GAME CHANGING DEVELOPMENTS IN PRECISION LINE SHAFTS

How US manufacturing is influencing mechanical design

All-in-one precision line shaft couplings are fast becoming the most popular method of synchronizing motion between belt drive and screw jack actuators, thanks to improved accessibility and shortened lead times. The idea of using a single-component solution to precisely link rotating shafts in large platform motion systems is not new, however uncertainty in exact machine layouts and unforeseen structural issues as projects come together have often made the relatively long lead times of this kind of tailor-made product prohibitive. This has left mechanical engineers and machine builders to look to otherwise unnecessarily complicated assemblies of couplings, shafting, keys, and bearings, while often making compromises in terms of the lengths which can be spanned, or the rotational speeds at which they can be run. Both concessions have obvious costs, with shorter distances often requiring more expensive designs or larger numbers of gearboxes, while slower speeds can restrain throughput. As US-based manufacturing continues to trend toward renewed growth, domestic production of historically European coupling technologies is also on the rise, making simpler and more elegant mechanical linkages easier to obtain and more realistic to use.

Built from precision straightened tubing, cut to length, and fabricated with zero backlash coupling ends, precision line shafts simplify both design and assembly, while offering smooth and stable running over distances of up to several meters between drive components. Unlike other types of industrial drive shafts, precision line shafts are designed to minimize weight and rotational inertia while maximizing torsional stiffness where it's needed, in such a way that is appropriate for high performance servo drives and mechatronics. Most designs feature fully split clamping hubs that are bored to size, allowing the line shaft coupling to simply drop-in between actuators after they are mounted in place. Knowing the exact distance between shaft ends (DBSE) that needs to be spanned is often only possible within a few days of when the final assembly needs to be completed, which makes the improved precision line shaft lead times resulting from localized production key to their often-newfound effectiveness.

Vibration damping or torsionally stiff

There are two basic types of flexible elements employed in precision line shafts: Elastomer inserts and flexible metal bellows. The former is intended to be an all-around solution where traditional flexible couplings would be used – although it has some key advantages. Fully machined with curved jaws from solid round bar stock, precision elastomer couplings hubs possess natural balance and strength beyond those of traditional jaw couplings, allowing the limits for speed and torque within a given size to be increased. They also make use of calibrated polyurethane spider inserts, which are preloaded between the curved jaws. While the curvature increases surface area contact between the jaw and the insert over a shorter distance, increasing torque-density, the preload eliminates backlash or lost motion, limiting any rotational positioning error to the compression of the elastomer itself under load. This performance characteristic offers an improved balance between vibration damping and shock absorption, and accurate transmission of rotational position. They are the go-to line shaft coupling type for multi-jack lift systems and belt driven linear actuators, absent the presence of highly dynamic loading, and they offer a slightly lower cost than their torsionally stiff counterparts.

