A Square Ball Will Steer You Right

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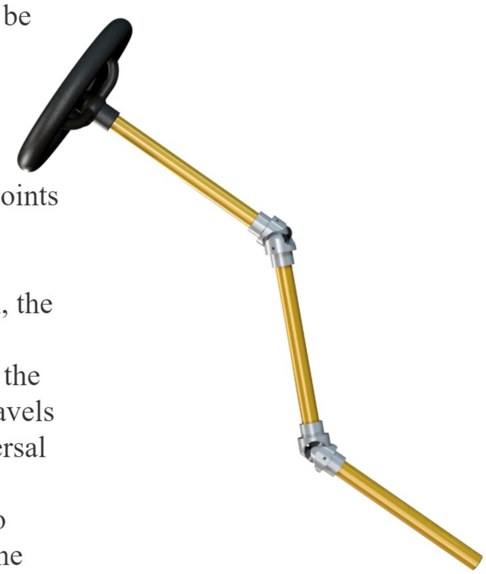
A Square Ball will Steer You Right

The universal joint has been fundamentally **unchanged for more than 100 years** … until now.

Universal joints are vital components in a steering system. They permit the wheel to be centered in front of the driver's seat and provide a tilting feature for personalized comfort. An optimized wheel placement seldom offers a straight path through the dashboard to the steering rack. Universal joints provide a solution.



When the driver rotates the steering wheel, the rate and degree of rotation needs to communicate directly and accurately with the rest of the steering system. This motion travels via multiple steering shafts mated to universal joints coupled with a steering rack. The universal joints allow the steering shafts to weave through available space in the engine compartment, and accurately transmit the driver's steering input.

Autonomous Driving Systems and Universal Joints

Universal joints are key components in the move toward driverless vehicles. Early generations of autonomous platforms require redundant systems that allow the vehicle to be controlled by either the driver or the autonomous driving software.

The back-and-forth transition between human and autonomous steering requires highly sensitive sensors to detect whether or not the driver is in control of the steering wheel. The instant the driver releases the steering wheel the autonomous system must take over to safely navigate until the driver re-engages.

A worst-case scenario is a false positive reading; when the system incorrectly detects the driver is in control creating a dangerous situation where neither the driver nor autonomous system is in control of the steering.

The cumulative starting torque value of all steering universal joints will directly influence the sensitivity of the sensors in the autonomous driving system. Higher starting torque values lower the driver detection sensitivity level, which reduces the ability to determine if the driver's hands are on the steering wheel. Lower and consistent starting torque values allow for more sensitive detection settings which increases safety.

Conventional

79 Components

Designing a link that can rotate through an angle, transfer torque, introduce minimal startup torque, and minimize backlash has required many components within a single link. Current universal joints utilized for steering applications involve most the following components:

(2) yokes
(1) central element, also known as a spider
(4) seals
(4) needle bearing cups
(64-108) needle rollers, (16-27) needles in each of the four bearing cups
(4) retaining clips, retaining screws, or no additional components (design dependent)
(4) thrust washers in the bottom of each needle bearing cup (design dependent)
(1) grease fitting (design dependent)

Square Ball Universal Joint ™

The central element for conventional u-joint and Square Ball Universal Joint designs have the same oscillating motion when rotated through an angle. This means when the driving yoke (input) is at a constant velocity, the driven yoke (output) will not rotate at a constant velocity.

Any phasing calculations already approved for existing designs will be consistent for the Square Ball Universal Joint. Also, two properly phased Square Ball Universal Joints connected to the same shaft and at equal angles will have a constant velocity output.

The Square Ball Universal Joint can mate to a steering shaft or pinion using the same methods; in most cases **it is backwards compatible to current linkage designs**.

