GLANDLESS PUMPS AND VALVES - A TECHNICAL UPDATE

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The use of glandless pumps and valves is increasing particularly for reasons of safety and environmental protection. The main types of glandless pumps and valves are described and their advantages and disadvantages examined. The factors to be taken into account when selecting the type of pump to be used in a given situation are briefly considered.

Pumps, valves, glandless.

INTRODUCTION

The use of glandless pumps is currently increasing despite the fact that their initial cost, and sometimes their maintenance costs, can be higher than those of a conventionally sealed pump.

A number of very different types of glandless pumps are available, each with their own particular advantages and disadvantages, but all offering the major benefit of totally leak-free operation. This is a feature which cannot be guaranteed with conventional pumps using packed glands or mechanical seals.

Most conventional pumps use a shaft to transmit power to the moving parts from an electric motor mounted outside the pump itself. The point where the shaft passes through the pump casing is an obvious potential leak path, and problems in this area are the most frequent cause of pump downtime.

In practice the leakage from conventionally sealed pumps varies enormously. However, typical leakage figures are 60 cm^3/h for a packed gland and 3 to 12 cm^3/h for a mechanical seal.

In many everyday pump applications a small amount of leakage from a shaft seal is perfectly acceptable, but this is not the case where the fluids handled are toxic, radioactive, flammable, corrosive, noxious or very hot. Apart from the moral duty of safeguarding employees, there are the legal requirements of the Health and Safety Acts and now, more specifically, the Control of Substances Hazardous to Health Regulations (COSHH).

In other cases, while there may be no immediate danger to personnel, there could be long-term effects on the environment due to chemical emissions - as in chlorofluorocarbon (CFC) recovery, for example.

Apart from the safety angle, there are a number of other instances where the use of a glandless pump may be preferred. This is the case, for example, where very precious fluids are being handled and leakage would cause an expensive loss of product.

Glandless pumps may also be preferred in high volume continuous processes, where any downtime caused by seal failure could be very costly in terms of lost production.

Some industries - particularly foods and pharmaceuticals - may have a need for glandless pumps in situations where leakage must be avoided for reasons of hygiene.

Although developments in materials technology over the past few years have resulted in new packing materials with improved performance, packed glands are 'designed to leak' (albeit very slightly) - otherwise they would burn out very quickly. Regular maintenance attention is therefore needed to maintain a satisfactory sealing performance.

A common alternative to the packed gland is the mechanical seal, of which there are many types in varying degrees of complexity. In all of them a virtually (but not entirely) leak-free seal is effected between the mating surfaces of the spring-loaded rotary sealing ring on the pump shaft and a stationary sealing ring on the pump casing. A thin film of the pumped liquid is formed between the mating surfaces to provide lubrication and if this become excessive, leakage will occur. Moreover, in cooling the mating surfaces, vaporisation of the product will inevitably take place, leading to a continuous emission of vapour into the environment.

Also, although mechanical seals are normally less leaky and need less maintenance attention than packed glands, they do suffer the major disadvantage that the seal can fail suddenly and without warning.

Against this background, a pump design which completely avoids the need for sealing has obvious attractions, and this is why the use of glandless pumps is increasing.

Let us now take a look at each of the main types of glandless pumps, which are: *magnetically driven, canned motor, peristaltic, diaphragm, and power fluidic. We will* consider each of these in turn.

MAGNETIC DRIVE PUMPS

The development of magnetic drive pumps has received new impetus from the advent of new permanent magnet materials such as samarium-cobalt and neodymium-iron-boron, which give much higher power and a longer life than earlier materials.

In a magnetic drive pump "see Figure 1", the pump shaft is not directly connected to the motor but has an annular magnet around it at the drive end. This is enclosed in a non-magnetic shroud which hermetically seals the inner chamber of the pump and prevents leakage.

Around the outside of the shroud, but not in physical contact with it, is a bell-shaped driving magnet which is coupled to the motor shaft. This transmits the driving torque, via the interconnecting electro-magnetic fields, to the inner magnet ring on the pump shaft.

One of the big advantages of magnetic drive pumps is that they utilise standard off-the-shelf motors whereas some kinds of glandless pumps require special motors. All the benefits of standard motors, with any enclosure from drip proof to flameproof, can therefore be utilised in a magnetic drive pump.

Another advantage is that nearly all types of pumps with conventional shaft seals can be designed to take a magnetic drive. Usually not only are the internal pump components identical but the connection dimensions are maintained, making it possible to exchange a pump with a shaft seal for a similar one with a magnetic drive.

