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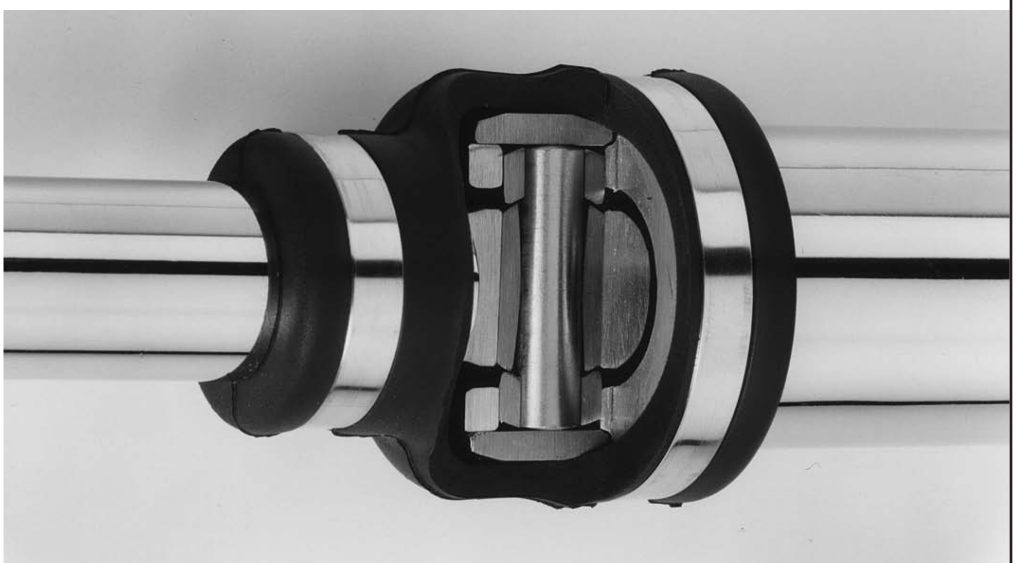
Universal Joint Design in Progressive Cavity Pumps



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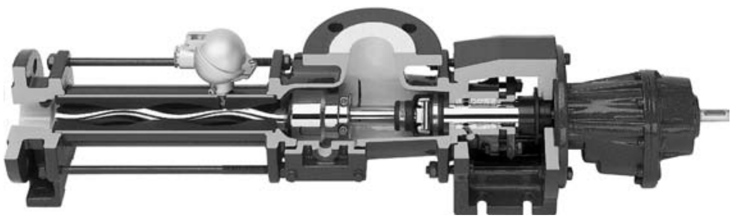
Progressive Cavity Pumps

Introduction

Progressive cavity pumps are a type of rotary positive displacement pump. Like all types of positive displacement pumps, progressive cavity (pc) pumps capture liquid in a defined cavity. This cavity is created between a rotating member, usually constructed of steel machined into a single helix, and a stationary member, normally molded elastomers, with a corresponding double internal helix that has a pitch length twice that of the rotating member.

The Rotor

The rotor has a compression fit with the flexible stator, and the two elements interface, creating sealed cavities. While the cavities created have an unusual shape, much like that of a football twisted around a pole, fat in the middle and pointed on the ends, it functions just like the cavity created between a piston and a cylinder or a gear and a casing in other positive displacement pump types.



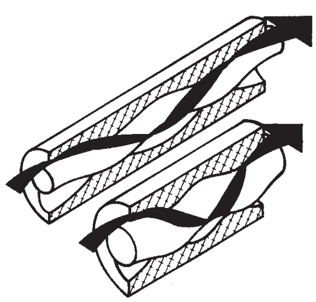
Contemporary Progressive Cavity Design (Cross Section)

Operating Characteristics

The progressive cavity pump has some unusual operating characteristics which make it particularly well suited for some difficult applications. Because the cavity spirals through the pump as the rotor revolves, it does not change its shape; hence, it is called a progressive, or progressing, cavity pump.

Since liquids are not displaced from the cavity by crushing the cavity, as in most other rotary positive displacement pumps, the progressive cavity pump has a very low shearing action and is ideal for pumping very sensitive fluids and emulsions.

Progressive Cavity Pump Element Design



Since the pump is "rubber-lined", it is also well suited for handling abrasives. It is also very good at pumping low viscosity materials, because it is not dependent on the fluid being pumped to form the seal between the pumping elements.

