

WHITE PAPER

Reducer Shaft Mounting Systems

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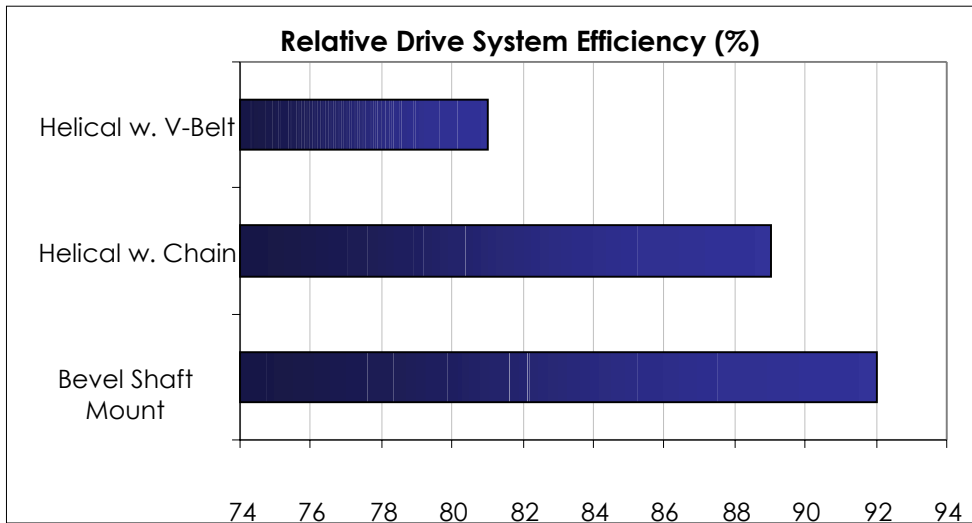
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Introduction

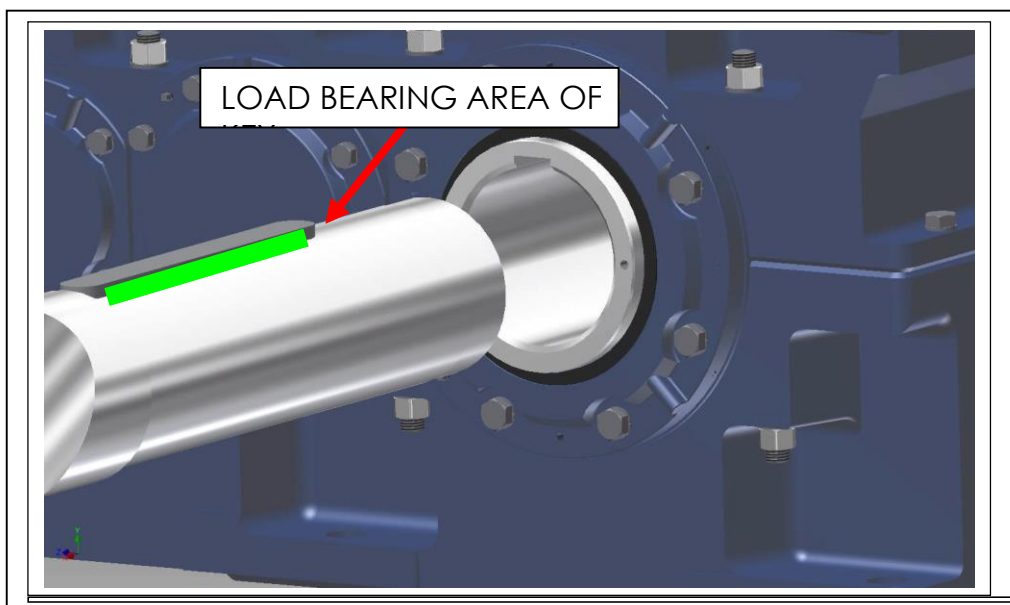
Direct shaft mounted speed reducers continue to grow in popularity. This drive arrangement saves space, reduces structural costs and increases safety. When the shaft mounted reducer is a direct connected right angle bevel unit, significant gains in operating efficiencies, typically 5% to 10% or more, as well as reduced maintenance expenses can be achieved:



In conjunction with this shift has been an explosion of shaft mounting systems. To enable users to make optimal selections, this paper will focus on the relative merits of five basic methods of mounting speed reducers directly onto a drive or head shaft. The methods to be evaluated include; keyed, splined, taper grip bushing, shrink disc and rigid coupling.

