



Coupling Corporation of America

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Discusses Coupling Failures

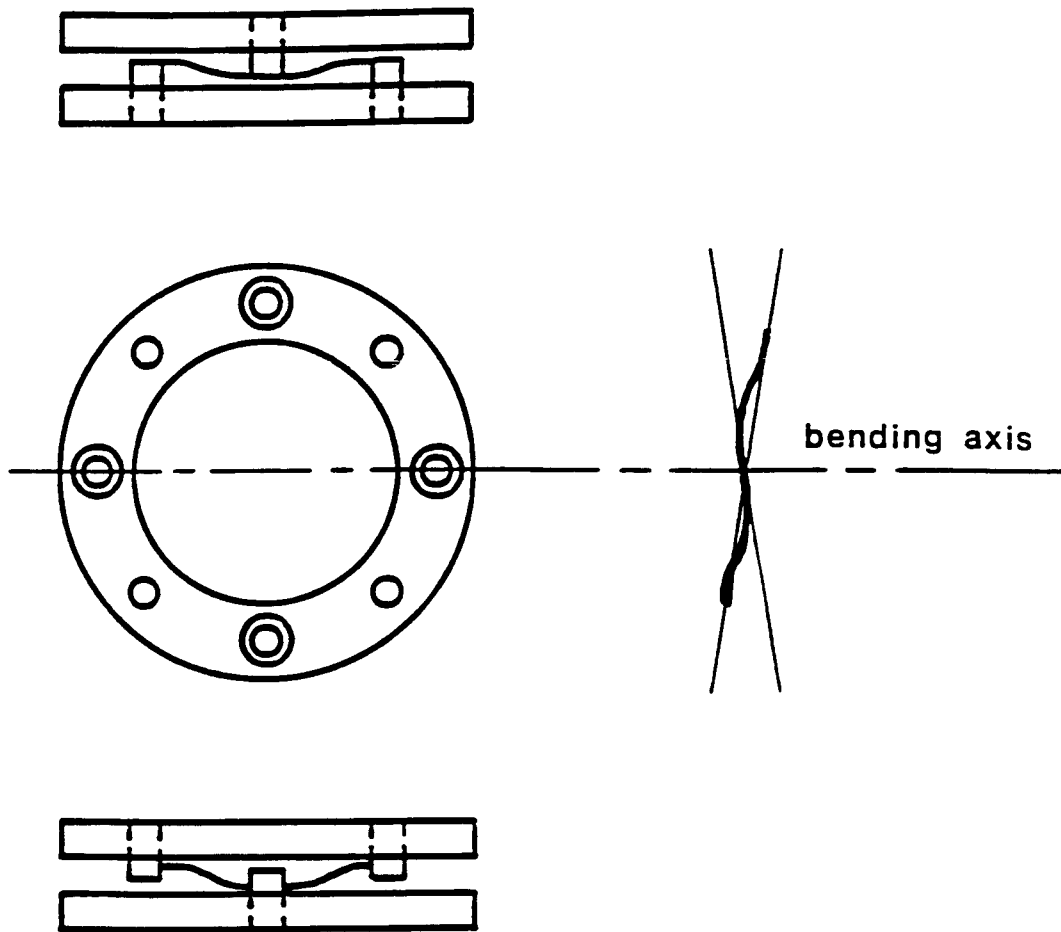
We normally like to think that flexible couplings do not fail in service, and we at Coupling Corporation are very proud of the fact that we can say that FLEXXORs do not fail in normal service. The reason they don't fail is that there is no frictional rubbing to cause wear, there is ample allowance for more than the usual misalignment, and the stress limits never reach the fatigue limit of the parts in normal service. Gear tooth couplings or spline couplings need to have frictional movement between the parts under high load during normal allowable misalignment, and therefore do wear out.

Not only do they wear out, but they also transmit high forces from one shaft to the other, because any movement due to misalignment must overcome the high frictional force caused by the load on the teeth.

Flexible disk or ring pack couplings transmit force from one flange to another by tension in the rings from the bolts in one flange, to the bolts in the opposing flange. Usually there are four bolts in each flange, so that there are then four sets of tension strips transmitting the torque from one flange to the other. This is illustrated in the diagram on the following page.

The diagrams also show the shape that the rings must take in the misaligned condition. The upper diagram shows the shape of the rings when the flanges are moved axially with respect to each other, or when they are misaligned in bending along an axial plane about the bending axis. The lower diagram shows the shape as a mirror image of that in the upper diagram. This would be the case for bending misalignment, or offset misalignment between two connected shafts.

The diagram at the right shows a radial view of the shape of the rings as they pass through the bending axis. Note that the bent shape of the rings is such that the bent shape is longer in the upper and lower diagram than in the diagram at the bending axis. This means that the ring must stretch a little more each time it reaches the maximum deflection, and there is more load transmitted at the maximum deflection position than at the bending line position. It also means that there is a variation in torque that occurs four times in each revolution. This torque pulsation that is typical of this type of coupling can cause vibrational stresses and failures in high speed machinery, if the torque pulsations happen to be in tune with the natural frequency of a highly stressed part. I know of one case where this caused fatigue failure of compressor impeller blades.