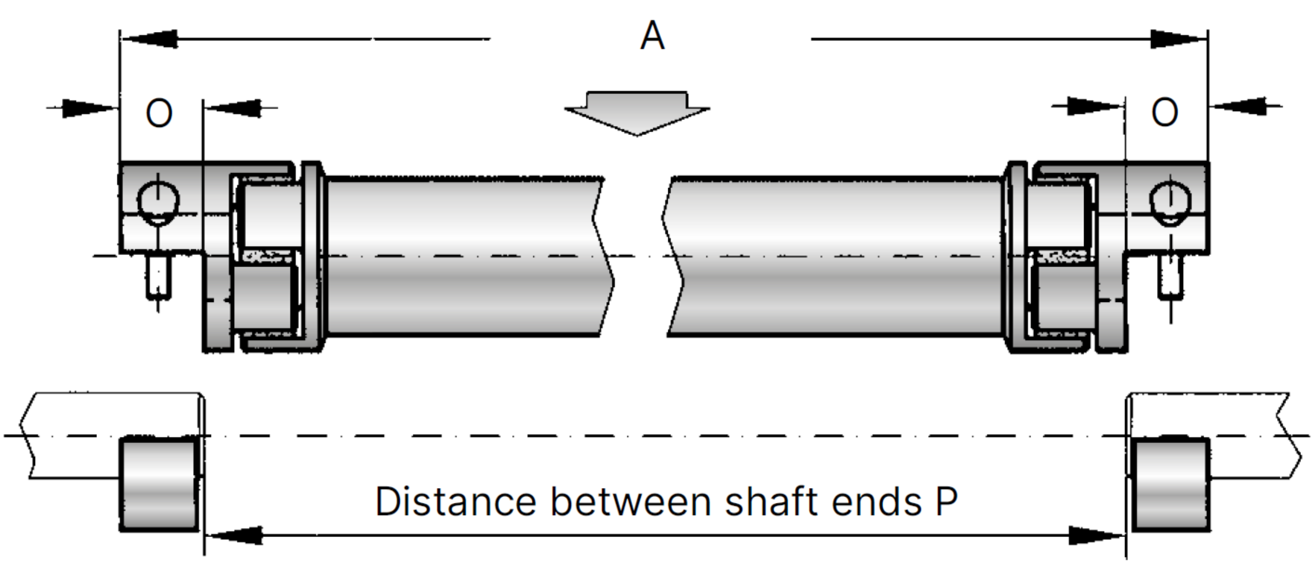
Flexible bellows joints are the best choice for dynamic precision positioning with servo drives. They possess a very high torsional stiffness, along with continuous symmetry; a characteristic that makes them unique among flexible couplings. Where true constant velocity is required between the input and output ends of a flexible coupling, this symmetry means that they lack the build-up and release of energy over the course of a single rotation under misalignment, as occurs with other types of flexible couplings. This performance advantage may only be apparent in demanding applications but contributes to bellows style couplings being the best choice for maximizing positioning accuracy in line shaft applications. Whereas most precision line shafts are sized by bore diameter, application torque, and rotational speed over a given length, bellows style precision line shafts are often sized by torsional stiffness. This is because they offer advantages in terms of how a multi-axis system might be arranged.

Properly sized torsionally stiff precision line shafts can help to prevent the need to center drive tandem belt driven linear actuators, wherein a dual output precision gearbox is placed between two parallel linear modules, with line shafts connecting each of the gearbox output shafts to their respective actuator input shafts. Center driving in this way provides some confidence that the torque load will be distributed evenly between the two actuators, while also shortening the individual line shaft length by using two instead of one. But there are clear drawbacks to this approach. Because the gearbox is not located directly adjacent to either actuator, additional machine framing is needed for mounting it. This adds cost and complexity to the project. Additionally, these types of dual output gearboxes are inherently more expensive than a traditional inline configuration with a single output. Lead time can also be a factor here. Not only are standard single output planetary gearboxes more readily available on the market, but newly shortened lead times for top performing precision line shafts also mean that a simpler and overall more economical solution can be had within a matter of a few days as needed.