Another unique characteristic, important to its operation and design, is the axial flow of material through the pump. Of course, most other rotary pumps, of both the centrifugal and positive displacement designs, move liquids in a radial direction to the pump shaft. Accommodation of thrust loads then becomes a primary concern in the design of progressive cavity pump drive trains.

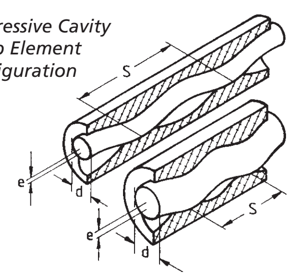
Eccentrically Rotating Pump Elements

The other important consideration for drive train design is the unfortunate characteristic of eccentric motion by the helical rotor. This is an inherent feature of the progressive cavity design. The eccentricity of its rotation is actually a design consideration affecting the capacity or cavity volume of the pump; hence, larger pumps have rotors with greater eccentricities than smaller pumps.

The eccentric action of the rotor has become a limiting factor for the flow capability of progressive cavity pumps. Large progressive cavity pumps may well have rotors weighing over 1,000 pounds (450 kg), moving in an eccentric diameter as large as eight inches. Unless properly installed, these pumps, with power requirements approaching 300 BHP (200 kw), can damage piping and be quite dangerous. This is true in spite of manufacturers making rotors that are hollow either by being cast or drilled axially. It has also limited the flow capabilities of progressive cavity pumps to about 2,500 gpm (500 m^3/hr).

Of course, the eccentric motion of the rotor cannot be conveyed into the sealing area of the pumps, where mechanical packing or seals must run on a concentric shaft. To accommodate this transition, a variety of mechanical devices have been employed, the most common of which are universal joints.

Progressive Cavity Pump Element Configuration



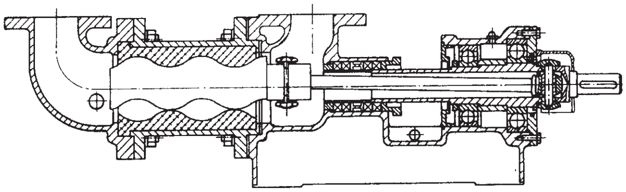
Universal Joint Design

The Original "Pin" Joint

Dr. Rene Moineau invented the progressive cavity pump in the early 1930's in France. His original design used a type of ball and socket joint commonly referred to as a "pin" joint.

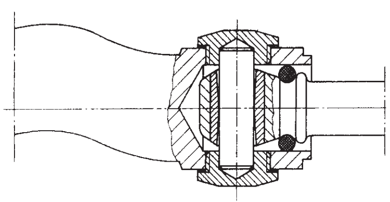
Every manufacturer of this pump still uses some variation of his original universal joint, a variation of the ball and socket joint found in our own shoulders and hips.

Unfortunately, mechanical universal joints are not self-lubricating nor do they have the elastic locating tendons and muscles that we have in our shoulders and hips. A "pin" must be used to locate and secure the "ball" within the "socket."



Original Progressive Cavity Pump Design with Pin Joint and hollow shaft

Typically, the "ball" part of the pin joint is placed on each end of the transition shaft between the eccentrically revolving rotor and the concentrically revolving drive shaft. This part is most often referred to as the coupling rod or connecting rod. The socket parts of the joint are normally on the rotor "head" and the drive shaft.



Original Pin Joint Design (modified for replaceable bushings)

Limitations

Dr. Moineau's joint had several limitations, the most notable being that it was an "open" or unsealed design. This exposed the joint components to the pumpage. Since the pumps are frequently used to pump corrosives and/or abrasives, the life of the joint was severely limited. Manufacturers have offered a number of solutions to this problem. Most try to locate some type of "O" ring or "lip" seal inside the "socket" part of the joint on the drive shaft or rotor head.

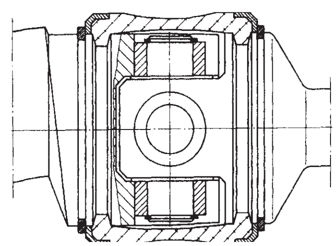
Normally, these designs are ineffective because they cannot accommodate all the dynamic forces of the joint. The most effective method is to completely seal the joint with an elastomeric cover, lubricate the joint and ensure against intrusion of the pumpage by positively sealing the joint.

