Vibration damping precision couplings

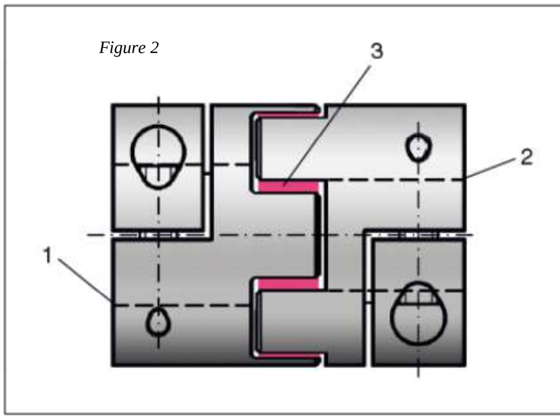
In light of the advantages of elasticity, strength, resilience, and damping effects, elastomer materials are now being used in most areas of mechanical engineering. In drive technology, beyond transmitting rotary motion and compensating for misalignment between shafts, elastomer couplings (Fig. 1) are used to damp rotational movement, especially in areas where vibration or impact loads are expected.

Figure 1

Design

Elastomer couplings, also known as spider or jaw couplings, are made up of three main components: the elastomer insert, and two hubs of various designs (Fig. 2). The hubs are used to connect the driving and driven shafts, and transmit rotary power across the insert between them. The hubs are available in a very wide variety of form fit and friction fit designs, depending on the application requirements. The elastomer inserts (spiders) can compensate for shaft misalignment while also adding a damping effect to the drive line. Precision elastomer couplings are generally used over a torque range of approximately 2Nm to more than 25,000Nm, with bore diameters ranging from 3mm to 170mm.

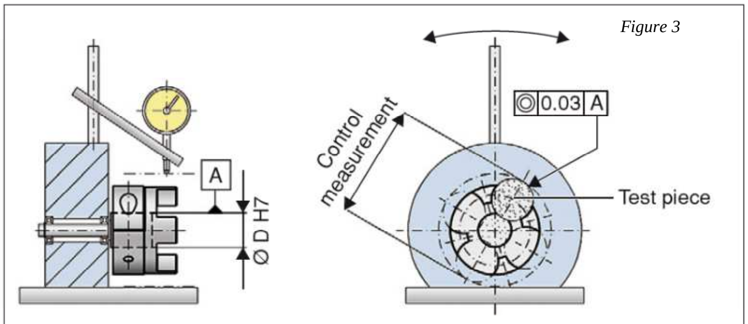
Figure 2



Hubs

Jaw coupling hubs are normally made of high strength aluminum, steel, stainless steel, cast iron, or fiber reinforced plastic. The precision variety of elastomer couplings are machined from solid round stock and can be used at speeds of up to 60,000 rpm. In precision applications the concentricity of the entire coupling and not just of the individual hubs is important. For the coupling assembly to be absolutely concentric, the bore and the jaw geometry need to match very accurately. To ensure a tight tolerance, the hubs are mounted on a mandrel, and the deviations of the individual jaws are measured with a pin gauge that has precisely the same diameter as the pockets between the jaws. Figure 3 is a schematic diagram of the dimensional accuracy check.

Figure 3



Elastomer insert

Precision coupling inserts are normally made of thermoplastic polyurethane (abbreviation: TPU). This thermally stable material can be used over a temperature range of –30°C to +120°C. They can also be made of HYTREL material, which has a special structure and is mainly used for applications with temperature extremes. On account of its elastic memory and damping characteristics, the elastomer insert reduces and compensates for torque impacts. It also damps vibration between the driving and driven shafts, and can serve to filter it out. This allows the entire drive system to run more smoothly. To compensate for the various torque impacts and vibration in specific applications, elastomer materials are available in various hardness levels, measured on the Shore hardness scale.

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There are two different testing procedures to determine the Shore hardness of the types of elastomers used in precision elastomer couplings. In both procedures, the penetration depth of a foreign object into the test specimen is measured. In the Shore A test, the object is a ball, and in the Shore D test, it is a sharp-edeged pyramid. “Soft” elastomer is measured with the Shore A test, and “hard” elastomer is measured with the Shore D test. Depending on their properties, R+W elastomer coupling inserts can be divided into five main groups (Fig. 4).

