THE PUMP-IN-PIPE

A NOVEL DESIGN OF SEA-WATER PUMP

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Introduction

Sea-water pumps for main condenser cooling in existing submarines have drive motors external to the pipework. Since any form of angled drive would produce too much noise, impeller and motor are mounted on the same shaft. This means that the pumps have to be positioned at bends in the pipework, and mechanical seals are fitted to the shafts where they pass through the pipework. As these seals have a limited life, their elimination would improve pump reliability. A simple shape for the pump casing is very desirable to reduce the problems inherent in the manufacture of high-integrity pressure vessels. The high stresses in the main sea-water systems when under diving pressure also put a premium on simple construction and on straight pipes with the minimum number of bends.

The pump-in-pipe has been designed to cater for these objectives in pursuance of a high degree of system integrity and reliability. As the name implies, the unit is a fully-enclosed pump and electric motor installed within the pipework. This means that access for maintenance is reduced and, therefore, one objective of the development is to provide a very high level of component reliability and to demonstrate this by extensive prototype testing.

A main sea-water system needs to provide varying quantities of water to keep main engine vacuum within an acceptable band over the full range of engine powers and sea-water temperatures. This has been variously achieved in existing designs by using two separate pumps of different sizes and by using a single pump with a variable-pitch impeller driven at different speeds by two separate motors. These arrangements involve a degree of complexity which is undesirable. Development of the pole amplitude modulated (PAM) winding system, which permits a motor with a single-wound stator to operate at more than one speed by external switching only, allowed consideration of a design with a single pump and motor.

The unit has a cylindrical outer casing with the pump and motor pod located inside it by support stubs and the flow guide vanes. The pumped sea-water passes through the annulus between the outer casing and the motor pod. The support stubs carry electric supply cables, instrument leads and small-bore pipes for venting and for supplying a low flow of filtered sea-water. These are the only external connections. No mechanical seals are needed.

The rotor and stator windings are protected from the sea-water within the unit by canning, and an auxiliary impeller circulates water through the rotor-stator gap to heat-exchanger grooves adjacent to the main pump flow in order to remove the heat generated in the motor.