Keyed Hollow Bore

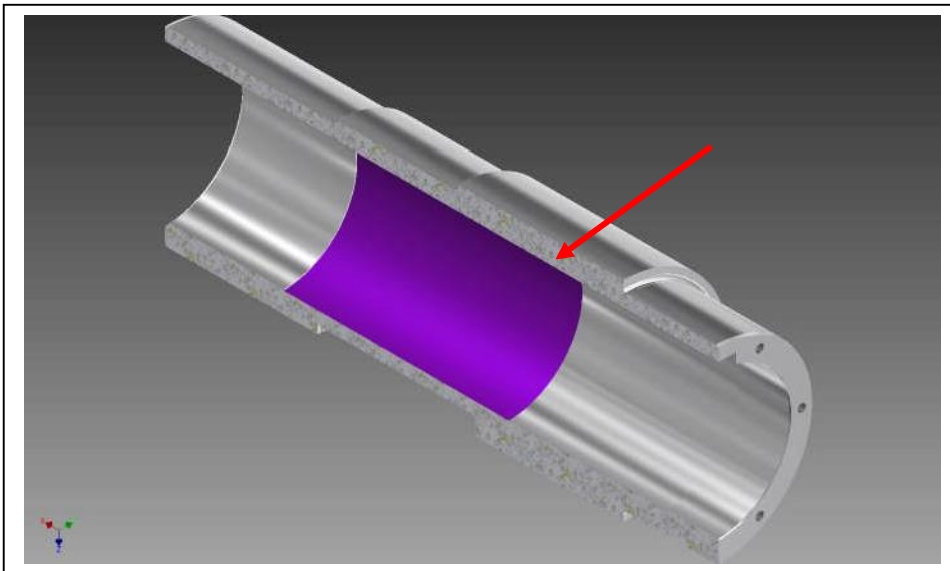
The system most frequently used to transmit torque is a key and keyway. Likewise for shaft mounted reducers and gearmotors, the keyed hollow bore is the prevalent method of connecting the shaft mount to the drive shaft. Torque is transmitted from one bearing surface in the driving hollow shaft across the key in shear to the bearing surface in the driven shaft. As is evident in the image below, the load bearing surfaces being utilized to transfer the torque from one machine element to another relatively small:



The advantages of this system are: easy and economical to make, widely understood, relatively simple to install, and standardized key sizes matched to the shaft diameters.

There are two primary failure mechanisms for a key: 1) shearing through the shear plane and 2) crushing the load bearing surfaces due to compressive forces. To minimize the possibility of either of these types of failures from occurring, machine designers can employ a variety of techniques, including; use longer keys, employ two keys, limit the bore diameters and/or torque levels, and minimize the clearance between the hollow shaft and driven shaft.

However, to be able to mount the unit onto the shaft, there must be some amount of space between the hollow bore and the shaft. For this reason, it is not uncommon for the center portion of the hollow shaft, shown in purple in the image below, to be bored out to a larger diameter to facilitate assembly.



Because of the need to balance reliability requirements with assembly considerations, it is not unusual for the reducer manufacturer to specify an acceptable shaft diameter range, based on the demands of the application.

Table 1 explains a typical example of matching the shaft tolerances to the level of anticipated shock loads:

Table 1: Inch Recommended Shaft Diameters (in)

