DUAL CONTAINMENT SHELLS— ADDED SAFETY FOR MAGNETICALLY DRIVEN PUMPS

by

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ABSTRACT

Proper function of the shroud is fundamental to the success of the magnetically driven pump. It provides the static seal of the product to the atmosphere without the need for conventional shaft seals.

The efficiency and safety of the magnetic drive can therefore be greatly influenced by the detailed design and material selection made for this component.

The function and features of magnetically driven pumps and the types of shroud available, including double walled shroud arrangements are described, and the development, test program, and experience gained on this important component are outlined.

INTRODUCTION

The current focus of both U.S.A. Federal and State legislation regarding the control of emissions for a wide range of substances has induced industry to improve technologies to provide leakless pumps.

The magnetic drive pump is one method of achieving that goal. Its use has increased exponentially. Development over the years has led to constant improvement of the design, with various degrees of sophistication in the design, control, and monitoring of these units. The main static seal component in a magnetic drive is the shroud, the static containment shell or shroud which is positioned between the rotating magnets. The basic construction, shown in Figure 1, of a magnetically driven, inline pump with a single metallic shroud.

Under normal design conditions, damage to this component is rare, due to the operating clearances between the magnets and

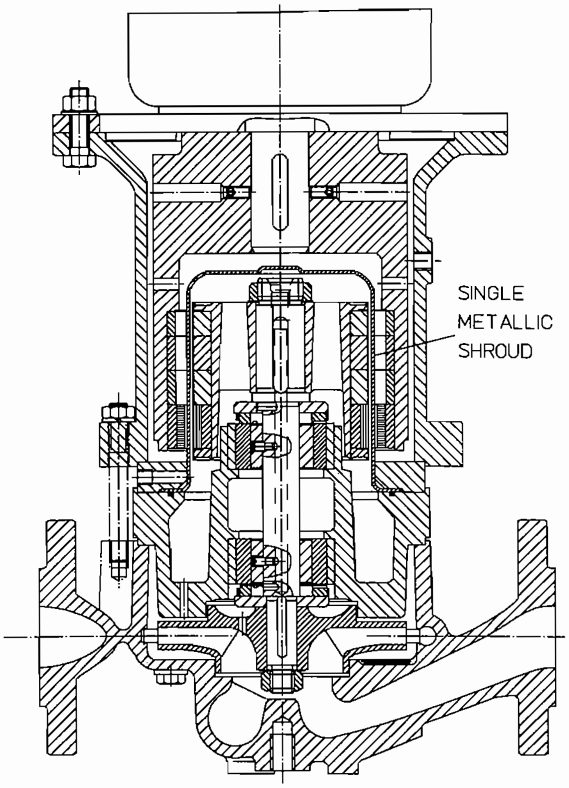


Figure 1. Inline Pump (ZLI) with Single Deep Drawn Shroud Made of Hastelloy C-4.

the shroud. When handling a particularly toxic or aggressive media, however, a dual walled shroud offers additional safety and the opportunity to monitor the area. Where demanding applications make a backup seal and constant monitoring for leakage essential, the double walled shroud provides the answer without the need for lip seals or mechanical seals, both of which are subject to wear, leakage, and failure. Shown in Figure 2 is a double walled shroud, the inner can in Hastelloy C-4, the outer can in ceramic/zirconium oxide.

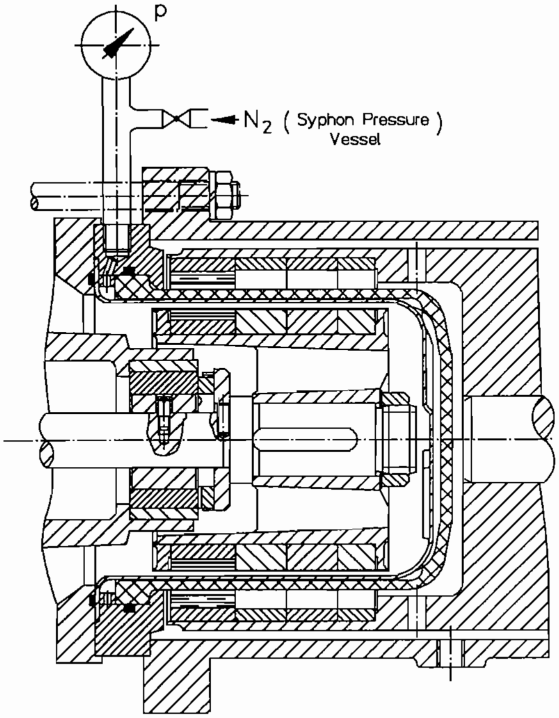


Figure 2. Magnetic Drive with Dual Shroud (Hastelloy C-4/Ceramic).

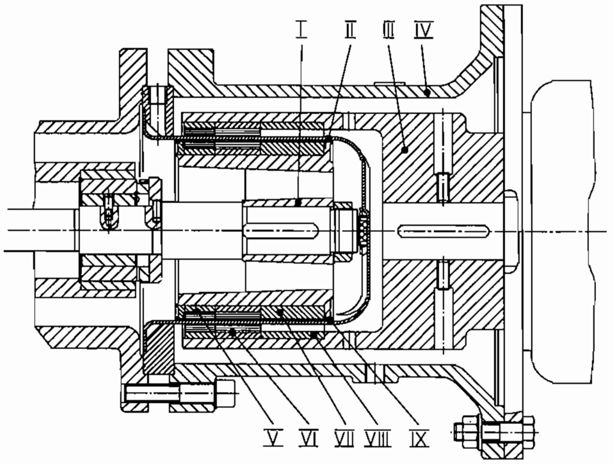
The particular features and problems in operating magnetic drive pumps are discussed, along with the various types of shrouds available, especially the dual shroud arrangement.

PRINCIPLE CONSTRUCTION OF A MAGNETIC DRIVE

The basic construction is shown in Figure 3 of a typical magnetic drive coupling. The primary components comprise an external magnet ring, a shroud, and an internal magnet ring. The external ring is arranged in the magnet carrier, which is attached to the motor shaft similar to that of a conventional coupling hub and rotates with the pump shaft. The shroud is a nonmagnetic component between the internal and external magnet rings and serves as a static seal, preventing product leakage.

The driving torque from the motor is transferred to the pump through the magnetic field. Permanent magnetic couplings work without slip; therefore, motor and pump operate synchronously. The internal magnet ring attached to the pump is sheathed to protect it against the pump product liquid. The torque capacity of the coupling can be varied by changing the number of magnet rings in the same coupling geometry. Free space, if any, will be filled with spacers.

The magnetic drive can be used on a wide range of existing pump designs. Generally, not only the same hydraulic components are used, but the same envelope dimensions also are maintained in relation to conventional pumps. As a result, conventional pumps may be replaced by magnetic dives without difficulty, if required.



I - INTERIOR MAGNETCARRIER
II - DEEPDRAWN SHROUD (HASTELLOY C-4)
III - MAGNETIC BELL
IV - STOOL
V - INTERIOR MAGNETRING
VI - OUTER MAGNETRING
VII - INTERIOR SPACER
VIII - OUTER SPACER
IX - PROTECTIVE PIPE AGAINST PUMPAGE

Figure 3. Construction of a Magnetic Coupling.

The magnetic drive arrangement normally replaces the area taken up by the stuffing box or mechanical seals and the outer bearing and coupling of the pump. This requires the pump shaft to be supported by product lubricated bearings capable of handling all axial and radial loads generated by the pump. These bearings are normally made of silicon carbide.

Special consideration must be given to ensure that the bearings are adequately lubricated, and a flow of product is maintained between shroud and coupling to remove the heat generated by eddy current losses. The main components in a magnetic drive shown in Figure 4 are, e.g., internal/external magnet carrier and shroud. Individual components are shown as well.