Products with viscosities of 37 mm^2/s can be handled by magnetic drive pumps, while temperatures can range as high as 400°C, depending on the magnetic materials used and the drive design.

Aluminium-nickel-cobalt (Al-Ni-Co) alloys, which are among the oldest magnet materials used for pump drives, will retain their magnetic properties at high temperatures but they are not acid resistant and can only transmit a relatively low torque. Also, if slippage occurs in a synchronous drive coupling, the alternating magnetic field set up can cause complete demagnetisation.

Samarium-cobalt (Sm-Co) alloys have high resistance to demagnetisation and are suitable for use at temperatures up to about 250 to 300°C. Higher temperatures will tend to lead to irreversible losses of magnetic flux density and loss of torque.

The latest neodymium-iron-boron (Nd-Fe-B) alloys offer the benefit of higher flux density than most materials, giving a higher torque for any given magnet dimensions, but the downside of these materials is a rapid irreversible drop in torque capability at temperatures above 100°C.

Among other possible magnet materials are ceramics made from low-priced iron oxide and strontium carbonate. Although chemically very stable, these materials are only suitable for synchronous couplings with low torque requirements and their performance at 160°C is only about half that at room temperature.

Materials used for shroud construction include stainless steel, Hastelloy C, plastics or ceramics. Where an electrically conductive shroud is used, rotation of the magnets sets up eddy currents which generate heat in the shroud. It is therefore necessary to arrange for the heat to be dissipated in order to avoid vaporisation of the product. This is done by circulating a small partial flow of the pumped product (approximately 10%) through the gap between the inner magnet and the shroud.

Apart from producing heat, the eddy currents also result in torque losses, which increase with speed. This means that the efficiency of a magnetic drive pump decreases with speed when an electrically conductive shroud material is employed.

The main applications of magnetic drive pumps are in the chemical and process engineering industries, and many of them are in hazardous area zones. Although the magnetic drive is not subject to the regulations concerning electrical machines in hazardous areas, care must obviously be taken that the maximum surface temperature does not exceed the temperature class required.

As we have seen, drives with Sm-Co magnets can cope with process media at temperatures of about 300°C, but it must be remembered that the higher the temperature the greater are the irreversible and reversible losses of magnetic flux density. For example, at 300°C, a magnetic drive will typically transmit only about 70% of the torque obtained at 20°C. and this must obviously be taken into consideration when determining the drive size.

Care is also needed to ensure that magnetic drive pumps are never operated without liquid, otherwise they will suffer a very rapid rise in temperature. To prevent this, particularly in hazardous area zones, a level control or other safeguard should be provided.

The shaft of a magnetic drive pump rotates in product-lubricated sleeve bearings which are typically made from extremely tough materials such as silicon carbide to give good all-round performance; but such pumps are not usually recommended for handling abrasive liquids.

A summary of the main advantages and disadvantages of magnetic drive pumps is given "see Table 1", for details of essential and recommended control features "see Table 2".

TABLE 1 - Advantages And Disadvantages Of Magnetic Drive Pumps

Advantages

Easy maintenance

High temperature resistance (typically 400°C, but depending on magnet material and design)

Low requirement for partial flow (10%)

Modular construction (available for all pump types)

No special tests needed for standard Ex 'd' motors

Power up to 100kW at 2900 rpm

Viscosities up to 37 mm^2/s

Drive can 'slip'

Disadvantages

Hard bearing materials subject to damage

Must not be run dry

Not recommended for abrasive liquids

High inertia has to be 'built in' to reduce motor acceleration or speed has to be 'ramped up'

Drive can 'slip'

CANNED MOTOR PUMPS

A popular alternative to the magnetic drive pump in applications where leakage must be avoided is the canned motor pump "see Figure 3". This has a special motor built into the pump itself instead of a standard motor mounted externally. Some versions employ a flameproof motor and can be used in hazardous areas.

The centrifugal impeller(s) and the motor rotor are both mounted on the same shaft and because all the moving parts are completely contained within the pump casing there are no shaft seals to cause leakage problems.

Normally the shaft is supported by product-lubricated bearings, so pumps of this type are not usually suitable for handling abrasive liquids or those of low lubricity.

A motor cooling fan cannot be fitted because the shaft is totally enclosed so the process medium is also used to cool the motor. This places certain limitations on the temperature of the product. If it has poor heat transfer characteristics or is operating near its flash point, it is necessary to provide external heat exchangers or other safety features to protect the motor against cooling failure.

