SUBMARINE SEA-WATER PUMPS

IMPROVING THEIR RELIABILITY

BY

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Introduction

If marine engineering were broken down into equipment groups, it is fair to say that the largest group would probably be pumps. If this group were further sub-divided to reflect reliability, sea-water pumps would probably be the most unreliable with submarine sea-water pumps faring worst of all.

There are many modes of failure of a sea-water pump but perhaps the most frequent is mechanical seal failure. It is the aim of this article to discuss contributions that can be made at the pump design stage to reduce the frequency of mechanical seal failures in submarine sea-water pumps, and to reveal future plans for eliminating mechanical seals from these pumps altogether. Some of the principles described apply equally to other pumps in service.

The Mechanical Seal

It might be helpful to refresh memories on basic mechanical seal construction. All mechanical seals, whatever the type or manufacturer, have several basic criteria in common. Referring to FIG. 1 they are:

(*a*) A rotating face.

(*b*) A fixed seat.

(*c*) A force to maintain rotating-face/fixed-seat contact.

(*d*) A secondary seal to the shaft.

(*e*) A method of drive from the shaft to the rotating face.

(*f*) A tertiary seal behind the fixed seat.

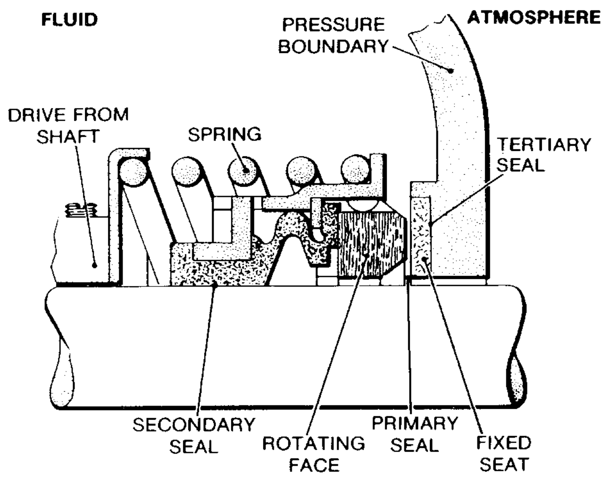

FIG. 1—THE MECHANICAL SEAL

The rotating face is usually of carbon but may be a ceramic. It mates with the fixed seat which, in R.N. applications, is usually coated with a ceramic such as chrome oxide. The mating surfaces are lapped to a very high finish and are maintained in contact primarily by hydraulic forces as a result of pressure from the sealed fluid. These forces are assisted by the seal spring(s) which may be in the form of one large coil spring or a number of smaller springs distributed around the perimeter of the seal. For high-pressure applications the rotating face is of the balanced type as exemplified by FIG.2. It will be observed that the step in the rotating face reduces the effective area on which the fluid pressure acts thus limiting the net axial hydraulic thrust on the mating faces at high pressure.