Bore Size	Low Shock Load JIS h6/js6		High Shock Load JIS js6/k6	
	Min.	Max.	Min.	Max.
3/4	-0.00050	+0.00025	-0.00025	+0.00060
13/16	-0.00050	+0.00025	-0.00025	+0.00060
7/8	-0.00050	+0.00025	-0.00025	+0.00060
15/16	-0.00050	+0.00025	-0.00025	+0.00060
1	-0.00050	+0.00025	-0.00025	+0.00060
1-1/8	-0.00050	+0.00025	-0.00025	+0.00060
1-3/16	-0.00050	+0.00025	-0.00025	+0.00060
1-1/4	-0.00060	+0.00030	-0.00030	+0.00070
1-5/16	-0.00060	+0.00030	-0.00030	+0.00070
1-3/8	-0.00060	+0.00030	-0.00030	+0.00070
1-7/16	-0.00060	+0.00030	-0.00030	+0.00070
1-1/2	-0.00060	+0.00030	-0.00030	+0.00070
1-5/8	-0.00060	+0.00030	-0.00030	+0.00070
1-11/16	-0.00060	+0.00030	-0.00030	+0.00070
1-3/4	-0.00060	+0.00030	-0.00030	+0.00070
1-7/8	-0.00060	+0.00030	-0.00030	+0.00070
1-15/16	-0.00060	+0.00030	-0.00030	+0.00070
2	-0.00070	+0.00030	-0.00030	+0.00080
2-1/16	-0.00070	+0.00030	-0.00030	+0.00080
2-1/8	-0.00070	+0.00030	-0.00030	+0.00080
2-3/16	-0.00070	+0.00030	-0.00030	+0.00080

Table 2 Metric Bore Shaft Diameters (mm)

Bore Size	Low Shock Load JIS h6/js6		High Shock Load JIS js6/k6	
	Min.	Max.	Min.	Max.
20	-0.0130	+0.0065	-0.0065	+0.0150
25	-0.0130	+0.0065	-0.0065	+0.0150
30	-0.0130	+0.0065	-0.0065	+0.0150
35	-0.0160	+0.0080	-0.0080	+0.0180
40	-0.0160	+0.0080	-0.0080	+0.0180
45	-0.0160	+0.0080	-0.0080	+0.0180
50	-0.0160	+0.0080	-0.0080	+0.0180
55	-0.0190	+0.0095	-0.0095	+0.0210

As is evident above, the preference of the speed reducer manufacturer is to minimize the clearance between the reducer hollow shaft and the drive shaft. The recommended tolerances for the applications subject to high shock levels are much tighter than low shock levels. A close fit with low clearances helps extend life, by maximizing the effective bearing area.

Because a keyed hollow bore is typically a loose, there is the possibility of micro shaft movements, which will

result in fretting corrosion to the shaft and or bore. This fretting damage can cause removal difficulties. In most cases, the generous application of an anti-seize compound, typically a moly-disulfide formulation, or an assembly paste to the shaft prior to installation of the unit can help mitigate fretting damage.

In addition, where moisture is expected, in keyed connections, stainless steel is frequently utilized to combat corrosion. Since the mechanical properties of stainless varies from the usual carbon steel, care must be taken to insure that the system retains an adequate level of torque capacity.

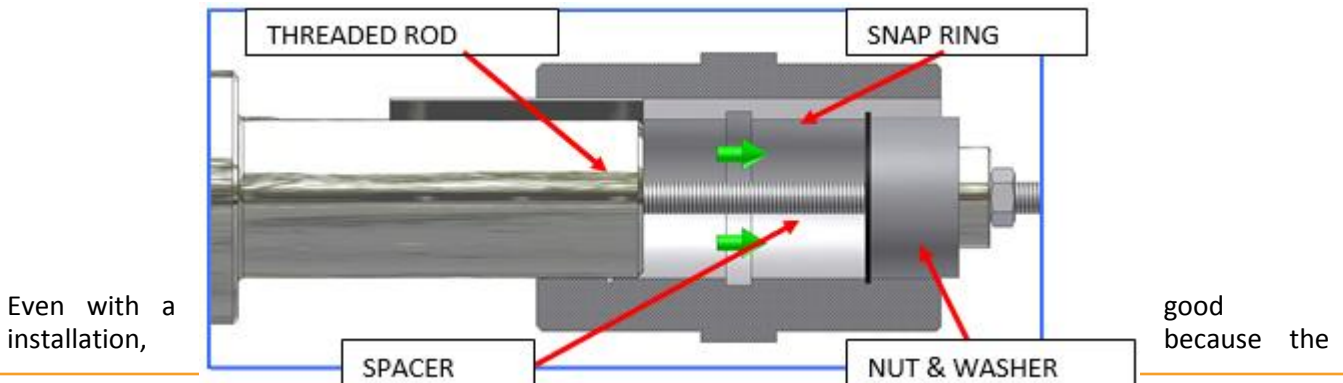
The biggest disadvantages of the keyed hollow bore all relate to the small bearing areas being used to transmit the torque. They include: 1) the need to balance the requirement for assembly clearances against possible edge loading of the key caused by looseness, 2) if a full length key is being used, the installation process cannot damage the key or keyway, or a real possibility of hanging up the reducer part way onto the drive shaft exists and 3) in high cycling applications, there is a real likelihood of fretting damage, key or keyway fracture and/or cold welding.