Also, because the fluid in the pump is heated up by both eddy current losses in the can and electrical losses in the motor, the temperature rise is much higher than is the case with magnetic drive pumps. For this reason the use of temperature probes to shut down the pump at the maximum allowable temperature is regarded as essential for canned motor pumps operating in hazardous areas.

For use at low temperatures, canned motor pumps can have the stator filled with foam to prevent condensation in the windings.

As with magnetic drive pumps, care is needed to ensure that a canned motor pump is not run dry. If this happens the motor will not be cooled, the bearings will not be lubricated and the can itself may fail. Similar problems can occur if the pump is operated in the reverse direction due to incorrect wiring. A number of different control methods can be used to guard against all these eventualities and keep the pump operating within defined limits "see Table 2".

TABLE 2 - Controls For Magnetic Drive And Canned Motor Pumps

Control	Magnetic Drive	Canned Motor
Motor protection switch	Recommended	Considered essential
Bearing temperature monitor	Recommended	Considered essential
Fluid level control	Considered essential	Considered essential
Pressure monitor	Recommended	Recommended
Stator temperature monitor	Recommended	Recommended
Current demand monitor	Optional	Recommended
Other Features		
Leakage indicator	Optional	-
Stator position indicator	-	Optional
Stator filled with foam	-	Optional

Because the containment can is interposed between the motor stator and the rotor, a canned motor pump operates at lower efficiency than a sealed pump. Efficiency is further reduced by the recirculation of pumped fluid to cool the motor and lubricate the bearings, so that in practice an overall efficiency of around 75% is usually obtained, which is much the same as that of a magnetic drive pump.

Besides handling hazardous chemicals - like liquid sulphur dioxide (SO_2), for example - canned motor pumps are used in the food and beverage industries and also for pumping refrigerants in air conditioning and refrigeration plants.

Also, because of their totally leak-free and maintenance-free benefits, smaller canned motor pumps are widely used in domestic central heating systems.

"See Table 3" for the advantages and disadvantages of canned motor pumps.

TABLE 3 - Advantages And Disadvantages Of Canned Motor Pumps

Advantages

Compact

Common shaft

Good for low temperatures (with foam filled stator)

Extreme high system pressure ability due to casing support (100 bar)

Low noise (<60 dB/A)

Power up to 105 kW

Viscosities up to $100 mm^2/s$

Temperatures up to 180°C

Disadvantages

Hard bearing materials subject to damage

Susceptible to scale build up e.g limescale or magnetite

Motor certification can be difficult

Not recommended for abrasive liquids or those of low lubricity

Must not be run dry

Modifications to impeller diameter upset axial balance

Temperature monitor required

PERISTALTIC PUMPS

Peristaltic pumps - perhaps best known for their use in laboratories and dialysis machines - work by a squeezing action on an elastomeric tube, which has the effect of inducing the product to flow along the tube.

For many years, peristaltic pumps were limited by the fact that the tube materials available had a very short working life and were usually only suitable for delivery pressures of less than 2 bar. But in recent years, new reinforced composite tube materials and developments in the mechanism of actually inducing the flow have increased both the output pressure and the tube life.

Even so, the maximum tube life that can be expected is still quite low, an average of 2,000 to 3,000 hours being regarded as fairly typical - or 5,000 hours under the most favourable conditions, Coe (1). These figures depend of course upon the pressure, temperature and chemical aggressiveness of the process medium as well as the tube material and pump design. Often circumstances will combine to produce a tube life very much lower than 2,000 hours.

There is room for argument about how these figures compare with the average time between breakdown of conventional pumps, but in any event the problem of tube failure can usually be overcome by planned replacement of the tubing at regular intervals, depending on the duty.

With regard to pressure, most peristaltic pumps still operate at less than 2 bar, although with some of the newer composite reinforced hoses pressures up to 15 bar are practicable.

Besides being glandless and valveless, peristaltic pumps are inherently self-priming and have no moving parts in contact with the liquid. They are therefore particularly suitable in applications where the process medium must not contaminate the pump or vice versa. Also, the fact that the tube can usually be changed quite easily opens up possibilities for handling a variety of different media without any risk of cross-contamination between consecutive batches.

The pumps have a gentle action which means that they can be used for shear sensitive products with little risk of damage. One UK manufacturer is reported to be using them for pumping whole strawberries into yoghurt.

