courtesy Jack

5.3.3.2 Shrink Fits on Tapered Shafts

Tapered coupling fits (shafts) are common on many equipment applications. The taper provides for easy installation and removal while allowing for a proper and tight fit from the hub to the shaft. Figures 5-14 and 5-15 illustrate examples of fretting due to either improper (loose) coupling fit or a loose coupling.

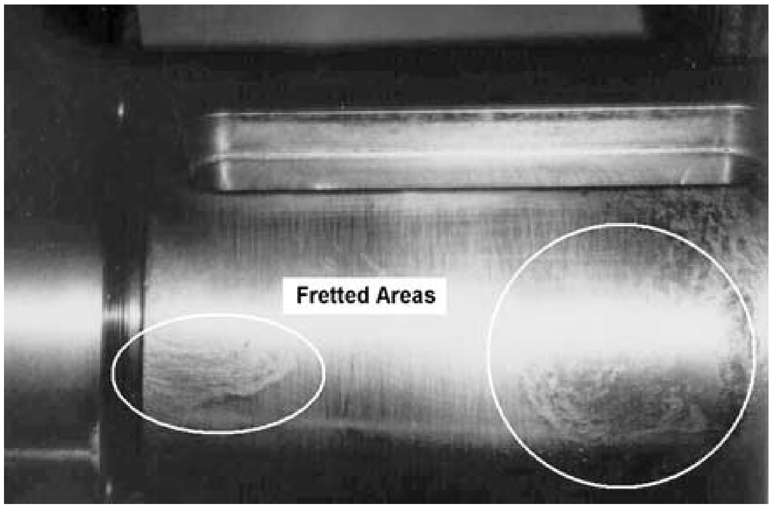


Figure 5-14
Fretting of Shaft Due to Improper Coupling Fit
Courtesy Jack

Figure 5-15
Fretting Due to Loose Coupling or Improper Fit
Courtesy Jack

Tapered shafts are common on what are typically referred to as high-energy machines, such as feedwater pumps, large fans, and compressors.

Shafts are manufactured using various tapers, normally ranging from 1/2 inch per foot to 1 1/4 inch per foot. Manufacturers design a particular taper based on the fit required and the size of the shaft. Tapers may be described as either a ratio or a taper per foot. The most common tapers are 1/2, 5/8, and 1 1/4 inch per foot. Table 5-3 illustrates a table of interferences.

Table 5-3
Table of Interferences
Courtesy Flexxor Couplings, Inc.

Coupling Hub Bores and Shafts			
Bore Shape	Straight	Tapered	
Drive Method	Keyed	Keyed	Hydraulic
Interference	0.5 to 2 mils total	1 mil/inch diameter	1.5 to 2.5 mils/inch
Minimum Contact Area		70%	80%
Bore out of Roundness (Max) Up to 4 inches; Over 4 inches		0.2 mil total indicated runout (TIR); 0.5 mil TIR	

Figure 5-16 illustrates the relationship between interferences and coupling advance. The chart depicts an example of an 8-inch shaft used with a 3/4-inch taper per foot. The resulting advance is approximately 0.130 inch (3.3 mm).

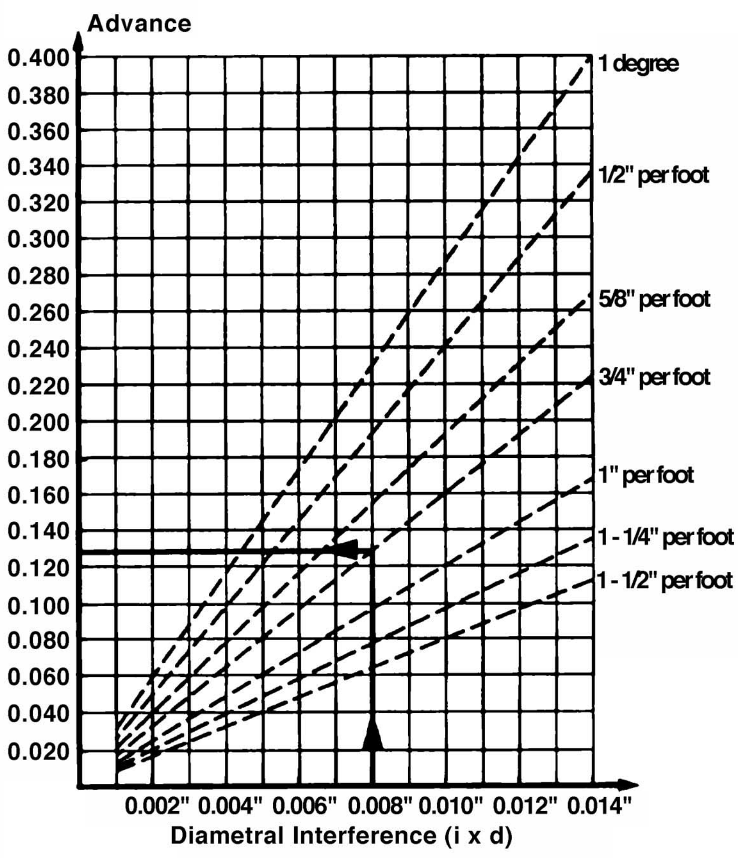


Figure 5-16
Chart of Interferences and Coupling Advance
Courtesy Flexible Couplings

The following example can be used to calculate the advance or pull-up of a coupling. In this example, assume the following:

Shaft diameter = 5 inches
Taper per foot = 1 1/4 inch/foot
Interference = 0.001 inch/inch = 0.005

Advance is calculated by dividing I_t (total interference) by T_{pi} (the taper per inch).

Advance = I_t/T_{pi}

$$\text{Advance} = \frac{0.005}{\frac{1.25}{12}} = 0.048\ \text{inch}\ (1.22\ \text{mm})$$

Tapers may also be expressed as a ratio. This ratio is based on the distance of a taper to change the shaft size or diameter by 1 inch. For example, a shaft having a 1/2 inch taper per foot would be 1:24 taper, changing by 1 inch for every 24 inches in length. Table 5-4 illustrates the relationship between expressing tapers as inches per foot and ratios.

Table 5-4
Expressing Tapers

Taper Expressed as Inches per Foot	Corresponding Taper Expressed as a Ratio
1/2 inch taper per foot	1:24
5/8 inch taper per foot	1:20
3/4 inch taper per foot	1:16
1 inch taper per foot	1:12
1 1/4 inch taper per foot	1:8

Proper heating of a tapered hub is extremely important: in many cases, more so than with a straight shaft. Getting the hub too hot will allow it to travel further on the shaft, making it almost impossible to remove when and if the time comes. This problem can be remedied by installing a stop behind the hub. Because the hub is too hot, however, it is also difficult to keep it on the taper. If the correct temperature is used, then the hub can be maintained on the taper until the shaft nut is installed. When the hub has cooled, it will also shrink some amount in the length direction. The coupling nut should then be tightened again and secured with set screw(s) into the face of the shaft or hub.

Key Technical Point
Proper heating of a tapered hub is extremely important.

Figure 5-17 shows a stop in place, in the form of a split collar secured to the shaft, to limit the tapered hub during its advance up the taper. This ensures the correct location of the hub. The nut should immediately be placed on the shaft to secure the hub and prevent the hub from "walking down the shaft."

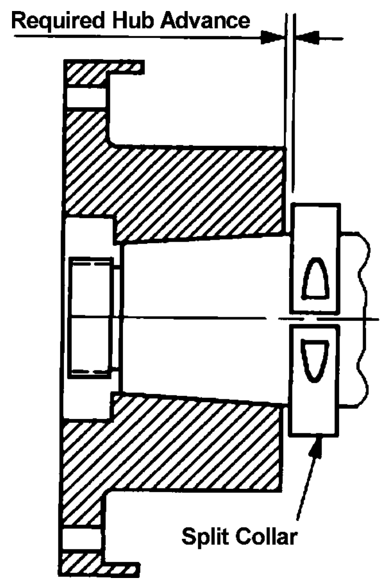


Figure 5-17
Hub Advance Stop
Courtesy Flexible Couplings

In many cases, there is not enough room between the hub and bearing housing to install a stop device. When this is the case, several alternative methods may be used to stop the hub. If a rotating seal is used on the bearing housing and set screws are provided to secure the seal to the shaft, the rotating seal can sometimes be used and set in a location to stop the hub. After the hub is secured, the seal can be reset to the proper location. If the seal is a type that cannot be moved, shims such as feeler gages can be placed between the hub and the seal to limit the travel of the hub. Another option is to bolt a "strong back" across the coupling face. A bolt in the center can be used as an adjustable contact stop with the end of the shaft.

5.3.4 Keyless Interference Fits

A keyless interference fit is usually referred to as a hydraulically dilated coupling. The hydraulically dilated coupling hub is used in locations where heat or open flame is not acceptable. This is an excellent method of installing and operating a coupling. Figures 5-18 and 5-19 illustrate a keyless hydraulically dilated coupling shaft and the installation tool, respectively.