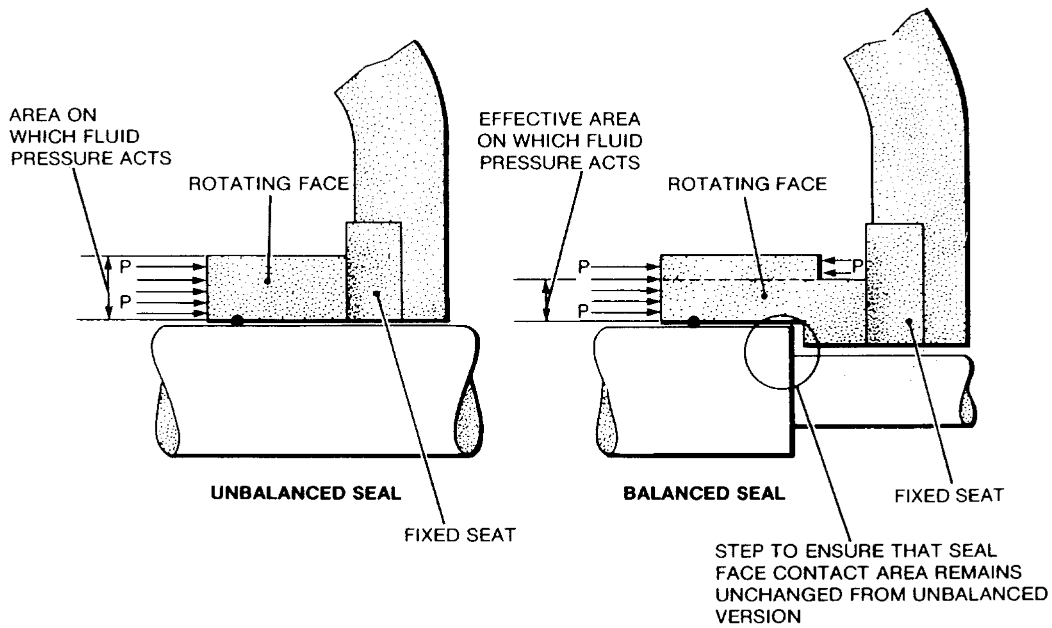

FIG. 2—THE PRINCIPLE OF THE BALANCED SEAL

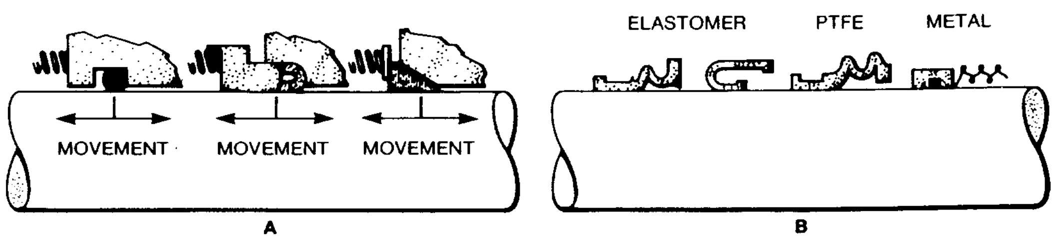

FIG. 3—TYPES OF SECONDARY SEALS
(A) SLIDING FLEXIBLE MEMBERS (B) BELLOWS FLEXIBLE MEMBERS

It is not generally realized that leakage across the rotating face must occur in order to provide lubrication between the face and the seat. In other words, all mechanical seals leak. In almost all cases however, the leaking fluid, which is heated by shear, vaporizes on contact with the atmosphere.

The secondary seal may be provided by either of two methods as shown in FIG. 3:

(*a*) A sliding flexible member.

(*b*) A bellows.

The high pressures encountered in submarine sea-water pump applications normally dictate the use of the sliding type of secondary seal which slides along the shaft as the latter moves axially and as the rotating face wears. A tertiary seal is required between the removable fixed seat and the pump casing.

The capability of a mechanical seal to fail by leakage across the secondary and tertiary seals is sometimes overlooked.

Discussion of Failure Modes

The study of the failure mechanisms of mechanical seals is a highly complex subject and can only be treated briefly in this article. Some of the factors that contribute to failure are discussed and possible solutions proposed.

Bearings

Mechanical seals cannot tolerate large angular or radial misalignment. (For the shaft diameters and speeds used in R.N. pumps, shaft deflections in excess of 0.05mm (0.002in) are not recommended). Shaft whip in way of the seal must therefore be kept to a minimum. Water-lubricated bearings do not provide the ideal support for a shaft in way of a seal: the sand contamination often encountered by submarine sea-water pumps causes heavy wear of water-lubricated bearings which have fairly large radial clearances even in the new condition. The subsequent change in shaft dynamics further aggravates bearing wear and the mechanical seal suffers from the result. The comparatively large clearances in oil-lubricated hydrodynamic bearings make this type also less than perfect as a form of restraint for the shaft. Ideally, rolling element bearings should be used and these should be sited as near to the seal as possible. The shaft should be made as stiff as possible by using a large diameter or a material with a high modulus of elasticity. These requirements are not always easily achieved because of noise restrictions or the need (in submarine applications) to provide an emergency packed gland as a back-up. Such difficulties are not insurmountable however, and there is still room for improvement in existing installations. It could be said that there are no mechanical seal failures, only bearing failures. Whilst the situation is, inevitably, not that simple there is a fair amount of truth in this maxim. It is certainly very prudent to renew the adjacent water-lubricated bearings whenever a mechanical seal is replaced, despite the fact that this invariably lengthens the repair time.