Other advantages include the ability to maintain consistent flow rates, making them suitable for metering duties, and the capability of handling corrosive and abrasive products provided the hose material is chosen to meet these requirements.

Pumps with a number of different mechanisms have been developed to produce the squeezing action on the tube. In a typical pump, "see Figure 2", the tube lays around a curved track and is squeezed in turn by a number of rollers mounted on a rotor. In some units, each of the rollers is individually powered by a planetary gear system. Another design squeezes the tube by the use of profiled compression shoes, while yet another utilises a straight tube which is acted upon by a series of fingers operating in sequence.

Flow rates obtainable typically range from almost zero to about 1,000 l/m, the bore size of a peristaltic pump being usually limited for practical reasons to not more than 100mm. The time taken for the tube to retain its shape determines its suction ability and self-priming characteristics.

A novel attempt to improve on the peristaltic principle in terms of suction and delivery pressures has been reported by Tom Robertson, a former Harwell engineer. Instead of running the process medium inside the elastomeric tube, this device runs it outside and surrounds it with a rigid outer tube "see Figure 4". Inside the elastomeric tube is a third inner tube containing a working fluid (air or hydraulic oil) and arranged in a series of compartments designed either to suck the elastomeric tube in against the inner tube or push it out against the outer tube.

By inflating and deflating the compartments in turn, the process medium is forced to move along between the elastomeric and outer tubes. It has been reported that this device can be applied to the pumping of corrosive, highly toxic or radioactive fluids at pressures which cannot be safely handled by conventional peristaltic pumps, Eureka (2).

TABLE 4 - Advantages And Disadvantages Of Peristaltic Pumps

Advantages

Inherently self priming (depending on strength of tubing)

Interchangeable tubes avoid cross-contamination between batches

Suitable for handling sterile products

Suitable for handling abrasive, corrosive and shear-sensitive products

Suitable for metering duties

Disadvantages

Generally low tube life (depending on tube materials, duty etc)

Not usually suitable for delivery pressures above 2 bar (or 15 bar with composite tubes)

Bore size usually limited to 100mm

Creates pressure pulsations in pipework

Not all designs offer containment in event of tube failure

DIAPHRAGM PUMPS

Diaphragm pumps are available in a number of different types and a wide range of sizes, using single or double diaphragms and handling an extensive range of products, from thin volatile liquids to viscous and abrasive slurries, corrosive or radioactive materials and, in some cases, fluidised powders.

A common type is the air-powered double diaphragm pump "see Figure 5", offered by a number of manufacturers. This has two pump chambers operating alternately, each with its own dish-shaped flexible diaphragm. The diaphragms are connected centre-to-centre by a rod and air is admitted behind each of them in turn. This creates a reciprocating side-to-side action so that as one diaphragm displaces the process medium from its pump chamber, the other diaphragm is pulled back towards the centre of the pump, creating suction in the other chamber and causing the product to flow into it. At the end of each stoke the air pressure is directed to the other side of the pump so that what was the suction chamber becomes the displacement chamber and vice versa.

Being entirely air-operated, this type of pump can be used safely in hazardous areas and offers the capabilities of providing infinitely variable capacity and discharge pressure by simple adjustment of the air supply.

Commonly available for pipe sizes from 15mm to 75mm, with flow rates up to 870 l/m, air operated double diaphragm pumps typically work at output pressures up to 8.6 bar and give suction lifts over 8m.

In addition to the double-diaphragm pumps, a number of different kinds of single diaphragm pump are available. These range from pocket-size glandless air-operated units to large process pumps in which a plunger is used to exert force on a hydraulic fluid, which in turn acts upon the diaphragm.

The latter are not strictly speaking glandless pumps because a gland is needed for the reciprocating plunger. However, the gland is isolated from the process medium by the diaphragm and special duplex diaphragms incorporating a rupture sensor have been developed for use where zero leakage is required, or where the process fluid must not come into contact with air.

Large process single diaphragm pumps are particularly suitable for low flows at high *pressures. With a PTFE diaphragm, duties of 350 bar and 150°C are possible, with a* diaphragm life expectancy of 20,000 hours, while metal diaphragms, suitable for services up to 700 bar and 200°C, have a typical working life of 8,000 hours, Dalley (3).