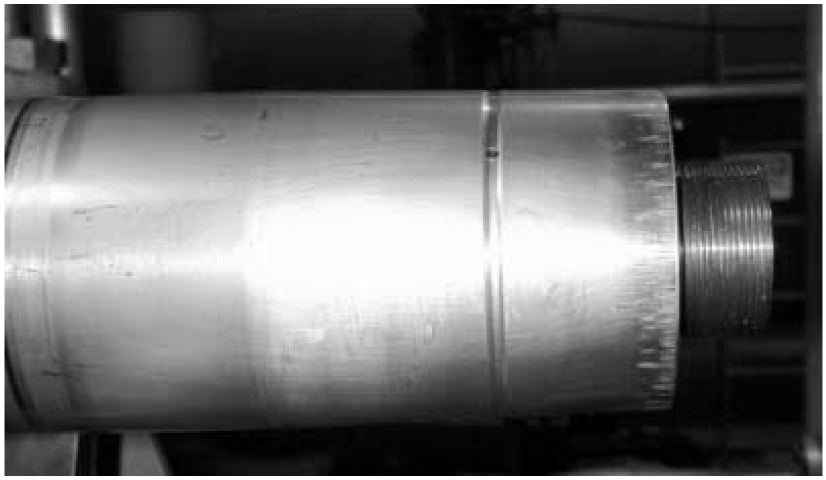


Figure 5-18
Keyless Hydraulically Dilated Coupling Shaft
Courtesy Jack

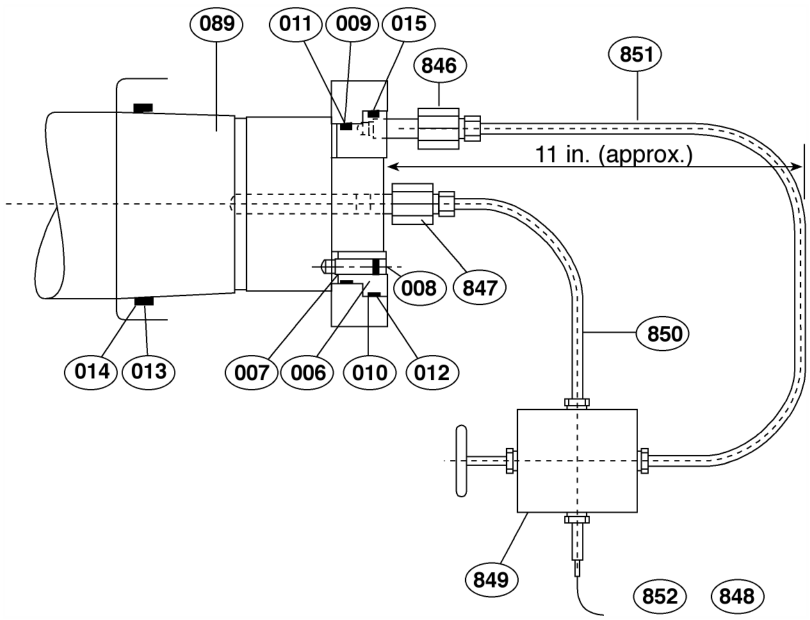


Figure 5-19
Hydraulic Coupling Hub Installation Tool
Courtesy DeLaval Pumps Instruction Manual

The hydraulically dilated coupling hub is keyless and is tapered at 1/2 inch per foot. The coupling hub has O-rings and Teflon-type backup rings on both ends of the coupling. A hydraulic pump should be used to pressurize inside the coupling via drilled passages in the shaft. (Note: Some coupling hubs have grooves to accommodate this, which facilitates installation and removal.) The coupling nut is two-piece and should have O-rings and backup rings inside it. When the hub is pressurized, the valve is diverted to push the piston inside the coupling nut and advance the hub the prescribed amount. The pressure is then released between the coupling and the shaft, and the hub shrinks to the shaft. Once this is accomplished, the pressure is relieved on the nut and the pump is removed. The inner portion of the nut is then tightened against the outer ring and set-screwed to the shaft. Figure 5-20 illustrates a typical configuration of a coupling nut.

Key Human Performance Point

Ensure that hydraulic equipment is in good working order to preclude the danger of hydraulic hoses under high pressure separating and causing personnel injury.

Figure 5-20
Coupling Nut for Hydraulic Coupling Showing Pressure Port, Set Screw, and Spanner Holes
Courtesy Jack

5.3.5 Proper Contact of Tapered Hubs to Shafts

Table 5-3 shows the acceptable contact between the coupling hub and the shaft: 70% contact by blue on a keyed shaft and 80% by blue on a keyless shaft. The shaft should be dyed using Prussian blue, and the coupling hub should be pushed straight up on the shaft in a swift, firm motion. Do not slam the hub home. When installed properly, the hub can then be removed, sometimes with the slight assistance of a mallet. The blue contact area can then be checked on the shaft to determine if the amount of contact is satisfactory.

If contact is not satisfactory, then one or both of the pieces must be lapped.

Key Technical Point

Under no circumstances should the taper bore coupling be lapped to the shaft. This will create a step on the shaft over which the coupling hub must pass, leaving a non-contacting area under the coupling hub.

The shaft and coupling hub can be lapped with a “ring and plug.” Ring and plug gages are devices fabricated, usually by the coupling manufacturer, to check contact of shafts and hubs. The ring is a female fit for the shaft, and the plug is a male fit for the hub. These are used as standards to verify correct fits of hubs and shafts. The original ring and plug should not be used for lapping. A reproduction, manufactured from highly finished cast iron, should be used for lapping.

Figures 5-21 and 5-22 show how lapping with the coupling hub can affect contact after advancement of the hub on the shaft. This will not typically show up during a contact check after lapping. Figure 5-23 illustrates a lack of contact exhibited after advance of the hub.

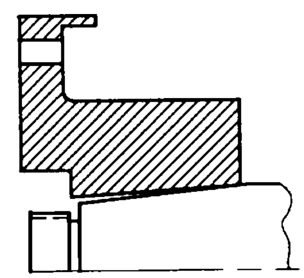


Figure 5-21
Improper Hub-to-Shaft Fit
Courtesy Flexible Couplings

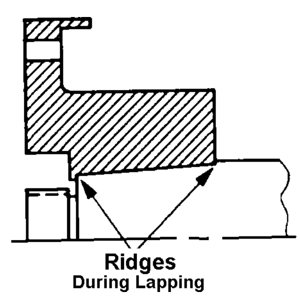


Figure 5-22
Ridges in Hub and Shaft after Lapping
Courtesy Flexible Couplings

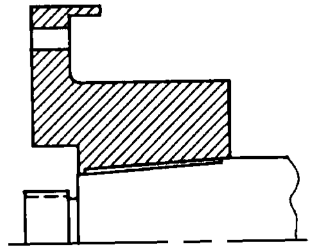


Figure 5-23
Lack of Contact after Advance of Hub
Courtesy Flexible Couplings

API 671 states that the machinery supplier who is responsible for supplying the coupling for a tapered shaft fit should also supply a ring and plug gage to verify the correct taper and fit of a coupling hub to the shaft. This is to be used as a standard to dye (blue) the shaft and hub for proper fits. Reproductions of these standards can be used to lap a shaft and hub to achieve the proper blue contact of the two parts.

5.4 Maintaining Alignment of Couplings

Coupling misalignment differs from shaft misalignment. Shaft misalignment is measured in offset and angularity. Coupling misalignment is measured in angle of degrees of misalignment.

Whether the shaft has offset, angularity, or both, the coupling misalignment is at an angle. Manufacturers may provide an offset as related to an angle for the design length of the coupling.

Each flex plane of the coupling can have a different amount of misalignment. The distance between flex planes and the angle of misalignment can be converted into offset at the coupling flex planes or the two shafts that it connects.

For how much misalignment can a coupling compensate? This depends on the type of coupling, the torque applied, and the distance between flex planes. Most couplings for rotating machinery in the power station are designed for a range of 1/4° to 1/2° of misalignment. This can still pose a problem for machinery if it is operated with this misalignment.

Key Technical Point

Coupling misalignment differs from shaft misalignment. Shaft misalignment is measured in offset and angularity. Coupling misalignment is measured in angle of degrees of misalignment.

Figure 5-24 shows a configuration involving a 0.1° coupling angle over a 10-inch (254 mm) distance between flex planes. To determine the offset between the two flex planes or the shafts being connected, the tangent trigonometric function at 0.1° of misalignment should be used, which is equal to 0.00175. This is the amount of misalignment per inch of coupling between the flex planes. Over a distance of 10 inches (254 mm), this results in an offset of 0.0175 inches (0.45 mm). Needless to say, the machines should not be operated with this amount of offset.

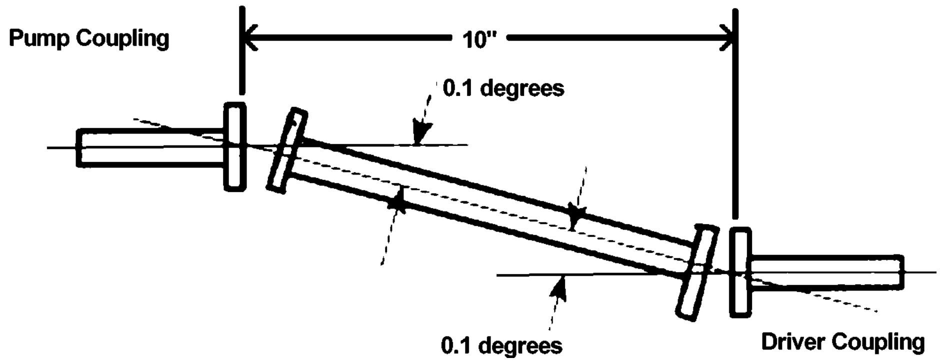


Figure 5-24
Coupling Angle
Courtesy Flexible Couplings

Figure 5-25 represents two spacers of different lengths with identical offset misalignments. The longer shaft separation will have less angular misalignment because of the larger distance between flex planes. Conversely, the shorter shaft separation results in higher angular misalignment because of the smaller distance between flex planes.