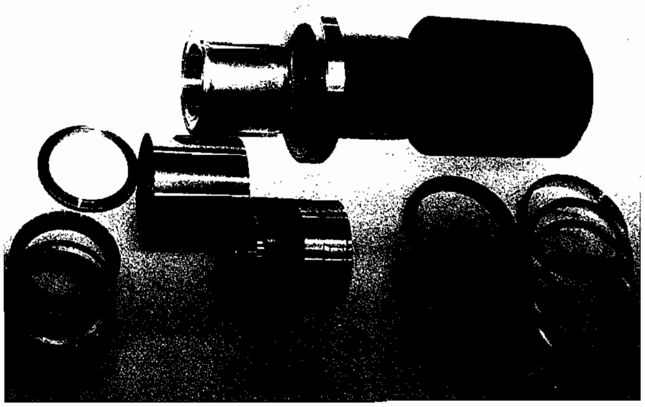


Figure 4. Main Components in a Magnetic Drive.

MAGDRIVE CHARACTERISTICS

Transferable Torque

Internal and external magnet rings comprise a series of individual magnets equally spaced around the short circuit rings. Each magnet is magnetized radially and alternately in polarity, respectively. Therefore, only an even number of magnets can be used. Nonidentical poles of the two magnetic coupling halves are opposite each other in unloaded state. The position and relationship to each other of internal and external magnetic rings in unloaded condition are illustrated in Figure 5. The field lines run radially between the poles and are closed by the short circuit rings.

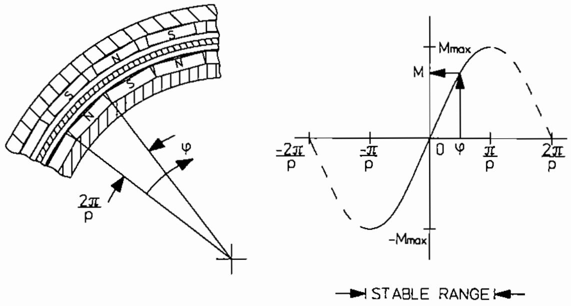


Figure 5. Principle Magnetic Drive Torque Characteristic.

If a torque is to be transferred, the outer magnet must be offset to the inner magnet by the phase angle $|\Phi|$. The field lines are tensioned in the peripheral direction just like rubber bands. The transmissible torque increases with the phase angle and achieves its maximum value at the positions $\Phi = \pm \pi/p$ the static rated torque of a specific size of coupling. Through the symmetrical construction the course and the amount of torque are independent of the direction of load. The change in sign only indicates the direction of rotation. The coupling is stable in the $-\pi/p < \Phi < +\pi/p$ range, i.e., torque and torsion angle increase in the same direction (Figure 5). This is the "normal" working range of the magnetic drive. External and internal magnets run phase displaced but synchronously. If the load torque exceeds the maximum value of the coupling, then same-named poles become superimposed to an increasing degree. The radial magnetic field is weakened to such an extent that the coupling halves run towards each other with considerable slip"the magnetic coupling is "broken."

This offers overload protection for both motor and pump. Both driver and component, however, must be stopped before the unit can be restarted.

If the unit is operated in the "break" state for a long period of time, the pump can be damaged as a result of torsional vibrations. Therefore, it is advisable to monitor pump data such as heat, flow, and/or motor amps.

Efficiency

It is difficult to compare the overall efficiency of a magnetic drive pump with that of a conventional pump, even when the identical pump wet end is used on both arrangements. The conventional pump has efficiency losses due to seal flush, gland packing or mechanical seal, coupling, and bearing losses. The magnetic drive pump has friction losses due to the drive itself, the electrical conduction of the shroud, etc.

The measured losses are shown in Figure 6 for the same pump end with different types of seals.

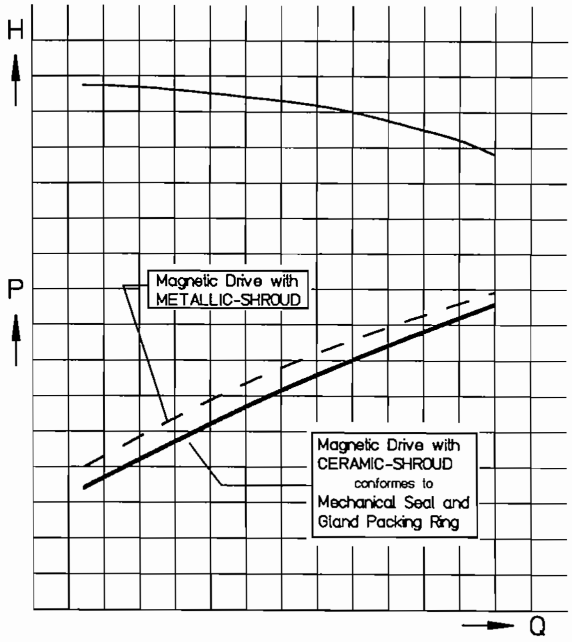


Figure 6. Power Requirement for Different Types of Seals with the Same Pump End

As can be seen from Figure 6, the power requirements for a magnetic drive pump equipped with a ceramic shroud are clearly lower than when using a metal shroud, and are comparable with losses of a conventional pump with mechanical seals or gland packing.

The application of magnetic drives with metallic shroud requires additional energy, because the synchronously turning magnetic field in the electrically conductive wall of the shroud generates a field strength whose related magnetic forces fw are directed against the turning direction of the pump in accordance with the laws of induction. These forces act on the mean radius of the shroud and produce a counter-torque:

$$Mw = r \int fw\, dA \qquad (1)$$

This results in the following relationships for a given magnetic drive:

$$dA = 2 \pi r d l \qquad (2)$$

$$fw = c1\ U = c2n \qquad (3)$$

$$Mw = c3n \qquad (4)$$

This results in the following eddy current losses

$$Pw = c\, n^2 \qquad (5)$$

As can be seen, the torque is directly proportional to the speed and the power loss proportional to the square of the speed. For practical application this means that the efficiency of a magnetic drive with a metallic shroud decreases with speed.

$$\eta K = \frac{P_K}{P_K + cn^2} \qquad (6)$$

The transferable torque and magnetic field change with the torsion angle so that dependency is to be expected not only on the speed but also on the torque to be transferred. It could be proven through tests [2] that not only the static torque of a magnetic drive but also the reaction torque of the eddy current can be described approximately with a trigonometric function. The static torque can be formulated as follows:

$$M_K = M_{KMAX} \sin^{p}/_{2}\, \Phi \qquad (7)$$

and the reaction torque:

$$M_W = M_{WMAX} \cos^{p}/_{4}\, \Phi \qquad (8)$$

Operating and limiting values are shown for various load points in the working range of a magnetic drive. (Figure 7). The efficiency of a magnetic drive coupling can be computed for any speed and load point once M_{KMAX} and C have been determined.

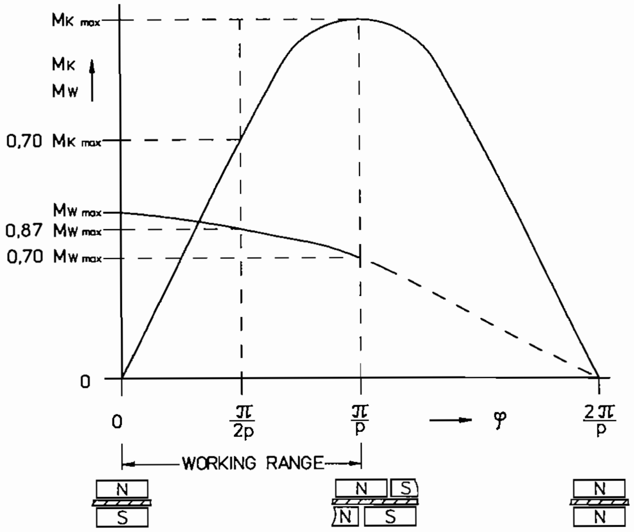


Figure 7. Operating and Limit Values of a Magnetic Drive [1].