The rings must pass through a complete cycle and completely reverse their shape twice during each revolution when misaligned in bending. This means that they must slide over each other while rotating. The disks are tightly clamped together by the bolts, and this then creates high friction between the rings. The sliding generates heat. The outer rings are cooled by the atmosphere, but the rings in the middle of the stack are not so cooled. Therefore, the inner rings become hotter, and expand slightly more than the outer rings. As a result, the outer rings take more than their share of the load, and are more likely to fail. The sliding under high stress also produces wear and contributes to failure of the rings.

When the rings eventually fail they are likely to fail between two adjacent bolts. This then eventually causes the bolts to strike each other and cause a high impact load that is likely to bend or break the shaft.

In contrast to the foregoing action of a ring pack coupling, the FLEXXOR transmits torque through struts from the inner hub to an outer ring, or vice versa. Usually there are 24 struts in each of the four flexible disks. This means that there are 96 struts transmitting the torque and the torque is constant throughout the rotation.

The disks are separated from each other so that there is no sliding and no generation of heat. The clamped inner and outer circles are located at low stress areas, so that misalignment produces very little stress increase in the struts where maximum tensile stresses due to torque transmission occurs. The lengths of the torque transmitting struts are longer than the length of the span between bolts on a ring pack coupling for a given torque rating, and this reduces the bending stress due to misalignment.

One of the fundamental differences between a FLEXXOR and a ring pack coupling is that in the FLEXXOR the misalignment stresses are small compared to the torque stresses, whereas in the ring pack coupling the misalignment stresses are very high compared to the torque stresses.

The following calculations made for a typical ring pack coupling, illustrates this point.

Coupling torque rating	17,000	lb.-in.
Coupling speed	7,613	RPM
Bolt circle diameter	4.75	in.
Ring outside diameter	5 23/32	in.
Ring inside diameter	3 25/32	in.
Ring thickness	0.012	in.
Number of rings	24	
Allowable axial misalignment per ring pack	± 0.0275 in.	
Allowable angular misalignment	0.25°	

The stresses in the rings are the sum of the following stresses:

- Tension stresses due to torque.
- Tension stresses due to centrifugal force.
- Tension stresses due to elongation under misalignment conditions.
- Bending stresses due to misalignment.

In this particular sample the calculated stresses are as follows:

- Tensile stress due to torque = 6412 psi.
- Centrifugal stress at ring bore = 3425 psi.
- Tensile stress due to stretching at max. deflection = 10,883 psi.
- Bending stress at edge of clamp washer at max. deflection = 23,761 psi.
- Total tensile stress = 44,481 psi.

The foregoing stresses were calculated on the assumption that the tension and bending acted on a straight beam. In actuality the stresses would be a little higher, because the beam is curved in a circular arc.

The important point to recognize is that the deflection stresses are much larger than the torque stresses.

In FLEXXORs the opposite is true. The deflection stresses are quite low compared to the torque carrying stresses. In the ring pack coupling both the torque stresses and the deflection stresses are variable throughout each revolution. In the FLEXXOR only the strut bending stresses are variable. They are generally small, because the overall design deflection tolerance is higher for FLEXXORs than for other couplings.

Some flexible disk couplings use convoluted disks to transmit torque from an inner hub radially through the disk to an outer ring, or vice versa. A convoluted disk is very similar to a corrugated diaphragm in a valve operator. It is more flexible than a flat diaphragm in the axial direction and allows greater deflection in the axial direction. However, in bending, or skewed deflection the disk is quite flexible in the section that lies in the plane of bending, but is quite stiff in the section through the bending axis. This results in high bending stresses at the bending axis, and high alternating stresses in each revolution. This type of corrugated disk has an unstable torque characteristic.

While we do not normally like to think of coupling failure, there are times when we actually want a coupling to fail. It is somewhat similar to the situation when you are traveling in an outboard motor boat. If you happen to hit a rock with a propeller, then you would much prefer to have a shear pin fail rather than the propeller itself fail. The flexible coupling between two high speed rotors is a link between the rotors, and if the bearing fails on one rotor, or an obstruction strikes one of the rotors, causing it to seize, then it would be much preferred to have the coupling fail between rotors, rather than having both the driving and the driven rotor failing and do a lot of internal damage. For this reason, it is often desirable to design a coupling that will fail at loads well above the normal load, but still low enough so that a shaft is not ruined or some other part of the rotor will not need to be replaced.

In the case of the gear coupling, it is difficult to design a failure mode that is safe and will not do damage to one or the other connecting shafts. The reason for this is that the gear teeth themselves must be lightly enough loaded so that they will not normally fail under excessive torque, so the usual point of failure is in the shaft mounting. This is likely to completely ruin the shaft, and the shaft of one or both rotors must be replaced, if there is a machine seizure.

FLEXXORs are designed so that the weakest link is the flexible disks which provide the flexibility. They are designed so that failure occurs by tension at the holes in the disks. If failure does occur, the two shafts simply can rotate with respect to each other, and there is no great eccentric load on the bearings or shafts. There is also usually no danger of shaft ends failing either by bending or by excessive torque. The inner part of the disks are contained within the outer part of the disk assembly and usually there is no damage except to the disks themselves.

While we don't normally want couplings to fail, it is good to know that FLEXXORs can fail when you want them to, and can fail in such a way that virtually no damage is done to any other parts of the machine. This is just another important feature of FLEXXORs that help to make the FLEXXOR the world's best coupling.

J. Hilbert Anderson - President
Coupling Corporation of America
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