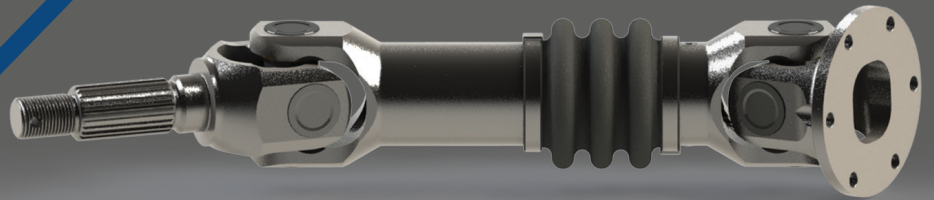


BELDEN
universal



**ADDRESSING THE COMPLEXITIES
OF UNIVERSAL JOINT ENGINEERING**

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UNIVERSAL JOINTS AND DRIVE SHAFTS - INTRODUCTION

Universal joints — also referred to as cardan, Hooke's, and U joints — are cost-effective power transmission shaft couplings, used to transmit motive power from one shaft to another. What makes them particularly useful is that they also compensate for significant misalignments and relative movement between the shafts they connect. Ideally, input and output shafts would be perfectly aligned with each other. In practice, displacement during operation — for example, due to technical restrictions or vibrations — is often unavoidable. There are three types of displacement between two shafts: parallel, axial, and angular. Compared to other compensating couplings, universal joints withstand and transmit power through much greater parallel and angular displacements.

SINGLE UNIVERSAL JOINTS

Single universal joints can compensate for an angular offset of up to 45° between the input and output shafts. This angle can be increased by using double universal joints and drive shafts.



DOUBLE UNIVERSAL JOINTS

Double joints can be made from two single joints by pinning or butting the hubs together, or specially designing the double joints with a single center section, to eliminate additional machining and assembling.



DRIVE SHAFTS

Drive shafts, also called articulated shafts, are shafts that include two universal joints. The simplest type of drive shaft contains a joint at each end, making it essentially an extended double joint. Often, articulated shafts contain an adjustable middle element that allows the shaft's length to be adjusted for easy installation or to compensate for axial play. This type of shaft can be used wherever drive shaft requires axial displacement. Whenever the position of the motor (drive) or the load (output) frequently changes, an articulated shaft with a telescopic segment enables quicker and simpler repositioning than possible with a rigid two-joint shaft. It is also used where installation between the drive & driven shaft requires compression for installation and removal without removal of the drive or driven shaft.



UNIVERSAL JOINT CONSTRUCTION

CENTRAL CONNECTORS

Universal joints usually consist of two yokes — also known as forks — and a typically cross-shaped central connector. The precise construction of this cross is not standardized and varies from design to design. It can be manufactured either as a single component or as an assemblage of several separate components. One-piece designs are found in large-volume production runs and are normally forged with machined and ground journals. The journal diameter is usually much smaller than the diameter of the corresponding yoke ear holes; this allows the cross to be fitted in the yoke without difficulty. For sufficient contact between the journal surface and yoke ears, bearing bushings or roller bearings can be fitted in the gaps between the journal and yoke ear hole.

CENTRAL CONNECTOR BEARING TYPES

PIN & BLOCK (PLAIN OR FRICTION BEARING) UNIVERSAL JOINTS

Pin & Block Universal joints (also called 'friction bearing' joints) are typically simple and easy to assemble, consisting of a few components: yokes, a block and pins. The pins are inserted after the yokes are positioned on the block. There are also ways to add roller bearings and bushings to a pin and block design.

Pin & Block Needle Bearing hybrids are suitable at high angles where side loads are present to redistribute the side loads to the yoke ears. Manufacturing them from various materials such as alloy or stainless steel and a combination of harder & softer materials like brass, bronze, or Polytetrafluoroethylene (PTFE) makes them adaptable for a variety of applications. High-grade alloy steel, hardened and ground components can make the joints highly suitable for carrying significant loads at low bearing speeds. High speeds can be problematic for joints fitted with plain/friction bearings. At higher speeds the heat generated by the friction can cause wear or galling. Proper lubrication helps resolve these issues. The contact surfaces can be pre-lubricated, but the tight clearances do a poor job retaining the lubricant. Lubricant retaining boots, self-lubricating or porous, lube-soaked raw materials present an acceptable solution.