Water Supply

Involvement of the seal manufacturer in the integration of the seal with the pump design is vital, as is the involvement of the shipbuilder to provide details of the intended pump orientation. This input is particularly important with regard to the circulation of fluid for the dual purposes of removing friction heat and detering the collection of sediment in the seal. It has already been stated that fluid must pass across the rotating face/fixed seat interface (the primary seal) to provide a lubricating film. This film is only of the order of a micron thick and, although there is some evidence that the primary seal tends to exclude dirt, the secondary seal can wear or jam so it is essential that the water supply to the seal be as clean as possible. Fresh water is not practicable for this purpose but clean sea-water can be provided by taking a tapping from the pump discharge and passing it through a cyclone separator before supplying the seal. Cyclone separators can be particularly effective at removing solids from liquids, efficiencies of 90 per cent. being possible. The dirty water from the separator is returned to the pump suction. Unfortunately pumps for main and auxiliary circulating water duties do not provide enough head to achieve high separation efficiency and a booster pump may be necessary. Since a boosted pressure is not usually available, a cyclone separator cannot always be used. In this event the seal water supply is provided direct from the pump discharge and care must be taken to ensure that the differential head is sufficient to provide a good flow to deter the collection of sediment. The use of an auxiliary impeller or inducer to boost the flow may be necessary.

Differential oxygen levels as a result of stagnant water can cause corrosion of the multiple peripheral springs in one type of seal. To prevent this, spring materials must be chosen with care and access to the spring locations should be clear to allow water to circulate freely around the area.

Shaft and Seal Face Wear

Wear of the rotating face and axial shaft movement causes the sliding type of secondary seal to move along the shaft, the surface of which must be of a high quality finish to facilitate this movement. Most metals are protected from corrosion by a thin oxide film and this can be rubbed off by the secondary seal movement, especially when dirt is present. Any resulting corrosion will degrade the shaft finish and leakage will soon follow. Ideally, therefore, the shaft in way of the seal should not only be highly polished but should be given a hard inert coating which is resistant to wear. Ceramic materials such as chrome oxide have the necessary properties and are deposited by flame-spray or detonation-gun process. Care must be taken, however, to ensure that a suitable substrate is used; if the coating is applied direct to the usual shaft materials such as nickel-aluminium-bronze, it can blister in service. This is because high-pressure sea-water can permeate the porous coating causing substrate corrosion which lifts the chrome oxide and destroys the surface of the shaft. Extensive research has shown that a proprietary nickel-chromium alloy is an ideal substrate for hard coatings in the sea-water environment. The alloy can be used either for the complete shaft or as a sleeve. The problem of substrate corrosion also occurs to the fixed seats of mechanical seals which, at present, are bronze coated with chrome oxide. To overcome this problem tungsten carbide or silicon carbide seats should be used. Seals employing these materials are the subject of current seal trials.

Consequential Effects of Leakage

Most submarine sea-water pumps are provided with packed glands for emergency use when the mechanical seal fails. Glands must be allowed to leak for them to work correctly and the resulting 'water carnival' can have considerable consequences. Apart from the adverse effects on nearby electrical equipment and machinery space preservation, there is at least one case where the orientation of the pump is such that leaking sea-water can seep into the pump motor directly below. Little can be done to reduce these consequential effects other than the use of ubiquitous polyethylene sheeting. The amount of water leaking from the packed gland can, however, be reduced by designing for intermediate leakoff.

Intermediate Vent

It has already been stated that the rotating face is kept in contact with the fixed seat primarily by the pressure of the sealed fluid. When the seal leaks and the emergency gland is tightened, the space between the mechanical seal and the packed gland becomes pressurized almost to full pump-casing pressure. Without a differential pressure across the mechanical seal, the latter tends to unseat itself despite the restraining effect of the seal spring(s); the leakage worsens and the seal damage increases. To overcome this problem, the space between the seal and the packed gland should be vented via a small-bore pipe to a tundish and hence to a bilge drain tank. This vent serves the dual purpose of indicating when the mechanical seal is leaking and preventing the intermediate space from becoming fully pressurized as the packed gland is tightened. In this way the mechanical seal continues to provide a contribution towards watertight integrity, albeit a degraded one, and the overall leakage is reduced.