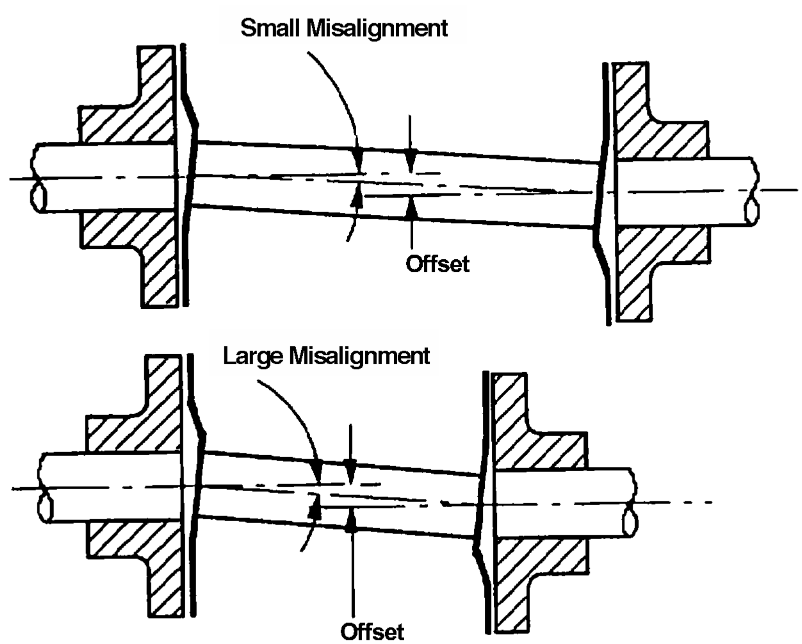


Figure 5-25
Offset vs. Coupling Angle
Courtesy Flexible Couplings

5.4.1 Maintaining Alignment of Gear Couplings

The flexibility (sliding) of a gear coupling is made possible by the clearance (backlash) between the internal and external teeth. The internal teeth are on the sleeve of the coupling, while the external teeth are on the hub or, in some cases, the spacer of the coupling.

In addition, the curvature of the tooth face, which is typically on the hub, allows for misalignment. The greater the curvature, the greater the misalignment capability, but the torque capability decreases with the curvature.

By design, gear couplings have the ability to move farther in the axial direction than other type couplings. Errors in shaft separation by small amounts are not necessarily a problem for these types of couplings. If a limited end float coupling is used, care should be taken to minimize the errors in shaft separation.

There are documented cases of coupling and shaft alignment being in such good alignment that the gear teeth do not move relative to each other, and thus, they cannot pump the lubricant through the coupling. When this is the case, failure of the gear coupling may occur due to lack of lubrication and heat buildup.

5.4.2 Maintaining Alignment of Disc Type Couplings

By design, the two flex planes are moved back on the shaft to allow for the coupling angle of misalignment, as shown in Figure 5-26. The flex planes are in that location in order to provide the necessary distance between flex planes and to compensate for an acceptable amount of misalignment. Remember that two flex planes are required to compensate for offset and angular shaft misalignment. The spacer in this case is a two-piece (clam shell) used to facilitate installation and removal.

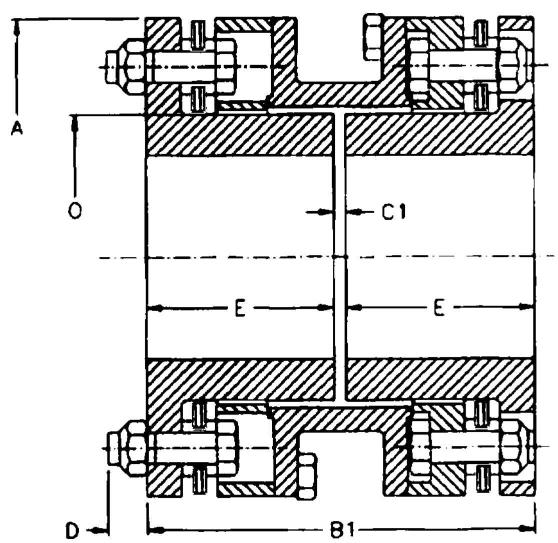


Figure 5-26
Close-Coupled Disc Coupling
Courtesy Kop-Flex

5.4.3 Retrofit Couplings

The trend for many utilities is to change from a lubricated gear coupling to a non-lubricated disc or diaphragm coupling to eliminate lubrication and lubrication schedules and to eliminate the possibility of gear coupling lock-up. Figure 5-27 illustrates a diaphragm coupling prior to installation that is intended to replace a gear coupling. This retrofitted diaphragm coupling is described in the data sheet shown in Table 5-5.

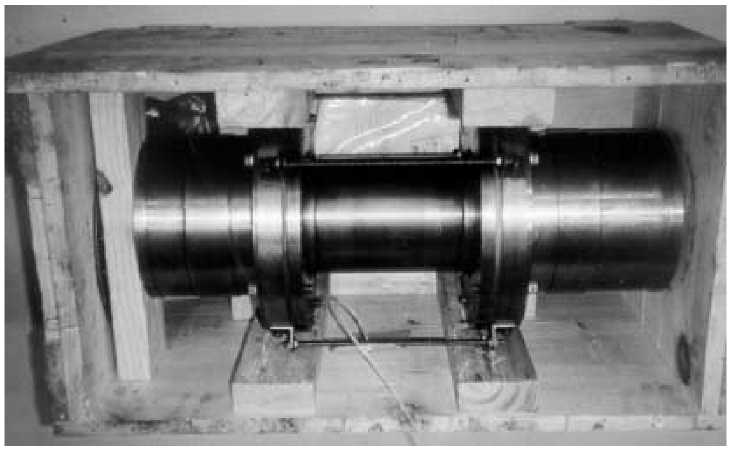


Figure 5-27
Retrofit Diaphragm Coupling Prior to Installation
Courtesy Ameridrive, Inc.

Table 5-5 is a reproduction of an actual coupling data sheet supplied for a feedwater pump retrofit from a gear coupling.

Table 5-5
Diaphragm Coupling Data Sheet
Courtesy Ameridrive, Inc.

Operating Conditions		**Application Requirement**	**Coupling Capacity**	
Power	Normal	13,673	HP/100 rpm	525
HP	Maximum continuous			
Speed	Normal	5200	Rated rpm	13,000
rpm	Minimum continuous	5200		
	Max continuous	5200		
Trip				
Torque (in.-lb.)	Normal	165,719	Rated	331,000
	Max continuous	165,719		
	Selection	290,000		
	Max transient	435,000	Rated	496,000
Service Factor		1.75	Actual	2.00
Axial Deflection from Neutral (Inches)			Rated	0.135 in.
Angular Misalignment (Degrees)			Rated	0.250°
Equivalent Parallel Offset			Rated	0.038 in.

The Equivalent Parallel Offset value in the table is calculated based on the rated misalignment in degrees, which is found by multiplying the tangent (0.250 (1/4) degrees) by the length of the spacer between flex planes (in this example, 8.79 inches (22.3 cm)).

Table 5-6 and Figure 5-28 illustrate examples of recommended tolerances for shaft alignment. Table 5-6 depicts both offset and angularity for determining correct shaft alignment.

Table 5-6
Tolerances for Shaft Alignment
Courtesy Ludecka

Tolerances for Shaft Alignment

	Short Couplings						**Spacer Shafts**	
	Excellent			Acceptable			Excellent	Acceptable
	Offset	Angularity		Offset	Angularity		Offset per inch	
rpm	(mils)	(mils)/(inch)	(mils)/(10°)	(mils)	(mils)/(inch)	(mils)/(10°)	(mils per inch of spacer length)	
600	5.0	1.0	10.0	9.0	1.5	15.0	1.8	3.0
900	3.0	0.7	7.0	6.0	1.0	10.0	1.2	2.0
1200	2.5	0.5	5.0	4.0	0.8	8.0	0.9	1.5
1800	2.0	0.3	3.0	3.0	0.5	5.0	0.6	1.0
3600	1.0	0.2	2.0	1.5	0.3	3.0	0.3	0.5
7200	0.5	0.1	1.0	1.0	0.2	2.0	0.15	0.25

Figure 5-28 depicts tolerances based on angularity or mils per inch of misalignment.

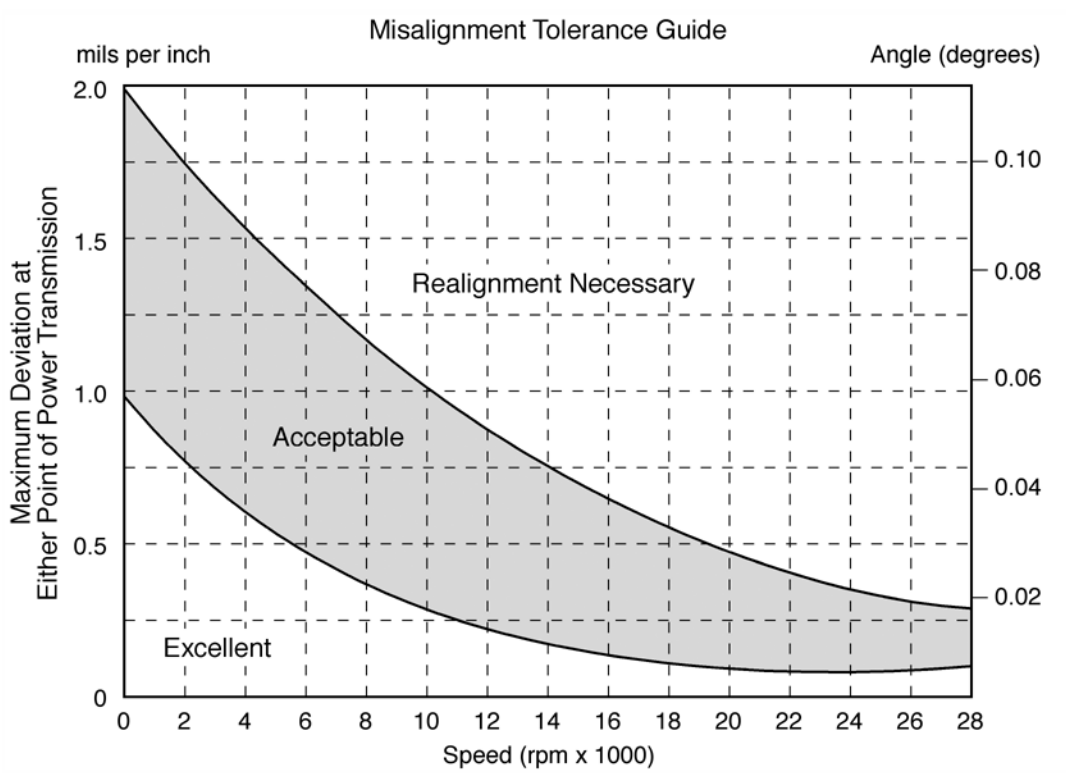


Figure 5-28
Misalignment Tolerance Guide
Courtesy Shaft Alignment Handbook

5.5 Forces and Moments

Misaligned couplings impose forces and moments on shafts and bearings while trying to restore themselves into an aligned position.