The photo of the key below illustrates many of the types of damages listed above:



Damaged Paramax Speed Reducer Key

To maximize the probability of a successful installation, the use of specialized fixtures is recommended to aid in the process of drawing the unit onto the shaft, as opposed to pushing it into position. The drawing below illustrates a typical arrangement:



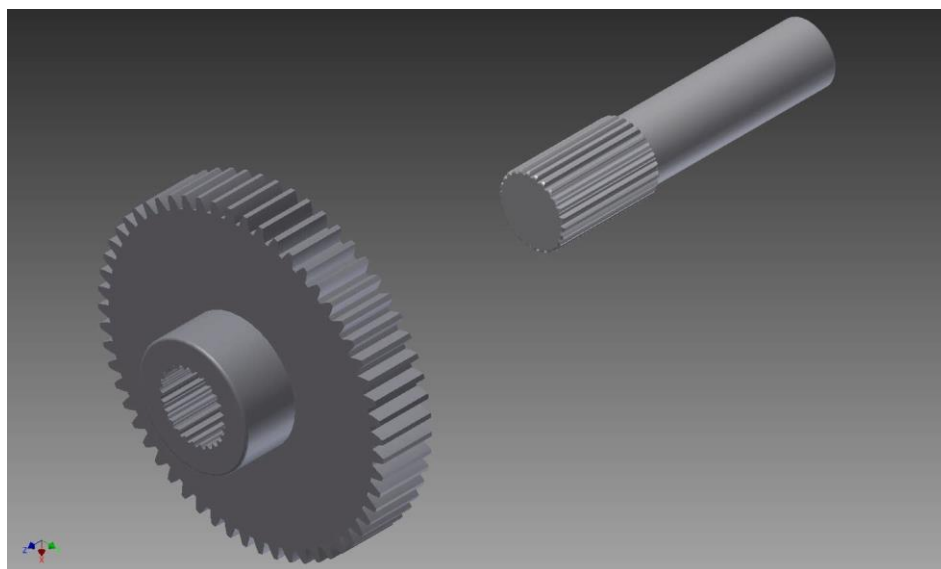
surfaces being used to transmit the torque are relatively small, over time in service with either high shock, or high cyclical loading, it would not be entirely surprising for the key to roll, or the side of the keyway to fracture.

While accommodations to extend service life include: minimizing clearances, (as shown above), increasing service factors, hand fitting keys and/or hardening keys, keyways and shafts can be made, ultimately another means of connecting the unit to the drive shaft is most likely superior.

Splined Hollow Bore

The splined hollow bore is a system frequently applied in the transportation industry in applications where single or double keys are considered inadequate for the application requirements. Reducer applications that may require splines include crane wheel drives dynamometers, and amusement rides

A splined hollow bore has a series of parallel keys and grooves machined, cast, extruded or forged into the bore. The drive shaft typically has a mating set of integral keys and grooves. The illustration below depicts a typical arrangement:



A typical splined shaft and hollow bore

Splined shafts are generally used in applications where relatively heavy torques, as compared to the bore size, are to be transmitted or where parts that may need to move axially, index or be removed. Because the splines are positioned all the way around the shaft circumference, the loads are more evenly distributed throughout the shaft.

There are numerous American National Institute (ANSI) splines, with varying forms, fits, hardness and service factor requirements. In general, due to this high degree of design variability, for applications in speed reducing machinery, as well as both cost and availability constraints, it is recommended to consult with a reducer manufacturer before specifying a splined output design. In low volumes, splined connections tend to be very expensive and not readily available.