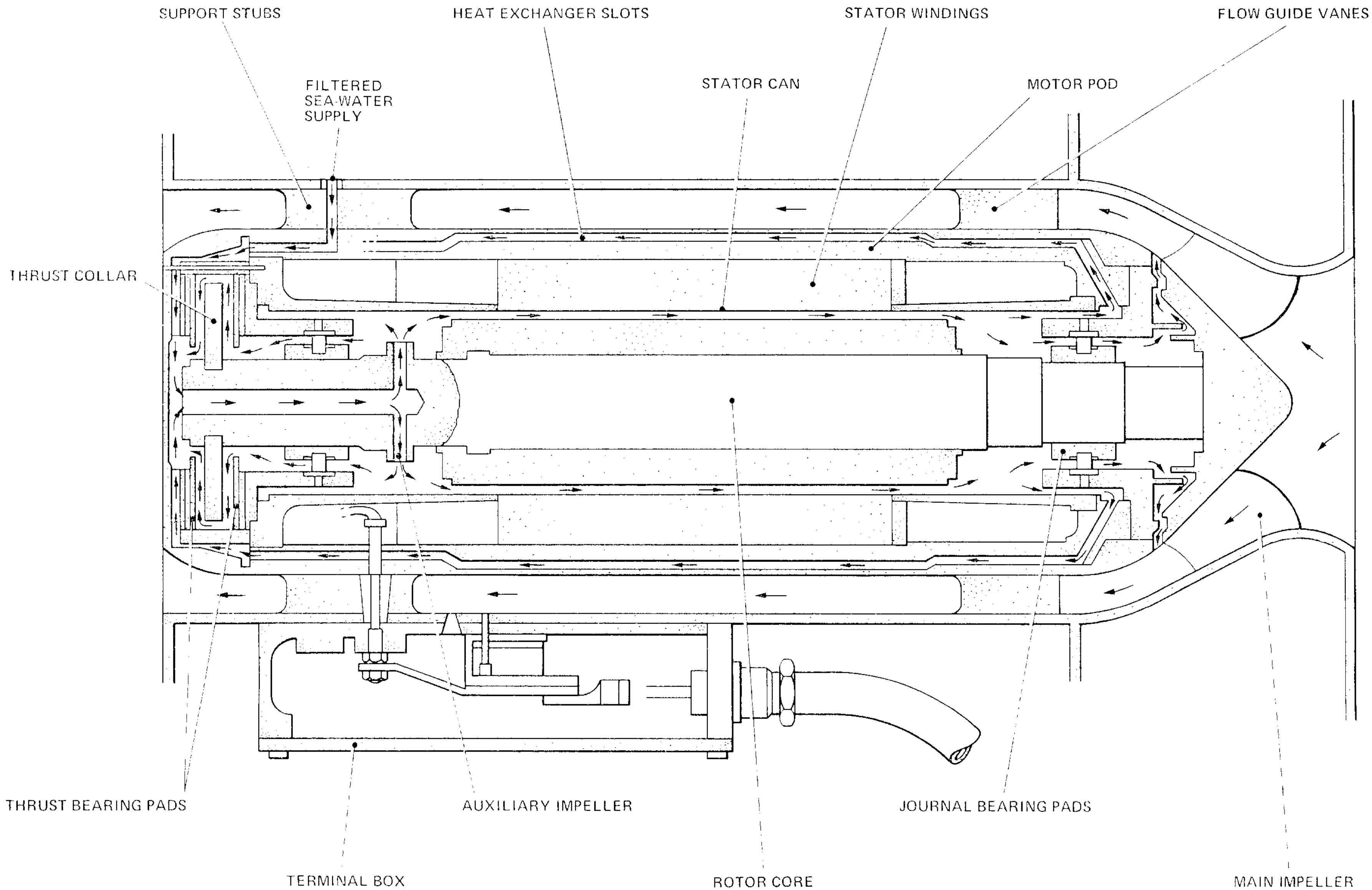

FIG. 1—DIAGRAMMATIC REPRESENTATION OF THE PUMP-IN-PIPE

Features of the Design

Motor

The motor comprises a copper-barred caged rotor and a conventional wire-wound stator. The design is a compromise between the short rotor needed to provide stiffness and a high degree of balance, the small stator diameter dictated by size restrictions, and the long stator required to minimize can losses.

The size of the rotor-stator gap is again a compromise between the minimum dictated by magnetic requirements, and the maximum needed to accommodate the cans and the cooling water flow, and to prevent contact under shock.

The large shaft diameter limits the radial depth of the rotor core. The close proximity of copper bars and cooling water permits the use of small copper bars at high current densities. A solid slotted core of magnetic material is preferred to the normal laminated design to improve rotor stiffness and to reduce deflection under shock. The rotor balance requirements are particularly stringent in the interests of achieving the noise target for the unit. The method of construction adopted requires that the impeller be removed from the shaft after balancing for installation in the machines. It is a design objective to demonstrate that the impeller fixing method should allow these balance requirements to be maintained even after repeated assembly and dis-assembly of the impeller from the rotor.

Although the unit would not operate after the stator can had failed, the terminal arrangements are designed to preserve the pressure integrity of the unit following a stator can failure.

The stator and rotor cans are only 0·5 mm thick to facilitate heat transfer and to satisfy the magnetic requirements already mentioned. The canning material is deformed onto the slot wedges and rotor conductors by fluid pressure. The method of wedging the stator slots has had to recognize the need for can support and the need to minimize cyclic stresses in the canning material during pressure changes from the fatigue point of view.

Internal Cooling Circuit

The heat exchanger consists of a very neat arrangement comprising twelve flat slots machined in the stator frame adjacent to the main sea-water flow and covered by canning, with flow passages at each end connecting them to the remainder of the circuit. This design provides sufficient area for reducing the temperature of the coolant and at the same time leaves adequate provision for heat to flow directly outwards from the stator.