Key Technical Point

All types of flexible couplings resist being misaligned. Flexible couplings resist axial movement of connected shafts.

The amount of forces and moments vary with the amount of misalignment and the type of coupling.

5.5.1 Axial Thrust Formula for Gear Couplings

The axial thrust formula for gear couplings is:

$$A = \mu F$$

$$F = \frac{2T}{PD \times \cos\beta}$$

$$A = \frac{2 \times T \times \mu}{PD \times \cos\beta}$$

Where:

β = pressure angle of the tooth profile in degrees
A = axial thrust in pounds
F = total tangential force in pounds
T = torque in inch-pound
PD = pitch diameter in inches
μ = friction coefficient

The pressure angle normally used by most manufacturers is 20°. Reducing the pressure angle reduces the forces. The axial thrust is relative to the PD (pitch diameter of the gear), whereby the larger the PD, the smaller the axial thrust.

The coefficient of friction varies relative to the movement of the teeth against each other. The static friction (no movement between teeth) is greater than the dynamic friction (movement between teeth). The friction is dynamic in lubricated couplings, because there is a minimal amount of misalignment. If misalignment becomes zero, all motion between mating teeth stops, the lubricant is expelled from between the teeth, and the friction coefficient increases to the static level.

Torque will create pressure between the teeth of the hub and the sleeve. When torque increases, the film thickness of the lubricant decreases. At this point, the friction coefficient becomes dependent on the torque.

The axial thrust (in pounds) for a gear coupling is linear with the axial displacement. This is not true for metallic element couplings. The increase is exponential for disc and diaphragm type couplings and is very complicated to ascertain. As such, many manufacturers perform tests to determine the axial thrust for these types of couplings.

5.5.2 Overhung Moment

The coupling can have a direct impact on or correlation to shaft position. The overhung weight or cantilever of the coupling may add more lateral vibration and can significantly change the shaft position within the bearing. Misalignment adds even more vibration and shaft displacement. Figure 5-29 shows the relationship between length and weight of the coupling and the forces and moments that can be applied to the shaft.

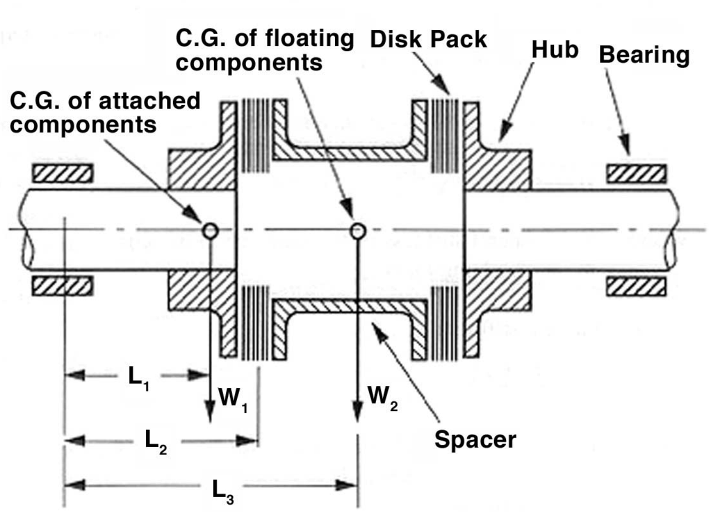


Figure 5-29
Original Design Thomas Disc Coupling with Disc Packs Overhanging Shaft
Courtesy Flexible Couplings

The figure also illustrates an installation with a general-purpose coupling that has an overhung moment, which can be calculated using the equation provided below.

$$M_o = W_1 \bullet L_1^3 + \frac{W_2}{2} \times L_2^3$$

Where

W_1 = weight of components fixed to the shaft. This includes the hub, fasteners, 1/2 the key, and 1/2 the disc pack.

W_2 = weight of all components supported by the shaft (through the flexible element), the spacer, fasteners, and 1/2 of 2 disc packs (1 disc pack).

L_1 = distance from the center of gravity of W_1 to the centerline of the bearing.

L_2 = distance between centerline of flex element and centerline of the bearing.

Figure 5-30 illustrates how the overhung moment can be reduced by moving the flex elements closer to the bearings of the connected machines and increasing the distance between the flex planes.

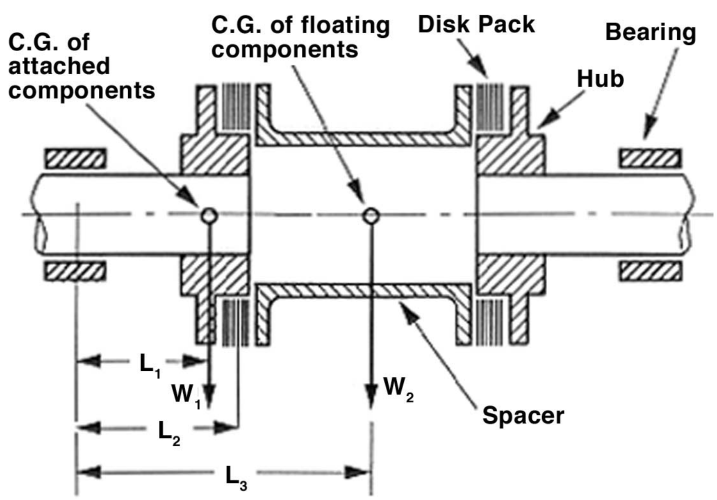


Figure 5-30
Reduced-Moment Coupling with Discs Over Hub
Courtesy Flexible Couplings

Figure 5-31 is a newer design of reduced-moment coupling that moves the flex planes to the extreme ends of the shaft hubs to further reduce the occurrence of overhung moments.

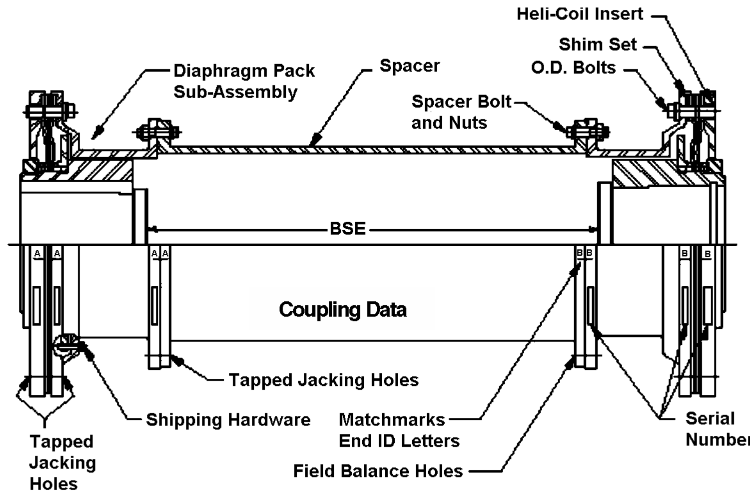


Figure 5-31
New Style Reduced-Moment Coupling
Courtesy Ameriflex

5.5.3 Restoring Forces and Moments

Because all couplings resist being misaligned while in the running condition, misaligned shafts will cause a coupling to impose forces and moments on those shafts.

Figure 5-32 illustrates how restoring forces can have an impact on the adjoining machines. In the case illustrated, the coupling places a vertical upward force on the gear box rotor while trying to place a vertical downward force on the motor rotor. As with the example of pumps and electric motors or steam turbine drivers, the weight of the rotor is consequential: the heavy rotor will usually dictate movement of the lighter rotor. Since the lighter rotor and the coupling restoring forces cannot overcome the weight of force of the larger rotor, the reverse happens. The forces from the coupling and the larger rotor actually impose the restoring forces on the pump rotor. As in the case below, this tends to force the rotor heavily upon the bearing. A very small amplitude of vibration will be present, but most likely, a high bearing temperature will result.

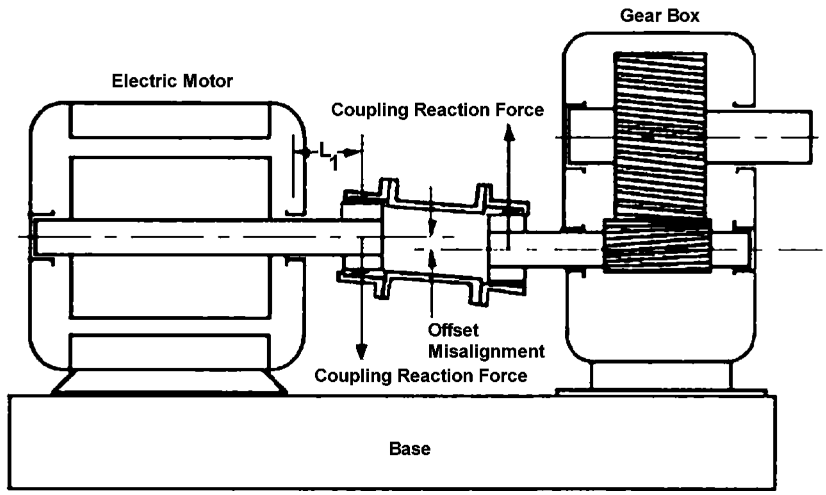


Figure 5-32
Restoring Forces
Courtesy Flexible Couplings

As restoring forces are applied to each shaft, moments are imposed on the respective shafts. Figure 5-33 illustrates that as the shaft rotates, the forces are also applied as moments about the axis of the shafts, with one moment opposite the other. When two planes of misalignment are present (vertical and horizontal), the moments will increase. This puts the two shafts, or at least the one with the smallest diameter, in a bending mode.