NEEDLE-BEARING (NON-FRICTION BEARING) UNIVERSAL JOINTS

Needle Bearing universal joints are equipped with pre-lubricated roller bearings that reduce friction in high-RPM applications such as automation and instrumentation. They can be constructed with a cross and bearings, or a block and pins with needle bearings. The cross design is the easiest to assemble and most economical approach. It also has the smallest contact surface between the moving components and thus the least friction. The joint has rigid axial stiffness for push/pull loads and can handle greater angles. They deliver superior life at high RPM and continuous operation.



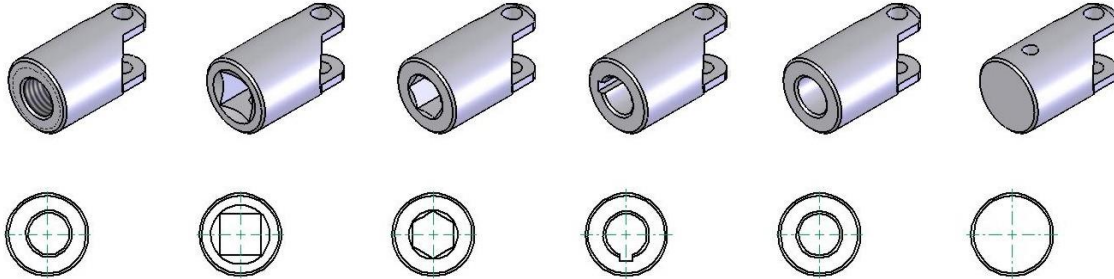
SECURING THE PINS

Often, snap rings engaged within grooves machined into the pins are used to hold the pins in position. Another option is topeen the ends of the through pin, to prevent it from sliding out. A third option is to join or secure all pins in the center of the block with a firm interference fit. The fourth method is to affix the pins to the yokes instead of the block. The bearing surfaces are then located in the block, not in the yoke ear holes. If needle bearings or bearing bushings are used, these are often secured with snap rings or screws to prevent the pins from sliding out.

CONNECTING TO THE APPLICATION

There are many ways in which input and output shafts can be connected to universal joints. The simplest way is a bore in the joint hub, into which the shaft is inserted and secured with a spring pin (or rolling pin). Alternatively, a keyway can be used to secure the shaft. A firm seat can also be achieved with square, hexagonal, splined, or threaded shaft ends. The choice of connection type depends primarily on the

application and the production capabilities. In some cases, the joints are permanently welded onto the shaft.



DURABILITY CONSIDERATIONS: RPM, ANGLE AND TORQUE

The durability of a universal joint is largely determined by the angle of operation, the rotational speed, i.e. RPM of the driven shaft and the transmitted torque. The higher the combined effect of torque, angle and RPM, the greater the stress on the joint. Excessive torque usually causes the joint to break, while an excessive RPM at an acceptable torque causes lubrication failure, which in turn leads to increased friction, heat generation, and wear.

RPM

High RPM is problematic for pin & block joints (fitted with plain bearings), even if the transmitted torque remains low. Proper lubrication of friction surfaces can be difficult where oil-bath or drip lubrication systems are not possible.

One solution is the use of needle bearings in place of hardened bushings. Although needle bearings reduce the joint's transmittable torque, they ensure that the joint can operate for longer periods of time without continuous lubrication.

Plain bearing joints can generally be operated at such speeds for short periods. However, their ability to handle these speeds for extended periods depends on the materials used, finishes, coatings and, of course, lubrication.

Plain bearings are also likely to experience increased abrasive wear on their running surfaces, causing play or backlash within the bearings. In motion control applications where precise positioning is vital, play is not tolerable. Here, the joint must work at minimal backlash, often for extended periods. For this reason, the wear resistance of the needle-bearing joints makes them the preferred choice in even low-speed motion control applications.