Other single-diaphragm pumps utilise mechanical systems, such as cams, rollers or reciprocating pistons, to actuate the diaphragm directly, using power supplied by an electric motor, or petrol or diesel engine. One of the latest of these, due to be launched in the UK in 1991, uses a diaphragm clamped between the curved surfaces of an upper and lower casing, the space between the diaphragm and the lower casing forming the pumping chamber "see Figure 6". The diaphragm is displaced by a rotor assembly carrying four rollers. As the rotor rotates, each of the rollers runs along the surface of the diaphragm, changing its configuration so that it is pressed against the lower casing at various points in turn. This creates a displacement action which is gentle, non-agitating and positive.

There is virtually no stretching of the diaphragm and this facilitates a long, trouble-free service life even with the most recalcitrant, gritty or stringy solids in suspension.

Applications envisaged for this pump include the efficient transfer of sewage sludge, slurries, shear-sensitive liquids, pottery slip, pastes, viscous liquids and other media with similar characteristics.

The pump is self-priming and can run dry for long periods. It is self-sealing and will sustain a vacuum when static.

Flow rates are up to 70 l/min and the maximum discharge pressure is 2 bar.

TABLE 5 - Advantages And Disadvantages Of Diaphragm Pumps

Advantages

Suitable for aggressive, abrasive and shear sensitive media

Suitable for a wide range of viscosities

Inherently self priming

Can run dry for long periods

Air-operated types inherently safe in hazardous areas

Disadvantages

Pulsating delivery

Temperature/pressure limitations

Diaphragm life limited

Diaphragm failure could be more catastrophic than seal failure on conventional pump

Not all designs offer containment in event of diaphragm failure

POWER FLUIDICS

The particular safety problems of the nuclear industry have led to the development of a number of completely passive pumping methods for liquids and slurries, using equipment with no moving parts and hence no potential leak path. These techniques have been pioneered in this country by the Power Fluidics Centre at the Springfields Laboratories of the UKAEA, along with other power fluidic devices for liquid diversion, liquid mixing and ventilation control.

One of the simplest power fluidic pumping systems utilises a 'reverse flow diverter' (RFD), "see Figure 7". This consists of two convergent nozzles separated by a small gap in a conventional pipework 'T'. One nozzle is connected to a gas piston cylinder and the other to the discharge pipework, the third leg of the 'T' being connected to the liquid supply vessel.

Pumping is carried out cyclically in three phases. First, liquid is drawn by suction into the gas piston cylinder via the RFD. Then a controller switches to the drive cycle, which feeds air to the gas piston, pressurising the cylinder. This forces the liquid back through the RFD and through the discharge pipework. Once the cylinder is empty, the controller switches again to allow it to vent before the cycle is repeated.

An alternative to the RFD uses the fluidic diode, which has been described as a 'leaky non-return valve'. The diode is a vortex chamber with a tangential port and an axial port. Flow into the tangential port creates a vortex, setting up a high resistance path. Flow into the axial port goes straight through the tangential port without creating a vortex, giving a low resistance path. Arranging two diodes to oppose each other in conjunction with a charge vessel, which is alternately pressurised and depressurised, creates a pumping action similar to that of the RFD "see Figure 8".

"See Table 8" for advantages and disadvantages of power fluidic pumps.

TABLE 6 - Advantages And Disadvantages Of Power Fluidic Pumps

Advantages

No moving parts in contact with fluid

Maintenance free throughout design life

Suitable for corrosive and abrasive materials

Gentle action - low shear damage

Easily cleaned

Suitable for molten liquids or glasses (with appropriate materials of construction).

Disadvantages

Low efficiency

Practical limits to head and flow imposed by low efficiency

GLANDLESS VALVES

There is obviously not much point in going to a lot of trouble to ensure zero leakage from a pump if leakage is going to occur elsewhere in the process. Most kinds of valves also have glands which constitute a potential source of leakage, but there are one or two exceptions - such as magnetic drive valves and diaphragm valves - which avoid this problem.

One special kind of diaphragm valve is the Roll Seal valve, which consists of only two parts - a cast body and an elastomeric liner which is the only moving element. Drip-tight closing, full opening or modulating control of flow are provided by the rolling action of the liner over a grillwork in the valve body "see Figure 9".

A system of pipework is used to feed a small partial flow of the process medium into a control chamber behind the liner and a pilot valve is employed to vary the loading pressure applied by this flow on the back of the liner. When inlet (upstream) pressure and loading pressure are equal, the liner remains in the fully closed position, but as the loading pressure is progressively reduced, the liner is inverted by the upstream pressure and begins to roll off the grillwork to partially or fully open the valve.