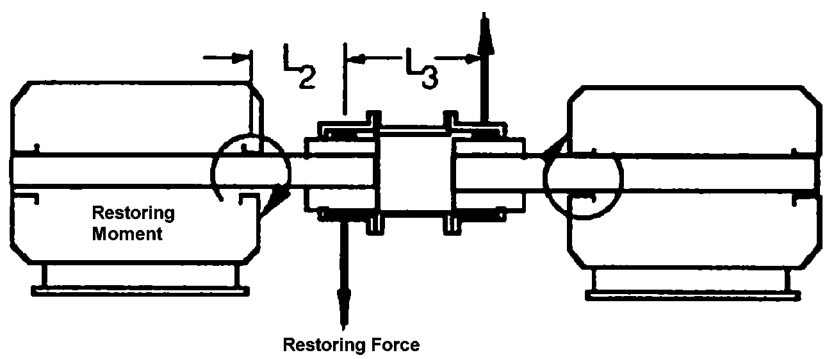


Figure 5-33
Restoring Moments
Courtesy Flexible Couplings

5.5.4 Restoring Forces and Moments in Gear Couplings

The resistance to being misaligned with a gear coupling only occurs while torque is transmitted through the coupling. With a flex element coupling, the resistance is always present.

Gear couplings that operate while they are misaligned have restoring moments that are divided into the following three categories:

- Moments caused by the tilting of the teeth
- Moments caused by the friction between the teeth
- Moments caused by torque transmission between misaligned shafts

Diaphragm and disc couplings have restoring moments and forces due to the resistance of bending of the flex elements. The restoring forces are much smaller in flex element couplings than in gear couplings. Force and moment calculations are quite lengthy and detailed and, as such, are not described in any further detail in this report.

5.6 Installation of Couplings

5.6.1 Installation of Gear and Grid Couplings

When couplings are installed on shafts, a sequence of events should take place to ensure that the couplings are installed properly.

For close-coupled applications, either one of the machines must be moved to make room for installation, or the rotor must be removed to facilitate installation. If the rotor is removed, an opportunity arises to install one-half of the coupling on the removed rotor. The other half is installed on the machine that is left in place.

With spacer type couplings, this problem is avoided because, typically, there is room to install both halves without removing component parts such as rotors or moving one machine out of the way.

If the coupling that was removed from the shaft(s) is the one that is being reinstalled, the processes of installation are usually streamlined as follows by ensuring that:

- Coupling halves are installed in the correct position on the shaft
- Shaft separation is correct
- Gaskets are in good condition and in place
- Bolts are torqued properly
- Shaft alignment is performed to align the two machines within specifications for the normal operating conditions (which accounts for factors such as pipe strain and temperature changes)

If a new coupling is being installed, the installation should also ensure the following:

- The coupling hub(s) are bored to the proper dimension without runout.
- The keyway is broached properly, is on centerline, and is not skewed off centerline in one direction.
- The keyway depth is correct to ensure that the hub will travel across the key during installation, and the key size (height and width) is correct.
- If the coupling is heated for installation to facilitate an interference fit, the hub will stand off the shaft at the key location after cooling. Figure 5-34 illustrates how this can create eccentricity and imbalance in the couplings and also create stresses in the coupling (which may cause it to fail).

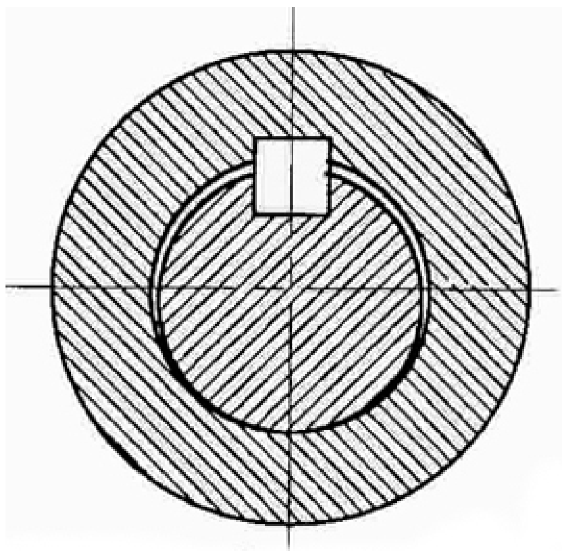


Figure 5-34
Coupling Standoff Creating Eccentricity and Imbalance
Courtesy Flexible Couplings

Key Technical Point
The hub will stand off the shaft at the key location after cooling if the coupling is heated for installation to facilitate an interference fit.

- The shaft-to-shaft (hub-to-hub) dimension is correct after installation.
- The coupling is lubricated if grease is used while the coupling is apart.
- Manufacturer's specifications are followed closely when greasing a coupling.
- After the coupling is bolted together, shaft alignment is performed to align the two machines within specifications for the normal operating conditions (which accounts for factors such as pipe strain and temperature changes).

5.6.2 Installation of Disc and Diaphragm Couplings

The installation process described for gear coupling hubs typically applies to disc or non-lubricated coupling hubs. The difference is that disc and diaphragm couplings are more restricted in the amount of axial movement they can accommodate. For this reason the shaft-to-shaft spacing is critical (see Section 4.5 for a discussion of disc coupling failures). The discs or diaphragm must be in a neutral position when shafts are in the running position. The spring rate (stiffness) of a disc or diaphragm coupling dictates how much deviation from neutral the disc or diaphragm can tolerate as a result of shaft separation.

5.7 Balancing of Couplings

Users are often unsure about coupling imbalance, whether there is a need to balance the coupling, or if the coupling is already balanced. The American Gear Manufacturers Association publishes data concerning coupling balance. Unless special-ordered, the couplings in service most likely have not been dynamically balanced, because most couplings in use in power plant applications fall into the general-purpose category.

Imbalance can be defined as a force caused by eccentricity or weight. Residual imbalance is the remaining imbalance of a rotor or part, which is below the required imbalance or criteria specified in accordance with industry standards.

Couplings, unlike shafts, must have mandrels or arbors inserted to achieve balancing. Methods of balancing couplings are component balancing and complete dynamic balancing of the entire coupling.

As noted above, the majority of couplings in a generating station are not balanced. However, the individual hubs are normally balanced with the rotor of a machine. In most instances, this is acceptable for an unbalanced coupling. If balancing is specified for a coupling, either by the end user or the equipment supplier, then the coupling can be component-balanced or dynamically balanced depending on what is necessary as determined by the coupling and equipment manufacturers.

Key Technical Point

The majority of couplings in a generating station are not balanced.

A typical coupling is balanced as follows:

1. Balance each hub separately.
2. Balance the sleeve separately.
3. Balance the hardware (bolts, nuts, and washers) by weight balance.
4. Balance as an assembly with corrections made to the sleeves.
5. Match-mark parts before removing them from the balancing mandrel.

(**Note:** When balancing a gear coupling as a unit, take extra care to ensure that the tooth clearance is correct. If a shrink fit is being utilized in the coupling design, then the test stand may require a shrink fit as well to expand the hub to obtain proper tooth tip clearance.)

Imbalance is usually expressed in terms of weight times distance (for example, ounce-inches or gram-inches). If an imbalance weight of 1 ounce exerted at a radius of 4 inches (10.2 cm) on the coupling, then the total imbalance would be 4 ounce-inches. This can also be mathematically changed into some convenient measuring form for the balancing machine. The centrifugal force of the imbalance may be specified in g-force or in micro inches of eccentricity by AGMA.

The primary goal is to reduce the centrifugal forces generated at a given speed. The force can be calculated as follows:

$$F = 1.77 \times \frac{\text{rpm}^2}{1000} \times (\text{oz.-in.}) = \text{lbs.}$$

Example:

2 ounce-inch of imbalance at 2000 rpm and 4000 rpm

F @ 2000 rpm = 14.1 lb. (6.34 kg)

F @ 4000 rpm = 56.6 lb. (25.5 kg)

Therefore, if the speed doubles, the same amount of unbalance produces four times the force.

6
PREDICTIVE MAINTENANCE OF COUPLINGS

Predictive maintenance should be the primary method of monitoring coupling performance or degradation while the plant is on-line. Preventive maintenance measures can only be taken when the unit is off-line. Coupling preventive maintenance inspections should be scheduled even if the adjoining machines are not scheduled for corrective or preventive maintenance.

6.1 Conditions to Be Monitored

6.1.1 Vibration Monitoring

The type of vibration data that is collected depends on the type of machine that is being monitored. If the machine has rolling element bearings, such as ball, roller, or spherical roller bearings, then all techniques are not available, since all of the data taken will be on the casing or housings. For coupling problems, a spectrum or, possibly, a time waveform is usually all that is available.

Problems with the coupling most likely have a root cause somewhere else in the machine. This could be due to misalignment or to preloads that are caused by piping strain. With rolling element bearings, the problems may be displayed at 1X running speed. This could be due to the rotor of the machine behaving as an imbalance or misalignment. If a high 2X is predominant, the problem could be due to pipe strain, misalignment, or uneven stiffness in the bearing housing.

