Couplings —
A User’s Point of View

Presented at the
8th Turbomachinery
Symposium
November, 1979
Couplings — A User’s Point of View

By Charles Zirkelback, Senior Staff Engineer
Union Carbide Corporation
Port Lavaca, Texas

Abstract
Couplings are one of the critical elements in a turbomachinery system. Malfunctions and failures result in significant outage time that, in most cases, is very costly to the user. This paper will deal with the application of coupling used in turbomachinery in petrochemical plants. A discussion of design selection, installation, operation, maintenance, retrofitting to improved designs, and experiences will be presented.

Introduction
The flexible coupling in a turbomachinery package represents a small percentage of the cost. However, it accounts for a disproportionately large percentage of outage time and machine problems. It is therefore in the user’s best interest to take great care in this critical area where his choices greatly influence the long term reliability of the machinery system. If the important task of coupling selection is left to the machinery manufacturer, it will naturally be a choice that will meet specifications at his lowest cost. This, in many cases, will not produce optimum results from the user’s viewpoint. So many options are presented to the user, making it difficult to choose the best for his application. This paper will develop points to consider in making these choices.

The proposed API 671 has done an excellent job of specifying both gear and diaphragm type couplings and should be used as a guideline once the choice of design type has been made.

Coupling installation has taken on new importance with the diaphragm type. Installing one outside its limitations virtually guarantees failure. Poor installation (alignment) will likely not be detected until failure results, whereas in the gear type poor installation is immediately detectable via vibration.

Replacing problematic gear type couplings with the diaphragm type has contributed to better equipment reliability and reduced maintenance costs.

Why Use a Flexible Coupling?
The coupling serves to connect the shaft between the driver and driven equipment in such a manner that it will transmit the required torque without imposing undue stresses on the shafts and bearings due to inherent misalignment and axial displacement. This can, in some cases, be accomplished without using a flexible coupling, i.e. with a solid shaft. However, it is rare to see this simple but superior technique used, particularly where the driver and driven equipment are produced.
by different manufacturers. Greater care must be taken to
insure proper alignment with the solid shaft coupling, or
bearing damage and shaft breakage may result. Quill shafts
are also a means of obtaining flexibility without the used
of flexible coupling. It should first be determined that a
flexible coupling is required before using one. It seems that
the petrochemical industry has, without due consideration
of solid couplings, committed itself to the almost total
use of flexible couplings, thus introducing unnecessary
complexity.

Coupling Selection

After all the data required for selection has been acquired
(such as maximum rated power, maximum rated speed,
maximum torque, the geometry that the coupling must fit
into, the thermal growths of each machine), the next task is
to determine what type coupling is best for the application.
Overall choices are a solid shaft, gear type coupling, or
a diaphragm type. Until about ten years ago, the gear
type coupling was the standard choice. The advent of the
diaphragm coupling gave the industry new features and
advantages that solve many of the chronic problems that
were characteristic of the gear type coupling.

Advantages of Flexible Diaphragm Over Gear Type Couplings

1. No lubrication required, thus eliminating the need for
regreasing or special oil filtration to reduce sludging.
2. Will tolerate greater parallel and angular misalignment
without the distress wear that results from large
misalignment in a gear type coupling.
3. There are no rubbing or sliding parts to wear. When
applied within the fatigue limitations of the materials,
the diaphragm type coupling will give much longer
life.
4. There are a lot fewer dynamic balance problems since
there are no pilot/tooth clearances that will allow the
spool to crank and create imbalance.
5. There is much less angular movement, which
is predictable since it does not depend on an
indeterminable coefficient of sliding friction. Seven
to ten times less angular moment is produced with a
diaphragm coupling.
6. It lasts as well at maximum rated misalignment and
axial distortion and load as at zero misalignment. In
the gear type, the wear rate depends on the degree
of misalignment, load, speed, and adequacy of
lubrication.
7. Zero backlash: Backlash in a gear type coupling can
amplify tooth loading from torsional vibrations that
may be present.
8. Longer life in radial and thrust bearings due to
predictable and lower moment and thrust loads.
9. High and low temperature capability is not limited to the
lubricant’s temperature limitations.
10. Coupling hub to shaft fit fretting wear is practically eliminated,
due to lower angular movement.
11. Hub, sleeve, and spool cracking is common in gear type
couplings due to large angular moments produced.