Different pilot valves can be used for a variety of services, including on-off, pressure reducing, pressure sustaining, pressure relief, liquid level control and rate of flow control. Remote operation is also possible.

Valves like the Roll Seal which employ elastomeric materials have obvious limitations in terms of temperature and chemical resistance.

In such cases more conventional valve types fitted with a magnetic drive can be employed, "see Figure 10". Magnetic drive valves use a similar drive mechanism to that used on magnetic drive pumps. As with the pumps, this means that all types of valve operated by a shaft drive can be designed to accept a magnetic drive.

PUMP SELECTION

In some cases pump selection is determined solely by the fluid to be pumped. Some very viscous or shear sensitive materials can only be pumped by a peristaltic or diaphragm type pump. Usually, though, several pump types could be used for a given situation and then safety and cost must be considered.

In cases where some risk of leakage is permissible, users may consider a more conventional solution, using a pump with a packed gland or mechanical seal. Pumps with double mechanical seals can reduce the risk of leakage quite substantially. Complex pressurised sealing systems incorporating double seals, a pressure switch and a pressure gauge, are also sometimes employed to reduce the risk still further. These systems are, however, expensive both in component costs and the cost of associated pipework and fitting. If all these costs are taken into account it may be cheaper in the long run to install the ultimate answer to the pump sealing problem - a glandless pump.

From a safety viewpoint some peristaltic pumps offer no containment in case of tube failure. Whilst they still offer many other benefits these are not suitable when total safety is required.

Selection of the most appropriate type of glandless pump can only be determined after considering the duty (i.e. head and flow required), the liquid (i.e. physical characteristics) and the estimated costs. When considering costs, several factors need to be taken into account, e.g.:

capital cost of the pump
direct maintenance costs
indirect maintenance costs (i.e. cost of downtime)
running costs (power)

Indirect maintenance costs may be particularly significant in high-volume continuous processes, where any lost production due to downtime can be very expensive.

Because there are so many variables there is no way to present a generalised cost comparison. Each case must be treated individually and take into account the advantages and disadvantages of the different types of pump.

One thing is certain the need for glandless pumps will continue to grow and the variety of glandless devices will continue to grow to meet the need.

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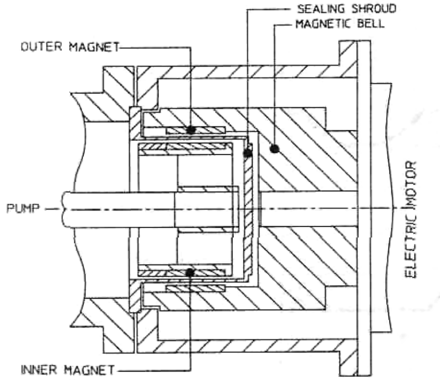