An inherent limitation of the universal joint is the locating pin. To allow the full range of motion to accommodate the eccentricity of the rotor, the locating hole in the ball part of the joint must be shaped like an hourglass. The high thrust load of the progressing cavity design is then concentrated into the interface of these components.

This was not a particularly serious problem until progressive cavity pumps of large, high pressure designs were developed in the late 1950s and early 1960s. The unprotected pin joints failed very quickly when exposed to capacities of greater than 180 gpm (40 m^3/hr) and pressures of more than 450 psig (30 bar). To solve this problem, manufacturers started to investigate other types of universal joints and drive train arrangements.

Double Pin Joints

An obvious answer was to develop a design that incorporated two pins in each universal joint. In theory, this design should allow twice the loading of a single pin joint. Unfortunately, this is not the case. With the double pin design, each pin takes the same loading. They do not share the loading. Elimination of the hourglass-shaped hole in the coupling rod also restricted the range of movement, leading to more material-related failures. The joint also became larger, increasing the size of the pump and restricting flow into the pumping elements. This raised the net positive suction head requirements and restricted the viscosities of liquids which could be pumped.



Double Pin Joint Design

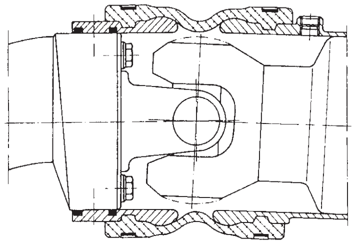
This design also increased the manufactured cost of the socket on the drive shaft and rotor head, two of the more common wearing parts. Joint sealing and lubrication were still important considerations.

Cardan Joint

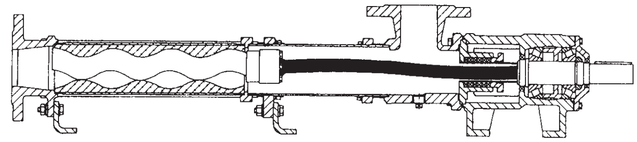
Cardan Joints

A further refinement, capitalizing on the purported advantages of the double pin joint, is the cardan joint. Everyone should be familiar with this design because of its universal use in the automobile industry.

Accepted and refined over the last 100 years, this joint can absorb massive amounts of thrust load and torque. Dynamic loading is distributed over large surface areas covered with needle bearings. Even when used in applications requiring several hundred horsepower, it has proven extremely reliable and durable.

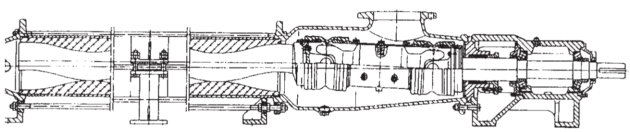


Cardan Joint



Flexible Shaft PC Pump showing Shaft Deflection necessary to accommodate Rotor Eccentricity

But, when applied to a pump, it too has some limitations. The bearings are normally only protected against intrusion from the pumpage by lip seals. Just as these seals are unacceptable for pin joint pumps, so are they unacceptable for cardan joint pumps. While produced in large numbers and relatively inexpensive, cardan joints are normally not practically used in applications for less than 75 hp, the power requirement for a fairly small automobile but a fairly large progressive cavity pump. For medium to small pumps, the cardan joint is too large and will restrict the pumping element inlet.



Sectional View of Large PC Pump equipped with sealed Cardan Joints

An interesting characteristic of the cardan joint is that it must operate with a great deal of angularity. It must “flex.” This motion is required to have the needle bearings rotate so they will wear evenly.

It becomes a latent advantage and helps to reduce the length of the progressive cavity pumps, a common complaint raised by customers. This will be discussed in more detail later.

Flexible Shaft PC Pumps

One of the more innovative solutions, used to transfer the concentric motion of the drive shaft into the required eccentric motion of the rotor, is the flexible coupling rod design. In this configuration, the coupling rod is replaced with a flexible shaft. The shaft is usually made of a relatively strong but flexible material.

The two most common metals have been 400 series stainless steel and titanium.

Unfortunately, titanium is not very cost effective and 400 series stainless steel can corrode easily in many environments. The common solution is to apply a corrosion resistant thermoplastic coating to the 400 series stainless steel shaft to prevent corrosion.