In addition, technical data and calculation methods for specific loads and speeds exist for roller and needle bearings. This allows for better estimation of the bearing service life. In contrast, service life cannot be calculated for plain bearing joints. Too many variables exist for the mechanical environment they create. As a general rule, roller or needle bearings should be used for frequent or continuous-duty applications with shaft speeds of more than 1,000 rev/min.

ANGLE OF DEFLECTION

The joint's angle of deflection is the third factor playing a role in durability. As the operating angle increases, the u-joint pins oscillate (sweep back and forth) in the yoke ears (bearing bores) in a greater magnitude (larger swept area). This creates more heat and could lead to increased wear (durability).

To illustrate, two different applications can operate at different angles & RPM, yet, handle the same torque if their resulting Angle x RPM value is identical. For example, an angle of 10° @ 100 RPM yields an Angle x RPM factor of 1,000; similarly, 20° angle at 50 RPM also results in an Angle x RPM factor of 1,000, allowing them to tolerate the same amount of torque.

TORQUE RATING DETERMINATIONS

A universal joint consists of two yokes, a block, pins, which creates a single, multi-directional pivot point. The pins sit within the ear holes of the yoke and oscillate as the joint articulates or rotates. In a pin-and-block (plain-bearing) universal joint with no rolling elements or bearings, precautions such as lubrication and/or surface coatings are applied to prevent pin failure in the ear holes.

There are several things to be considered in determining the torque rating or suggested operating torque of a universal joint. The product of the operating speed and angle of operation, which is a standard unit on a torque rating chart, are considered and verified as a practical limit on the torque to be transmitted. Another item is the bearing area, where the thickness of the ear and the distance from the center of the block (the center of rotation/oscillation) are factors contributing to this. These two considerations limit certain parameters - the product of the operating speed and angle of operation limit the allowed operation angle, and the bearing area limits the PV (Pressure-Velocity) parameter, all of which limit the allowable torque to be transmitted.

A needle bearing universal joint removes the yoke and pin contact or connection and replaces that interface with a rolling element – needle-roller bearing universal joint. The needle bearing universal joint also experiences nonuniform rotational/oscillation speeds. The basic torque rating for this type of joint is evaluated along with the B10 bearing life calculation. This takes into consideration the joint angle correction factor, speed correction factor, bearing pin diameter, length of needle bearing rollers, and the bearing spacing. There are several equations that formulate the joint angle correction factor and the speed correction factor. A life factor is then defined as the ratio of the actual transmitted torque/applied torque to the basic torque rating. Once this has been established, the expected life of the bearing can be calculated which is the B10 life.

When calculating the operating torque, it must also be compared to the ultimate breaking torque as it must not exceed this. An appropriate safety factor must also be applied or considered based on the application and operating conditions. Taking into consideration the factors that limit the operation of a universal joint, speed x angle factor being the largest, a torque rating curve is to be used as a guideline and used with care when sizing a universal joint.

TORSIONAL BACKLASH – PLAY

High-precision applications require minimizing torsional backlash, or play. Information pertaining to the acceptable amount of backlash for each application is taken into consideration during the design and manufacturing phase of the universal joint. The engineering and production teams then make a recommendation as to the best product to use and suitable design based on that criteria. Achieving optimal play typically involves modeling and testing the joint for stresses and weak spots. Certain manufacturing processes, such as increasing pin diameter or reducing bore size can reduce the amount of play present. However, zero backlash is neither attainable, due to the clearances required to prevent seizing of the moving components and to allow for lubrication; nor is it maintainable, due to wear of the components. In addition, standard operation and load in the application will result in a certain degree of backlash over time as well.

COMPONENT MATERIALS

Special applications and custom solutions often require innovative and unique materials to deliver higher strength, improved wear, corrosion resistance and other desirable qualities.

ALLOY STEEL

Alloy steel is typically the strongest widely-used metal for universal joints, suitable for handling high-torque applications and can be further strengthened by hardening. Standard alloy blocks and pins can be manufactured from hardened steel for increased strength, durability, and better performance than other industrial-grade models. Most standard alloy yokes can be selectively hardened.



STAINLESS STEEL

Stainless steel components are commonly used in sterile, sanitary and harsh environments where corrosion resistance and proper sanitation are top considerations.