Packed Glands

The packed gland itself can be improved by the use of preformed chevron packing rings acting against a suitably hard-coated polished shaft. Such rings cannot be repacked without partial dismantling but their greater effectiveness, combined with the overall design improvements already mentioned, more than compensate for this disadvantage. If preformed packing rings are used, care must be taken to ensure that they are inserted the right way round and that they are not tightened beyond the requisite fixed amount.

THE FUTURE

Mechanical seals and packed glands can be eliminated altogether by the use of either:

(*a*) Canned motor pumps.

(*b*) Magnetic couplings.

Both the above options are already established in the chemical industry where leakage of noxious chemicals can be highly dangerous, but there is no commercial experience of pumping sea-water using these innovations. Canned motors are already at sea in the Royal Navy being used as main coolant pumps (MCPs) in the primary circuits of reactors, and as lye pumps in electrolysers. The first sea-water pump to use this principle, the Pump-in-Pipe, has already been described in the *J.N.E.*[1,2]. Testing is progressing well and this machine will first enter service as the circulating-water pump in the new class of SSBN being designed for the Trident strategic weapon system.

Canned Motor Pumps

Description

A canned-motor pump can be described as a machine in which the motor is manufactured as an integral part of the pump. The pumped medium is allowed to circulate round the motor internals and, indeed, provides essential cooling to the windings. A typical drawing of such a pump is shown in FIG. 4. The motor is basically a squirrel-cage induction motor but both the rotor and the stator are protected from the pumped medium by canning (thin sheet metal of suitable magnetic permeability and corrosion resistance). For sea-water, a proprietary nickel chromium alloy has been found that is ideal for this purpose, being highly resistant to corrosion and possessing sufficient strength, when supported, to withstand high pressures. Canned motors are slightly less efficient than standard induction motors but the resulting increased heat energy losses are readily accommodated by the cooling provided by the pumped medium. The technology employed in manufacturing such machines