It is important to understand that this flexible shaft does not really “flex,” as repeated bending in one spot on the shaft would build up heat and reduce the material strength in the isolated area, causing premature failure. The flexible shaft is actually deformed into an “S” shape by the thrust load experienced during pumping.

This deformation is the cause of both the flexible shaft’s success and its failure. For the shaft to be properly deformed, it must be of uniform strength throughout its length. During the machining process, the crystalline structure of the shaft is disturbed and certain spots in the shaft will have less strength than others.

Under compression, the rod will break in these spots. To alleviate this problem, the crystalline structure of the machined piece must be “normalized”, or realigned, into a homogeneous state. This is usually done by heat-treating, shot blasting or forging the part. This too can substantially increase the cost. Since the flexible shaft requires that it be deformed under compression for proper application, the pump cannot be run in reverse. Reverse operation is quite common for progressive cavity pumps.

For suction lift applications, there is a decided advantage to running the pump in reverse, as there is then no stuffing box on the suction side of the pump, minimizing the loss of prime and dry running. The thrust loading is then reversed and the shaft is no longer under compression. Under tension, the shaft will flex in isolated spots and soon fail.

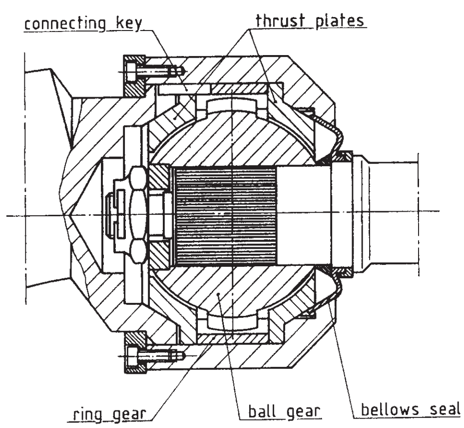
While compression of the shaft is necessary, too much compression is also a problem. If the pump is deadheaded by a momentary pipe blockage or inadvertent valve closing, pressure and thrust loading on the pump drive train will increase. Since these are positive displacements pumps, if they are operated against a closed discharge, pressure and thrust loading will increase until something breaks. On flexible shaft pumps, it is the flexible shaft that breaks.

Flexible shaft pumps also tend to be quite long and are necessarily designed for a rather narrow range of flow and pressure capabilities. Few manufacturers use this design and generally apply them to low pressure applications for the municipal sludge service. The inherent sensitivity of the flexible shaft makes its proper function very application-specific and narrow in its scope of industries.

Gear Type Joint

Gear Type Joint

The gear type universal joint was initially developed for high-pressure applications. Modified from a gear type shaft coupling, it was adapted to progressive cavity pumps for its ability to handle high thrust loads but to do so in a compact envelope.



Cross Section of Standard Gear Type Universal Joint

Like the pin joint, it is an extension of the ball and socket design. While high torque loading is considered a distinguishing characteristic of the gear joint, its torque loading capabilities are more limited than most users realize.

A ball gear, which is connected to a splined coupling rod by a bearing lock nut, interfaces with a ring gear that is attached to either the rotor head or drive shaft with two rectangular keys. They keys have normally less mass and strength than the pins used in the equivalently sized pin joint pump. The ball and ring gears are hardened because of the small contact area between the two gear sets.

To accommodate the full range of motion, the gears on the ball must be curved axially and radially or “crowned and contoured.” As the necessarily curved faces of the ball gear teeth contact the flat faces of the ring gear, the small contact area requires strengthening and the same normalizing, as mentioned on the flexible shafts.

If the pump is jammed, high torque loading will not damage the gears or the keys, since they are hardened. Failure normally occurs on the softer rotor head key slots or the coupling rod. Unfortunately, these are two of the more expensive components in the pump. The true strength of the gear joint is its ability to handle very high thrust loads.

High Thrust Loads

Thrust load in progressive cavity pumps is determined very simply. Differential pressure (psi or pascals) is multiplied by the cross section of the rotor diameter (in^2 or m^2) to arrive at the loading (lbf. or newtons). Rotor diameters must necessarily increase, if the other design characteristics of helix pitch length and eccentricity are held constant, to increase the flow capability of the pump.

High capacity pumps have higher drive train thrust loads than low capacity pumps and high-pressure pumps have higher drive train thrust loads than low-pressure pumps. High capacity, high-pressure pumps have very high thrust loads.

