Universal joints can be the most efficient and cost effective method of driving mill rolls including applications in high-impact reversing roughers and Steckel mills.

Design and selection of universal joints for rolling mills

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THE application of universal joints has significantly increased in steel and aluminum rolling mills. It is generally known that the most unique feature of universal joints is misalignment capabilities of 15° or greater. While this is significantly higher than the 6° capability of gear couplings and spindles, there are other advantages for the high torque loads and almost continuous operation of today's mills. Universal joints resist lubrication loss and contamination in harsh environments because of their bearing and seal design. Simplicity and ease of lubrication can significantly reduce maintenance time. When compared to other types of high-angle couplings, universal joints operate with negligible backlash and radial clearance that can improve product quality.

Selection and retrofitting procedures of universal joints for mill gear spindles are discussed in this article, including a review of operating characteristics, bearing life, length compensating features, roll end support design and maintenance requirements.

Background

Universal joints are defined as a mechanical device that can transmit torque and/or rotational motion from one shaft to another at fixed or varying angles of intersection of the shaft axes. They are categorized by their motion characteristics as a single joint, which can be nonuniform or uniform. A uniform or constant velocity (CV) universal joint assembly transmits motion with an angular velocity ratio of unity between input and output members. The device commonly referred to as a universal joint transmits motion with various ratios of instantaneous angular velocity between driving and driven members when operating at angles greater than 0° and only a single joint is used. The average angular velocity is unity. This type of universal joint is normally referred to as either a Cardan or Hooke universal joint (Fig. 1). Placing two universal joints in tandem with proper phasing allows the velocity fluctuations of the first joint to be cancelled by the second joint, allowing for a constant output speed equal to the input speed.

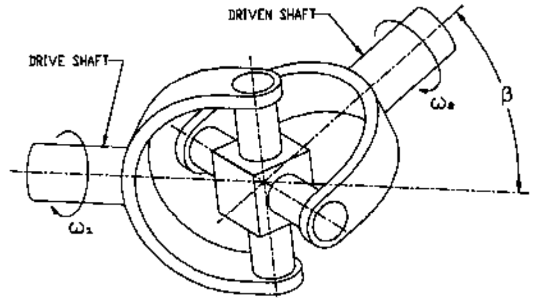

Fig. 1 — Cardan universal joint.

Historical evidence indicates the Greeks invented the universal joint approximately 300 B.C. The name Cardan was derived from the sixteenth century Italian mathematician Geronimo Cardano, who utilized a similar mechanism to suspend a ship's compass horizontal, regardless of the ships movement. During the seventeenth century, Robert Hooke made the first application of a universal joint to a rotating shaft in a clock drive.[1] The development of the automobile accelerated the refinement of universal joints. Other uses include: marine; railway; aircraft; agriculture; and industrial applications.

Compared to high angle, low torque automotive applications, industrial applications, such as rolling mills, require high torques and relatively low operating angles for universal joints. Historically, the most common type of spindle used to drive rolling mill rolls were wobbler couplings (Fig. 2) and slippers (Fig. 3). Wobblers are typically cast pods and are not sealed to prevent lubricant leakage.

Heavy metal to metal contact produces high wear and high noise levels. A slipper coupling has the same rotating characteristics as a universal joint. In fact, a shaft can be made with a Cardan joint at one end and a slipper at the other. The slipper elements are normally made from bronze and, more recently, nonmetallic materials. Slippers wear through repetitive sliding of loaded metal to metal interfaces. Excessive tolerances inherent in the design cause loss of concentricity.[2] These characteristics can contribute to product flaws resulting from mill chatter. Additionally, lubricant is not contained and, in some cases, must be continuously supplied.

The inherent disadvantages of wobblers and slippers combined with market demand for greater productivity and improved quality of rolled products led to the application of

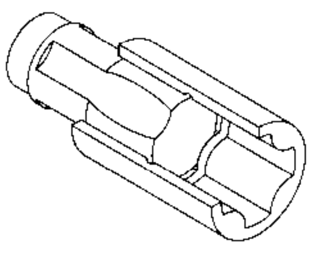

Fig. 2 — Wobbler coupling.

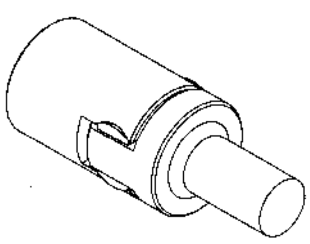

Fig. 3 — Slipper coupling.

crowned gear tooth spindles (Fig. 4). Higher operating speeds, torques and misalignment capabilities in rolling mills were possible with geared spindles. They provide constant angular velocity at misalignment angles and minimize vibration. Generally, seals are used to minimize the leakage of lubricant. The high hardness and controlled crown of the gear teeth provide efficiencies, longer life and greater value than found in wobblers and slippers.