Temperature Increase through Eddy Current Losses

The eddy current losses in the metallic shroud generate heat which must be removed to cool the shroud and avoid pumpage vaporizing in the shroud area. This is typically achieved by means of internal circulation from pump discharge to the suction side.

The temperature increase of the partial flow can be determined for any pumpage:

$$T = \frac{P_W}{m\, c_p} \qquad (9)$$

To minimize power losses and, as a result, keep the temperature increase as low as possible, material properties and shroud wall thickness in the effective magnetic field require serious consideration.

$$P_W = c\, \frac{s}{\rho} \qquad (10)$$

Obviously, the power loss is directly proportional to the wall thickness "s" of the shroud, and inversely proportional to the specific resistance of the shroud material. Therefore, efforts must be made to keep the wall thicknesses of the shroud as thin as possible but with due consideration to mechanical loads.

Apart from its high resistance to corrosion, the material 2.4610 (Hastelloy C-4) has a relatively high specific resistance in comparison with high grade stainless steel 1.4571 (A276Gr316Ti). When using 2.4610:

$$2.4610 = 1.25\ \Omega\ \mathrm{mm}^2/\mathrm{m}$$

instead of the conventional high grade steel 1.4571:

$$1.4571 = 0.75\ \Omega\ \mathrm{mm}^2/\mathrm{m}$$

as shroud material the eddy current losses can be reduced by approximately 40 percent. Therefore, it is recommended that the material 2.4610 be selected as a matter of principle when using metallic shrouds.

A new universal solution is available with the developments in the field of ceramic materials. A zirconium oxide shroud is not only superior with regard to corrosion and wear resistance, but also a more economical alternative.

MAGDRIVE STARTUP CHARACTERISTICS

Direct online starting of an asynchronous motor causes low frequency oscillations of current and torque. High in-rush currents that build up the moment the unit is energized produce a high torque and, thus, rapid acceleration of the unit. Unit acceleration is immediately followed by a torque acting in opposite direction to the oscillating motor torque characteristic. The situation stabilizes once in-rush current has dropped to its rated value. A characteristic direct start is shown in Figure 8.

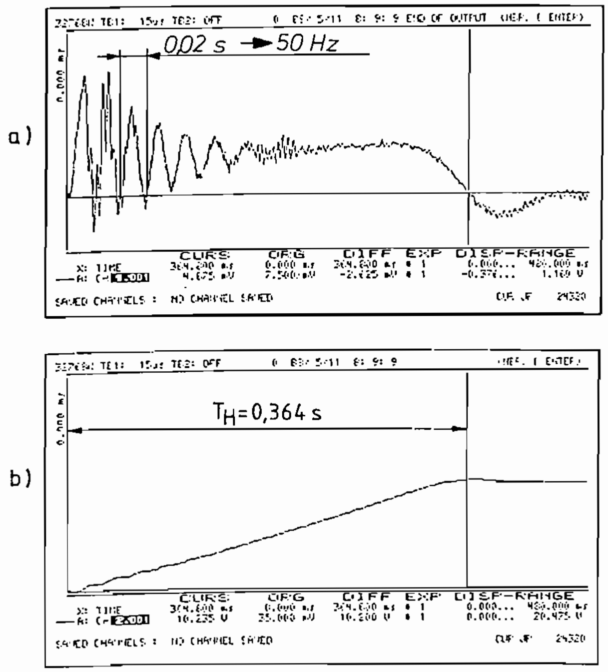


Figure 8. Acceleration of an Asynchronous Motor after Direct Start. a) Motor torque as function of time; b) Motor speed as function of time.

The effect of this excitation on the pump unit, which with the typical torque characteristic of the magnetic coupling in connection with the masses on the motor and pump side, is to be viewed simply as an oscillation system, was studied with a typical test arrangement shown in Figure 9. Actual magnetic drive pumps of various types and sizes were used [3]. To determine the size of a magnetic drive, not only the hydraulic data must be known but also the torque of the drive motor and more especially the moment of inertia of the motor, coupling, and pump. The very fast process sequences are recorded by a transient recorder on a special test stand (Figure 9).

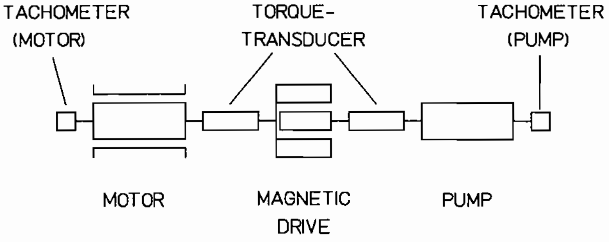
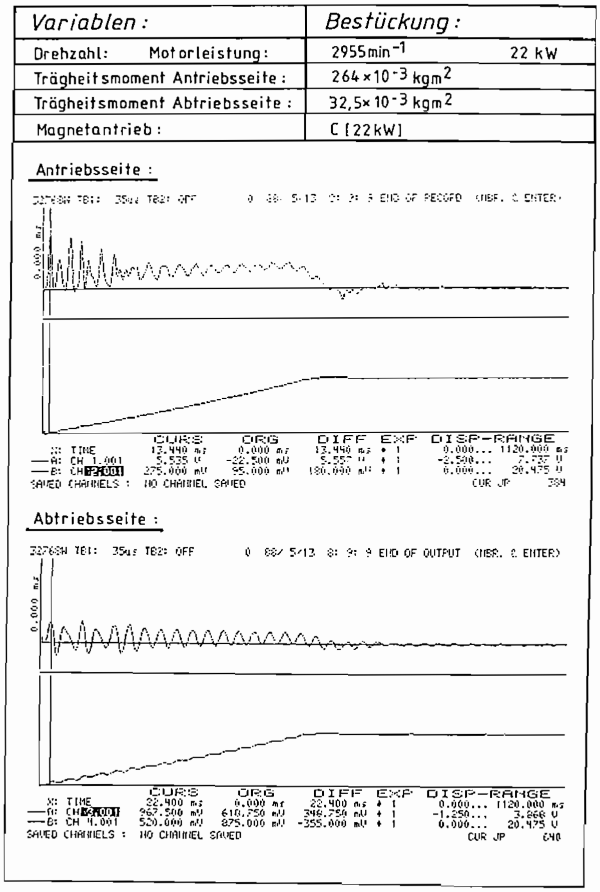


Figure 9. Schematic Test Stand Arrangement.

An official test report showing the dynamic course of pump and motor side torque as well as speed over time is represented in Figure 10.



Variablen :	*Bestückung :*
Drehzahl: Motorleistung:	$2955 \min^{-1}$ 22 kW
Trägheitsmoment Antriebsseite :	264×10^{-3} kgm^2
Trägheitsmoment Abtriebsseite :	$32{,}5 \times 10^{-3}$ kgm^2
Magnetantrieb :	C [22kW]

Antriebsseite :

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32768W TB1:  35us TB2: OFF        0  88/ 5/13  8: 9: 9 END OF RECORD  (NBR. & ENTER)
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                 CURS        ORG          DIFF     EXP   DISP-RANGE
   X: TIME      13.440 ms    0.000 ms    13.440 ms  • 1     0.000... 1120.000 ms
 —A: CH 1.001    5.535 V   -22.500 mV     5.557 V   • 1    -2.500...    7.737 V
 —B: CH 2.001  275.000 mV   95.000 mV   180.000 mV  • 1     0.000...   20.475 V
SAVED CHANNELS :  NO CHANNEL SAVED                                  CUR JP     384
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Abtriebsseite :

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32768W TB1:  35us TB2: OFF        0  88/ 5/13  8: 9: 9 END OF OUTPUT  (NBR. & ENTER)
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                 CURS        ORG          DIFF     EXP   DISP-RANGE
   X: TIME      22.400 ms    0.000 ms    22.400 ms  • 1     0.000... 1120.000 ms
 —A: CH 3.001  967.500 mV  610.750 mV   348.750 mV  • 1    -1.250...    3.868 V
 —B: CH 4.001  520.000 mV  875.000 mV  -355.000 mV  • 1     0.000...   20.475 V
SAVED CHANNELS :  NO CHANNEL SAVED                                  CUR JP     640
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Figure 10. Test Report: Dynamic Course of Torques and Speeds during the Direct Starting Phase.