When machines have journal bearings (for example, sleeve, cylindrical, journal, elliptical, and tilt pad), more options are available for diagnosing the problem. One of the best methods available is evaluating shaft orbits, if the machine is equipped with X and Y eddy current probes.

Figure 6-1 illustrates a series of shaft orbits, proceeding from left to right in increasing preloads on the bearings. The first orbit essentially has gravitational preload from the weight of the rotor. The size of the orbit in amplitude or mils is based on the residual imbalance in the rotor. The residual imbalance does not change, but the orbit gets flatter with preload until it progresses into a “banana” shaft or a “figure 8.” Once in this state, the probes and monitor reveal that this is a 2X vibration.

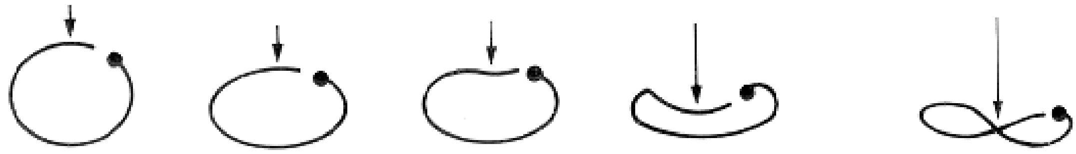


Figure 6-1
Shaft Orbits
Courtesy Bently-Nevada

Preloads can be either internal or external. Hydraulic forces and rubs internal to the machine are examples of internal preloads. Shaft misalignment, coupling overhung moments, and excessive piping strain are a result of external preloads. A gear coupling operating in lock-up is another example of an external preload.

6.2 Methods of Monitoring: Predictive Maintenance Recommendations

Power stations typically employ some form of predictive maintenance programs that consist of vibration analysis, oil analysis, and infrared thermography. For machines with gear or grid couplings, the oil or lube analysis may apply. This can provide an indication that further work must be performed on the adjoining machines.

Inspection of couplings should be performed in accordance with both the scheduled predictive maintenance rounds for the given type of rotating equipment and the equipment manufacturer's recommendations.

Vibration analysis and infrared thermography are useful in isolating machine problems that are occurring at the coupling. Since vibration analysis is not performed on the coupling itself, the coupling problems must be identified through the vibration of the machines. Heat is a result of misalignment, axial movement, or torsion. In this case, infrared thermography should be used to measure the heat of the coupling. For this to be possible, the coupling guard must be of a mesh type or, if solidly constructed, have an inspection port or window in the guard.

Figures 6-2 and 6-3 illustrate two types of coupling guards with inspection ports to assist visual (stroboscopic or infrared) inspections. Figure 6.1 is a typical OEM-supplied coupling guard modified with a hinged door. Figure 6-2 is an aftermarket OSHA-approved fiberglass guard fitted with PVC plugs that facilitate removal and inspection. The fiberglass model can be modified or ordered with the plugs in either the top or the side.

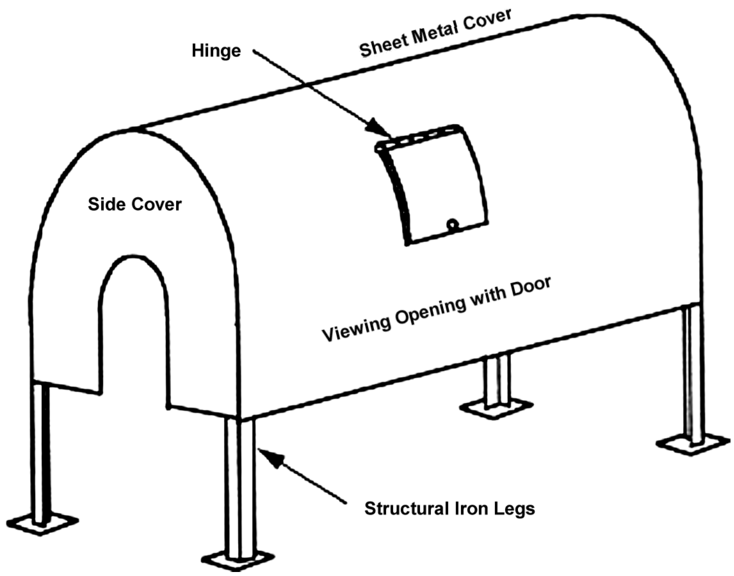


Figure 6-2
Coupling Cover Modified with Inspection Door
Courtesy Flexible Couplings

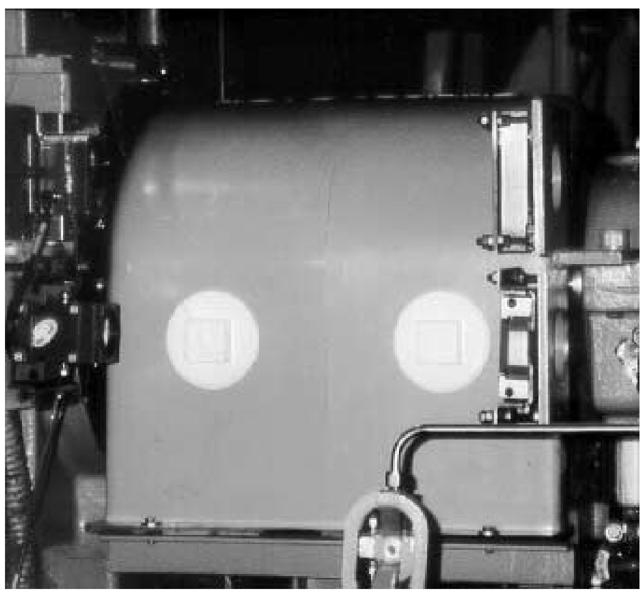


Figure 6-3
Aftermarket Fiberglass Coupling Cover with Inspection Ports
Courtesy Rota-Tech Inc.

7
PREVENTIVE MAINTENANCE RECOMMENDATIONS

Key Human Performance Point

Ensure that equipment is tagged out or locked out before maintenance is performed.

7.1 Lubricated Couplings (Grid and Gear Types)

The following activities are recommended as general preventive maintenance measures to identify premature failure or accelerated degradation:

- Visually inspect for wear, corrosion, cracking, or leakage of lubricant.
- Verify that the proper lubricant is being used.
- Perform stroboscopic inspection while operating equipment.
- Disassemble, clean, and replace lubricant.
- After greasing, ensure that the coupling is not bound.
- Perform infrared thermography.
- Perform a precision shaft alignment after each lubrication.
- Inspect gaskets and O-rings for elasticity.

A number of manufacturers specify preventive maintenance and lubrication schedules based on six months of operation. Due to the long fuel cycles in most plants, this is not always feasible. The coupling manufacturer should be consulted concerning the recommended length of operation without lubrication inspections. At a minimum, lubricated couplings should be inspected at each refueling outage.

7.2 Metallic Element Non-Lubricated Couplings (Elastomeric, Disc, and Diaphragm)

The following activities are recommended as general preventive maintenance measures to identify premature failure or accelerated degradation:

- Visually inspect for wear, corrosion, or cracking while the machine is idle.
- Disassemble, clean, and replace flex element as required.
- Perform a precision shaft alignment after each coupling inspection.

At a minimum, non-lubricated couplings should be inspected each time that the machine is scheduled for routine refurbishment or inspection (or every three years, whichever occurs first).

Sections 4 and 5 provide details on what to look for during inspections of the couplings.

8
TROUBLESHOOTING

8.1 Variance from Design Parameters

The first step when troubleshooting a failure of a flexible shaft coupling is to determine whether there is any variance from design parameters. Specifically, the licensee should determine if the coupling was used in an application suitable for its design and whether it was exposed to different design parameters (for example, torque, rotational velocity, etc.) or ambient conditions than those specified by the manufacturer.

8.2 Detailed Troubleshooting Guidance

The troubleshooting of flexible shaft couplings is somewhat unique in that, unlike the machines to which they are attached, the machine most often must be shut down to make an in-depth analysis and troubleshoot the problem in detail.

To troubleshoot couplings, problems with the adjoining machines should be addressed first. Typically, the coupling is not the first component in the system to be investigated. In fact, although it should be part of the overall analysis, it may be one of the last components to be evaluated when the system is not performing as designed.

The next step is to determine if there have been any modifications (planned or inadvertent) to the rotational system. Tables 8-1, 8-2, and 8-3 provide troubleshooting guidance based on the type of coupling and each type's inherent design characteristics.

8.2.1 Configuration of Rotational System

Table 8-1 provides a number of typical symptoms of premature wear, and their causes, that can lead to degraded performance of mechanical (gear and grid) couplings.

Table 8-1
Detailed Troubleshooting Guidance for Flexible Mechanical (Gear and Grid) Couplings

Symptom	Possible Causes of Problem	Recommended Actions
Torsional or speed differentials across the coupling	Broken teeth	Visually inspect the coupling. Replace the coupling if required.
	Sheared key	Remove the coupling hubs and replace the key. Inspect shaft and coupling for damage. Replace coupling if damaged.
	Broken bolts	Determine cause; replace bolts and/or coupling as required.
Excessive vibration measured at either of the machines	Excessive shaft misalignment	Perform hot alignment (see Note). Implement alignment changes while at shutdown.
	Pump or motor imbalance	Check balance of the motor or the pump.
	Imbalance of the coupling	Monitor for imbalance location. Attempt to dynamically balance the coupling if it is found to be the problem. Check for dynamic balance spanning across the adjoining machines.
Noise	Lack of lubrication	Visually inspect surfaces of adjoining equipment for signs of lubricant. Add lubricant, if needed, at shutdown.
	Improper enclosure	Redesign configuration of the enclosure to reduce windage, or install replacement.
	Loose coupling fit on a shaft	Visually inspect coupling with a strobe light to identify slippage or movement. Inspect shaft and coupling at shutdown. Replace with coupling of proper fit or repair, as necessary.
	Broken teeth	Visually inspect the coupling. Replace the coupling at shutdown.
	Excessive shaft misalignment	Perform hot alignment. Implement alignment changes while at shutdown.