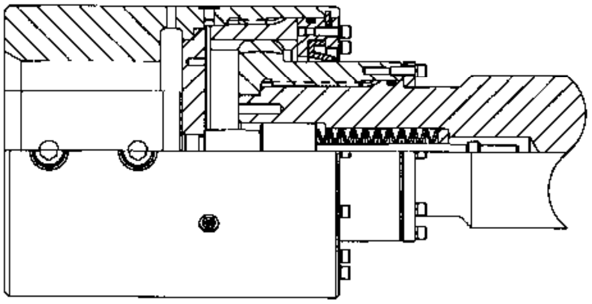

Fig. 4 — Mill gear spindle.

Advantages of universal joint

Universal joints have always been recognized for their inherent advantage of large misalignment capabilities upward of 15° compared to a maximum of approximately 6° for typical gear-type spindles. In recent years, research and improvements in design and manufacture have contributed to substantial increases in the torque capability of universal joints. Achievement of power transmission densities that allow universal joints to meet rolling mill diameter limitations has increased their competitiveness with gear spindles. Today, U-joints are generally available with power densities equal to or greater than geared spindles, especially when operating misalignment angles exceed $1^1/_2$°. The advantages of universal joints include:

- Consistent operating characteristics.
- Reduced backlash and runout.
- Reduced maintenance.
- Elimination of possible mill chatter.
- Lower operating costs.

Operating characteristics — U-joints utilize a cross and bearings instead of engaging gear teeth for the flexing component.

Gear spindle teeth are constantly sliding and wearing during their operational life, which can have significant effects on the life and capacity of the gear spindle.

U-joint bearings roll and have minimal and relatively predictable wear during their operating life.

The torque capacity of gear spindles decreases as misalignment increases because fewer teeth are in full contact to share the load.

U-joint torque capacity is not significantly influenced by the misalignment angle, and reduction in bearing life is statistically predictable regardless of operating angle.

Backlash and runout — Gear spindles, by design, must have 0.020 to 0.100 in. of backlash in order to flex—this backlash increases as the spindle wears.

U-joints typically have less than 0.003 in. of backlash, which does not increase until after complete bearing failure.

Gear spindles typically have 0.020 to 0.060-in. runout as a result of heat treatment distortion (which will increase due to wear).

U-joints are assembled with virtually no radial runout.

Maintenance — Gear spindles should be lubricated weekly for optimum life. U-joints typically require only monthly relubrication (Table I).

Gear spindles typically expel small amounts of contaminated grease as a result of wear.

Since bearing seals are not subjected to eccentric loading regardless of operating angle, U-joint seals have long service life and expel comparatively little grease.

Mill chatter — The use of gear-type spindles can, under certain conditions, provide a vibration forcing function that causes mill chatter and resultant product quality defects.[3,4]

Operating costs — Life expectancy for U-joints is 3 to 6 times that of gear spindles (less change-out frequency).

Initial cost of U-joints is generally 1.5 to 1.8 times the cost of gear spindles. Additional cost reductions include: maintenance and repair; lubricant quantity; and clean-up (Table II).

TABLE I Typical 7-stand hot finishing mill with 26-in. OD gear spindles and U-joint lubrication man-hours

Coupling type	Lubrications/ year	Man-hr/ stand	Total time, hr*	Total cost/ year, $**
Gear spindle	48	3	1008	60,640
U-joint	12	1	84	6720

* 7 stands

** $60/hr

TABLE II Typical 7-stand hot finishing mill with 26-in. OD gear spindles and U-joint lubrication quantity and clean-up costs

Coupling type	Lubricant, lb/unit	Lubrications, number/year	Lubricant,* $/year	Lubrication clean-ups, $/year	Total, $/year
Gear spindle	20	48	13,440	57,600	71,040
U-joint	1	12	168	720	888

*$2/lb, 7-stands

Universal joint designs

Cardan joints for industrial applications consist of variations using a cross and bearing design. All designs (except for plain or composite bearing types) transmit torque through anti-friction bearings, two forged or cast yokes and a forged cross member. Heavy-duty lip seals that are not subject to eccentric loading prevent lubricant leakage and contamination. This allows operation in contaminated atmospheres such as caster applications. Since crowned rollers are typically used, the U-joint life can be statistically determined. Hardened precision tolerance raceways are used with the bearing-steel rollers for optimum life.