By evaluating numerous combinations in which:

- motor output (starting torque) (M_{MN})
- the power at coupling (coupling torque) (M_K)
- the moment of inertia on the motor side (J_M), or
- the moment of inertia on the pump side (J_P)

were varied, it could be proven in a direct start that the magnetic coupling is loaded for a brief period with at least four times the rated torque of the drive motor.

Excitation oscillations are determined by the local mains frequency and must be taken into consideration. On the one hand, the dampening effect of a magnetic drive is obvious, but on the other hand, the higher load when starting has to be taken into consideration when sizing the unit. The large number of measurements taken resulted in the characteristic curve, shown in Figure 11, for sizing a magdrive unit suitable for direct online starting.

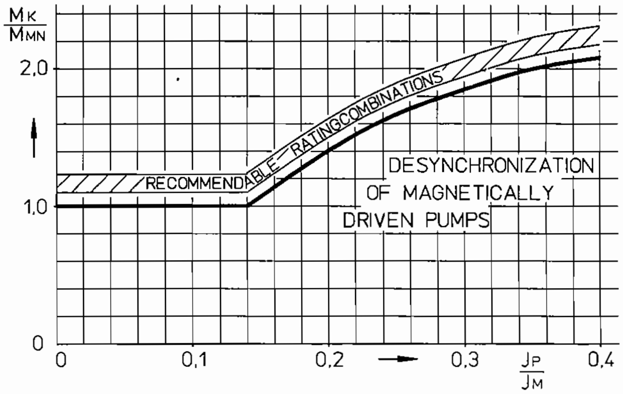

Figure 11. Influence of the Moment of Inertia on the Required Torque of the Magnetic Drive.

The magnetic drive torque must exceed the motor torque rating at least by the limiting M_K/M_{NM} factor for a given moment of inertia ratio J_P/J_M, or stalling will occur during startup.

Increasing the motor drive's moment of inertia by means of enlarging the mass of the external magnet carrier reduces the minimum required M_K/M_{NM} ratio (Figure 11), allowing the designer to select a smaller, more economical magnet drive.

For pumps with larger moments of inertia, it is recommended to reduce the motor starting torque by means of a "soft starter," allowing the size of a magnetic drive to be determined by the power requirements at the rated operating point. This measure not only reduces the actual magnetic drive size but also actual eddy current losses which would be higher in a larger size coupling. Planners and users may, therefore, consider acceptance of soft starters for certain applications.

SHROUD CONSTRUCTIONS: MATERIAL, PRODUCTION AND APPLICATION

The choice of shroud, its material, and construction largely depends on specific application related requirements.

Single Metallic Shroud

Single metallic shrouds are suitable for a broad range of applications. Despite the negative aspect of generating heat as a result of energy losses through eddy current induction, the typical metallic properties such as strength, elasticity, and, with the correct choice of material, corrosion resistance, outweigh this disadvantage. Power losses were discussed in the *Temperature Increase* through *Eddy Current Losses* sections and can be minimized by utilizing a high strength material with high electrical resistance.

First designs were of welded construction, but it was soon recognized that the welds were the weak points of the structure and sources for corrosion susceptibility. A shroud produced by a plastic deformation process such as deep drawing, spinning, or stretch spinning avoids welded seams in the product area (see Figures 1 and 2). Unfortunately, the material 2.4610 (Hastelloy C-4) tends more towards strain hardening due to its high nickel content when deformed by the above mentioned methods. The material hardness increases strongly with the amount of cold shaping, and the properties are influenced negatively. Extensive tests regarding the behavior dependent on the degree of cold shaping have shown that the original ductility of the material can only be maintained if a number of solution annealing operations are carried out at a temperature exceeding 1000°C during production of a deep drawn shroud. Presented in Figures 12 and 13 are deep drawn shrouds which can be produced with different wall thicknesses and in different diameters for standardized use. Deep drawn metallic shrouds are being used for a broad range of applications and fluid temperatures up to 300°C.

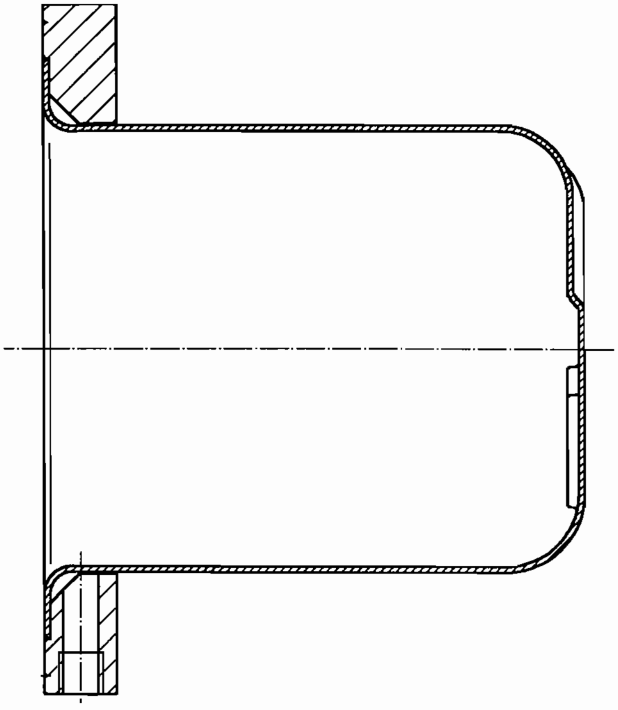

Figure 12. Deep Drawn Shroud.

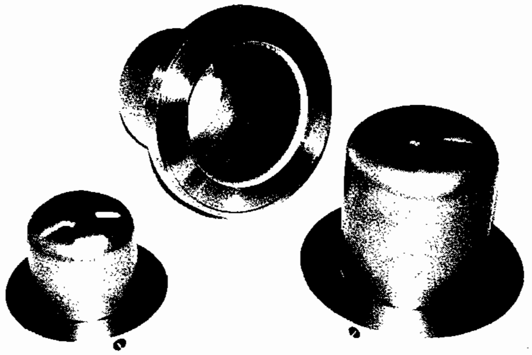

Figure 13. Deep Drawn Shrouds with Different System Diameters.

Single Ceramic Shroud

The search for a shroud made of nonconductive material led to tests with various plastics, whose application can unfortunately never be very universal, and to industrial ceramics"zirconium oxide. The main advantage of the ceramic shroud, i.e., its ability to drive a magnetic drive without losses, has already been described in the *Temperature Increase* through *Eddy Current Losses* sections.

The isostatically pressed shroud is not conductive and, thus, generates no heat through eddy current losses.

Apart from being an alternative to the metallic shroud, the ceramic shroud is used particularly when there is a tendency towards polymerization, crystallization, or solidification when the pumpage is heated. Moreover, the ceramic shroud is employed optimally with magnetic drive pumps for handling media with temperatures T > 300°C. The most used magnet material, samarium cobalt, can only be operated up to a temperature of T = 350°C under the exclusion of oxygen.

A special design, shown in Figure 14, features a heat barrier that separates the pump from the magnetic coupling area, thereby reducing the temperature at the pump dead end. The heat barrier reduces the temperature at the magnetic coupling end to an extent that dead end operation is possible without internal or external cooling. To be mentioned apart from the greatest advantage of no loss operation are:

- zirconium oxide is corrosion resistant to almost all caustic solutions and acids and has been optimized particularly for applications in chemical apparatus construction,
- the great hardness and good sliding properties through which high resistance to abrasion is achieved, and
- the high mechanical strength and elasticity (E module 2 10^5 N/mm^2), whereby finite element optimalized shrouds can be employed at nominal pressures < 25 bar at high temperatures.