Standard stainless-steel yokes of universal joints are manufactured from 303 stainless steel; and standard stainless-steel blocks and pins from hardened 416 stainless steel to prevent premature galling and wear. All components can be precision machined, selectively heat treated and manufactured to close tolerances.

For extreme corrosion resistance, 316L stainless steel is often the preferred choice.

Precipitation-hardened stainless-steel grades, such as 17-4PH and 15-5PH, yield excellent high-temperature strength and are commonly used in aerospace, for example.

Since stainless steel is 20-30% weaker than alloy steel, super-duplex steel may be more appropriate for high-strength applications.

SPECIAL MATERIALS

Special applications, performance criteria or environments often require the use of unique materials:

Titanium not only offers the highest strength-to-weight ratio among metals but corrosion resistance as well. Due to these qualities, depending on size and functionality requirements, this material is often suitable for special applications.

Aluminum delivers a high strength-to-weight ratio, but its bearing and wear characteristics are less favorable. Design concepts such as bushings can be a way around this.

Bronze and certain brass alloys also offer corrosion resistance and can be used as bushing material.

Nitrogen strengthened materials (e.g. Nitronic 60) provide vastly increased galling resistance over regular austenitic stainless steel and are sometimes considered for pins and blocks in applications where typical lubrication methods are not an option.

In some instances, the use of a highly specific material may be prescribed, even if a technically suitable substitute is readily available. Locating rare or hard-to-source materials can pose a significant challenge. This can be the case, for example, in reverse engineering where part qualification and acceptance can depend on using the same exact material as the original part.

COATINGS

In addition to selecting the appropriate raw material, corrosion resistance and performance qualities can be attained or improved by applying special coatings or finishes to the components, either locally or to the entire universal joint. Examples of special coatings:

- Nickel
- Zinc
- Cadmium
- Zinc-Nickel
- Xylan
- PTFE / MoS₂
- Anodizing
- Black Oxide
- Polishing
- Surface Passivation

PROTECTIVE BOOTS AND LUBRICATION

LUBRICANT RETAINING BOOTS

As mentioned, keeping universal joints fully lubricated reduces friction, wear and heat generation and can significantly prolong the useful life of the assembly.

If pre-lubrication, such as in needle-bearing joints, or continuous lubrication with oil drips for example is not attainable, the joints can be fitted with lubricant-retaining boots (bellows). In addition to maintaining component lubrication, boots can prevent contaminants entering and damaging the joints in environments polluted with chips, dirt, acids and/or other abrasives. Since boots retain the lubricants, they can also prevent contamination of the environment by keeping the lubricant contained within the boot.



Standard boots are typically manufactured from Nitrile. However, special operating environments might require other boot materials and lubricants. For instance, if the universal joint operates in a vacuum environment, boots might collapse or the lubricant might gas out; in such and similar instances, metal boots may offer the ideal alternative solution.

Some boot materials are more heat resistant than others. Extreme high and low temperatures can cause changes in the material's composition as well as make the boots contract and expand past an acceptable range. Boots can also crack at low temperatures or swell if submerged in fuel or exposed to other harsh chemicals. Such issues can cause oils from the grease to seep through the silicone. For such operating conditions the development of alternative boot materials or special design engineering solutions may be necessary.

BOOT MATERIALS

- Nitrile (standard), also known as Buna-N, has excellent resistance to petroleum-based oils and fuels, silicone greases, hydraulic fluids, water and alcohol. It possesses high tensile strength and high abrasion resistance. Silicone boots are recommended for high temperature applications.
- Silicone (-SL) is resistant to high, dry heat. It is also fungus resistant, odorless, tasteless and non-toxic. It has a high resistance to the aging effects of both sunlight and ozone.
- Neoprene (-CR) was developed as an oil-resistant substitute for natural rubber. It features moderate resistance to petroleum oils and good resistance to ozone, sunlight, and oxygen aging. It has good resilience and is highly resistant to Freon® and Ammonia.
- Viton (-VT) combines high temperature toughness with wide chemical agent compatibility. It features excellent resistance to petroleum products and solvents.
- EPDM (-EPDM) has excellent ozone and chemical resistance. Effective resistance to steam up to 400 degrees Fahrenheit, hot water, silicone oils and greases, diluted acids and alkalis, alcohols and automotive break fluids.