Mill universal joints can be categorized as one of the following five types:

- Closed eye (1-piece) yoke design (Fig. 5)—A 1-piece yoke surrounds the bearing housing.
- Split yoke design (Fig. 6)—Yokes are split axially to produce a 1-piece bearing housing with a solid bearing end cap whose yoke halves are held together with a tie bolt during assembly, shipping and installation. After mill assembly, the halves are held together by the bolted connection to the drive shaft flange.
- Split bearing eye (Fig. 7)—Bearing bores are split into two sections and retained by a combination of serrations and bolts.

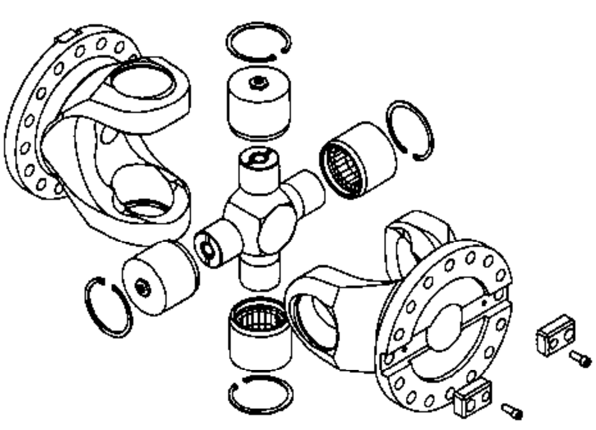

Fig. 5 — Closed-eye (1-piece) yoke.

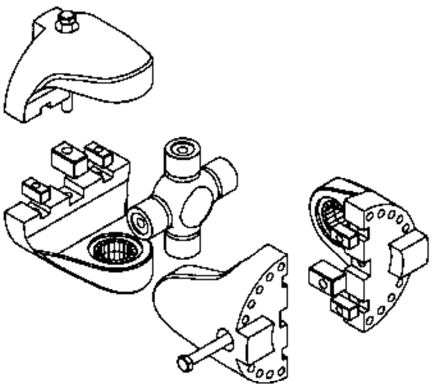

Fig. 6 — Split yoke.

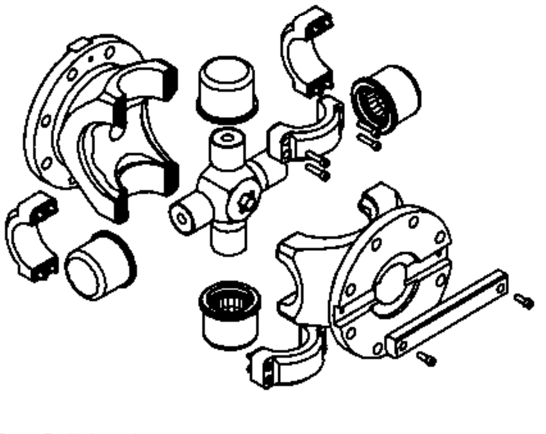

Fig. 7 — Split-bearing eye.

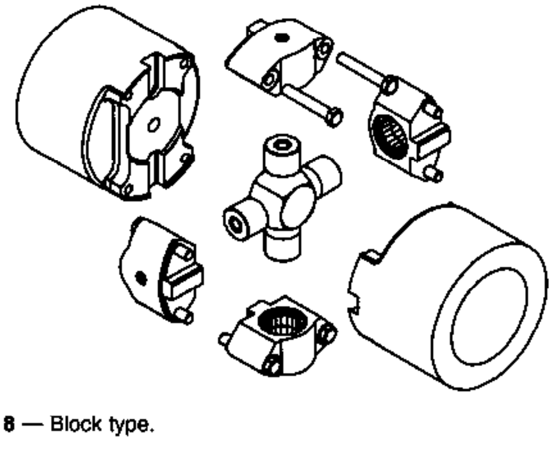

Fig. 8 — Block type.

- Block type (Fig. 8)—Bearing housings are bolted to yokes with face keys, 1-piece bearing housing bore.
- Composite plain bearing—Only design without roller bearings. Bearings are generally made of a nonferrous material such as self-lubricating composite (used on low speed, highly contaminated, high temperature applications such as steel continuous slab casting machines).

The 1-piece yokes have the advantage of no maintenance requirement to verify if bolted connections have loosened and elimination of precision matching of components for equal bearing loading. Corrosion issues associated with split bearing eye designs are also avoided. The 2-piece yokes and block type designs were developed to increase the cross trunnion diameter and torque capacity of the U-joint while allowing for assembly. Split-yoke designs are unique since the tie bolt is not used for torque transmission or retention of yoke components after installation.