Disadvantages of Flexible Diaphragm Couplings

1. Limited axial travel and is less forgiving in shaft separation
error. The axial growths of the machines must be known and the
rotor accurately located axially to insure success.
2. Axial resonance that if, in the range of the operating speeds or
multiples of it, must be dealt with in original design.
3. Failure mode may allow runaway without warning; wear in
gear teeth is progressive and will normally give warning of an
impending runaway.
4. Heat generation due to windage. It does not have the lubricant as
in a continuous lubrication gear type coupling to dissipate heat.
This can be dealt with in design.
5. The gear coupling will be a smaller diameter if designed on the
basis of torque.
Discussion

Instantaneous failure of the diaphragm type coupling permitting machine runaway, is the greatest risk in this design. However, the gear type coupling is not immune to runaway. Gear type coupling runaway can result from loss of gear teeth due to wear which is gradual and normally gives warning. Fatigue cracking of hubs sleeves or spools, which the gear type coupling is more likely to experience, can be instantaneous and with little warning.

Eliminating shaft to hub fit fretting by reducing the angular and axial forces transmitted from one machine to the other will avoid the high cost of recutting or replacing the shaft and coupling hub. This also reduces the need for special hub/shaft fastening such as hydraulic mounting. The flexible diaphragm will reduce the transmitted axial forces. Since this axial force is more predictable in a diaphragm coupling, use of smaller energy saving thrust bearings is allowed.

Comparing Available Diaphragm and Disc Couplings

Considering the above advantages and disadvantages, the requirements of our specific application and a review of the specific data supplied by the coupling manufacturers, the appropriate gear type or diaphragm type coupling can be chosen. There are significantly different designs available in diaphragm and disc type couplings using flexible metal membranes to consider. A choice of the best diaphragm coupling for the application should first be made before comparing to the gear type. There is the single diaphragm type, the single convoluted/wavy profile type, the multiple convoluted diaphragm type, and the bolted flexible disc type. Table 1 and Table 2 show that, unlike gear type couplings which all have similar mechanical characteristics, the diaphragm differs in general mechanical characteristics according to type.

Analysis of Mechanical Data

In connecting the two machines, the coupling can introduce problems that must be dealt with.

1. The torsional stiffness and WR² of the coupling must not produce torsional vibrations; that is, not tune the system to the rotating speeds. Computer programs are employed to avoid this problem. On retrofitting, matching the torsional stiffness and WR² of the old design is sufficient, if a torsional vibration problem is not present in the existing design.

2. The lateral vibration response of the system should be checked out via computer also. The lateral response will depend on the overhung moment and the WR². A judgement can be made on this effect by comparing the critical speeds of the existing deign if retrofitting.

3. The axial stiffness will affect thrust bearing loads, particularly if the axial force from the coupling is a significant portion of the axial load.

4. The bending moment is a good measure of how much radial force one machine transmits to another. Radial bearing wear/distress, vibration, hub/shaft fretting, hub and spool flange cracking, and internal seal rubs can all occur due to high bending moment.

5. The axial natural frequency must not be near one times or lower multiples of running speed. High diaphragm stress and failure can result if a coupling spool resonates.

Installation

Whether a gear, diaphragm, disc or rigid type coupling, it must be installed such that it does not operate outside of its alignment capabilities. To insure this, the thermal and mechanical movement of each machine with relation to each other must be known so that cold condition alignment can be established. The equipment manufacturer’s estimated rise and axial displacement data are first used. On critical installations and problematic machines, it is justified to monitor the movements in the field. It is not uncommon to see actual movements vary 50% from predictions.

It is found that optical alignment equipment, for determining hot rise, and a computer for the shim change calculations work well. The commercially available programmable calculators reduce errors and are real time savers, when compared to plotting (graphing) the alignment data.

The coupling manufacturer should be consulted if there is any doubt or question on the alignment procedure or tolerances for the particular coupling being installed.

For the continuous lubricated gear type, the oil spray must be of adequate volume (correct opening size) and directed to the appropriate point. Observing the oil spray pattern with the cover open or with a borescope is necessary to insure proper lubrication.