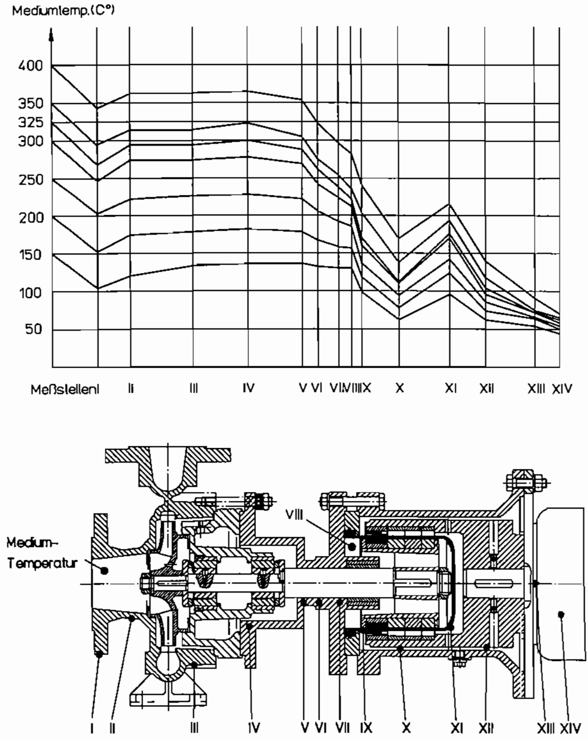

Figure 14. Temperature Course in a Magnetic Drive Pump Unit for Fluids up to 400°C.

Use of the magnetic drive with a ceramic shroud should be considered especially for pumps which are to be operated at high speed, because the power loss is proportional to the square of the speed (see Efficiency). Such shrouds are shown in Figure 15.

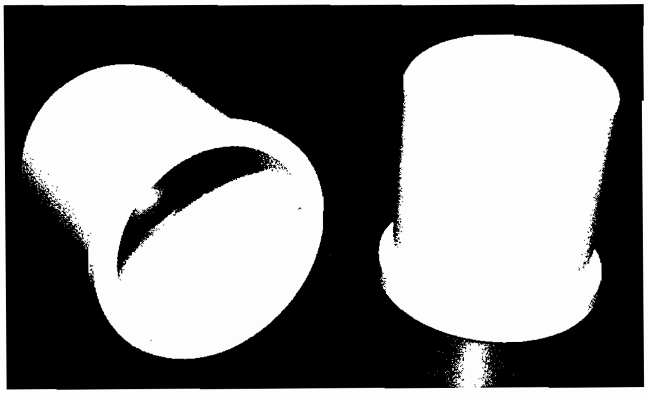

Figure 15. Zirconium Oxide Ceramic Shroud.

The disadvantages in the use of ceramic shrouds are:

- heavier walls require larger volume magnets, and
- the fact that a ceramic material cannot be plastically deformed. Only skilled personnel should be employed to handle ceramic shrouds.

DUAL SHROUD CONSTRUCTIONS: MATERIALS, TESTS AND EXPERIENCE

When shroud damage occurs, fluid can escape immediately from a magnetically driven pump unit with a single shroud. Such damage may be caused by corrosion, abrasion, or failure of the typically used ceramic bearings that guide the pump shaft. The pump shaft would shift, and the inner magnetic rotor could damage the shroud which is usually adequately sized. As far as abrasion is concerned, there is a particular risk when handling ferritic polluted media or even media containing ferrite. Welding beads, particles of rust, or inadequately removed burrs in the plant could be attracted by the inner magnet and damage the shroud from the inside. Corrosion damage is rare, due to the deep drawn shroud produced as standard in Hastelloy C-4. Corrosion can be controlled to a large degree by adapting the pump material to the properties of the medium being handled. Apart from this, damage can occur from the outside if the roller bearing supporting the outer magnets fails and mechanical contact between magnetic bell with outer magnets and shroud occurs.

Dual shrouds in different materials or various combinations of material have been studied and their design is discussed.

Metallic Dual Shrouds

High strength and elasticity naturally support the aim to use a dual metallic shroud, separated by a defined and monitored gap. Generally, this combination is technically very difficult without the use of external cooling arrangements. Eddy current losses in both metallic shrouds must be dissipated by the pumpage. Heat transition from the outer shroud, however, is prevented by insulating air.

Welded and deep drawn constructions were joined together by means of shrink fits to positively provide metal to metal contact between the inner and outer metallic shroud. Indicator groves are machined in the outer surface of the inner shroud to facilitate leakage detection. Such a deep drawn dual shroud construction is shown in Figure 16.

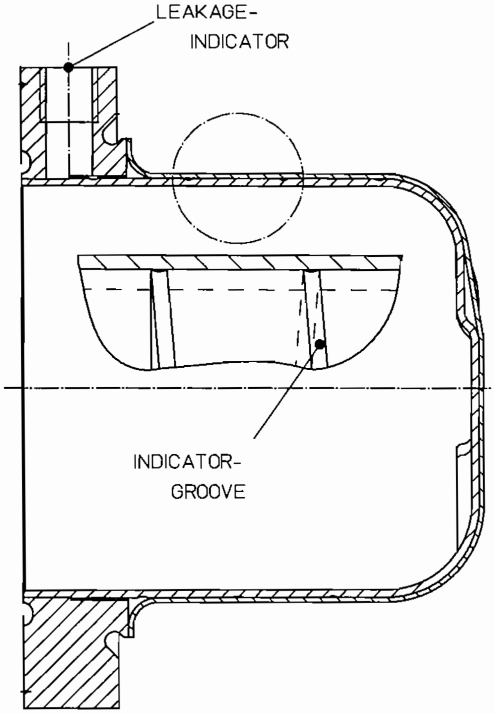

Figure 16. Deep Drawn Metallic Dual Shroud with Indicator Grooves (Shrink-Fit).

Deficiencies were noticed when testing these expensive designs. The outer jacket was painted with a temperature indicating paint. The metallic dual shrouds were built into a suitably sized pump with adequate cooling flow being provided.

After a short period of operation, zones with either no or reduced heat transition became clearly apparent. The temperature in the areas exceeded T = 300°C after two minutes of operation.

A deep drawn and welded shroud after the test with "hot spots" clearly visible is shown in Figure 17.

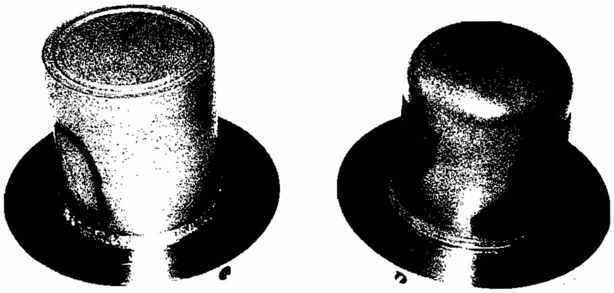

Figure 17. Metallic Dual Shrouds after Tests with a Temperature Indicating Paint.

Temperature excursions like these are not acceptable, particularly in explosion protected areas. Production of this dual shroud design, if at all, would require most stringent manufacturing and quality assurance standards to secure adequate heat transfer.

However, a dual metallic shroud may be utilized if a defined gap is provided and sufficiently sized to facilitate either heating or cooling by means of an external fluid. Cooling flow must be continuous and is, in many cases, pumped through a heat exchanger to remove heat generated by eddy current losses. However, this design is only conditionally suitable for monitoring leakages and requires an extended scope of instrumentation. Shown in Figure 18 is such a shroud, which is usually used for heating the magnetic drive when handling highly viscous fluids.