All designs have the option of splined center sections to allow for length compensation for axial travel and alignment changes during operation. Splines can be hardened, typically by nitriding, for applications with frequent axial travel. The center sections can be tubes welded directly to the yokes or flanged to allow for more economical replacement sparing of U-joint parts. It is not uncommon to machine integral face pads or special spline teeth between the flange faces (Fig. 9 and 10) on high load applications.

Selection criteria

Torque requirements — The first step in selecting a Cardan shaft is determining the maximum torque to be transmitted (see subsequent section: Special considerations for reversing roughers and Steckel mills for additional considerations). The maximum torque should take into account the maximum prime mover torque including inertial effects from the prime mover when decelerating during overloads. The prime mover torque is generally considered as being unequally split through the pinion stand in the range of 40 to 67% to allow for unequal torque loading of the mill rolls.

This application torque is adjusted by applying the appropriate service factor(s) in accordance with the joint manufacturer's recommendation. The resultant selection torque is compared to either: the U-joint's endurance or fatigue torque rating for reversing applications; or the

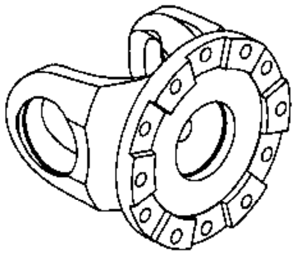

Fig. 9 — Integral face pads.

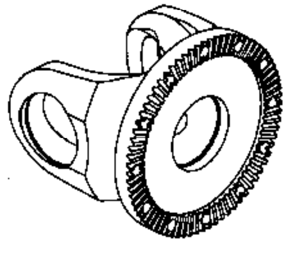

Fig. 10 — Radial face spline.

1-way or pulsating fatigue torque rating for nonreversing applications. Both ratings are based on the material strength of the shaft. The 1-way torque rating is typically 1.5 times the reversing fatigue torque rating.

Next, compare the expected maximum peak torque to the peak torque rating of the U-joint selected. The peak torque rating is typically based on the yield strength capacity of the joint. If the peak operating torque occurs on a frequent basis, brinelling of the bearings is possible. This will shorten the life of the bearings. The U-joint manufacturer should be consulted for confirmation of proper sizing for the case of frequently occurring high momentary load applications.

The final torque analysis involves the calculation of bearing life, which is unique for U-joints when compared to other types of spindles. Each manufacturer's technical literature will provide an equation with constants for calculating the bearing B-10 life in hours. B-10 life is defined as the life exceeded by 90% of a large sampling of bearings. The actual average bearing life is four to five times the B-10 life for a large number of identical bearings operating under identical conditions.[5] This is similar to the calculations used by roller bearing manufacturers except the B-10 life for universal joint bearings is based on oscillating motion of the trunnions. B-10 life is a function of transmitted torque, rotational speed and misalignment angle. The torque used for analysis is usually the application torque, although for certain applications, such as diesel engine drivers, the U-joint manufacturer may recommend using a selection torque that includes service factors. A rule of thumb is to target a minimum B-10 life of 5000 hr.

Since bearing life can be statistically analyzed, for applications where the torque, speed and operating angle vary predictably during a typical load cycle, a duty cycle can be determined. First, the load cycle must be analyzed and divided into groups of fixed combinations of torque, speed and operating angle. These groups represent percentages of the total operating time of the load cycle. Life expectancy can then be calculated using Miner's Rule, which takes into account the cumulative effect resulting from operating at varying conditions.[6] The total life expectancy is calculated using the following equation:

$$\text{Total life expectancy} = \frac{1}{\dfrac{N_1}{L_1} + \dfrac{N_2}{L_2} + \dfrac{N_3}{L_3} + \cdots \dfrac{N_m}{L_m}}$$

where

N_1 = fraction of total time at operating condition 1
L_1 = life expectancy at operating condition 1, hr
N_m = fraction of total time at operating condition
L_m = life expectancy at operating condition

Rotational speed considerations

Cardan shafts have unique angular velocity characteristics that are dependent on the operating misalignment angle when compared with gear spindles. At the same time, long and/or high speed joint center sections have different bending or lateral critical speed limitations based on the acceleration and deceleration of the center section. As a general rule for most mill applications, critical speed is not a concern for speeds less than 300 rpm.

As a U-joint driving yoke rotates in misalignment, the driven yoke alternately rotates faster and slower than the driving yoke twice during each revolution in a sine wave pattern. However, the average velocity is the same for the driving and driven yoke. Accordingly, if the driving yoke rotates one revolution, the driven yoke rotates one revolution. As a result of the nonuniform motion of a single U-joint, most spindle applications require placing two universal joints in tandem. If the misalignment angles at both ends of the shaft are equal and properly phased to be in the same plane, the velocity fluctuations of the first U-joint are cancelled by the second joint. Proper phasing requires not only equal operating angles of the joints, but that all sections of the U-joint lie in one plane and the inboard yokes of the center section must be in the same plane (Fig. 11). Acceleration and deceleration or inertial excitation will still occur, but only to the intermediate shaft. Although this mass acceleration variation is not typically a concern for spindle speeds less than 850 rpm, the U-joint supplier should be consulted for the maximum speed and misalignment angle allowable based on the mass acceleration limitations.