Figure 4

The most commonly used elastomer insert (type A) has a medium hardness level at 98 Sh A. It provides a good combination of vibration damping and load carrying capacity. They are generally suitable for torques from 2 to 20,000 Nm and over a temperature range of –30°C to +100°C.

The softest elastomers (type C) offer the best damping characteristics, with a hardness of 80 Sh A. They are primarily used for applications with a high level of vibration. Due to the composition of the TPU material, the temperature and torque range covered by the softest elastomer is smaller than that covered by the other types. They can be used over a temperature range of –20°C to +80°C and over a torque range of 2 to 400 Nm. They also exhibit a much larger twisting angle under load than do the harder inserts, as a result of having a lower torsional stiffness in coupling applications.

Elastomer inserts which belong to the hardest group (types, B, D, and E) have a Shore hardness of 64-65 Sh D, a relatively high torsional rigidity, and a rather low damping capacity. Compared with the other elastomer inserts, they cover the widest temperature range, and transmit the highest torques (up to 25,000 Nm). On account of the high rigidity of the elastomer insert, the angle of twist under load is the lowest. Torque impacts and vibration can therefore only be damped to a limited degree.

Figure 5 shows a sample chart of the angle of twist, and thus the torsional rigidity, of the three main hardness levels offered. Since the angle of twist depends on the torsional load and the hardness of the elastomer, it can be said that the more vibration damping the elastomer inserts are, the larger the angle of twist. The more rigid the elastomer inserts are, the smaller the angle of twist.

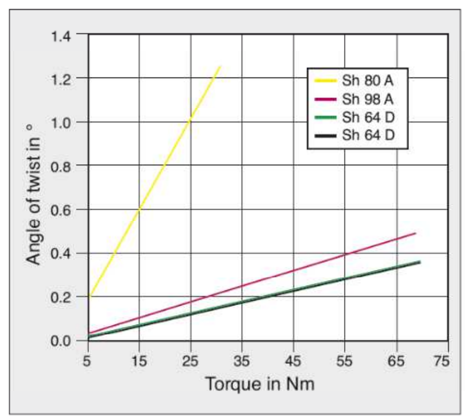

Figure 5

One specialty insert in this group (type D) is used for its electrical conductivity, which is achieved by the addition of graphite to the plastic granules. They have a Shore hardness of 65 Sh D and cover a temperature range of –10°C to +90°C. Due to their electrical conductivity, these elastomer inserts are suitable for explosion proof applications (ATEX zones 1 and 2). The conductivity helps to prevent an arcing of electrostatic loads from one hub to the other, providing a path to ground for any current running through the shafting. The other specialty elastomer (type E) is made from HYTREL, and, as stated above, is used for temperature extremes.

Properties

In addition to their primary functions, to damp vibration and transmit torque, elastomer couplings are also designed to compensate for some limited amounts of all three types of axis misalignment. When misalignment levels are kept below the maximum recommended values for a given insert type, they are maintenance free and have a very long service life. This is because when they are aligned within the allowable limits, remaining misalignment is taken up in the flexing of the elastomer, rather than rubbing against the jaw. Because there are small spacers on the face of the elastomer insert, the hubs are always separated slightly, causing an electrically isolating effect, except in the case of the specialty insert (type D) mentioned above. Even though elastomer couplings exhibit a torsion angle under load (as do all drive components to a certain degree), precision elastomer couplings are noted for being backlash free, a characteristic achieved by preloading the oversized elastomer insert between the jaws. This means that there is no lost angular motion resulting from mechanical clearances.

Being injection molded, the elastomer inserts start with large dimensional tolerances. Calibration is therefore necessary in order to improve dimensional consistency from one unit to the next. The elastomer inserts are pressed into a master hub and heated in an oven at a specific temperature for a specific amount of time. This leads to a larger contact surface between the insert and jaws, so the torque load on the insert is no longer concentrated on high points, but is distributed over a larger area, as shown in Figure 6. This improves the hysteresis characteristics as well as improving service life. It also allows the coupling to slide together more easily, reducing bearing loads during assembly and axial movement.