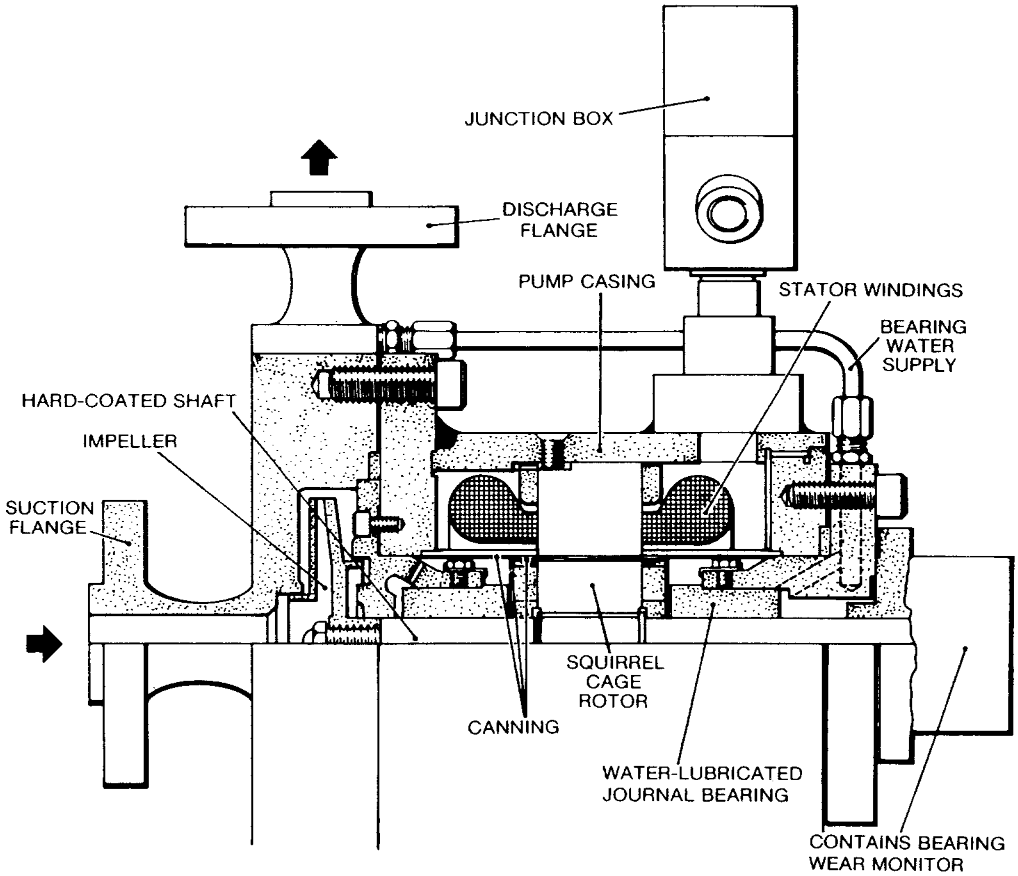

FIG. 4—TYPICAL CANNED-MOTOR PUMP

Courtesy of APV Osborne Craig Limited

sometimes means that they are more expensive than their more conventional counterparts, but this increase in initial capital cost for canned motors must be weighed against the running cost and maintenance load of conventional machines which require frequent renewal of mechanical seals.

Application

Development of canned-motor sea-water pumps for certain applications in submarines is already well under way by the Ship Department. The Pump-in-Pipe which will supersede the main circulating-water pump in future classes of nuclear submarine has already been mentioned. A commercial canned-motor pump is currently undergoing trials at AMTE(NAMD) Haslar and, if these are successful, it is planned to retrofit that particular model into SWIFTSURE Class submarines as shaft seal pumps. It is hoped that a variant will also be fitted in the new class of SSBN. Retrofit of canned-motor sea-water pumps for TRAFALGAR Class submarines will be considered.

Magnetic Couplings

Description

Magnetic couplings use the basic principle employed in a car speedometer in that the motor drives a rotating magnet which is physically separated from the driven member. The latter follows the rotation of the magnet because of magnetic forces. In a magnetic-coupling pump, the driver and driven parts of the coupling are separated by a thin shroud which forms the pressure boundary of the pumped fluid. There are basically two types of coupling as