If the U-joints at the opposite ends of a connecting spindle are not at equal misalignment angles, the velocity variations will not be cancelled and the output shaft will pulsate or vibrate. As the difference in misalignment angles increases, the greater the vibration and torsional excitation. An out of phase condition will effect product speed and transfer fluctuating loads to the U-joints on other stands.

The critical speed of a spindle assembly is that speed at which excessive vibration amplitudes set in. It is a function of the natural frequency of the shaft assembly. The maximum operating speed should be sufficiently below the critical bending speed. The effect of the secondary couple occurring twice per revolution is to create a critical speed at approximately half the lateral critical speed. Again, this is not normally a concern for typical mill speeds. The lateral critical speed is a function of the intermediate shaft tube diameter, wall thickness and effective length. The lateral critical speed can be provided by the U-joint manufacturer or estimated from the following equation:

$$N_c = \frac{4.53\text{x}10^6 \sqrt{(D_o^2 + D_i^2)}}{L^2}$$

where

N_c = lateral critical speed, rpm
D_o = shaft tube outside dia., in.
D_i = shaft tube inside dia., in.
L = effective shaft length = centerline to centerline of flex element, in.

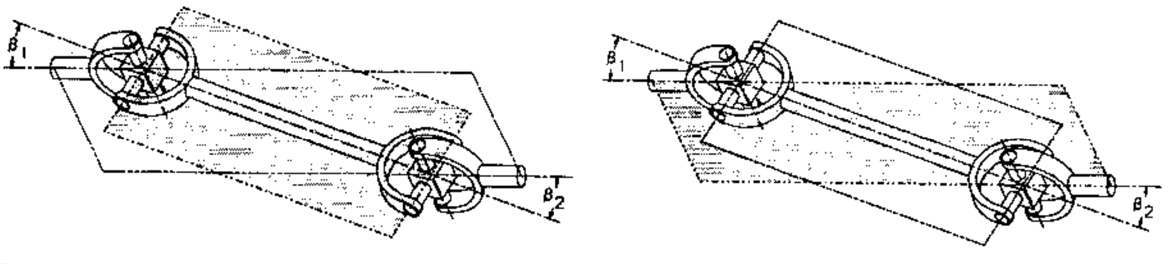

Fig. 11 — Correct phasing requirements.

The allowable operating speed should not exceed 75% of the lateral critical speed nor be within ±15% of half the lateral critical speed to avoid unacceptable vibrations and reducing the life of the parts.

Universal joint unbalance forces are related to part eccentricities and rotational speed squared. Unbalance is caused by manufacturing processes in components, such as casting voids and accumulation of part tolerance, and mating part clearances. As a general rule, balancing is not required for speeds under 300 rpm. At speeds over 300 rpm, the U-joint supplier should be contacted for balancing recommendations.

Maximum bending moment — During U-joint operation, bending moments occur in the connecting shafts as a function of the operating misalignment angle and driving torque. This bending moment causes a load on the supporting bearings that is periodic with two complete cycles per revolutions of the shaft. The bending moment is always in the plane of the ears of the yokes. The maximum value of the bending moment is given by:

$$M = T \tan \lambda$$

where
M = maximum bending moment
T = operating torque
α = operating angle,°

For a gear spindle, the bending moment is generated from the driving torque and operating misalignment angle and frictional loading between the teeth and moment generated from displacement of the load from its center. Typically, a gear spindle will generate 2 to 5 times the bending moment of a U-joint. A comparison of gear spindle to U-joint bending moments is provided by Table III.