The gear joint is equipped with thrust plates on each side of the ball gear. It is designed to distribute thrust load over a large surface area to dissipate the load. The trade-off for this capability is the generation of a great deal of friction which in turn generates heat. Design compromises are therefore necessary to accommodate the limitations of lubricants and materials.

To minimize friction, the range of motion must be restricted and the joints are separated to maintain angularities of 1^o to 2^o. The resultant long coupling rod makes the pump quite long, an already-discussed user complaint. One alternative to a longer pump is to house the coupling rod in a hollow drive shaft, to utilize the space in the stuffing box and bearings for accommodation of the longer coupling rod. This increases the drive shaft diameter and manufactured cost.

The larger shaft diameter accelerates wear of packing because of the higher surface velocities at equivalent rotational speeds (rpm) and dramatically increases the cost of mechanical seals, bearings and bearing casings.

The hollow shaft is also susceptible to filling with fibers or solids as the eccentrically rotating coupling rod tends to work in conjunction with the rotating shaft as a decanter, forcing solids into the rear of the shaft cavity. If solids compress to the point that the motion of the coupling rod is restricted, it will break.

Gear Type Joint

Reduction of Heat

Since reduction of heat becomes a primary consideration in the design of a gear joint, lubrication and materials selection is extremely important. Since grease is more limited in its temperature resistance than oil, special metallurgy must be considered in grease lubricated gear joints. Since the torque transmitting components (ball gear and ring gear) must be made of hardened steels, the most important design variable becomes the thrust plates.

In grease-filled joints, the thrust plates must function like sleeve or "Babbitt" bearings, which are normally made of a relatively soft, self-lubricating metal such as lead or bronze alloys. Since they are softer than the hardened ball gears, lubrication is extremely important to help prevent deformation under high loading. Deformation of the thrust plate can lead to failure of the bellows seal. Optimization of joint life by matching materials and lubricants is therefore an important consideration.

Since oil can withstand high operating temperatures without breakdown, materials selection is not quite as critical, and manufacturers with oil-filled gear joints commonly use cast iron thrust plates which are less prone to deformation over time than the lead or bronze thrust plates. Maintenance on oil filled joints is inherently much more difficult than on grease filled joints and can normally only be performed by taking the pump out of service and performing all necessary repairs on a work bench.

Maintenance Repair

Maintenance and repair of the gear type universal joint is the major complaint lodged by its users. The individual components are very expensive as they are all custom manufactured by the pump vendors and not used or accepted by other manufacturers who use universal joints in their equipment. Sealing of the gear joint is also very difficult, as all the components are internal to the joint.

Of course, integrity of the joint lubricant is paramount to its longevity. All the metal components of the joint are secured in a cylindrical cover that is affixed to the rotor head with a pin and set screw. Sealing integrity between the rotor head and this cylindrical cover is effected by an "O" ring.

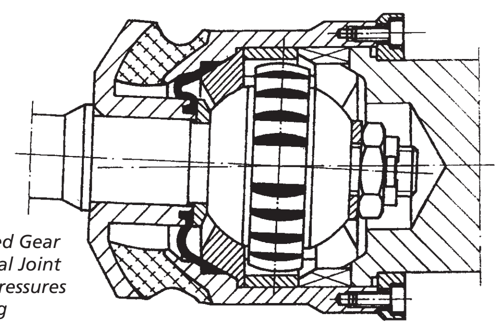
Unfortunately, the cover must be slid over the "O" ring, often leading to displacement, deformation or separation of the "O" ring. Since the "O" ring is internal to the joint, it is impossible to inspect its integrity.

On the coupling rod side of the joint, the seal must be dynamic to accommodate the eccentric motion of the coupling rod. A "bellows" seal is used here, constructed of the appropriate elastomer. Since elastomers are not dimensionally stable under changing temperatures, the bellows seal must be clamped in place.

This is also critical to accommodate the expansion of air or hydrocarbon vapors in the joint, as temperatures in the joint increase during pump operation. Some manufacturers reinforce this rubber bellows with fibers to prevent displacement of the bellows seal because of this expansion. The bellows is clamped on its internal diameter by compression between a ring on the coupling rod and the front thrust plate. On its outside diameter, the bellows is clamped between the same thrust plate and a retaining plate that affixes to the cylindrical universal joint cover.