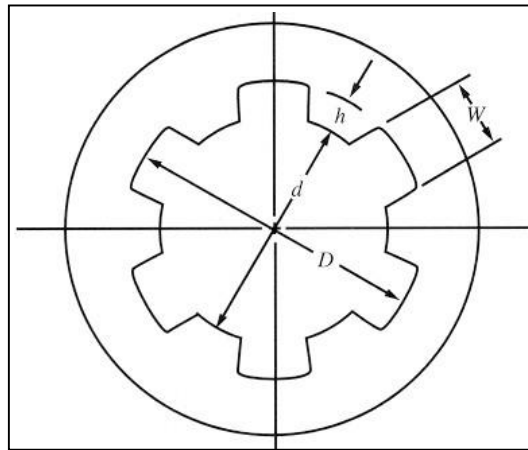


Image of a typical splined hollow bore

A properly specified and designed splined system can work extremely well, but is generally best for primarily single direction operation. The design also requires some clearance for assembly, which means backlash considerations must be made. In addition fretting damage possibilities are a concern. Depending on the application requirements, the addition of lubrication or anti-seize paste may offer enhanced life and serviceability.

Because of the extensive and specialized machining, or tooling that may be required, where lower volumes are under consideration, in most cases, alternate mounting systems may be more cost effective and available solutions.

Consequently, high costs and limited availability are typically the biggest drawback for this arrangement.

Taper Grip Bushing

The Taper Grip Bushing (TGB) is the first of the systems that use friction exclusively to transmit torque. This means that special attention must be taken to insure that both the shaft and bore surfaces are prepared and finished in a manner that results an acceptable coefficient of friction. Typically, in addition to other considerations, both surfaces need to be clean and dry.

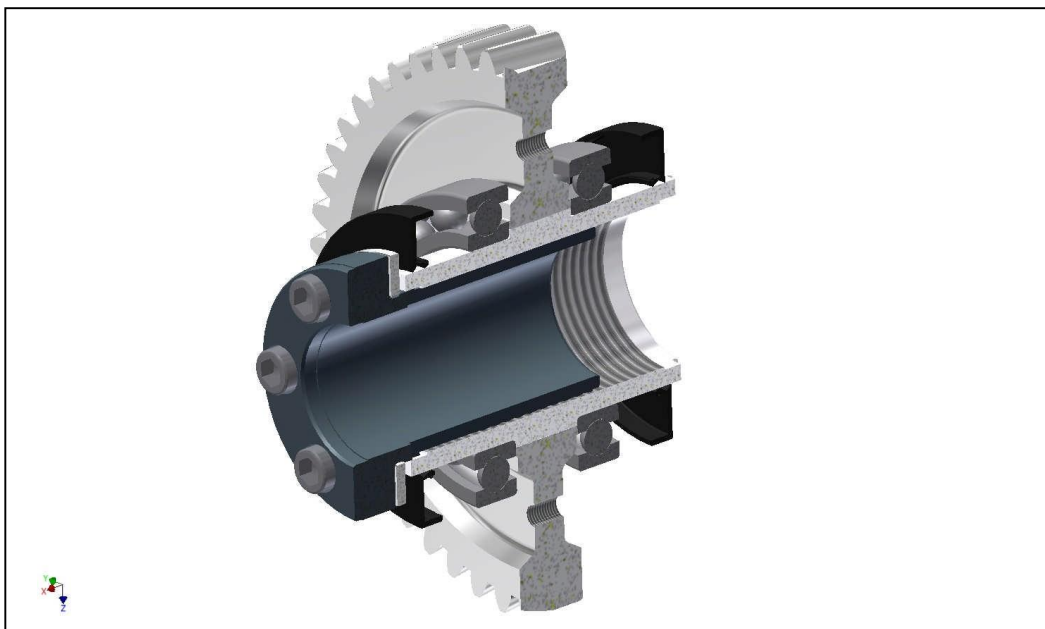
The taper Grip Bushing is a thin walled, externally threaded, axially split tube with a flange on one end. The Taper Grip Bushing fits inside of a threaded the reducer hollow shaft.



Taper Grip bushing, thrust plate and hardware

After the bushing/spacer plate assembly is screwed into the bore, jacking bolts inserted thru the flange displace the bushing axially a slight amount and wedge the threads on the outside of the bushing against the threads cut into the hollow bore. The portion of the bushing and hollow bore inside the low speed gear are unable to deform bore of the gear, which results in the bushing being compressed between the gear, hollow shaft and solid shaft. This resultant compressive force is used to transmit the torque.