TABLE III Bending moments for 26-in. OD gear spindle and U-joint

Coupling type	Torque, in.-lb	Operating angle,°	Pitch dia, in.	Friction coefficient	Bending moment, in.-lb.
Gear spindle	3,165,000	2.25	18.86	0.10	508,000
U-joint	3,165,000	2.25	NA	NA	124,000

NA - not applicable

Axial travel requirements and axial forces — Gear spindles are designed to accommodate angular misalignment and small changes in axial travel length by having their hubs traverse within or pull-out in the sleeves. However, U-joints are required to have a clearance fit in the connected equipment (such as the roll end adapter) or a spline travel section in the intermediate shaft. A clearance or slip fit allows the roll end to pull out under misalignment. The amount of pull-out required can be calculated from:

$$\mathit{Pull\text{-}out} = CL(1 - \cos \alpha)$$

where
CL = centerline to centerline of the U-joint flex location
α = operating misalignment angle,°

Axial travel of the U-joint telescopic spline under torque results in axial forces being applied to the support bearings. These forces are a function of the spline coefficient of friction, operating torque, operating angle and spline pitch diameter. The axial force can be calculated by:

$$F_{\text{axial}} = \frac{2T\mu \cos \alpha}{PD}$$

where
T = operating torque
μ = coefficient of friction (0.10 to 0.15 for lubricated steel on steel)
α = operating angle,°
PD = spline pitch diameter

The same equation is used for gear spindle force with a length compensating spline. For spindles without length compensating splines, the same equation is applicable except that the pitch diameter of the crowned gearing is used. The larger pitch diameter would reduce the axial forces proportionally.

Universal joint support considerations

Roll change support is an important consideration in the application of universal joints. In new installations, the mill builder takes the support requirements into account at the beginning of the mill design. The universal joint and roll end hub must be held nearly horizontal during the roll change procedure so that the roll ends can be easily engaged with and disengaged from the spindle hub. Gear spindles are commonly supplied with spring loaded thrust buttons to support the roll end adapter during roll changes (Fig. 4). When the roll neck is removed from the spindle hub, the spring force drives the sleeve assembly until it locks against the hub while the spindle is supported on its intermediate shaft.

Retrofitting a gear spindle with a U-joint is often a relatively simple job in mills where there is an existing spindle support. In this case, the existing spindle support can often be used as-is with angle limiters attached to the universal joints, or the spindle support mechanism can be modified to support the intermediate shaft and roll end adapter simultaneously. Spring packages (Fig. 12) are designed for mills with relatively small operating angles and an existing intermediate shaft support. The springs are not in contact during normal operation. When the roll end is removed, the yoke is permitted to misalign to a larger than operating angle that still permits the roll end to engage the adapter chamfer.

In mills that are being retrofitted with a U-joint where there is no spindle support, there are a variety of mechanical methods that can be used to support the spindle during roll changes. Methods of support range from techniques as simple as slinging the spindle from an overhead crane to building spindle support devices.

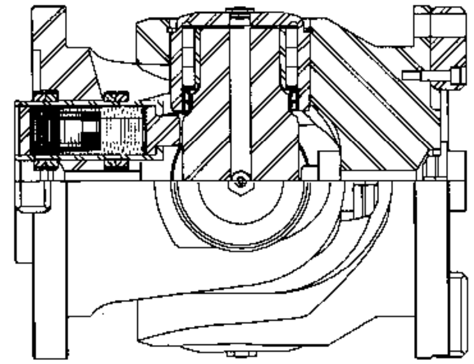

Fig. 12 — Spring angle limiter.

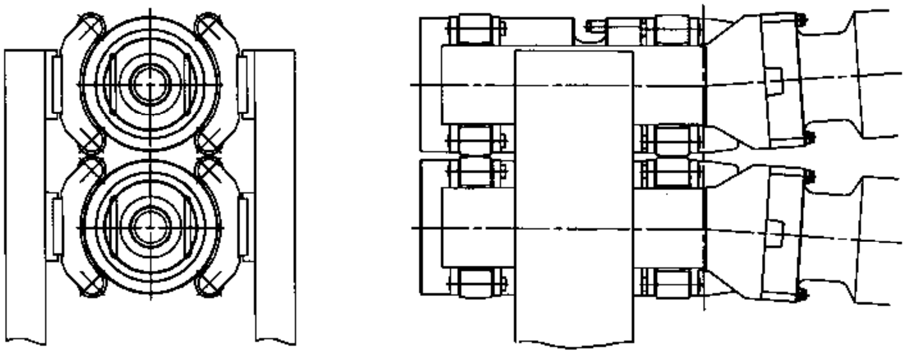

Fig. 13 — U-joint support mechanism.

Because of existing equipment, each installation usually requires a different design. An example of a custom spindle support is shown in Fig. 13.

Hydraulically operated U-joint angle limiters can be used to hold a small angle in a mill where large spindle angularity is required during operation. Hydraulic angle limiters (Fig. 14) utilize a small hydraulic cylinder built into the yoke. Before a roll change, the cylinder is energized and extended to support the universal joint and roll hub in the horizontal position. This technique is particularly useful on mills where the owner desires to retain existing spindle carriers, and not add additional capital equipment to capture the roll end of the universal joint during roll changes.