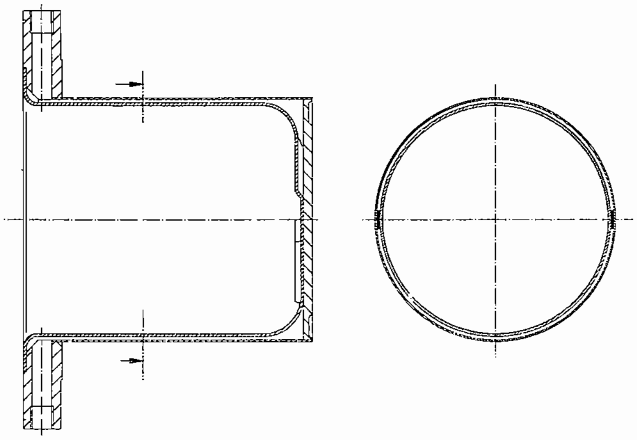

Figure 18. Dual Metallic Shroud with Defined Gap (for Heating/ Cooling).

Nonmetallic Dual Shrouds

Efforts to develop a nonconductive and, thus, no loss dual shroud have led to a combination of the existing ceramic shroud with an outer sheath made of carbon fiber reinforced plastic. The inner shroud fulfills the requirements in respect of strength and resistance to corrosion and abrasion. The outer shroud, also designed for full system pressure and manufactured out of high strength carbon fiber material, is arranged around the ceramic inner shroud. By means of a defined gap, a space is created which serves to monitor the function of the dual shroud and indicates leaks, if any. Shown in Figure 19 is a cross section through a dual shroud made of ceramic combined with carbon fiber reinforced plastic compound.

This magnetic drive design does not require any forced cooling. The induction of eddy currents in the conductive carbon fibers is almost compensated by optimalizing the coil angle and bedding in the plastic. The little heat generated is dissipated through ventilation. A nonmetallic dual shroud with its various components is shown in Figure 20. Despite the good results which have been achieved with this construction there are still a few negative characteristics when looked upon critically. The mechanical properties of the plastic bonded carbon fibers decrease rapidly as the temperature increases through the fluid being handled. Moreover, the strength is drastically reduced by the slightest mechanical damage to the fibers. Apart from these disadvantages the plastic matrix and carbon fibers are only resistant to chemical attack to some extent.

Dual Shroud Combination in Hastelloy C-4 with Zirconium Oxide

The broadest range of applications may possibly be covered with a design that utilizes the materials that have served in a

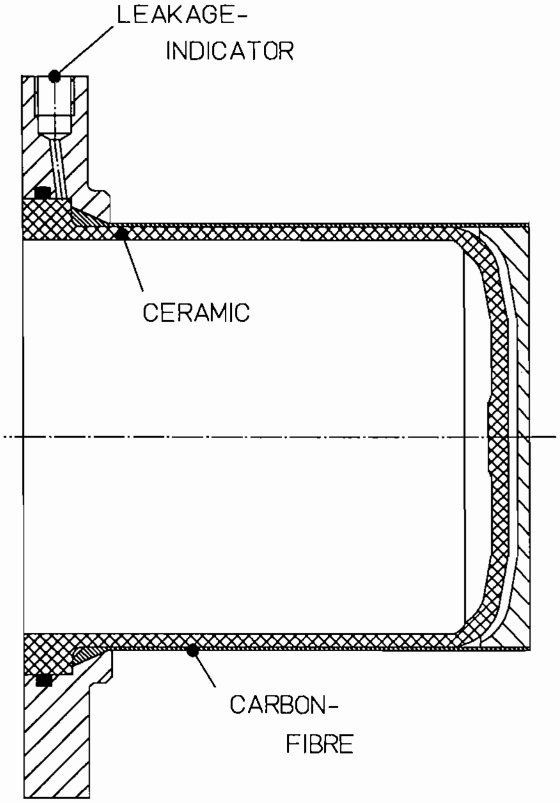

Figure 19. Dual Shroud Made of Components in Ceramic and Carbon Fiber Reinforced Plastic Compound.

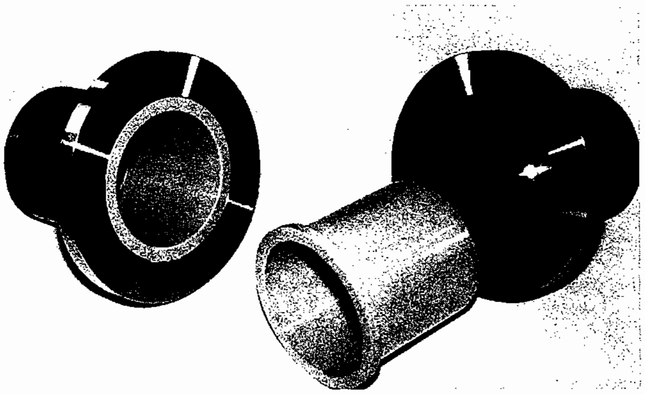

Figure 20. Nonmetallic Dual Shroud with Its Various Components Made of Ceramic and Carbon Fiber Reinforced Plastic Compound.

large number of applications as single shroud, i.e., ceramic (zirconium oxide) and metal (Hastelloy C-4). Both materials feature excellent mechanical properties, high corrosion resistance, tolerate a high temperature environment, and are abrasion resistant, zirconium being superior in comparison to Hastelloy in this regard. A dual containment shell design featuring Hastelloy C-4/ceramic material combination is shown in Figure 21.

The metallic shroud, in which losses are induced through the rotating magnetic field, forms the inner sheath. Heat generated by the eddy current losses can be dissipated without difficulty by the pumpage. As with the nonmetallic dual shroud, the defined gap between the inner and outer shroud creates an air space which is sealed by means of an O-ring. Naturally, the

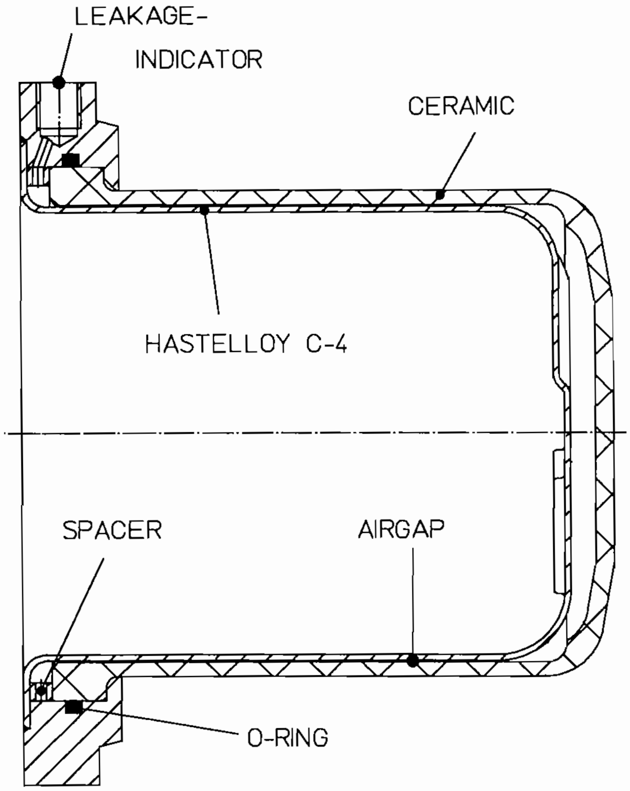

Figure 21. Dual Shroud Combination Made of Components in Metal and Ceramic.

nonconductive ceramic shroud forms the outer protective shell. The other properties of this industrial ceramic fully justify the application of this material in a dual shroud for magnetically driven pump units. Shown in Figure 22 are dual shrouds in the described combination of materials.