The circuit is designed to limit the temperature of wetted surfaces to below 55°C to give a margin against scale formation, and to provide flow velocities which are fast enough to discourage marine growth and slow enough to prevent erosion. Fouling by marine growth will also be discouraged by the copper alloys used in the construction of the unit.

The design of this circuit was sufficiently critical for a full-scale model to be constructed to verify coolant flow rates in all parts of the circuit. This information was then used as the input to a thermal network representing the flow paths for heat transfer within the motor and the water circuit. Conductance values between adjacent nodes were determined and used to build up a complete picture of the temperature distribution, providing values of temperature at 139 points.

The decision as to whether or not the circuit should be sealed from the main water flow presented an interesting design problem with major implications for the bearing design and the materials to be used in the circuit. A shaft seal would have to operate at pressures from zero to diving depth despite the axial float of the shaft, and it would need a very high reliability if the design of the internal components were to rely on its operation. The seal duty could be reduced by providing a compensating bellows to limit the differential pressure across the seal, but such a device would itself be liable to fail. The target life for the pump is very long, and the consequences of its failure to the installation would be serious; it was therefore decided that the internal circuit should be supplied with filtered sea-water with a continuous leak off to the main flow, and that the bearings should be designed to withstand the largest particles which would pass through the filter. All the wetted components are in materials suitable for service in sea-water.

Bearings

The journal bearings are of the tilting-pad type to ensure dynamic stability. The minimum film thicknesses with water as the lubricant are as little as a few microns, so that their fine accuracy has to be achieved in manufacture and assembly. Each pad is supported on a spherical-headed pivot pin, giving the bearings a self-aligning capability which is made essential by the close tolerances involved. The bearings need very high wear resistance to maintain the rotor position and to prevent the occurrence of large unbalanced magnetic forces which would occur if the rotor became even slightly eccentric to the stator. Achieving these objectives with a lubricant which could contain sand is an extremely arduous duty, and a hard-on-hard materials concept was the only promising solution. The materials selected are monolithic, hot-pressed silicon nitride (HPSN) for the pads running against a carbide coating.

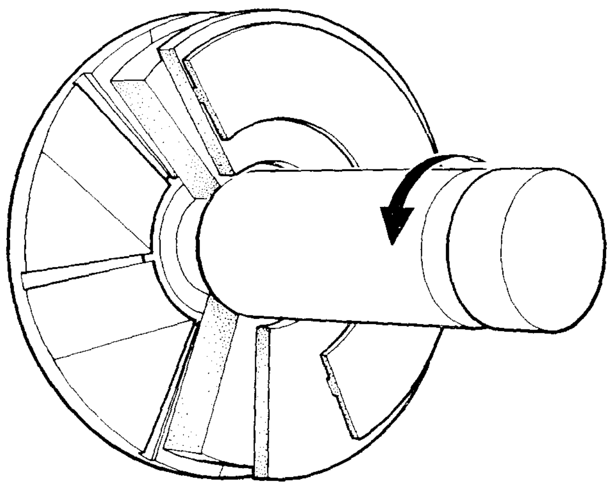

FIG. 2—SKETCH OF THRUST BEARING

The hydrodynamic design of the bearings was confirmed on a full-scale test rig using sophisticated instrumentation to measure the very small displacements involved. A full-scale materials test rig is now in operation to prove the materials aspects. Initial results are most encouraging, with several thousand stop/starts already completed in sandy sea-water. The hardest sand has a VHN of 1200, while HPSN has a VHN of over 1700 and the shaft coating has a VHN of more than 1200; it was interesting to note that particle counts of the sand showed that the larger particles had disappeared during testing, presumably by being ground up in the bearing.

The small variations of film thickness with load for the thrust bearing allowed selection of a tapered-land fixed-pad bearing; this has the advantages of simpler construction and installation compared with the tilting-pad type. The materials follow the journal selection, the bearing being monolithic HPSN running against a thrust collar with a carbide coating on its bearing surfaces.