8 Components

The four moving components of the Square Ball Universal Joint that are:
(2) yokes
(1) square ball central element
(1) boot seal

The remaining components are needed to hold the unit together:
(2) retaining pins
(2) seal clamps

Conventional

Tolerance stackup becomes an issue when this many components are assembled into a single universal joint, encouraging inconsistent performance due to clearance differences within each bearing cup and between units. The starting and dynamic torque values will be affected by any one of the following manufacturing challenges and design limitations:

1. The extended tongs of each yoke need to have bores that are concentric, parallel, round and cylindrical (not cone shaped). The size of each bore needs to be held to a tight tolerance capable of maintaining the correct press fit for the needle bearing cup.

2. Needle bearing cup concentricity tolerance between the ID to the OD must be near zero. The inner diameter of the cup needs to have a hardness and surface finish good enough to work as one of the bearing race ways.

3. Thin walls of the bearing cup will take the shape of the yoke bore it is pressed into, so the roundness tolerance of each bore needs to be close to perfectly round. If the bearing cups are secured in place with staking deformation around the perimeter of the bore, the deformations can create stresses that reduce the roundness of the bearing cup they are securing in place.

4. The central element has four trunnions oriented every 90 degrees in the same plain. Each opposing trunnion needs to have outer diameters that are concentric, parallel, round and cylindrical (not cone shaped). The hardness and surface finish must be good enough to work as one of the bearing race ways.

Square Ball Universal Joint

1. Steering sized conventional universal joints utilize a range of 71-127 components. On average, they have 12 times more components than a Square Ball Universal Joint. Since only three of the four moving parts require machining, tolerance stackup issues are minimized in the Square Ball Universal Joint.

2. Tolerance stackup issues are reduced to only the OD of the Square Ball and the ID of the mating yoke, resulting in very low and consistent starting torque values.

When a steering shaft assembly has two Square Ball Universal Joints each serving angles of 25 degrees or less, the starting rotational torque value will be under 0.05 N·m.

Steering shaft assemblies with conventional universal joints have difficulty achieving consistent starting torque values under 0.2 N·m., four times greater than the Square Ball Universal Joint.

3. When the unit is stationary, the retaining pins prevent the central element from sliding out of either side of the yoke's ID by engaging with centered circumferential groove. When the Square Ball Universal Joint is rotating through an angle, the central element seeks its own center within each yoke. This means the retaining pins are not touching the square ball or responsible for the transfer of torque.

4. All of the torque is transferred from yoke #1, through the central element via its square features, to yoke #2. The radius features of the central element allow it to oscillate within the ID of its mating yoke. It oscillates in two directions simultaneously - the same as a conventional universal joint.

Conventional

Very small amounts of water and/or snow melting chemicals may breach the seal and begin to break down the small volume of grease. If there are two universal joints in the steering system only one of the eight seals need to be compromised for a problem to occur.

Most steering universal joints are maintenance free. It is a fair expectation for steering universal joints to last as long as the expected life of non-commercial vehicles. The seal limitations noted below and the low volume of grease challenge the life expectation of a conventional design.

1. Seals (four per universal joint) need to compress enough on the outer diameter of the trunnion to prevent ingress of liquid and solid contaminates, hold in grease, and not create excessive drag resistance. Seal drag adds to the starting and dynamic torque forces required to rotate the universal joint through an angle.

2. The ability to truly seal is challenged by the trunnion oscillating against the seal as the universal joint rotates through an angle. Overtime, it is difficult to maintain a true seal between two moving surfaces.

3. Space available for grease is limited to the space remaining between the ID of the bearing cup and the OD of the trunnion minus the full complement of needle bearings positioned between them. An average capacity of grease fill is 70-95% of the void space. This means a common amount of grease within each assembled bearing cup is about 0.125 mL of grease by volume.