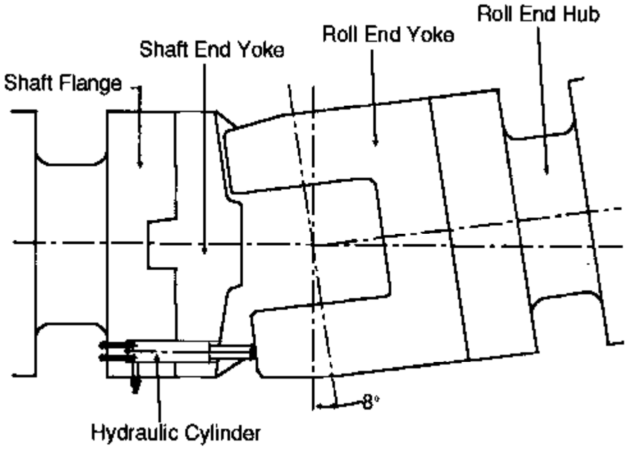

Fig. 14 — Hydraulic angle limiter.

Special considerations

Applicability — Universal joints are particularly well-suited for the angularity requirements of reversing rougher and Steckel mill applications. The rolls of these mills are usually powered by two separate direct-drive motors that are speed synchronized by the mill control system. The mills are required to operate through a relatively large range of angularity. A range from 5° to 2° during a single schedule is common. Angularity in excess of 6° is not recommended in these applications.

Due to the motor overload capabilities built into these mills, and the low minimum speed of the motors, it is more appropriate to consider the torque density of the application rather than the power density. Motors for these applications normally have a current limit setting between 220 and 250% of the nameplate motor rating. When the overload factors and minimum motor speeds are taken into account, the designer can be faced with an 8000 or 10,000-hp mill motor that can produce 1.5 million ft-lb of torque at current limit, and is capable of generating torque spikes in excess of 2.0 million ft-lb. This torque must be transmitted through a universal joint that has a smaller diameter than the discard diameter of the work roll. Experience has shown that a properly designed and maintained universal joint spindle is well suited for these applications.

Compared to finishing stand applications, these types of mills run relatively slowly. The faster Steckel mills rarely exceed 120 or 140 rpm. Accordingly, dynamic balancing of spindle components is not normally required.

Size selection — Size selection for reversing roughers and Steckel mills requires careful consideration of all operating conditions. Because of the overload capabilities, using catalog torque ratings are usually not useful and can be misleading. When designing a mechanical drive system for these types of mills it is recommended that the U-joint manufacturer be contacted as early as possible in the design process. The two main factors that usually determine the final U-joint sizing are: minimum work roll diameter; and who is specifying the U-joint?

To obtain the maximum possible reductions per pass, mill designers (particularly on Steckel mills) specify the work rolls as small in diameter as possible. The question of how to get the required torque to the work rolls is usually a secondary consideration. As a result, the discard diameter of the work rolls is, in many cases, the deciding factor when choosing the size of the universal joints, at least for the roll end U-joint. Often, the spindle designer finds that a universal joint that is, for example, 900 mm dia may be required to meet the desired overload criteria. However, the discard size of the work rolls for the mill is 850 mm. The swing diameter of the roll end joint must be equal to or less than 850 mm. This does not adversely affect the functionality of the mill. It only means that the service life of the universal joint bearings will be shortened.

The party that specifies the U-joint also influences the final size selected. Because of the objective of end users to minimize capital expenditures on new projects, new mills are typically built with the smallest spindles adequate for the application. In many cases, the universal joint size that is required at the roll end is also used at the motor end, even though the allowable size on the motor end is usually much larger. In this case, maintenance intervals of 12 to 24 months are usually considered acceptable, and the mill builder reduces the initial expense to the end user by using the same size universal joint on both ends of the spindle.

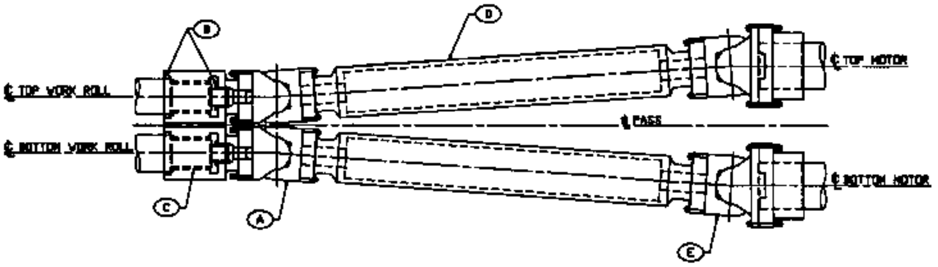

Fig. 15 — Reversing mill application.