LUBRICANTS

There is a wide variety of lubricants available for various operating environments. Project requirements or certifications will determine the kind of lubricant or grease to be used. For example: Medical and Food Grade Grease conforming to FDA and REACH regulations; Aerospace Grade Grease for a variety of aerospace applications; Marine Grade Grease for naval applications, etc.

Examples of lubricants and their applications:

LUBRICANTS	USES
Lubriplate #1200-2	Standard Joints
Tribolube-12T	Standard Needle Bearing Joints
Aeroshell 7 & 22	Aerospace
Tribolube-9	Aerospace & Military Special
High-Temp Lubriplate	Glass and Metal Processing (High Heat)
Tom-Pac & AP Gear Lube SAE 80w-90	Pumps
Lubriplate SFL-2 Food-Grade Grease	Food Processing
Lubriplate – Marine Grease	Subsea Environments
Aeroshell Fluid 3	Automotive
Lubriplate #3000	Metal Processing
Dry Lubricant – MoS2 Dry-Film Coating	Provides Good Friction for Applications without a Boot

QUALITY, TESTING AND CERTIFICATIONS

Quality certifications and requirements often call for the highest standards for universal joint manufacturing – especially in the medical and aerospace fields. Typically, the medical and aerospace industries require quality systems that are equivalent to AS9100 or ISO9001 standards. AS9100 takes the ISO 9001 requirements and supplements them with additional recording and reporting requirements, which are established by the aerospace industry, to satisfy DOD, NASA and FAA quality requirements for flight critical applications.

It is vital that the quality system is integrated into all aspects of the manufacturer's operations to ensure that the products consistently meet applicable regulatory and safety requirements and specifications. The quality system establishes a framework for developing and implementing design controls that both comply with industry regulations and are most appropriate for their own design and development processes. Depending on the application, universal joints and drive shaft assemblies can require compliance to DFAR, REACH and/or RoHs standards. To meet these requirements, it is important to ensure raw material, COTS (Commercial Off the Shelf) hardware and lubricants are sourced from suppliers that provide compliance certifications for DFAR, REACH and/or RoHs clauses as applicable. This triggers manufacturers to have products traceable to raw material using serialization of assembled lots.

It is the responsibility of the manufacturer to establish requirements for each type or family of universal joints/drive shaft assemblies that will result in products that are safe and effective, and to establish methods and procedures to design, produce, distribute, etc. products that meet the quality system and customer specific requirements. Hence, the new product introduction process starts at the quote phase and transitions to the various stages of design concept, prototype, testing and production readiness,

ending at the production release stage. The customer should be involved at every stage to ensure requirements are being met.

The prototyping stage is the longest and most involved step as the design concept and production process are validated at this stage. Depending on the application, the design concept can be validated using backlash testing, dynamic and static life tests. Validation of production processes include performing measurement system analysis (MSA) on measurement techniques/devices and ensuring a 6-sigma process capability. In a world of industry 4.0, machines are connected to automated measuring systems (CMM) to collect live production data that tracks and ensures process stability during a production run. Finally, at the production release stage, certifications and FAIRs are developed per AS9102 or customized to meet customer shipping and release requirements. Incorporating these measures into the new product introduction process ensures that risks are analyzed and mitigated effectively.

ABOUT BELDEN UNIVERSAL

Belden Universal is an AS9100D and ISO9001:2008 certified manufacturer of high-quality special-purpose universal joints, drive-shaft assemblies and complex mechanical components. Cutting edge, innovative manufacturing technologies and processes provide Belden the flexibility to produce small batches and custom parts just as cost-effectively as high-volume standard universal joints. Capabilities include custom hub configurations or the complete redesign of joints for special applications. Belden delivers solutions to all industries and applications where power is transmitted. Belden universal joints are available as heavy duty, high strength, leveler strength or needle bearing, manufactured from a broad array of materials and coatings. Belden Universal was established in 1997 and is headquartered in Hillside, IL, USA.

For more information, e-mail us at info@beldenuniversal.com or visit www.beldenuniversal.com