Sizing and selection tips

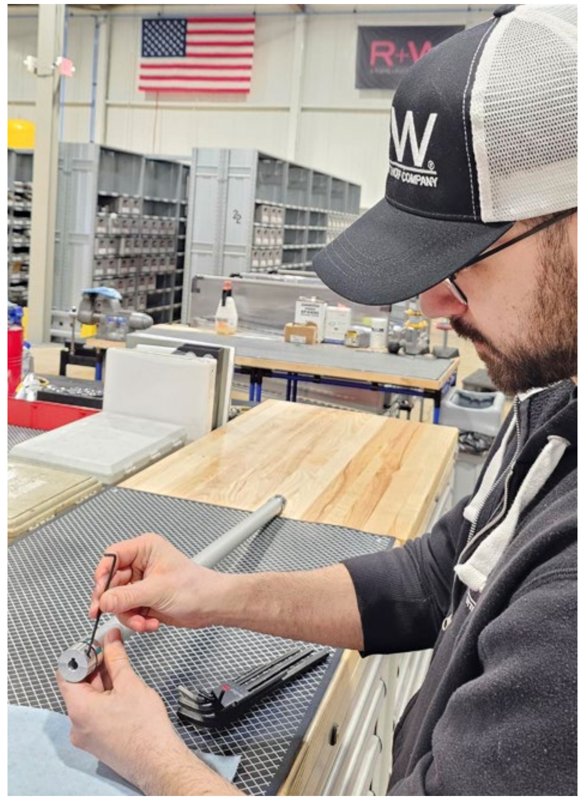
There are four key factors to consider when selecting a precision line shaft model: Bore size, torque capacity, application speed vs. overall length, and torsional stiffness. Ensuring that a precision line shaft is physically large enough to fit over the coupled shafts is as simple as quickly checking manufacturer catalog data. Torque capacity is nearly as simple, though it is important to keep in mind that precision line shafts normally divide loading between multiple mechanical axes from a single main drive unit. As a rule of thumb, assuming that the line shaft will receive up to two thirds of a shared drive torque will ensure some safety factor in case of any uneven loading of the mechanism overhead. Critical speed is another important consideration. This is the speed at which the natural frequency of the tube assembly will become excited and build up to high amplitude vibration. For the most part it's best to stay 20% below the calculated critical speed of a line shaft, though it's also possible to accelerate through the first order critical speed range and level out above it. High quality line shafts use precision straightened tubing, which serves to reduce natural imbalance, and increase critical speeds while also making them more accurately predictable. The longer a line shaft is, given the same material characteristics, the lower its calculated critical speed will be. Increasing the lateral stiffness of the tubing by selecting a model with a larger tube diameter and wall thickness for the same overall length will lead to a higher critical speed value. Manufacturers often publish charts displaying various available sizes and comparing overall length with maximum rotational speed. Most will also assist with selection on this basis and can recommend special tube materials where they are needed. The fourth key selection criterion is torsional stiffness, which is of varying importance depending on the application. Torsional stiffness is especially important when sizing for belt driven linear actuators with dynamic or heavy loading. In situations where there is concern over causing the farther actuator (often referred to as the X' axis) to lag behind the one closest to the servo motor, best practice is to ensure that its linear position error attributable to line shaft coupling wind up be kept below 0.2mm. This is a function of the pitch diameters of the drive pulleys in the actuators, the anticipated torque load, and the torsional stiffness of the line shaft coupling. Manufacturer catalogs will include the torsional stiffness values for the coupling ends of a given model, a well as for incremental lengths of the tubing that goes between them. Application engineers are normally available to assist here as well. For dynamic precision applications involving belt driven linear actuators, it is not uncommon for bellows style line shafts to be somewhat oversized in relation to torque and bore size, in the interest of increasing torsional stiffness.

Once the appropriate precision line shaft model and overall length have been identified, ensure that the manufacturer part numbering as it pertains to overall length is understood. The correct overall length selection is always based on the distance between shaft ends (dimension P below). Some manufacturers use the DBSE in their model numbering to identify the correct length, and others use the overall length of the line shaft. The latter is often preferred so that the engineer making the selection can verify that the coupling ends will fit within the framework of the machine, and given the available lengths of the connected shaft ends. Well designed line shaft couplings feature a slightly longer than normal coupling clamping length (dimension O below) to account for any inconsistencies in shaft spacing as the machine assembly comes together. There are built-in tolerances to account for the shafts being 2-3mm closer together than expected, and the clamping hubs offer ample reach in case the shafts end up being farther apart. In situations where limited space is available between the connected shaft end and the frame of the machine, shorter clamping hubs can be provided.



Impact of US manufacturing

A growing number of US companies are manufacturing precision line shaft couplings to order. In the wake of the recent surge in demand for automation components, combined with supply chain disruptions and uncertainty surrounding global trade, several manufacturers of drive components have started to produce precision line shaft couplings closer to the customer. The resulting reduction in order lead times has become a game changer for machine builders looking to get their products to market more quickly. Rather than piecing together a connecting shaft solution from off-the-shelf components, designers are now able to configure motion systems based on the assumption that a higher performance solution is readily available – often in less than a week. This means that jacks and gearboxes can be spaced farther apart, while some can be eliminated completely, and that less costly and time-consuming methods can be employed for synchronizing linear motion axes.



When planning new design for a large platform motion system, keep in mind that component technologies once considered out of reach are now close at hand.

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