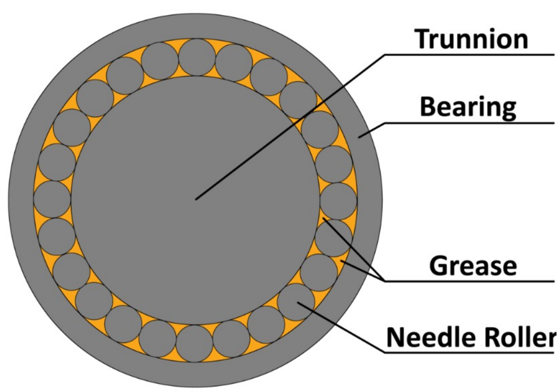


Illustration Enlarged to Show Detail

Square Ball Universal Joint

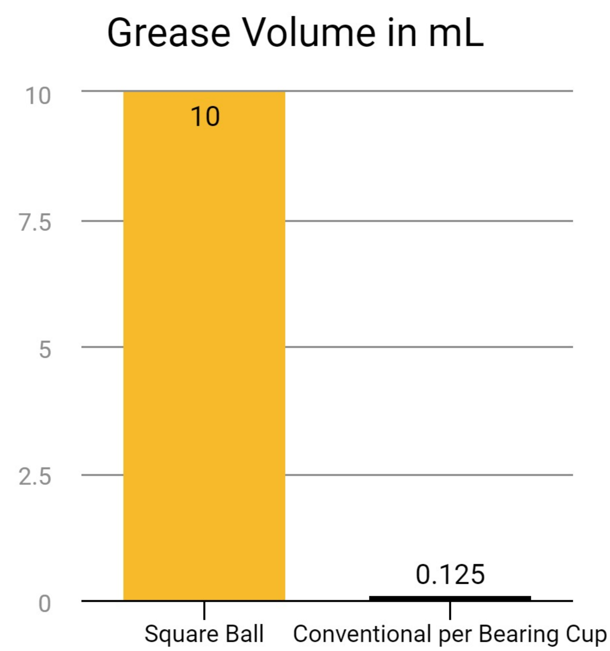
1. The seal is a boot with bellows protecting all of the moving components. The boot is clamped over a rubber notch pushed into a groove on the OD of each yoke providing a true seal. Since the bellows of the boot only expand and contract as they rotate through the angle, there is not any seal drag increasing the rotational torque values in contrast to conventional u-joints.

2. The boot seal allows for 8-12 mL of grease storage by volume. If small amounts of water and or snow melting chemicals in a fluid form breach the seal, the larger volume of grease will continue performing well.

3. A large volume of grease eliminates dry start issues. The Square Ball Universal Joint can be placed in any orientation and the central element will always be in contact with grease. Even if the unit is dormant and the grease experiences gravitational settling, the majority of the central element will remain submerged in lubrication.

4. Contact area between the central element and each yoke is much larger than steering-sized needle bearing universal joints can achieve. In the example on page 8, the total contact area between the needle rollers and their four trunnions is 33 mm^2. A steering-sized Square Ball Universal Joint has approximately 302 mm^2 of contact area between the central element and the two yokes. This is more than nine times the contact surface area of the conventional needle bearing design.

5. The ID of the yoke is concentric with the OD of the Square Ball. When the Square Ball oscillates within the ID of the yoke it glides on a grease film. The oscillating motion exposes significant area of the Square Ball to new grease with each oscillation promoting a continued grease film on all sliding surfaces. There is not a rolling squeegee effect pushing grease from between the central element and its raceway, which occurs with needle rollers.



Comparison of grease in the Square Ball Universal Joint (yellow) vs. conventional universal joints (black)

A larger grease volume is less susceptible to degradation if contaminates are introduced.

Conventional

When a conventional universal joint is subjected to a torque load that exceeds the assembly's yield strength, it will result in permanent deformation. The center cross and yokes are frequently the first to yield. The degree of deformation is directly related to how high the torque load exceeds the joint's yield strength.

While the driver may not notice when the part has experienced minimal deformation from excessive torque, it could be an issue when autonomous features are used, such as assisted parking. Even a moderately deformed assembly will have binding issues that will increase the effort required to rotate it through an angle.