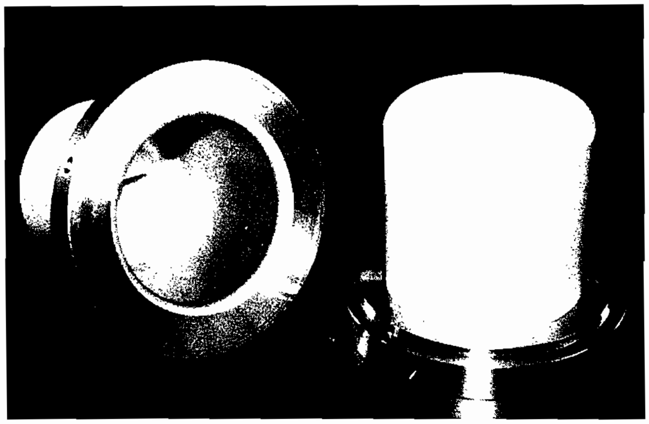

Figure 22. Dual Ceramic/Hastelloy Containment Shells.

Monitoring a Dual Shroud

The monitoring of a dual shroud cannot be limited to just the indication of any leakage of the pumpage. Damage of the inner shroud of the magdrive would result in fluid escaping into the control space of the dual shroud. However, the monitoring system should also provide for detecting possible malfunction of the outer shroud. Evacuation or pressurization of the control space between the shrouds facilitates monitoring the condition of the inner and outer containment shell.

Should the pressure sensor indicate ambient pressure in the space between inner and outer shroud, a malfunction of the outer shroud can be assumed, possibly as a result of bearing failure, thus allowing mechanical contact between the stationary outer shroud and the rotating external magnet carrier.

The intent of a dual containment shell design is to prevent pumpage from escaping to the atmosphere, even when a malfunction of this nature occurs. The pressure signal should trigger unit trip with subsequent unit inspection. If the pressure in the control space increases to prevailing system pressure, it can then be assumed that damage through abrasion, corrosion, or mechanical damage has destroyed the inner shroud.

The high pressure signal should trigger unit trip with subsequent unit inspection.

A possible monitoring system would be a contact pressure gauge subject to pressure by means of a siphon pressure receiver wired up to the control room (Figure 2).

Influence of the Design Gap between Inner and Outer Magnets

A basic disadvantage when using thick walled or double walled shrouds should be explained now that sufficient shrouds and combinations of shrouds have been presented. The use of a ceramic or a dual shroud calls for a larger gap between the interactive pairs of magnetic poles. A cross sectional drawing featuring the section between the poles is presented in Figure 23.

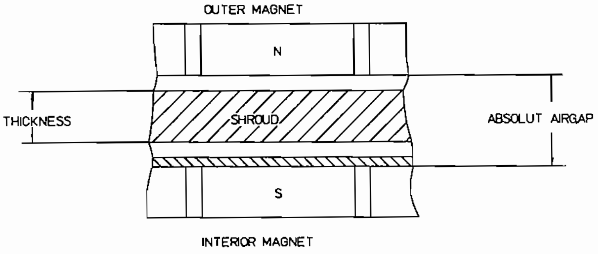

Figure 23. Shroud Wall and Resulting Total Gap between the Pair of Poles.

Listed in Table 1 are the different wall thicknesses and the appropriate relative gaps of different type single and dual containment shells in relation to the "relative gap" (1, one) of a single metallic 16 bar containment shell. The logical conclusion to this fact must be an increased number of magnets when using a thick walled shroud with the same power transfer. The linear dependency of the required volume of magnets with an enlarged gap can be seen from the characteristic curve in Figure 24. An assessment of the various criteria is given in Table 2 to somewhat simplify the decision for the optimal application for one of the types of shroud discussed in detail.

FINAL OBSERVATIONS AND PROGNOSIS

Development of new materials and the endeavor of the industry to offer innovative solutions continuously provide extensive possibilities in plant and process engineering. No loss application of magdrives and successful application of dual containment shells, the performance of which can be monitored during operation, has been achieved as a result of the development of the ceramic shroud.

Finally, following a critical assessment of the given peripheral conditions, plant operators can choose between

Table 1. Wall Thicknesses and Appropriate Relative Gaps for Various Types of Shrouds.

Type of Shroud	Wallthickness (mm)	Rel. Airgap (L/Lo)
	SINGLE-SHROUD	
single-metallic (16 bar)	1.6	1
single-metallic (25 bar)	2.0	1
single-ceramic (25 bar)	4.0	1.4
	DUAL-SHROUD	
dual-metallic with heating appliance (16 bar)	3.6	1.4
dual-metallic with heating appliance (25 bar)	4.0	1.4
dual-ceramic/ carbonfibre (25 bar)	5.2	1.65
dual-metallic/ ceramic (16 bar)	6.0	1.9
dual-metallic/ ceramic (25 bar)	6.4	1.9

Table 2. Assessment of Various Types of Shrouds against Different Criteria.

		TYPE OF SHROUD				
		single-metallic (Hast.C-4)	single-ceramic	dual-metallic (with heating appliance)	dual-ceramic/ carbonfibre-compound	dual-metallic/ ceramic
CRITERION	reducing of eddy current losses	◐	●●	—	●●	◐
	pressure-load capacity	●●	●	●●	●	●●
	safety against corrosion	●●	●●	●●	●	●●
	safety against abrasion	○	●●	○	●●	○
	safety against shock	●●	○	●●	○	○
	safety against leakage	●	●	●●	●●	●●
	possibility of monitoring	—	—	○	●●	●●
	possibility of extern heating	—	—	●●	—	—
	cost	▲	▲	▲▲	▲▲▲	▲▲▲

●● : excellently suited
● : well suited
◐ : suited
○ : conditionally suited
— : not suited

▲ : low
▲▲ : higher
▲▲▲ : high

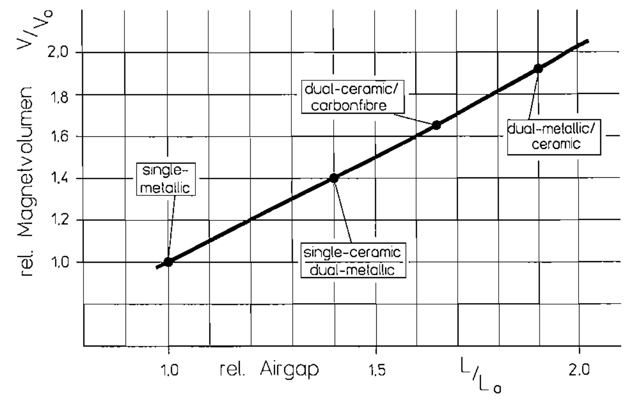

Figure 24. Required Magnet Volume as Function of Relative Total Gap.

- a magnetic drive with an optimally designed single metallic shroud usable on a broad basis,
- a no-loss ceramic shroud, which is particularly resistant to corrosion and abrasion, or
- on a particularly critical application, a sophisticated dual shroud that may be monitored.

Of course, the manufacturers of magnetically driven machines are able to provide assistance at any time when this decision has to be made. Apart from the application of pumps for handling liquids, whether a chemical standard pump with free shaft end to DIN 24256 (Figure 25) or a sealless side channel pump (Figure 26), glandless magnetic drives find their justified application as standard equipment in the vacuum pump industry (Figure 25) and also serve in other special applications, such as valve drive mechanisms, with a static seal.