This system does not require a key and works satisfactorily using shafts with or without keyways. Because the torque is being transmitted by friction, as stated earlier, the shaft and bushing bore must have a clean, dry and oil free surfaces. As compared to the other systems, slightly wider shaft diameter tolerances, as shown below have been proven to work well:



Cutaway image of a Taper Grip hub and bushing, with bushing not yet backed out

Table 3 Recommended Shaft Tolerances

TGB Bore Size	Shaft Tolerance	
	Max.	Min.
3/4" to 1-1/8"	+0"	-0.0013"
1-3/16" to 2"	+0"	-0.0015"
2-1/16" to 3-1/8"	+0"	-0.0018"
3-3/16" to 4-3/4"	+0"	-0.0021"
4-13/16" to 6-1/2"	+0"	-0.0025"

An added advantage of this system is the ability to adapt to a range of bores simply by changing bushings. As long as the desired bore falls within a predetermined range of diameters, a bushing of the correct bore will work. The difficulty with respect to the bore diameters occurs below the minimum recommended diameters, where the bushing walls become so thick that it is difficult to wedge them in place.

Other advantages of the TGB include; no backlash, no keys or keyways, no shaft pastes needed, lots of clearance during the installation process and if installed correctly, easier removal, by simply loosening the bolts and driving the bushing into an unwedged position.

Disadvantages for this system include; a more complicated installation, the added cost for the bushing, the space required for the bushing itself, as well as the need for open space for tool access on one side and as always, for an incorrectly installed bushing, the possibility of cold welding.

In addition, at this time Taper Grip Bushing are made exclusively of carbon steel, so they may not be suitable for wet or high humidity applications.

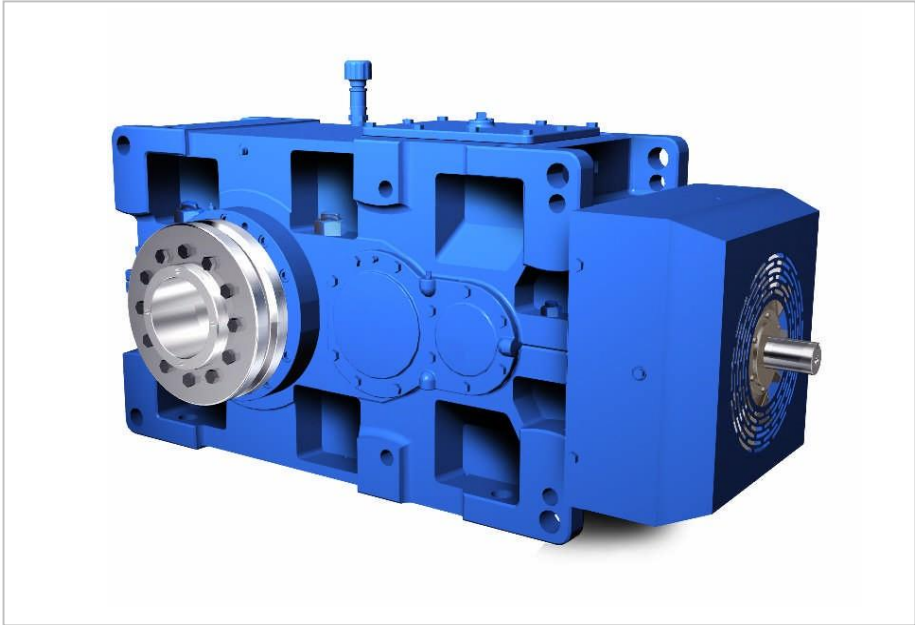
Shrink Disc

Another shaft mounting system that relies strictly on friction to transmit torque is the shrink disc:



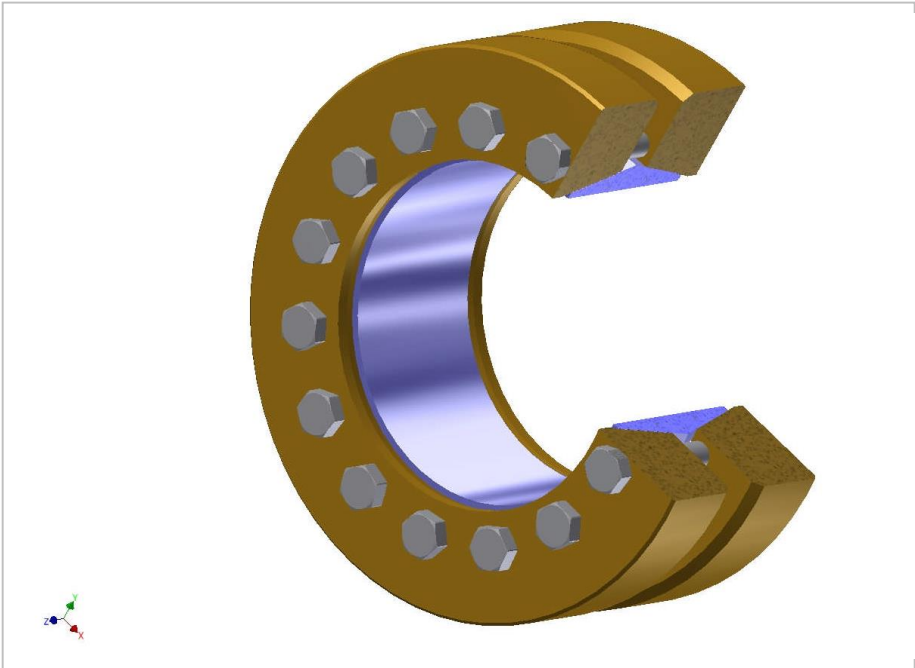
Typical Shrink Disc Source: TAS Schafer

Unlike the Taper Grip Bushing which fits in the reducer hollow output shaft, the Shrink Disc fits on the outside of the hollow output shaft, as shown on the right angle bevel reducer below:



Spiral Bevel Paramax with a Shrink Disc Style Hollow Low Speed Shaft

Shrink disc styles typically used on speed reducers are a three piece design that consists of a pair of machined, hardened steel plates, with multiple threaded holes arranged in a circular pattern. The plates are fitted over a precise, hardened steel sleeve.



The sleeve has a cylindrical internal bore, with the outside diameter of the sleeve being machined into a double taper. Locking screws are inserted into the plates to draw the plates together. As the plates are drawn closer together, they begin to move up the taper on the outside of the sleeve.

When the plates can no longer move up, they begin to press downward on the sleeve, which in turn compresses the bore of the shrink disc. This force, in turn, starts to compress the outside of the reducer hollow output shaft. This squeezing of the outside of the hollow bore is transmitted to the inside of the hollow bore, which results in the drive shaft being clamped to the hollow shaft.

Because friction is being used exclusively to transmit the torque, care must be taken to insure that the clamping forces are adequate. Besides following the instructions exactly regarding bolt torques, the shaft and bore sizes need to be carefully controlled. Consequently, the specified shaft and bore tolerances tend to be on the narrow side:

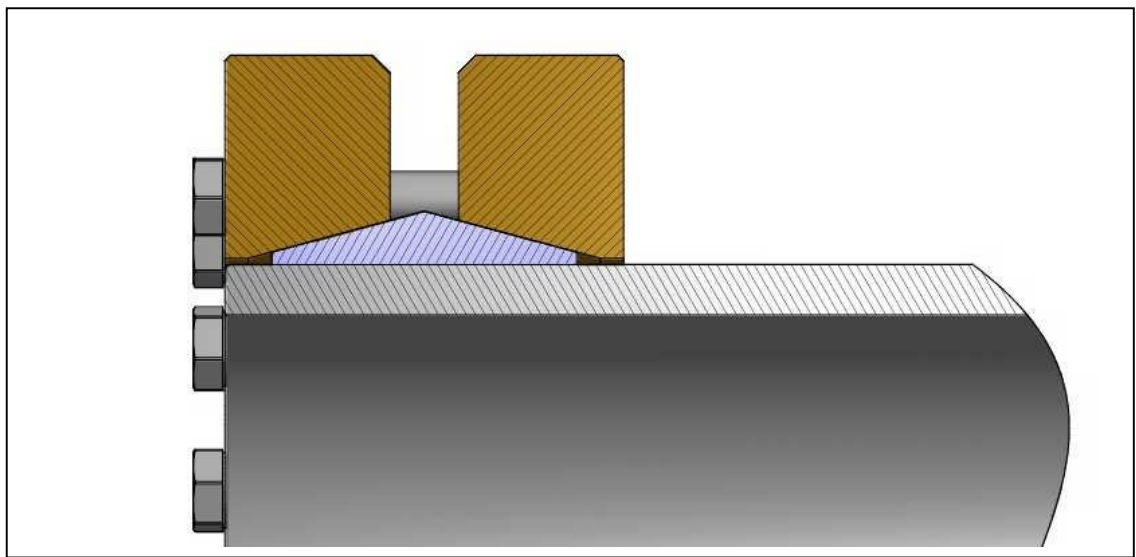


Illustration of the plates and taper in a self-centering style shrink disc

Recommended Shaft Sizes -Shrink Discs

Shaft Diameter	Shaft Tolerance j6	
	Max.	Min.
55 mm	+0.0005"	-0.0003
65 mm	+0.0005"	-0.0003
75 mm	+0.0005"	-0.0003
90 mm	+0.0005"	-0.0004
105 mm	+0.0005"	-0.0004
115 mm	+0.0005"	-0.0004
125 mm	+0.0006"	-0.0004
145 mm	+0.0006"	-0.0004
150 mm	+0.0006"	-0.0004
165 mm	+0.0006"	-0.0004
175 mm	+0.0006"	-0.0004

For applications in moist or high humidity environments, many vendors offer plated versions, coated with either thin dense chrome (TDC) or Electro less Nickel. In addition, a few manufacturers offer shrink discs with reduced capacities made from stainless steel.

In addition, because like the Taper Grip Bushing, it is only utilizing a small portion of the shaft to transmit the torque, systems using shrink discs can be designed with built in clearances to aid the installation process. Also, when properly installed, after the bolts are loosened, the hollow shaft will release its grip on the driveshaft, which makes removal of the unit easy.

Possible weaknesses for this system include; the additional space needed to accommodate the shrink disc, the added cost of the shrink disc, precise machining recommendations for the drive shaft, along with the resultant additional machining time or costs required to complete the machining. Also, when incorrectly installed either cold welding or permanent deformation of the reducer hollow shaft may occur.

A shrink disc mounting system that is properly selected, correctly installed, with appropriately dimensioned parts is equivalent to a shrink fit and suitably robust for even the most difficult applications.

Rigid Coupling

This system, also known as “alignment free” is different from all the previous systems in that rather than fitting a reducer with a hollow output shaft onto the driveshaft, a reducer with a solid output shaft is fitted with a rigid coupling half, using an interference or shrink fit. On the exterior face of the coupling flange there is a pilot. The other coupling half is mounted onto the drive or head shaft, also using interference fit. This coupling half has a pilot that mates with the pilot in the other half. To install the reducer, it is simply a matter of lifting the unit into position, bolting the coupling halves together, leveling the reducer and securing the anti-rotation device.



The benefits of this system are a simple, speedy reducer installation, onto keyed shafts with standard commercial tolerances. In addition, less head shaft length is required.

The possible disadvantages include; the cost and availability of the rigid couplings, sufficient space to install and tighten the coupling bolts, the need to install the rigid coupling with interference fits and potential difficulties removing the coupling hubs to replace either the reducer bearings and seals or the driveshaft pillow block bearings.

Conclusion

- The hollow shaft with a key remains the most popular and economical style for smaller, less than three horsepower units. Since a key transmits power, it is also relatively forgiving.
- Splines operate like multiple keys and provide additional capacity in a small space. However, they are high sensitive to the economies of scale.
- Taper Grip Bushings eliminate the need for a key and provide bore size flexibility, but are not available for all products.
- Shrink disc mounting systems provide a fit equal to an interference fit, are excellent for high cycling requirements.
- Once the coupling hubs are installed, reducers with rigid output coupling are the quickest and simplest to mount.

The chart below summarizes the relative merits of the different systems:

Connection System Summary					
Customer Benefit	Key	Spline	Taper Grip Bush	Shrink Disc	Rigid Coupling
Simple	▲	▲			▲
Cost	\$	\$\$\$\$	\$\$	\$\$\$	\$\$\$
Easy to Install		▲			▲
Easy to Remove		▲		▲	▲
Impact Resistant		▲		▲	▲
Torque Capacity		▲		▲	▲
Readily Available	▲		▲	▲	
Bore Dia. Flexibility			▲		
Moist Environment	▲	▲		▲	