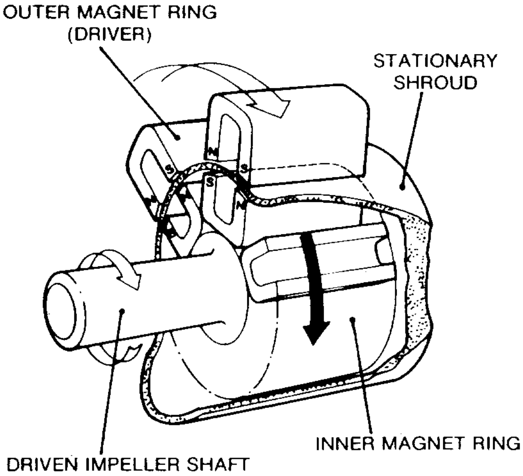

FIG. 5a—SYNCHRONOUS MAGNETIC COUPLING: SHROUD FORMS PRESSURE BOUNDARY

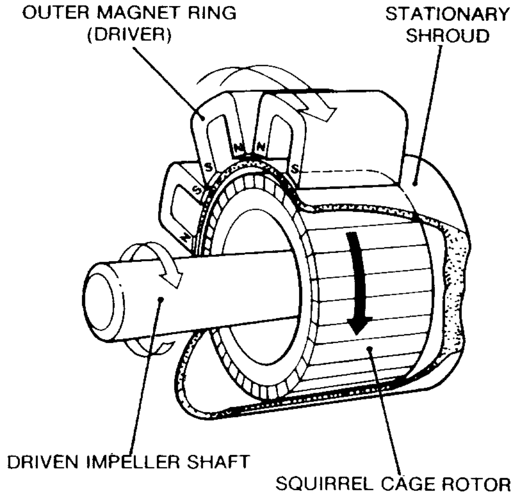

FIG. 5b—INDUCTION-TYPE MAGNETIC COUPLING: SHROUD FORMS PRESSURE BOUNDARY

shown in FIG. 5: the synchronous type and the induction type. In the synchronous type (FIG. 5a), both the driver and the driven parts of the coupling contain strong permanent magnets in iron cores and both parts rotate at exactly the same speed. The induction type (FIG. 5b) uses the same principle as an induction motor in that the driven part contains no magnets and is identical to a squirrel-cage rotor. The driver is fitted with permanent magnets as before and, as it rotates, the magnetic field, which passes through the magnetically permeable shroud material, rotates with it. An e.m.f. is induced in the rotor bars of the driven part and, because these bars are short circuited by end rings, a current flows. Hence the driven rotor sets up its own magnetic field which assists the flux on one side and decreases it on the other, a net torque being produced. Like an induction motor the two parts never rotate at the same speed because slip is required to generate the torque between them.

