Beyond Bearings: Unleashing the Potential of Ball Splines in Robotic Designs

The often-overlooked benefits of integrating high-speed, multiaxis motion on a single shaft

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When motion system designers need complex, high-speed, multiaxis motion, they might first think of elaborate, prepackaged robot arms. Or, if they need only a few axes, they might configure a separate profile or round rail for each axis. But hiding between those options is simple and proven ball spline technology. This multiaxis motion solution has existed for years and is still highly relevant to today's complex motion schemes. Ball splines use a unique architecture integrating rotary and linear motion on a single shaft. This gives them more flexibility to implement complex motion schemes in tighter spaces, providing a two-for-one deal in motion control (Figure 1).

Figure 1—Ball splines, which enable rotary and linear motion on a single shaft, deliver high reliability and life expectancy under varying operating conditions. All figures courtesy of Thomson Industries, Inc.

Integrating Rotary and Linear Motion

Ball splines allow both linear and rotational motion. This is accomplished with a common shaft performing two independent motions (Figure 2). The shaft includes axial ground grooves called "splines" along its length. This also includes a ball spline nut that rides along the axial ground grooves, locking rotational movement or radial moment loads.

To drive the axial rotation, the ball spline nut is turned. This nut houses a series of balls allowing free motion along the axis (i.e., the nut can slide along the shaft with minimal friction). When rotated, these balls apply a perpendicular force to the shaft via the spline cut grooves, turning it.

To drive linear motion, the spline shaft is moved forward or backward using a linear actuator, like a piston. Since the ball bearings roll within the grooves (instead of gliding), a lower coefficient of friction and wear creates a smooth, precise linear movement and higher velocities.

Because of the anchoring/support, this arrangement also resists torsional loading (i.e., the shaft resists rotation unless driven by the motor). If a torsional load is applied externally to the shaft as it is extending/retracting/stationary, the spline nut supports it, resisting that load.

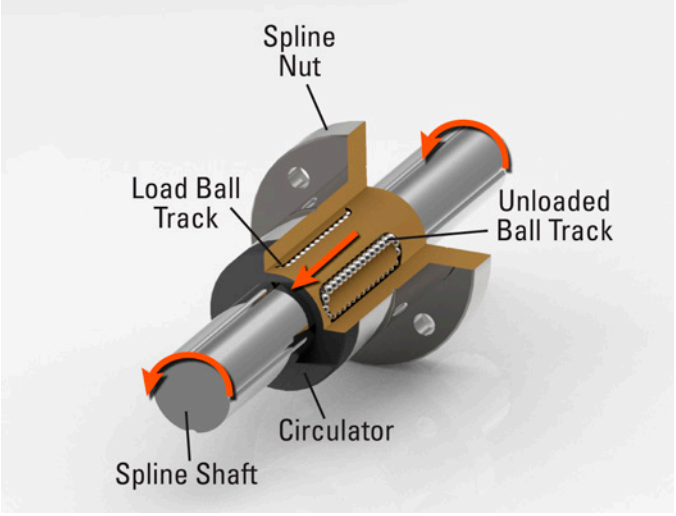

Figure 2—Enabling linear and rotary motion on a single shaft, ball splines deliver many benefits to robotic designs, including increased compactness, load capacity, speed, and accuracy.

Benefits

Better Space Utilization

Compressing multiple axes into one makes ball splines more space-efficient than traditional bearing solutions. This entails fewer components and moving parts, plus a larger load capability within that space than comparable linear bearings offer.

Higher Load Capacity

Wide, precision-ground grooves increase load-carrying capabilities and improve rigidity and stiffness for handling up to twice as much moment load as traditional bearing assemblies. Ball splines also distribute more load along the shaft's length. This lets them carry higher loads than conventional bearings, which may be more subject to localized stress concentrations. Ball splines are also better with off-center loads, common in tool change and pick-and-place applications.

Negligible Friction

The ball guidance system provides nearly friction-free motion through precise contact with tangential points of rolling balls guided by spline shaft grooves and the race within the nut.

Higher Speeds

Ball splines need only small forces to displace the spline nut axially while transmitting torque and minimizing friction. This contributes to about 20 percent increased speed over a traditional ball screw and smoother operation. Ball splines can handle speeds up to 2 m/s.

High Precision and Accuracy

Ball splines offer high precision and accuracy in positioning, making them ideal for applications requiring exact control. Zero backlash ensures no rotational play or lost motion when changing directions. Ball splines maintain this precision and low friction even under heavy loads.

Easy Installation and Maintenance

Installation is easy, typically requiring a rough bore and mounting holes drilled and tapped to secure the flanged nut, or a rough bore and keyway for a round nut. The simple design makes ball splines easier to troubleshoot and service. The maintenance team can pull the spline from the shaft, lubricate it and put it back in, while profile rail and ball screws require higher upkeep.

High Durability

Ball splines have a longer service life than some traditional bearings due to increased ball-bearing point contacts, which reduces stress and increases load capacity. The less stress on the balls, the heavier the load they can handle while resisting wear and providing consistent performance.