Experiences

A compressor, originally using four gear type couplings on two trains, at 12,500 rpm, had coupling gear teeth wear, severe coupling hub and shaft fit fretting, hub breakage, and resulting high vibration. Coupling life was one to two years. Oil sludging was present, and the coupling oil dams were cut out to provide oil flushing. This helped, but sludging persisted. A ½ micron coupling lube oil filter system was installed and sludging was significantly reduced. Concurrently, the machines were optically aligned and the coupling teeth were nitrided, but the problem was only alleviated, not eliminated. Diaphragm couplings were installed and have been running for two trouble-free years.
<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>SINGLE DIAPHRAGM (SD)</th>
<th>SINGLE DIAPHRAGM WAVY PROFILE (SDWP)</th>
<th>MULTIPLE CONVOLUTED DIAPHRAGM (MCD)</th>
<th>BOLTED DISC (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Spring Rate</td>
<td>Nonlinear</td>
<td>Linear</td>
<td>Linear</td>
<td>Nonlinear</td>
</tr>
<tr>
<td>Axial Stiffness</td>
<td>Stiff/Moderate</td>
<td>Moderate</td>
<td>Soft</td>
<td>Soft</td>
</tr>
<tr>
<td>Axial Displacement</td>
<td>Requires 2 diaphragms per end to obtain large displacements</td>
<td>Same as SD</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Angular Misalignment</td>
<td>$\frac{1}{4}^\circ$/diaphragm maximum</td>
<td>$\frac{1}{2}^\circ$/Diaphragm</td>
<td>$\frac{1}{2}^\circ$/Diaphragm pack maximum</td>
<td>$\frac{1}{4}^\circ$/disc pack maximum</td>
</tr>
<tr>
<td>Runaway Potential</td>
<td>Immediate with little warning; may need redundant gear drive for special application</td>
<td>Same as SD</td>
<td>Outer diaphragms fail in bending and produce imbalance before failing torsionally</td>
<td>Will give warning</td>
</tr>
<tr>
<td>Overhung Moment</td>
<td>Low with single diaphragm normally lower than gear type</td>
<td>Same as SD</td>
<td>Moderate</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>Diameter</td>
<td>Large</td>
<td>Large</td>
<td>About 2&quot; less than types SD &amp; SDWP</td>
<td>About same as MCD</td>
</tr>
<tr>
<td>Axial Damping</td>
<td>None</td>
<td>None</td>
<td>Air damping between separated diaphragms. Available with special air damper.</td>
<td>Friction damping from rubbing discs</td>
</tr>
<tr>
<td>Failure Mode</td>
<td>Fatigue of diaphragm in bending mode, if operated outside alignment limitations</td>
<td>Same as SD</td>
<td>Fatigue of outer diaphragm in bending mode, self-healing, less bending stress on remaining diaphragms</td>
<td>Fatigue, can be initiated by fretting and bolt hole stress concentrations. If fails, may destroy adjacent equipment with large asymmetrically radial and axial forces produced by bolt engagement.</td>
</tr>
<tr>
<td>Diaphragm Materials</td>
<td>Coated high strength steel</td>
<td>Same as SD</td>
<td>Variety of noncorrosive materials available</td>
<td>Same as MCD</td>
</tr>
<tr>
<td>Replaceable Diaphragm Element</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Inspection Interval</td>
<td>Same as type SDWP &amp; MCD</td>
<td>Same as SD &amp; MCD</td>
<td>Same as SD &amp; SDWP</td>
<td>Shorter due to disc fretting.</td>
</tr>
<tr>
<td>Safety from Flying Parts</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Pilot Fit Elements</td>
<td>Available/standard</td>
<td>Available</td>
<td>Standard</td>
<td>No</td>
</tr>
<tr>
<td>Lateral Stiffness</td>
<td>Stiff</td>
<td>Moderate</td>
<td>Soft</td>
<td>Stiff</td>
</tr>
<tr>
<td>TYPE</td>
<td>GEAR</td>
<td>MCD</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>---------------</td>
<td>--------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>Required Horsepower (Hp @ rpm)</td>
<td>25,000 hp @ 5,100</td>
<td>Same</td>
<td>Same</td>
<td></td>
</tr>
<tr>
<td>Required Torque (in-lb)</td>
<td>308,824</td>
<td>Same</td>
<td>Same</td>
<td></td>
</tr>
<tr>
<td>Rated Torque Diameter (in-lb)</td>
<td>345,200</td>
<td>308,824</td>
<td>316,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11¾&quot;</td>
<td>14&quot;</td>
<td>16,250&quot;</td>
<td></td>
</tr>
<tr>
<td>Misalignment Capacity</td>
<td>± .044*</td>
<td>± ¼°</td>
<td>± ½°</td>
<td></td>
</tr>
<tr>
<td>Parallel Offset (in)</td>
<td>.084</td>
<td>.248</td>
<td>.322</td>
<td></td>
</tr>
<tr>
<td>Required Axial Capacity (in)</td>
<td>.500</td>
<td>.500</td>
<td>.500</td>
<td></td>
</tr>
<tr>
<td>Axial Capacity (in)</td>
<td>.750</td>
<td>.625&quot;</td>
<td>.570</td>
<td></td>
</tr>
<tr>
<td>No. Of Diaphragms</td>
<td>2 gear elements</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>WR² (lb-in²)</td>
<td>4,160</td>
<td>6,750</td>
<td>3,739</td>
<td></td>
</tr>
<tr>
<td>Torsional Stiffness (in-lb/Rad)</td>
<td>28.7 x 10⁶</td>
<td>13.13 x 10⁶</td>
<td>7.5 x 10⁶</td>
<td></td>
</tr>
<tr>
<td>Total Weight (lb)</td>
<td>370</td>
<td>317</td>
<td>256.3</td>
<td></td>
</tr>
<tr>
<td>Axial Stiffness (lb/in)</td>
<td>NA</td>
<td>6,600</td>
<td>6,842</td>
<td></td>
</tr>
<tr>
<td>Maximum Axial Force (lb)</td>
<td>4,632*</td>
<td>2,062</td>
<td>1,950</td>
<td></td>
</tr>
<tr>
<td>Bending Moment @ Maximum Misalignment (in-lb)</td>
<td>29,490*</td>
<td>1,787</td>
<td>2,600</td>
<td></td>
</tr>
<tr>
<td>Overhung Moment (in-lb)</td>
<td>3,335</td>
<td>3,641</td>
<td>2,597</td>
<td></td>
</tr>
<tr>
<td>Axial Natural Frequency (cpm)</td>
<td>NA</td>
<td>2,500</td>
<td>2,606/3,682</td>
<td></td>
</tr>
</tbody>
</table>