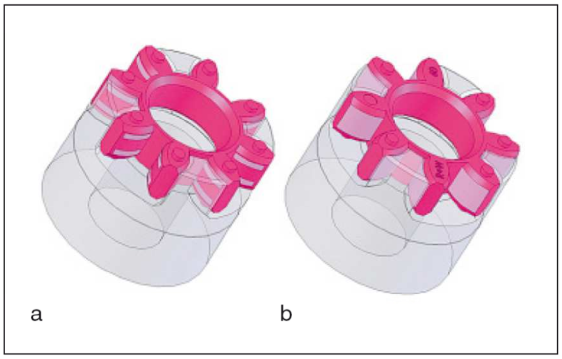

Figure 6

Sizing and Selection

Precision elastomer jaw couplings are normally sized according to the DIN 740 guidelines.

The three main safety factors applied include:

Temperature factor
Start factor
Shock / load factor

The temperature factor takes into account the behavior of the elastomer at various temperatures. Temperature directly affects the hardness of the insert and therefore its capacity to transmit torque. Application of the temperature factor is as follows:

$T_{KN} \geq T_{AN} \cdot S_{Temp}$
T_{KN} = Rated torque of the coupling [Nm]
T_{AN} = Rated torque of the driving element [Nm]
S_{Temp} = Temperature factor

For example, a standard elastomer insert with a 98 Sh A hardness and a torque rating of 60Nm must have a temperature factor of 1.4x applied if it will be run at 60°C by a drive with a 60Nm torque rating. When run at this temperature the rated torque is actually 43Nm, and in order to transmit the 60Nm torque it would need to have a nominal torque rating of at least 84Nm. The table of temperature factors is shown in Figure 7.

T_{KN} = 60 Nm · 1.4 = 84 Nm

Temperature factor S_υ	A	B	C	E
Temperature (υ)	Sh 98 A	Sh 64 D	Sh 80 A	Sh 64 D
> -30°C to -10°C	1.5	1.3	1.4	1.2
> -10°C to +30°C	1.0	1.0	1.0	1.0
> +30°C to +40°C	1.2	1.1	1.3	1.0
> +40°C to +60°C	1.4	1.3	1.5	1.2
> +60°C to +80°C	1.7	1.5	1.8	1.3
> +80°C to +100°C	2.0	1.8	2.1	1.6
> +100°C to +120°C	–	2.4	–	2.0
> +120°C to +150°C	–	–	–	2.8

Figure 7

TPU of different Shore hardness levels softens at different rates with increased temperature. Figure 8 shows the test structure for determining the individual temperature factors for elastomer inserts with various hardness levels. First the coupling is deflected (twisted) at room temperature (20°C) until the rated torque has been applied. The torsion angle is measured with a precision dial gauge. The resulting angle serves as the reference value for maximum allowable twisting for the subsequent tests at various temperatures. The elastomers are then heated to the desired temperature while mounted in the test fixture. The transmittable torque is determined by exerting the torque load resulting in the maximum allowable twisting angle corresponding to the torque rating at room temperature. This quotient yields the temperature factor for the coupling.

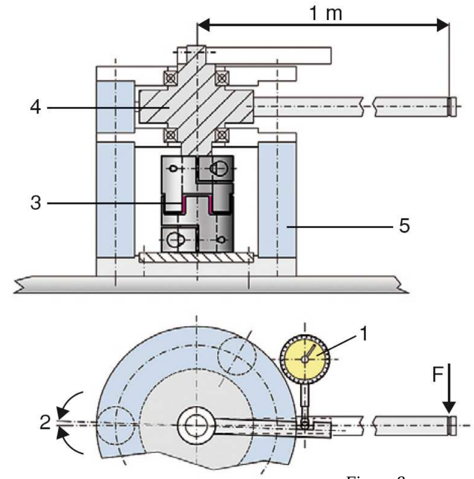

Figure 8

Precision elastomer couplings have two torque ratings: the *rated torque* and the *maximum torque*. In smooth running, continuous motion applications the temperature factor simply needs to be applied to the *rated torque* to complete the sizing. In cases where there are intermittent loads, reversing loads, or shock loads, the shock / load factor (S_A) and the start factor (S_Z) need to be applied to the *maximum torque* rating of the coupling.