For the case of retrofits, spindle specifications are often driven by maintenance considerations. In these cases, it is normal to see U-joint assemblies with roll end joints that are nearly the same diameter as the minimum roll diameter, but with much larger universal joints on the motor end of the spindle. Some maintenance groups have decided that it is easier to remove a universal joint from the roll end of the shaft and pull it through the mill stand rather than remove the entire spindle, which would have included the motor-side U-joint. In these cases, they have chosen to retrofit the motor end of the spindles with a considerably larger universal joint where the maintenance intervals are often 36 to 60 months. This combination results in a reduction in overall maintenance expense.

Universal joint life in reversing roughers and Steckel mills — The service life of universal joints in roughing and Steckel mills is a function of maximum motor load, and mill operating and maintenance practice. Another factor is the torque amplification factor (TAF) that the spindles are subjected to. TAF is the ratio of torque that would be measured with a strain gage on the spindle shaft as compared to the theoretical torque produced by the motor. This number is always greater than unity. On tight, well maintained and properly operated mills the TAF usually ranges from 1.1 to 1.4. The TAF can be in excess of 1.7 during some passes for mills that are poorly maintained and/or not properly operated.

Experience has shown that the average torque that a universal joint is subjected to during service does not usually determine the life of the universal joint in a reversing mill. Spindle life is ultimately determined by the number of high magnitude torque spikes that it experiences. The failure mode of a properly designed and maintained universal joint will be the fatigue failure of the U-joint bearings. Reducing the number and magnitude of shock loads imposed upon the U-joint's bearings is the best way to maximize their service life.

In general, if the roll end and motor end U-joints are of equal size, roll side universal joints tend to require more maintenance attention than motor side U-joints. Torque spikes are often higher at the roll end and, in the case of the bottom spindle, the U-joint must work in a cascade of coolant. In general, a service interval of 12 to 24 months can be expected for the roll end U-joint. As previously mentioned, this number is heavily influenced by the discard size of the work rolls. If the motor end U-joint is sized appropriately, 36 to 60-month maintenance intervals can be achieved. A maintenance interval is defined as the interval between bearing replacement.

Lubrication intervals for universal joints in reversing roughers and Steckel mills should be more frequent than in other applications because of the extremely high unit loads and tighter bearing tolerances. Where U-joints in other applications should be lubricated approximately once a month, U-joints in these applications should be lubricated every one or two weeks.

Installation of modern universal joint spindle in a reversing mill — The following is an overview of a spindle design in a fictitious reversing mill. The design is illustrated in Fig. 15. Even though the mill is fictitious, all the features discussed are currently in service:

- Roll end universal joint slightly smaller than work roll discard diameter—For a reversing rougher or Steckel mill, this results in an estimated service interval of 12 to 24 months.
- Dual guidance hub on the work roll—This feature eliminates loping common on older U-joint designs.
- Liner plates in roll hub—This feature facilitates set-up of proper clearances between roll and spindle hub to be maintained, thereby helping to reduce TAF.
- Hollow shaft—This design results in a shaft with high stiffness and reduced weight, which can lead to elimination of spindle carriers when used in conjunction with dual guidance roll hubs.
- Motor end joint with 50% more capacity than roll end—These larger universal joints are sized for maintenance interval of 36 to 60 months.

Summary

In today's global market, universal joints can be an efficient, cost-effective method of driving mill rolls. Research and improvements in design and manufacture have enabled universal joints to become a popular choice for new mills, but viable retrofit for existing slipper and gear spindles. Universal joints have achieved successful operation in virtually every type of mill drive including high impact reversing rougher and Steckel mills. As environmental concerns continue to increase and the cost of waste disposal (such as lubricants) and preventive maintenance continues to increase, U-joints could become even more cost effective in the future.

REFERENCES

1. Potgieter, F. M., "Cardan Universal Joints Applied To Steel Mill Drives," *AISE Year Book*, 1969, pp 216-222.
2. Kamii, N., and Okuda, H., "Universal Joints Applied To Hot Strip Mill Drive Lines," *AISE Year Book*, 1975, pp 478-482.
3. Keller, N., and Lesonick, M. S., "Vibration Analysis of Stand F2 of Wheeling-Pittsburgh's 80-In. Hot Strip Mill," *AISE Year Book*, 1990, pp 205-210.
4. Keller, N., "Spindle Involvement in Rolling Mill Vibration," *AISE Year Book*, 1992, pp 335-340.
5. Shigley, J., *Mechanical Engineering Design*, 3rd ed., McGraw-Hill, 1977.
6. Spotts, M., *Design Of Machine Elements*, 5th ed., Prentice-Hall, 1978.

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