Figure 1 Typical magnetic drive arrangement

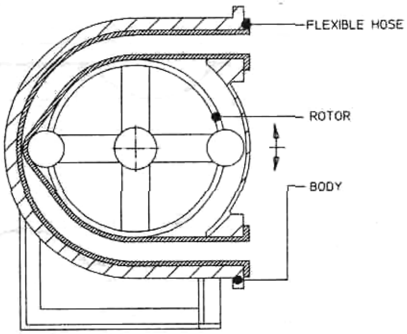


Figure 2 Peristaltic pump

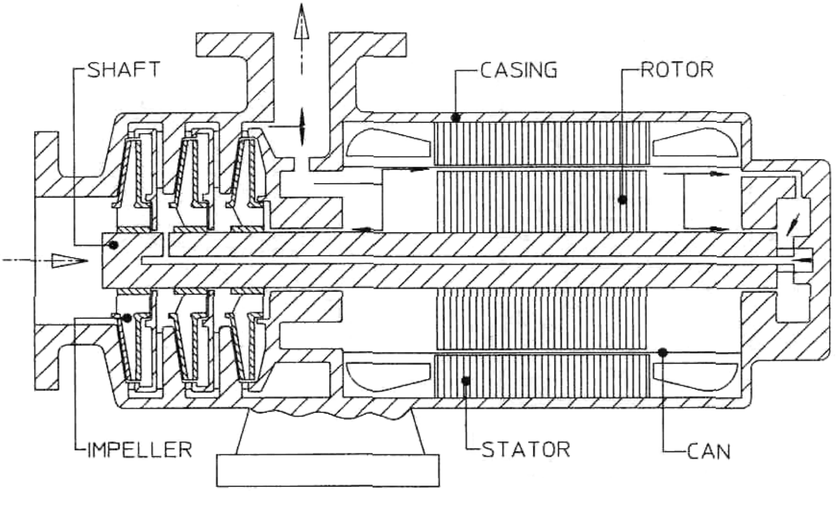


Figure 3 Typical canned motor pump

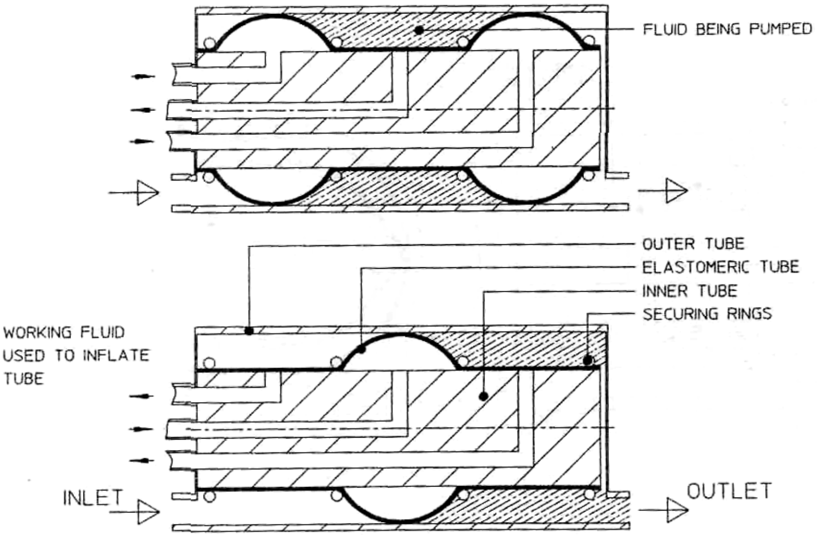
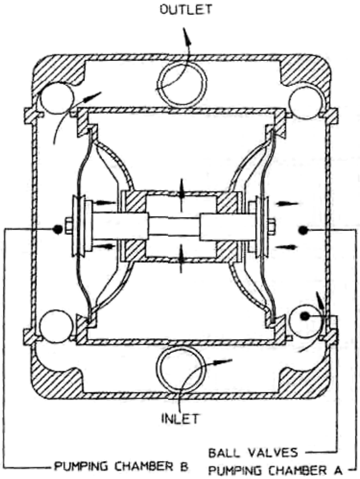