Some designs have this retaining plate threaded on its outside diameter, so that it screws into the cylindrical cover plate. Turning of this plate while it effects compression with the bellows seal can often displace or damage the bellows seal. Some designs effect this compression by drilling and tapping axial holes in the cylindrical cover and fixing the retaining plate with screws. In either case, the use of threaded components in the pumpage leads to corrosion and fusing of the parts.

This makes disassembly very difficult; and, if heat is applied to disassemble the parts, additional damage to the components usually results. Because all sealing components are internal to the joint, which is encased in a metal cover, it is not easily damaged by tramp metal or glass; but, it cannot be inspected for sealing integrity prior to installation, which is unfortunate because proper lubrication is inherent to this device's longevity.



Double Sealed Gear Type Universal Joint for suction pressures above 50 psig

Advances in Pin Technology

Because of the inherent difficulties with all the other universal joint types, manufacturers of progressing cavity pumps have re-examined Dr. Moineau's original pin joint design.

By positively sealing the pin joint and lubricating it properly, as was discovered with the gear joint, pin joint life increased dramatically. A simple rubber cover, molded to minimize restriction of fluids into the pumping elements, can be easily sealed with the same metal bands used to connect hoses to metal fittings. The metal bands are available in a wide range of metals, including 304ss, 316ss, titanium and Hastelloy C, to ensure compatibility with the pumpage.

New Materials

By using the materials lessons learned through experimenting with flexible shafts and gear joint components, new materials were utilized for the pin joint components. Since the pin is sealed and lubricated, it no longer had to be constructed of the same materials as the wetted parts of the pump. By inserting replaceable bushings in the socket head and ball of the joint, hardened, bearing-like materials could be used. This substantially increased the thrust and torque load capabilities of the pin joint.

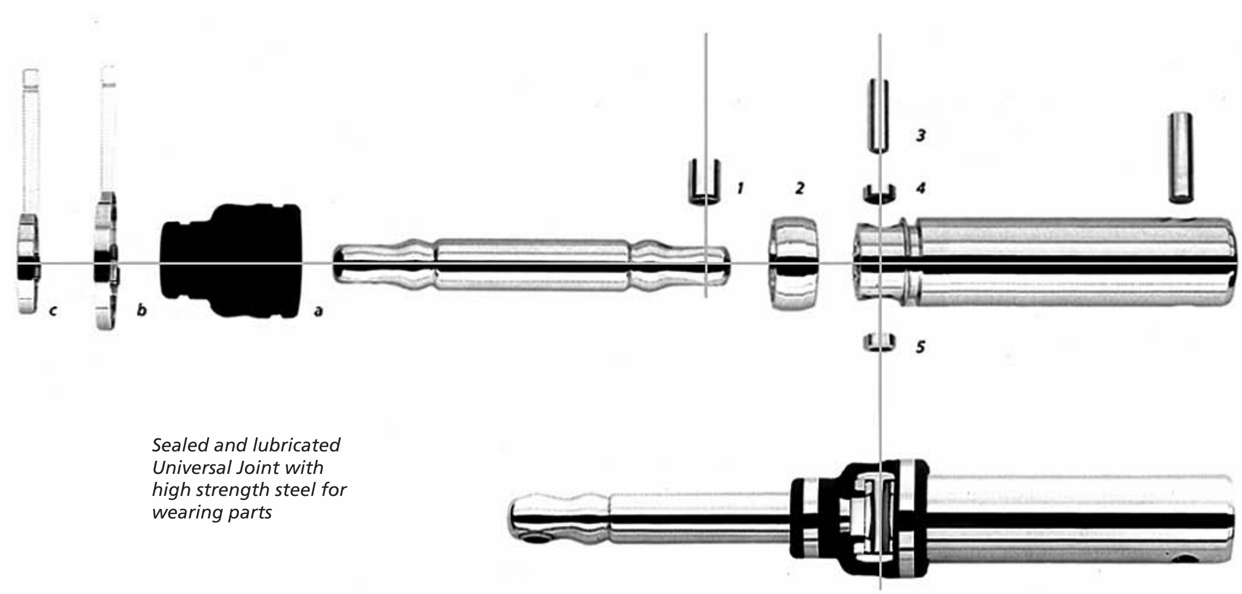
The parts can be easily and inexpensively replaced as well, further reducing the long term operating costs. Pin joints can also be fitted with split metal covers to offer the protection from being cut or torn by tramp metal or glass.