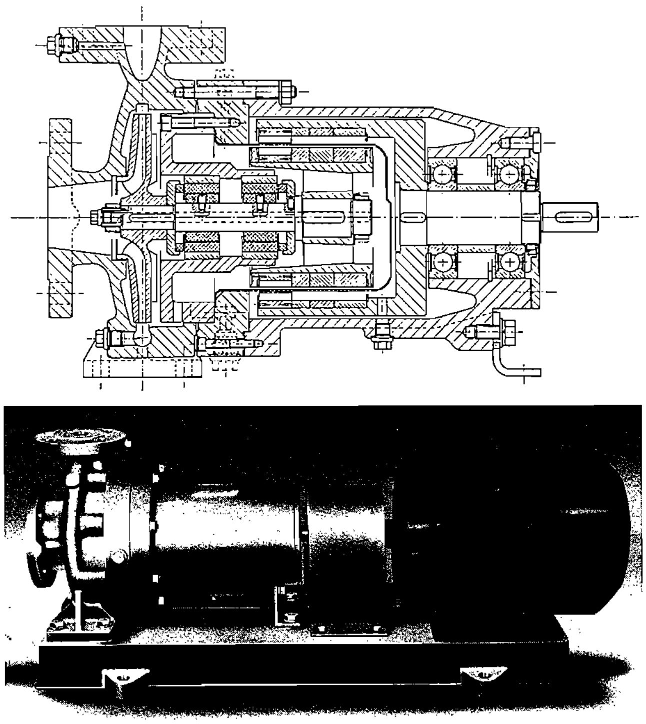

Figure 25. Magnetically Driven Chemical Standard Pump (CBS) with Free Shaft End to DIN 24256.

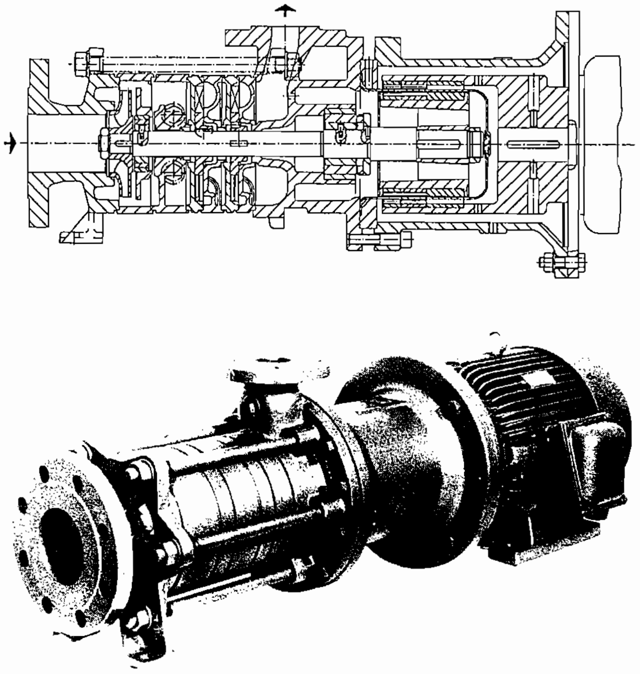

Figure 26. Side Channel Pump (CEH) with Magnetic Drive.

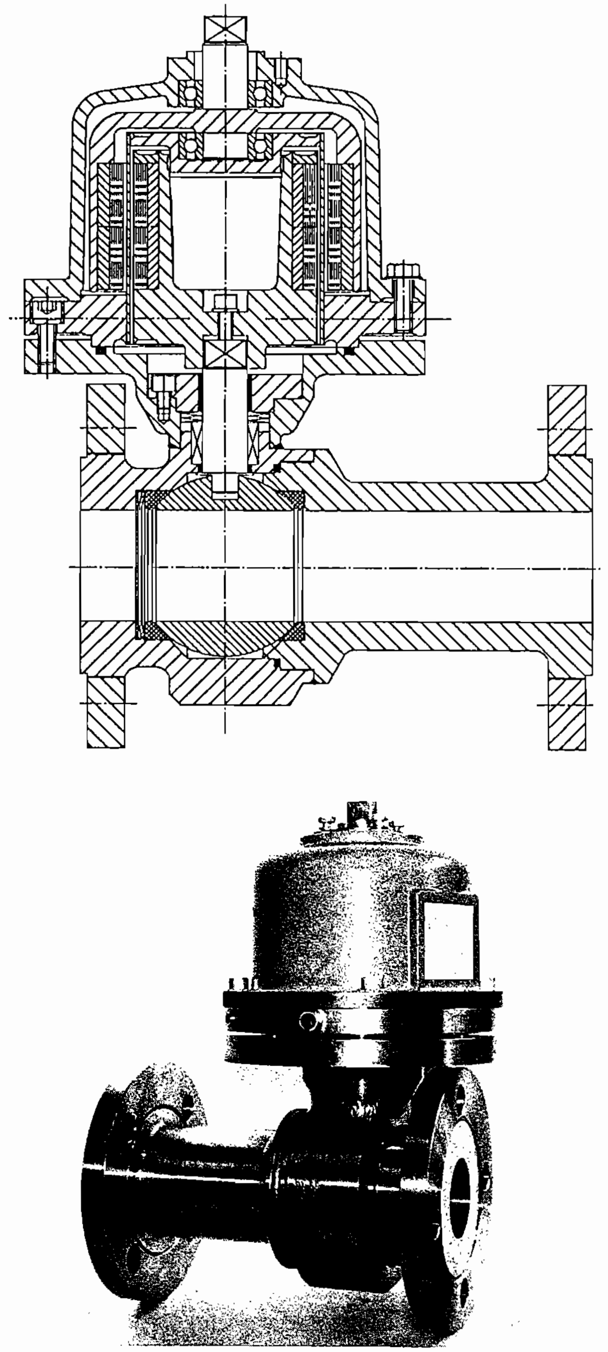

Figure 28. Ball Cock with Static Sealing Magnetic Coupling.

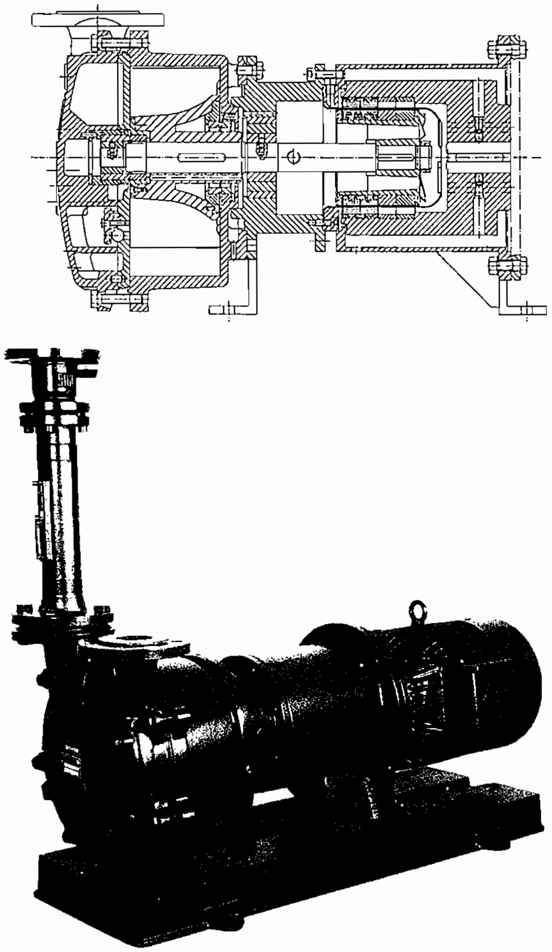

Figure 27. Liquid Ring Vacuum Pump with Magnetic Drive.

NOMENCLATURE

Symbol	*Unit*	*Designation*
A	m^2	Area
J	kgm^2	Moment of inertia
M	Nm	Torque
P	kW	Power
U	m/s	Peripheral speed
s	m	Wall thickness shroud
c	–	Constant
r	m	Effective radius

f		N/m^2	Related magnetic force
l		m	Magnet length
n		1/min	Speed
p		–	Number of poles on magnets
T		K	Temperature
m		m^3/s	Mass flow
cp		kJ/KgK	Specific heat capacity
Φ	(Phi)	degree	Phase angle
η	(Eta)	–	Efficiency
ρ	(Rho)	$\Omega\ mm^2/m$	Specific electrical resistance

Indices

K	Coupling
M	Motor
W	Eddy current
P	Pump
N	Rated

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