Table 8-1 (Cont.)
Detailed Troubleshooting Guidance for Flexible Mechanical (Gear and Grid) Couplings

Symptom	Possible Causes of Problem	Recommended Actions
Noise (Cont.)	Imbalance of the coupling	Visually inspect with a strobe light to identify if bolts or parts are missing to cause the imbalance. Monitor for imbalance location. Attempt to dynamically balance the coupling, if possible. Check for dynamic balance spanning across the adjoining machines.
Overheating	Excessive misalignment	Perform hot alignment. Implement alignment changes while at shutdown.
	Lack of lubrication	Visually inspect surfaces of adjoining equipment for signs of lubricant. Add lubricant, if needed, at shutdown.
	Improper enclosure	Redesign configuration of the enclosure.
	Tooth wear	Visually inspect the coupling. Replace the coupling.
Leakage of lubricant	Excessive misalignment	Perform hot alignment. Implement alignment changes while at shutdown. Add lubricant.
	Failed gaskets	Inspect gaskets and replace as needed. Replace lubricant. Torque bolts to design parameters.
	Over/excessive lubrication	Check for overheating of the coupling due to inability to transfer heat. Visually inspect surfaces of adjoining equipment for signs of lubricant. Add lubricant if needed.
	Improper lubricant	Analyze suitability of the lubricant that is installed. Replace if lubricant is unsuitable.

Note: To perform a hot alignment, take an alignment while the machine is running at normal conditions. Next, obtain data when the equipment has cooled to near-ambient temperature. Finally, compare the data to determine how the equipment is changing, which is causing the misalignment.

Table 8-2 provides a number of typical symptoms of premature wear, and their causes, that can lead to degraded performance of metallic (disc and diaphragm) couplings.

Table 8-2
Detailed Troubleshooting Guidance for Flexible Metallic (Disc and Diaphragm) and Elastomeric Couplings

Symptom	Possible Causes of Problem	Recommended Actions
Torsional or speed differentials across the coupling	Sheared key	Remove the coupling hubs and replace the key. Replace coupling if damaged.
	Fractured diaphragm or disc	Remove the coupling hubs and replace the disc. Install new diaphragm coupling.
	Shear of elastomeric elements	Separate the hubs and install a new element.
	Broken bolts	Determine cause; replace bolts and/or coupling as required.
	Excessive shaft misalignment	Perform hot alignment. Implement alignment changes while at shutdown.
Excessive vibration measured at either of the machines	Excessive shaft misalignment	Perform hot alignment. Implement alignment changes while at shutdown.
	Pump or motor imbalance	Check balance of the motor or the pump.
	Imbalance of the coupling	Visually inspect with a strobe light to identify any missing or broken parts that could cause the imbalance. Attempt to dynamically balance the coupling, if possible. Check for dynamic balance spanning across the adjoining machines.
Noise	Broken diaphragm or disc	Remove the coupling and replace the diaphragm or disc pack. Replace the diaphragm coupling.
	Broken elastomeric element	Separate the hubs and install a new element.
	Improper enclosure	Redesign configuration of the enclosure.
	Loose coupling fit on a shaft	Visually inspect with a strobe light to identify looseness. Inspect shaft for damage. Replace the coupling with correct item.
	Excessive shaft misalignment	Perform hot alignment. Implement alignment changes while at shutdown.

Table 8-2 (cont.)
Detailed Troubleshooting Guidance for Flexible Metallic (Disc and Diaphragm) and Elastomeric Couplings

Symptom	Possible Causes of Problem	Recommended Actions
Noise (cont.)	Imbalance of the coupling	Visually inspect with a strobe light to identify any missing or broken parts that could cause the imbalance. Attempt to dynamically balance the coupling, if possible. Check for dynamic balance spanning across the adjoining machines.
Overheating	Excessive misalignment	Perform hot alignment. Implement alignment changes while at shutdown.
	Improper enclosure	Redesign configuration of the enclosure.
	Fretting or fatigue of the flex elements (metallic disc or elastomers, for example)	Remove the coupling hubs and replace the disc pack or elastomeric flex element.

8.2.2 Material Incompatibility and Misapplication

Table 8-3 illustrates various failure mechanisms and metallurgical-type problems that are common to flexible shaft couplings. The table should assist in troubleshooting the cause of metallurgical failure and offers proposed solutions.

Table 8-3
Common Metallurgical Problems and Troubleshooting

Failure Mechanisms	Cause	Frequently Used Solutions
Fatigue failure of coupling elements (for example, disc, teeth, keys, elastomers, or housings)	Lack of lubrication (gear or grid coupling)	Visually inspect surfaces of adjoining equipment for signs of lubricant. Visually inspect lubrication levels. Add lubricant if needed.
	Excessive misalignment	Perform hot alignment. Implement alignment changes while at shutdown. Add lubricant.
Fatigue failure of coupling elements (for example, disc, teeth, keys, elastomers, housings) (cont'd)	Corrosive atmosphere (as a result of moisture, oils, chemicals, or particulates)	Eliminate the source of the corrosive particulates. Inspect and reconfigure the coupling guard or enclosure where corrosive liquid or particulates could enter. Isolate the corrosive liquid or particulates from the coupling.
	Unsuitable material	Analyze the design; consult manufacturer for recommended alternate materials.

8.2.3 Installation Practices

Premature failure of couplings may be a result of improper installation practices. Table 8-4 provides a checklist that may be used to determine possible causes for the failure of the coupling.

Table 8-4
Installation Practices Leading to Flexible Shaft Coupling Failure

Improperly locating the hub onto the shaft
Installing an improperly sized coupling given the established distance between shaft ends
Installing a properly sized coupling between shafts that are not at the prescribed end distance
Attempting to install a coupling without the necessary fit or clearance between the coupling and the shaft
Installing couplings with keys that are too tight
Installing a coupling into a system that exhibits more misalignment than the coupling is designed to accommodate
Improperly setting shaft spacing for motors with sleeve bearings
Failing to use the appropriate lubricant and/or failure to apply the correct amount of lubricant
Over- or under-torquing of bolts to secure the coupling components
Improper machining of the bore (usually performed in the field) immediately prior to installation of the coupling (that is, coupling run-out)

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Zirkelback, Charles, "Couplings–A Users View." 8th Turbomachinery Symposium, Texas A&M University, College Station, TX (1978).

9.3 Manufacturer's Literature

Ameriflex High Performance Coupling Catalog, Ameridrive Couplings

DeLaval Pump Instruction Manual

Falk Steel Flex Coupling Catalog

Flexxor Couplings Catalog, Coupling Corporation of America

Kop-Flex Coupling Catalog, Emerson Power Transmission

Lovejoy Coupling Catalog

Rexnord Coupling Catalog

TB Wood's Coupling Catalog

Westinghouse Steam Drive Turbine Instruction Manual

A
SELECTING AND SPECIFYING COUPLINGS

A.1 Design Considerations when Selecting a Coupling

A.1.1 General Guidance

There is no such thing as “one size fits all” when it comes to flexible shaft couplings. The coupling that is presently installed and that was shipped with the equipment was specified for a reason: to achieve the best possible fit for the equipment under the specified operating conditions. Every detail is scrutinized when making a coupling selection. Listed below are some of the design parameters that should be considered when selecting and specifying a coupling:

- Motor or drive horsepower
- rpm
- Shaft dimensions and keyway information
- Type of driver
- Distance between shaft ends
- Space constraints or diameter limitations
- Shaft fits and tapers
- Retrofit or new installation
- Limited float or axial slide
- Lubricated or non-lubricated

A.1.2 Horsepower and Speed of the Driver

Manufacturers often rate couplings as described in their technical catalogs with “horsepower per 100 rpm.” But because horsepower per 100 rpm is the same as torque, couplings are actually rated by torque in inch-pounds. Torque measured in inch-pounds and rotational speed in rpm uses a constant of 63,025.

Using the equation for horsepower,

$$HP = \frac{T \times rpm}{63{,}025}$$

Where:

HP = horsepower
T = torque in inch-pounds
rpm = speed

Transposing the formula and dividing both sides by 100 yields torque in inch-pounds:

$$\frac{HP}{rpm/100} = \frac{T}{630} \quad \text{Therefore, } T = \frac{HP \times 630}{rpm/100}$$

As an example, a pump will require a 500 HP motor. The motor and pump operate at 1800 rpm. What is the necessary torque in inch-pounds, and what is the rating in HP/100 rpm?

$$T = \frac{500 \times 63{,}025}{1800} = 17{,}507 \text{ inch-pounds}$$

The coupling rating is $\frac{HP}{rpm/100} = \frac{500}{\frac{1800}{100}} = \frac{500}{18} = 27.8$ HP/100 rpm

With this information, personnel can refer to the coupling manufacturer's catalog and determine what size coupling is required for this application. Keep in mind that this is for rating only, and sizes may have to be "stepped up" in order to accommodate the particular sizes of the shaft and keyways necessary for this application.

Table A-1, an excerpt from the manufacturer's catalog, demonstrates how the correct coupling can be determined. Assume that the motor shaft is 2.5 inches in diameter, and the pump shaft is 2 inches in diameter.