*NOTE: 1. The bolted disc type coupling was not considered because it would not meet the required axial displacement.
2. The maximum axial force and bending moment for the gear type coupling is based on .15 coefficient of friction.
3. Misalignment capacity of gear type coupling based on maximum tooth sliding velocity of 1.3 IPS.
4. The single diaphragm (SD) required two (2) diaphragm elements on one end to meet the required axial displacement. This introduces a greater degree of complexity.

There has been an overall improvement in vibration levels, and inspection has shown a total absence of shaft fretting. Several retrofits from gear to diaphragm couplings have yielded similar results.

A propane compressor driven by a condensing steam turbine, 9,000 H.P. At 6,000 rpm, experienced high vibration on the shaft monitoring system. An orderly shutdown was in progress when the gear coupling failed, throwing its spool into and rupturing a propane line. A fire ensued. The compressor bearing housing was damaged and the turbine shaft was bent 5/8”. This failure points out that gear type couplings do give warning of impending failure, but the warning may be of short duration.

A horizontal water pump and motor was extensively damaged when the disc-pack on the motor side failed. The coupling spool moved off center and the motor side failed. The coupling spool moved off center and the unbalanced weight broke the bearing housing from the pump and bent the pump shaft. The motor shaft was driven against the outside end bell damaging the motor.

There is no means to restrain the spool once a disc-pack fails in this design. Failure has been catastrophic in several instances. The hazard to property and persons from catastrophic coupling failure must be avoided.

Summary
1. The effort spent in design selection and application will be rewarded with increased reliability and plant safety.
2. The coupling must fit the dynamic and geometry characteristics of the machinery.
3. The flexible diaphragm couplings are proving to eliminate many of the problems of the gear type coupling.
4. Retrofitting from problematic gear to diaphragm couplings is a profitable business.
5. Proper installation of diaphragm type couplings is required to prevent failure, since it will not warn of poor installation via vibration such as the gear coupling does.
References

About Altra Industrial Motion

Altra Industrial Motion (NASDAQ:AIMC) is a leading multi-national designer, producer and marketer of a wide range of electromechanical power transmission products. The company brings together strong brands covering over 40 product lines with production facilities in nine countries.

Altra’s leading brands include Boston Gear, Warner Electric, TB Wood’s, Formsprag Clutch, Wichita Clutch, Industrial Clutch, Ameridrives Couplings, Kilian Manufacturing, Marland Clutch, Nuttall Gear, Bauer Gear Motor, Stieber Clutch, Twiflex Limited, Bibby Turboflex, Matrix International, Inertia Dynamics, Huco Dynatork, Lamiflex Couplings, Ameridrives Power Transmission, Delroyd Worm Gear and Warner Linear. For information on any of these technology leaders, visit www.AltraMotion.com or call 815-389-3771.