This very simple principle is by no means new but it is only as a result of the latest technology that suitable permanent magnets capable of transmitting high torques have been developed. For low cost and high temperature (400°C) capability, Alcomax magnets are used but rare-earth magnets are more compact although they are also more expensive. These magnets only lose their magnetism if heated to extremely high temperatures.

The synchronous coupling is more efficient than the induction type but it is more expensive. Losses in the form of heat energy are due mainly to eddy currents in the shroud and are easily removed by circulation of the pumped fluid.

Because it cannot operate with slip the synchronous coupling must be designed to transmit the peak net torque of the motor during starting. This gives it ample overload capability and in the event of the driven machine becoming seized it will generally stall a normal induction motor. On the other hand, if driven by a motor with high overload torque (e.g. a d.c. motor) a coupling can be forced out of synchronism if the driven machine becomes seized and no torque will be transmitted. In this event the motor must be stopped to allow the coupling to re-synchronize. For some applications, this could provide a useful type of protection.

Drives of up to 150 kW are produced in magnetic couplings but this does not represent the limit.

Application

The magnetic coupling is ideal for retrofit action since it can use existing pump impellers and motors and so reduce modification costs. The

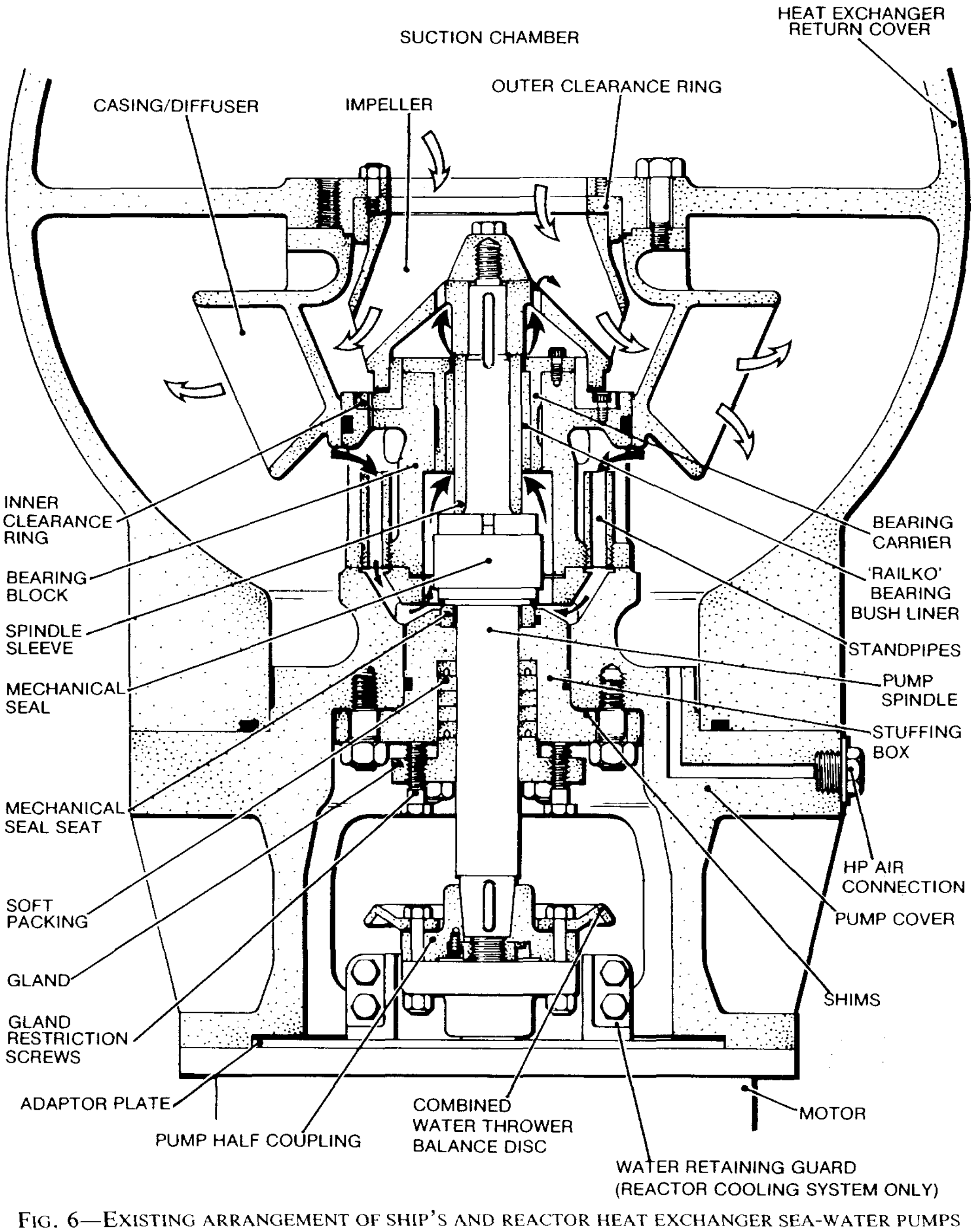

FIG. 6—EXISTING ARRANGEMENT OF SHIP'S AND REACTOR HEAT EXCHANGER SEA-WATER PUMPS IN SWIFTSURE CLASS

synchronous type of coupling is being considered for use in the Royal Navy and a prototype conversion kit for SWIFTSURE Class ship's and reactor heat-exchanger sea-water pumps is currently under test at AMTE (NAMD), Haslar. If it proves successful, kits will be retrofitted to this Class of submarine whose reactor heat-exchanger sea-water pumps have a poor reputation for leakage. Magnetic-coupling drive is also being considered for the heat-exchanger sea-water pumps of the new Class of SSBN and for the same application in TRAFALGAR Class submarines. Retrofit of magnetic-coupling drive for other sea-water pump applications may also prove worthwhile, due regard being given to the maintenance load of the existing conventional pumps and the remaining life of the boats. FIGS. 6 and 7 compare the proposed magnetic-coupling drive for SWIFTSURE Class reactor heat-exchanger sea-water pumps with the existing 'conventional' installation.