Figure 4 Concentric tube peristaltic pump



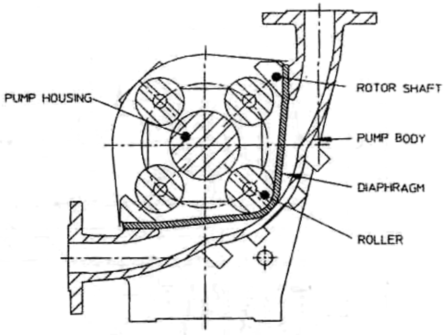


Figure 5 Air operated double diaphragm pump

Figure 6 Rotary diaphragm pump

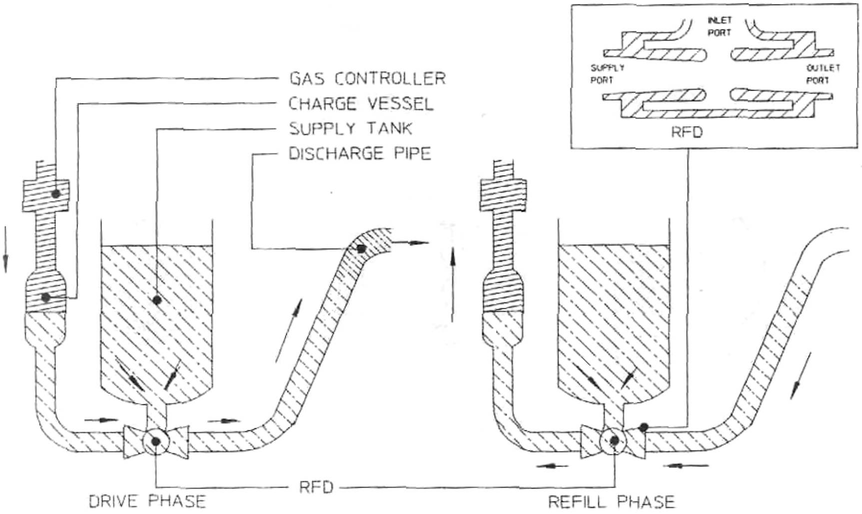


Figure 7 Reverse flow diverter (RFD) pump

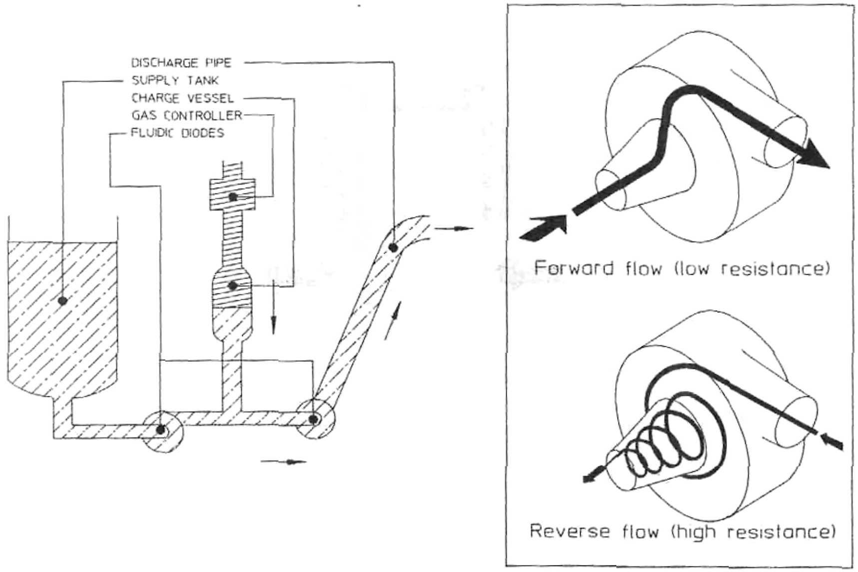


Figure 8 Diode pump

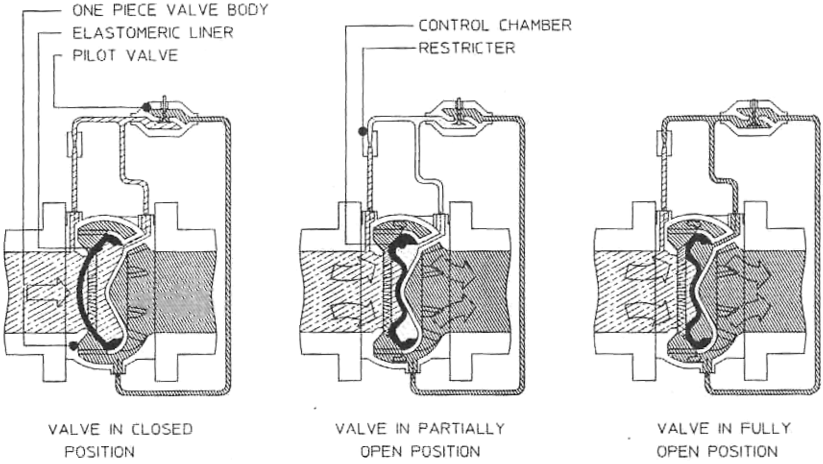


Figure 9 Roll Seal Valve

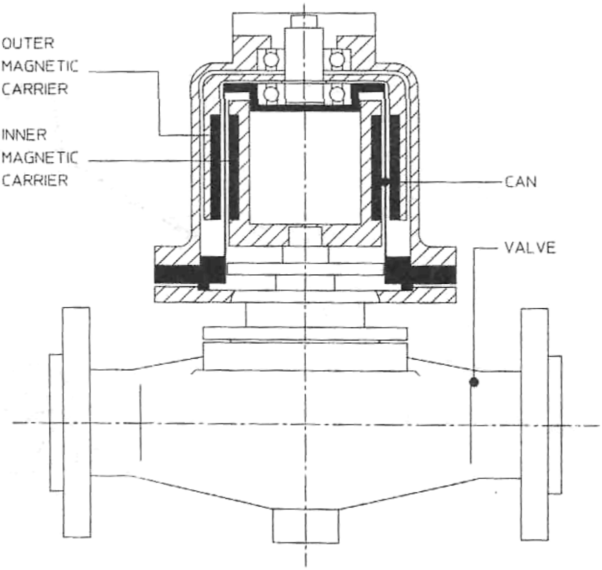


Figure 10 Magnetic drive valve