Square Ball Universal Joint

The Square Ball Universal Joint has a more controlled failure mode than the conventional design. The only component that deforms under excess load is the yoke, which will not cause binding. When the yoke yields, the result is an increase in the assembly's backlash, yet it remains functional until the ultimate torque value is realized. The results below show the ultimate torque value as 80% higher than the yield torque value.

The preliminary static torsional yield test results of a steering Square Ball Universal Joint are:

- **384 N·m** = Yield torque value
- **538 N·m** = 40% over yield torque value and resulted in a 1.4° increase in backlash – the joint remained functional without binding issues
- **690 N·m** = Ultimate torque value (breaking load of assembly)

Conventional

1. Needle bearing service life is reduced by the continuous vibration of the steering system when it is not rotating (static). For example, when a diesel truck is traveling straight on a highway or idling. The contact area between a needle roller and the bearing raceway is a line. Continued vibration creates excessive friction between the roller and the raceway. The eventual consequence is erosion of the bearing raceway surface at the line contact area, also known as raceway fretting.

2. When a needle bearing rolls on its bearing raceway with a load, it pinches the grease away, much like a rolling squeegee pushing liquid away. The result is a significant amount of metal-to-metal contact in the load zone, preventing the grease from acting as a damper between the rolling elements and their raceway when vibration is present.

3. The total contact area between the needle rollers and a raceway for a steering-sized needle bearing universal joint is limited, it can be calculated as follows:

Contact Area = Needle Bearing Length x Width of Line Contact x Number of Needles in the Load Zone

In one example which uses 22 needles/cup, a needle length of 6 mm, a load zone of 115 degrees, and a line contact width of 0.2 mm (a 115 degree load zone will incorporate 7 needles/cup * 4 cups = 28 needles) will result in about 33 mm^2 of contact area between the needle rollers and their trunnions.

The assumption above is that the needles are parallel with the axis of the trunnion raceway they roll on. If they are slightly skewed to the trunnion the line contact area changes to a point contact area. A point contact will concentrate pressure that was intended to be distributed over a line contact area. Raceway fretting will happen more rapidly on a point contact verses a line contact.

Square Ball Universal Joint

Additional load zone contact area utilized by the Square Ball Universal Joint reduces its vulnerability to fretting bearing surfaces. The same vibrating pressures experienced by the needle rollers discussed previously are reduced by a factor of nine for the Square Ball Universal Joint.

Starting rotational torque is very low, ranging from 0 to 0.025 N·m when the operating angle range is 0 to 25 degrees.

Taking Advantage of Increased Reliability

The conventional universal joint design has not significantly changed since needle bearings were incorporated a century ago. Incremental improvements over time have only minimized some of the effects of tolerance stackup.

- The overall complexity and number of machined parts leads to tolerance stackup that results in inconsistent performance.
- Seals protecting each bearing cup create drag causing higher starting and rotational torques values.
- The seals rub on the trunion surface and eventually wear resulting in the ingress of contaminats.
- The small amount of grease within each cup assembly can be saturated by small amounts of contamination resulting in grease degradation and bearing surface corrosion.

The Square Ball Universal Joint simplifies the design and increases reliability needed for steering applications in both operator and autonomously controlled machines. Steering system engineers can now take advantage of:

- More consistent and lower starting torque values that range between 0-0.025 N·m at operating angles of 0-25 degrees.
- Precise movement transfer and minimized tolerance stackup due to fewer parts.
- Larger grease volumes which are more resistant to contaminant saturation.
- Elimination of fretting leading to premature part failure that results in vehicle down time and service repair costs.
- An external seal free of frictional wear.
- A bind-proof design.

Improving reliability in steering systems is vital as the next generation of vehicles become more reliant on lower starting torque values. As steering systems increase in complexity, linkages will benefit from the simplicity of a square ball.

To find out how your design can benefit from the Square Ball Universal Joint, contact CCTY Bearing.

Visit CCTYBearing.com/SBUJ for additional product information.