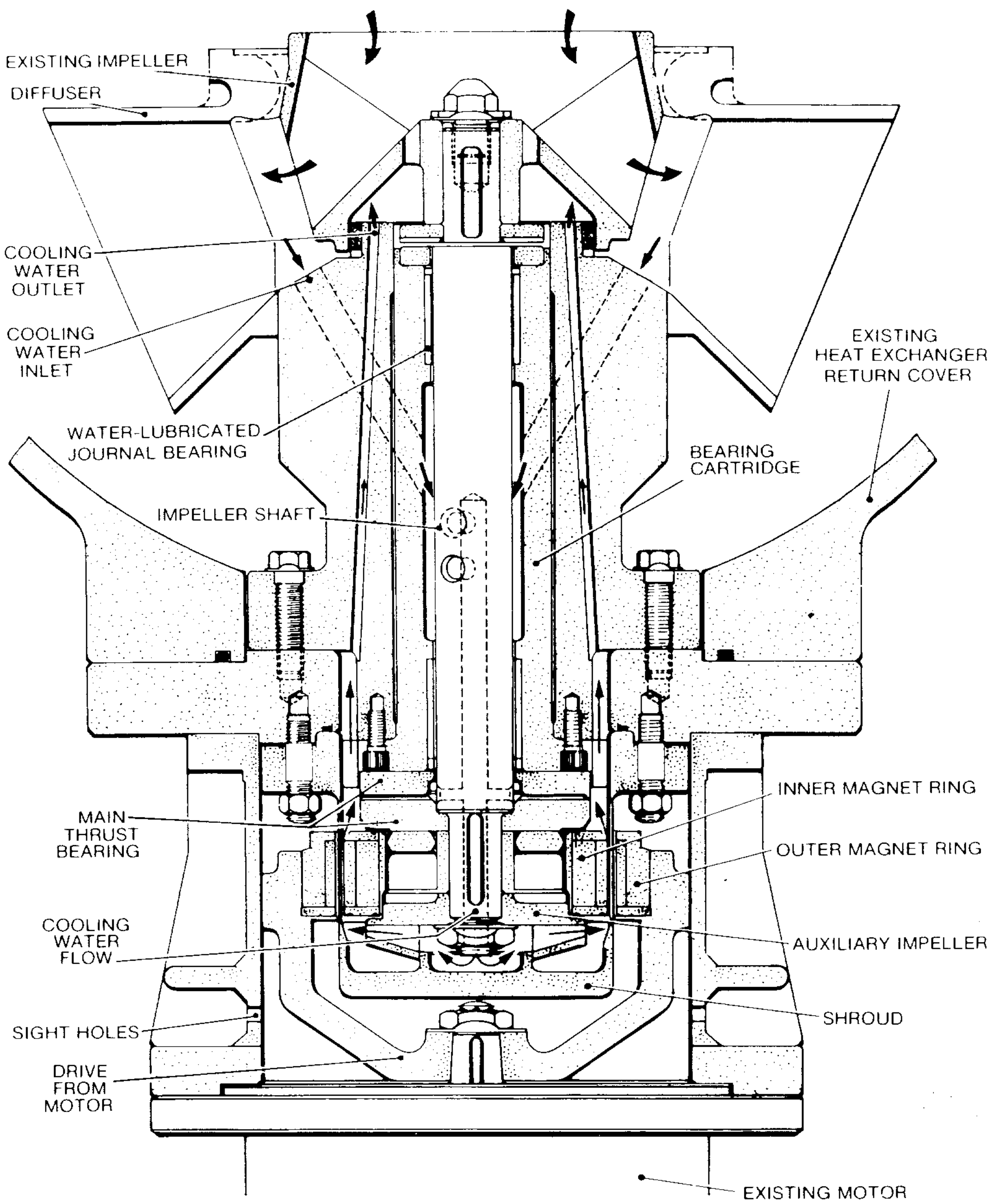

FIG. 7—PROPOSED MAGNETIC COUPLING DRIVE FOR SHIP'S AND REACTOR HEAT EXCHANGER SEA-WATER PUMPS IN SWIFTSURE CLASS

Bearings

Of course, magnetic-coupling kits and canned-motor pumps both use water-lubricated bearings whose wearing properties in sand-contaminated water have already been described as poor. In terms of the reliability and maintainability of these pumps, the emphasis therefore swings from the life of a mechanical seal with its frequent but comparatively easy replacement to the life of a water-lubricated bearing with its less frequent renewal but concomitant pump strip-down.

Research to find long-life seawater-lubricated bearings capable of withstanding sand contamination has been under way for some time, mainly in support of the Pump-in-Pipe project. It has been concluded from this, and independent commercial research, that the 'hard-on-hard' concept is the most promising. This concept uses very hard materials for both bearing shells and shaft journals such that both components are virtually immune to damage by debris in the lubricating water. The first bearings used in this manner were in a full-size test rig in support of the Pump-in-Pipe project and ran for some 8000 hours with no adverse affects. Sand and swarf deliberately introduced into the water was reduced in mean particle size by the crushing action of the bearings which were undamaged themselves.

Ceramics such as hot-pressed silicon nitride (HPSN), silicon carbide, or alumina are the leading candidates for bearing shell materials. A proprietary tungsten carbide coating has been found to be the best material for bearing journals and, as this is deposited by detonation-gun process, the substrate requirements stated earlier in this article equally apply. Due regard is being given to the shock resistance of these potentially brittle bearing materials.

Trials of canned-motor pumps using hard-on-hard bearings are currently being carried out at AMTE (NAMD), Haslar, and one trial is aimed specifically at assessing the performance of these bearings under deliberately sandy conditions. While it is realized that submarines do not spend their time 'Hoovering' along the sea bottom, running these bearings in sand is regarded as the ultimate test of their viability. It is too early to predict the life of hard-on-hard bearings in sea-water but it is hoped to achieve seven years between refits.

Conclusions

Modern engineering has developed pumps that can deal with substances ranging from sewage to salad cream and from molasses to mud but the unique properties of dirty high-pressure sea-water still prove a major challenge. This article has considered how the life of such pumps may be extended by combining good engineering practice with the latest material technology. Although the work is still at an early stage, there are good reasons to believe that substantial improvements in the availability of submarine sea-water pumps are now within our grasp.

Acknowledgements:

The author wishes to acknowledge the assistance given to him by his colleagues and various pump manufacturers in the production of this article. In particular, the advice given by Mr. N. M. Clark of YARD Limited and Mr. N. S. Hackett of the Ship Department has been invaluable.

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