The advent of synthetic lubricants, some filled with PTFE that impregnated the surfaces of the intermeshing parts, further increased capabilities, especially in regard to thrust loading of the pin joint.

The use of special lubricants is extremely important, as inferior formulations are likely to vaporize and explode the rubber joint cover or break down under the temperature or load requirements. This is true for all lubricated joints, as inferior lubricants are prone to the evaporation of solvent residues or water components.

Under high thrust loads, the inherent pressures and heat can 'coke' certain petroleum components, which is why synthetic materials are preferred. As a general rule, the lubricants should be free of thermal decomposition at temperatures up to 570° F (300° C).

Pin joints of this type are now being used on applications with thrust loads of up to 8,400 lbf (37,500 N) and torques to 1,800 lb/ft (2500 Nm), with tens of thousands of successful operating hours. This equates to performance ranges as high as 1800 gpm at 90 psi or 160 gpm at 500 psi (410 m^3/hr at 6 bar or 36 m^3/hr at 34 bar). For performance beyond this range, other types of joints must be employed.



Sealed and lubricated Universal Joint with high strength steel for wearing parts

Conclusion

The gear joint and the cardan joint are the two rational choices for high head and high-pressure applications.

Because high head and high flow result in high horsepower requirements, the cardan joint appears to be a logical choice. As the rotors for high flow conditions are necessarily large, the cardan joint does not impede flow due to its relative size. Its ability to withstand severe loading is unsurpassed and its cost in high power requirement applications (above 75 hp or 50 kw) is very low, because of its high volume use in transportation applications.

High Head/ High Flow Applications

The cardan joint, like the other universal joint designs, must be sealed, isolated from the pumpage and lubricated.

The sealing mechanism must be designed to accommodate the high angularity associated with the cardan joint, and the same hose bands used on the pin joint cover can be employed to ensure sealing integrity. Due to the high volume of lubricant required for the joint and the necessity to freely circulate within all of the bearings inside the cardan joint, oil lubrication is best suited for these relatively large units.

The only inherent limitation of the cardan joint is its capacity to accommodate high pressures in the suction casing. The standard design, an elastomeric bellows seal, required to be very flexible, can only accommodate about 25 psig (1.7 bar) of pressure around the joint. This severely limits the application of the product in suction lift applications which require reverse rotation.

Actually, all of the sealed universal joints have certain limits as to their ability to handle high suction pressures. Sealed pin joints and gear joints are both limited to about 45 psig (3 bar) of suction head.

Pressures higher than this will cause the elastomeric joint covers to implode and become pinched by the ball and socket action of the internal mechanical joint components.

Double seals on the gear joints can help alleviate this condition up to 75 psi (5 bar). Pin joints can be preloaded with grease to evacuate all air and vapors, by drilling holes into the coupling rods and fixing grease fittings for the filling operation. Pin joints with these modifications can now withstand suction pressures to 350 psi (24 bar).

Summary

Since Dr. Rene Moineau invented the progressive cavity pump in the early 1930's, a variety of drive mechanisms have been employed to transfer power from the concentric rotation of the drive shaft to the eccentrically revolving pump rotor.

Over the last several decades, a number of devices have been employed. They include double pin joints, cardan joints, flexible shafts and gear-type universal joints.

The pin joint, used in Dr. Moineau's original progressive cavity pump design, has endured and is suitable for all applications, save those with extremely high pressures and flows. Because of the high thrust loads, these applications require either cardan joints or gear joints. The pin type universal joint has enjoyed renewed popularity as its performance capabilities have been increased by using positive sealing mechanisms, improved lubricants and better materials.

The sealed pin type joint has become the preferred design of maintenance and operating personnel because of its good value and easy maintenance. In Europe, Canada, and Asia, the pin joint is now the standard joint for all industries. In the USA, pin joints are preferred in the chemical, petroleum, food, and construction industries and are becoming more accepted in the paper and waste treatment industries. The continued acceptance and refinement of Dr. Moineau's application of the pin-type universal joint to the progressive cavity pump is as much a tribute to his design abilities as the progressive cavity pump itself.