Noise requirements dictated that the bearing swash should be minimized. Components, therefore, have to be manufactured to fine tolerances and the location of the thrust collar on the shaft has to be most accurately arranged. The HPSN components are flexibly mounted in the casing using flexible annular supports similar to Belleville washers to improve swash compensation.

Reverse thrust produced when scoop effect drives the pump as a turbine is taken by an identical bearing on the opposite side of the thrust collar.

Hydraulic Design

The major requirements of the hydraulic design are low noise emission, good cavitation performance, and minimum duct height along the length of the motor pod. One of the most important aspects of the design has been optimization of the hydraulics to achieve differing performance targets at the two operating speeds and with different scoop and inlet pressure conditions. The diffuser is positioned further away from the impeller than is usual in this type of pump, and the numbers of impeller and diffuser blades were selected to reduce noise.

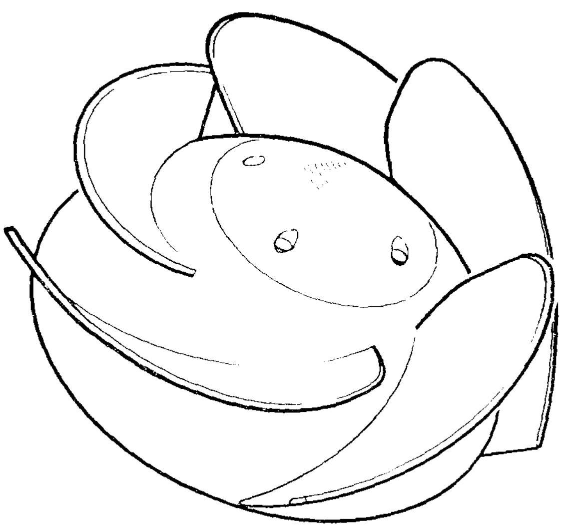

FIG. 3—SKETCH OF IMPELLER

The profiles of the impeller and diffuser blades were designed using a suite of computer programmes which consist of two interactive flow methods. One of these computes the meridional stream surface distribution through the pump, and the other computes the design of blade elements on a number of stream surfaces. This gives the required flow deflection for the design head rise. The diameter of the impeller eye was optimized to obtain good cavitation performance.

A full-scale hydraulic model of the pump has been built into a closed-loop test rig to prove the hydraulic performance. The rig includes perspex sections and acoustic equipment for the observation of cavitation.

Materials Selection

The materials used in the construction of the pump need a variety of general mechanical properties and have to resist all the harmful effects of sea-water. The individual requirements of each component were tabulated before a selection was made and a careful balance had to be struck between the known performance and shortcomings of established materials and the partly substantiated promise of new materials. Where new materials have been selected, materials development has had to be undertaken and non-destructive techniques established. A large welding development programme has been necessary to establish methods of welding new material combinations to required standards of integrity.

The canning material is a nickel alloy with the necessary erosion resistance to combat the high sea-water velocities in the rotor-stator gap.

The impeller is of cast nickel-aluminium-bronze to give the necessary mechanical and corrosion properties.

The pump casing has to withstand pressure and shock stresses as well as resisting corrosive effects of sea-water. Parts of the casing, particularly in the area of the main support webs at the thrust-bearing end of the pump, are of complex shape so that casting is preferred to forging and machining as the method of manufacture. A high-strength cast cupro-nickel has been selected for the duty although titanium could become a strong candidate for future pumps. Development work has been required to produce castings of the necessary size and integrity.

Conclusions

Design and manufacture of the pump-in-pipe is nearing completion and a full programme of prototype testing has been arranged. The philosophy of development, which has aimed at producing a pump of established reliability by close attention to design and quality assurance, will justify the considerable expense involved if the operator is given a unit of which he can be fully confident, and if the system designer is freed of some of the more difficult restraints that have hampered him in the past.