Impacts, shocks and changes in the direction of rotation are taken into account by the shock / load factor. These influencing factors can shorten the service life of the coupling significantly if not considered. DIN 740 sizing guidelines offer safety factors for three different load profiles. A specific shock / load factor is assigned to each load type, as shown in figure 9. The shock / load factor is used to determine a peak torque value (T_S) which is then used in a subsequent calculation to determine a value which must not exceed the *maximum torque* rating of the coupling:

$T_S = (T_{AS} \cdot S_A) / (m + 1)$
T_{AS} = Peak torque rating of the driving element [Nm]
S_A = shock / load factor
m = Ratio between the moments of inertia of driving to driven element
$m = (J_A + J_1) / (J_L + J_2)$
J_A = Moment of inertia of the driving element [kgm^2]
J_L = Moment of inertia of the driven element [kgm^2]
J_1 = Moment of inertia of coupling half 1 on the driving shaft [kgm^2]
J_2 = Moment of inertia of coupling half 2 at the load shaft [kgm^2]

Figure 9

Shock or Load Factor S_A		
uniform load	non-uniform load	highly dynamic load
1	2	3
Common factor for servo drives in machine tools: S_A = 2-3		

The start factor corresponds to the number of machine starts per hour, which is also typically the number of times per hour the peak torque will be applied to the coupling. Since the moment of inertia of the load puts an additional strain on the coupling at start-up, the coupling sizing needs to account for the rate at which this will occur. While DIN 740 does not offer guidelines for greater than 240 starts per hour, R+W precision elastomer couplings are routinely applied in dynamic motion applications, which can involve thousands of starts per hour. Except in extreme cases a 1.5x start factor has proven to be a reliable start factor when the coupling is frequently receiving its maximum torque load, as long as the other safety factors have also been applied. The two lower values for start factors are shown in Figure 10.

Figure 10

Start factor S_z			
Z_h	up to 120	120 to 240	over 240
S_z	1.0	1.3	contact us

The final calculation step for selecting the appropriate *maximum torque* rating for the coupling takes all three sizing safety factors into account, with the shock / load factor already having been incorporated into the T_S value.

$T_{MAX} \geq T_S \cdot S_Z \cdot S_{Temp}$
T_S = Calculated *maximum torque* [Nm]
S_Z = Start factor
T_{MAX} = required maximum torque rating of coupling [Nm]

Here is a complete example of an elastomer coupling selection for an application with intermittent, reversing, or shock loads:

EK2/300/A which has a *rated torque* of 325Nm and a *maximum torque* of 650Nm

Given:

Rated drive torque: 120 Nm
Peak drive torque: 260 Nm
Temperature: 35°C
Driving moment of inertia: 0.0495 kgm^2
Load moment of inertia: 0.1369 kgm^2
Driving coupling half moment of inertia: 0.0004 kgm^2
Load coupling half moment of inertia: 0.0004 kgm^2
Starts per hour: 270
Load characteristic: non-uniform load

$S_{Temp} = 1.2$
$m = (0.0495+0.0004) / (0.1369+0.0004) = 0.364$
$S_A = 2.0$
$S_Z = 1.3$
$T_S = (260 \cdot 2) / (0.364 + 1) = 381.23$

$T_{MAX} = 381.23 \cdot 1.3 \cdot 1.2 = 594.72$ Nm

The coupling is qualified for use in the application.

To summarize, here is an overview of the most important properties of R+W precision elastomer couplings:

• vibration damping
• electrically isolating
• press-fit design
• compensation for misalignment
• absolutely backlash-free
• temperature range from –30 to +150°C
• speed up to 60 000 rpm
• very wide variety of hub mounting options

As always, make sure to contact coupling manufacturers in case of any questions during the sizing, selection, and application of precision elastomer insert couplings. For help with an R+W precision elastomer insert coupling, don't hesitate to contact info@rw-america.com.