Ball splines often feature seals and protective covers that shield the ball bearings from contaminants like dust and debris, further extending life. The ball spline architecture has a safe load capacity from every angle, unlike a radial bearing, where the balls must be carefully positioned to balance the load.

Cost Savings

Upfront savings are substantial for two axes of motion, and savings multiply with higher volumes. Ball splines are significantly less expensive than packaged, multiaxis systems. Having fewer components and moving parts makes them more economical than profile rail assemblies. They deliver better moment load resistance for the price and require less surface preparation for installation. Ball splines' cost is like round rail assemblies, but within

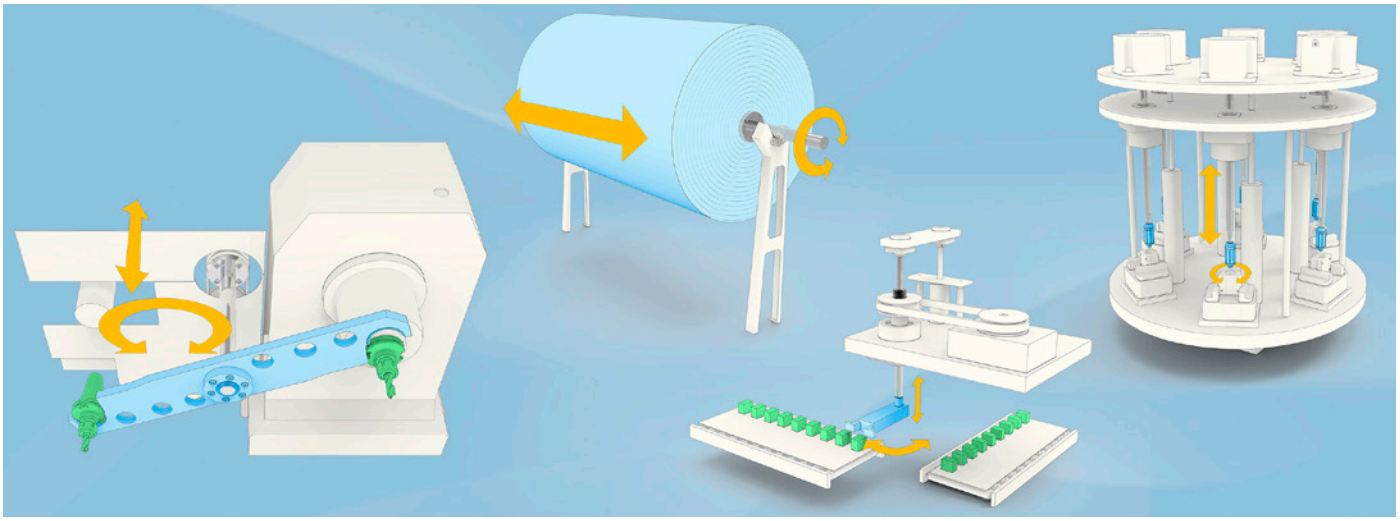

Figure 3—The benefits of ball splines make them ideal for various applications, including (from left to right) CNC machining, paper mill drums, pick and place, and machine automation.

a smaller footprint and fewer axes. Long term, fewer components need maintenance, saving time and money.

Applications

Motion designers integrating linear and rotary motion should evaluate ball spline technology to see if configuring them on the same shaft is beneficial. Here are some application examples in factory automation, transportation, and healthcare/research that have taken advantage of ball spline functionality:

Factory Automation

- Repeatable pick-and-place assembly, such as high-speed semiconductor object positioning in which an arm picks an item from the assembly stage, rotates and places it on another.
- CNC tool positioning in machining and milling operations.
- Packaging equipment for precise control of filling and capping mechanisms.

Transportation

- Aircraft controls, such as flap deployment and throttle adjustment.
- Military vehicles to facilitate rotation, gun elevation and vehicle steering.

Healthcare and Research

- Robots to assist in surgical procedures.
- Medical imaging devices to facilitate the precise motion of CT scanners, or other high-precision image acquisition devices.
- Laboratory analysis, such as microscope stage and sample positioning.

Some vendors offer online guidance to help machine designers optimize ball splines for their applications. For example, one ball spline selection tool offers visual aids that give users the best configuration in minutes.

Finding Their Place

Ball splines are perfect for machine designers needing motion on multiple axes. Compared to packaged, multi-axis systems, ball splines require less space and can be deployed at higher speeds, with lower friction; greater precision; longer, more predictable life; and easier maintenance. They can also be less expensive.

While a ball spline might replace packaged robotic arms, their space efficiency and zero backlash make them usable as components of those assemblies, possibly extending a vertical stroke or assisting with heavier radial and axial loads.

As business operations become more complex, and digitalization, AI and mobility advances bring more axes of motion into automation strategies, the ball spline's unique performance and versatility may finally receive the respect it deserves.

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