Table A-1
Coupling Rating Data
Courtesy Kop-Flex

Selection Data

Size	Max. Bore (in.)	Coupling Rating (HP/100 rpm)	Torque Rating		Maximum Speed Not Balanced (rpm)	Maximum Speed Balanced (rpm)	Total Weight (lbs)	Total WR^2 (lb-in.^{2})	Axial Capacity (in.)
			Continuous (in.-lb)	Peak (in.-lb)					
103	1.50	6.3	4000	8000	5400	9700	6.9	16	±0.080
153	2.12	21.6	13600	27200	4500	7500	17.5	73	±0.140
204	2.62	57.1	36000	72000	4100	6700	27.2	148	±0.110
254	3.25	82.5	52000	104000	3600	5600	47.2	400	±0.140
304	3.75	141	89000	178000	3200	5100	78.0	916	±0.170
354	4.25	238	145000	290000	2900	4400	134	2140	±0.200
404	4.75	340	215000	430000	2600	4000	193	3850	±0.225
454	5.50	405	255000	510000	2400	3800	229	5540	±0.250
504	5.75	570	360000	720000	2200	3500	316	8640	±0.275
554	6.25	800	505000	1010000	1900	3000	404	13100	±0.300
604	6.75	1050	660000	1320000	1850	2900	559	22200	±0.320
705	8.50	2400	1510000	3020000	1800	2800	925	56400	±0.270
805	9.50	3670	2100000	4200000	1600	2500	1340	102000	±0.310
905	11.50	4130	2300000	4600000	1500	2300	1700	163000	±0.400

In the data field above, the model number 204 is acceptable to use. Note that this example is a disc type coupling selection sheet for a close-coupled application.

A.1.3 Service Factors

Service factors are used to account for the higher operating torque conditions of the equipment to which the coupling is connected. In API 671, a service (or experience) factor is applied to the normal operating torque of, for instance, a turbine or compressor. This factor accounts for torque loads that are not normal but that may be encountered continuously. Also, service factors are sometimes used to account for the actual operating conditions, which may be 5–20% above the equipment rating.

Different service factors are used or recommended depending on the severity of the application. API 671 defaults to a 1.75 service factor that is to be applied to the normal operating torque. API cautions that if reasonable attempts to achieve the specified service factor fail to result in a coupling weight and subsequent overhung moment commensurate with the requirements for rotor-dynamics of the connected machines, then a lower factor may be selected upon the mutual agreement of the purchaser and the supplier. The selected value is typically not less than 1.25.

Service factors assist the user in selecting the appropriate coupling and ensuring that it is specified correctly. Service factors are based on torque, whether constant or cyclical. Constant speed machines such as electric motor drivers may have a different service factor than a turbine or engine driver.

Torque is more cyclical on a plunger-type positive-displacement pump than on a centrifugal pump or fan. Starting and stopping of machines also must be taken into account in the selection of coupling.

Electric motors accelerate rapidly and apply torque through the coupling to the driven machine more rapidly than a turbine-driven application. Accordingly, a reversal in torque occurs upon deceleration on shutdown.

The power consumed, and not the power available, should be used in determining the appropriate service factor.

For example, assume a 38 HP motor driving a pump, at 1800 rpm, with a recommended service factor of 2. Using the above concepts, we would consider an actual power consumption of:

HP = 38 x 2 = 76 HP

Using the following formula, we can see that the appropriate coupling size from Table A-1 is 103, since the smallest coupling rating is 6.3:

$$\text{or } \text{HP/100 rpm} = 38 \times \frac{2}{18} = 4.2 \text{ HP/100 rpm}$$

Table A-1 also depicts how a service factor can be derived, because the smallest coupling available (size 103) is rated at 6.3 HP/100 rpm. The required service factor of 2 results in a coupling rating of 4.2 HP/100 rpm. Dividing the 6.3 coupling rating from the table by 4.2 results in an additional service factor of approximately 1.5 for a total of 3.5 (2 + 1.5).

However, consideration should be given to the total weight of the coupling. In this case, the coupling manufacturer and the machine manufacturer should be consulted prior to a final decision on the coupling.

A.2 Advantages and Disadvantages of Various Styles of Couplings

Coupling selection is best made by evaluating the characteristics of the various types of couplings and the size of the machines that they couple.

Low-horsepower machines are characterized as being less than 100 HP.
Medium-horsepower machines are between 100–1000 HP.
High-horsepower machines are over 1000 HP.

The high-horsepower machines are typically most critical to plant operations, with only a few exceptions. There are a number of medium-horsepower machines in safety applications whose failure could lead to a plant shutdown. However, it is the high-horsepower machines that are most critical to generation capacity.

Table A-2 evaluates couplings based on horsepower and type of coupling.

Table A-2
Coupling Selection
Courtesy Kop-Flex

Coupling Type	Type of Machine (by HP)	Axial Forces	Torque Capacity to Outside Diameter (OD) of the Coupling	High Speed Capacity	Inherent Balance	Flexible Elements Easily Replaced	Torsional Stiffness	Backlash
Mechanical Element Type								
Gear Type								
Straight Tooth	M-H (see Legend)	M-H	H	H	G	N	H	Y
Crowned Tooth	M-H	M-H	H	H	G	N	H	Y
Grid Type	L-M	M	M	M	G	Y	L-M	Y
Elastomeric Type								
Compression Donut	L-M	L-M	L-M	M	G	Y	L	N
Jaw	L-M	M	M	M	G	Y	L-M	L
Gear Type								
Urethane Tire	L	L	L	L	F	Y	L	N
Shear Type	L	L	L	L	F	Y	L	N
Metallic Element Type								
Disc	M-H	L-M	M-H	H	E	Y	M	N
Diaphragm								
Tapered	H	M	H	H	E	?	H	N
Multiple	H	M	H	H	E	?	H	N

Legend: L = Low HP, M = Medium HP, H = High HP; E = Excellent, G = Good, F = Fair, P = Poor; Y = Yes, N = No

B
LISTING OF KEY INFORMATION

Key O&M Cost Point

Emphasizes information that will reduce purchase, operating, or maintenance costs.

Referenced Section	Page Number	Key Point
2.2.2.2	2-9	Grid couplings do not transmit as much power but are generally less costly than gear couplings.
2.6	2-18	Proper lubrication is important to long coupling life.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Referenced Section	Page Number	Key Point
2.0	2-1	All flexible couplings will resist being misaligned and exhibiting axial displacement. As a result, forces are imparted back onto the coupled equipment.
2.2.3.2	2-12	In a disc coupling, if the misalignment is beyond 1/2 to 3/4 degree during operation, then the flexible element will probably fail in fatigue.
3.2.1	3-3	Over-sizing of synthetic gear couplings can lead to premature failure.
3.5	3-7	Elastomeric flexible shaft couplings are typically not balanced, because they are not suited for high-performance applications.
4.2.1	4-1	Misalignment is a leading contributor to vibration and to structural fatigue failure.
4.2.1	4-2	Fatigue failures occur in gear couplings due to their being operated outside of the designated misalignment parameters.

Referenced Section	Page Number	Key Point
4.2.1	4-2	Disc and diaphragm couplings give no warning of impending failure, whereas a gear coupling will generate noise and vibration prior to failure.
4.3	4-4	Improper maintenance can lead to inadequate coupling performance and/or failure.
4.3	4-4	Installation practices that, if incorrectly performed, could lead to coupling failure are improperly torqued bolts, inadequate tolerances or fits, and/or improper lubrication.
4.4.2	4-6	Extreme misalignment can lead to coupling lock-up and can result in a misinterpretation of machine operating conditions.
4.5	4-9	Shutting a machine down to take hot readings (while it is cooling) is not an appropriate way to perform hot alignment.
5.1	5-2	Proper lubrication and maintenance are important elements of an overall coupling maintenance program.
5.1	5-4	Overfilling with grease in a gear or grid coupling is a very common mistake and should be avoided, because heat can build up in the coupling or cause a hydraulic lock.
5.2.1	5-8	Disc and diaphragm couplings limit end float but are very stiff in the axial direction. It is very important to remember that shaft separation is critical, and the motor is on magnetic center when using this type of coupling.
5.2.1	5-11	The shaft spacing or hub separation is not the same as the limited end float.
5.3.2	5-13	Clearance fits should be limited to 0.002 inch (0.05 mm) maximum. On larger-diameter shafts, heat may be required to expand the hub.
5.3.3.2	5-20	Proper heating of a tapered hub is extremely important.
5.3.5	5-23	Under no circumstances should the taper bore coupling be lapped to the shaft. This will create a step on the shaft over which the coupling hub must pass, leaving a non-contacting area under the coupling hub.
5.4	5-24	Coupling misalignment differs from shaft misalignment. Shaft misalignment is measured in offset and angularity. Coupling misalignment is measured in angle of degrees of misalignment.
5.5	5-30	All types of flexible couplings resist being misaligned. Flexible couplings resist axial movement of connected shafts.
5.6.1	5-36	The hub will stand off the shaft at the key location after cooling if the coupling is heated for installation to facilitate an interference fit.
5.7	5-37	The majority of couplings in a generating station are not balanced.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or to ease completion of the task.

Referenced Section	Page Number	Key Point
2.2.1.1	2-7	Care should be taken when making coupling changes on all machinery but especially high-energy machines such as steam generators or reactor feed pumps. Manufacturers should be consulted prior to making such changes.
5.0	5-1	Placing a worn or damaged coupling back in service leaves personnel open not only for operational problems but machine problems and the potential for catastrophic damage or personal injury.
5.3.3.1	5-14	CAUTION – Care must be taken to prevent contact with the hub, which will cause severe burns. Threaded rod inserted in the puller holes works well to handle heated components during installation. The use of welder’s gloves can prevent burns.
5.3.4	5-22	Ensure that hydraulic equipment is in good working order to preclude the danger of hydraulic hoses under high pressure separating and causing personnel injury.
7.0	7-1	Ensure that equipment is tagged out or locked out before maintenance is performed.

Program:

Nuclear Power

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