ROYAL NAVY PROPELLER SHAFT SEAL AND BEARING DEVELOPMENT

BY

T. ADAM
(*WSA – MPSIPT*)
and
P. HUTCHINSON
(*BMT DSL*)

ABSTRACT

The requirement to test underwater bearing materials was borne out of the need to find a replacement for asbestos based bearings and to extend the life of underwater bearings in service. As there was no commercially recognized method of testing these types of bearings or seals and to understand the features of each manufacturers material, the RN developed with BMT a series of test rigs and procedures to emulate the conditions found in service. These procedures would also provide confidence in the bearings performance during a representative duty cycle.

The Haslar site

The Ministry of Defence has for many years supported a testing and development contract for propeller shaft seals and underwater bearings for the Royal Navy's surface ships and submarines. The department responsible for this work is Marine Propulsion Systems Integrated Project Team, Section 212 (MPS212).

The test rigs for this work are operated by BMT Defence Services Limited for MPS212 at the Haslar Marine Technology Park in Gosport. Gosport was chosen for the location of the test rigs as the Royal Navy has traditionally used sea water lubrication and cooling in almost all external shaft seals and bearings. Sea water is available at Haslar, the water being remarkably representative of littoral water quality. BMT operates the test rigs as a test centre, which is independent of any bearing or seal manufacturer, to provide the Ministry with an unbiased view of new developments.

Benefits

Water lubricated shaft bearings and seals have been successfully used in both large and small craft worldwide for many years. So why should the Royal Navy be interested in maintaining its own test facility? There are a number of reasons; Royal Navy ships, unlike most merchant shipping, use their propeller shafts over a wide spectrum of rotational speeds and rarely steam from one point to another at constant speed. In particular, for surface ships, operation at very low shaft speeds for long periods is quite normal, particularly in anti-submarine operations.

Also, submarines will operate at very low shaft speed to avoid detection. For a water-lubricated bearing, this slow speed operation is the most difficult to cope with as hydrodynamic lubrication is difficult to maintain. Stick-slip may occur, causing high torsional variation and attendant noise. This slow speed operation would be easy to overcome by using an oil-lubricated bearing, but this leads to increased complexity, particularly with the A-bracket bearings; and there would also then be the potential pollution and detection problems to take into account. In the area of seals testing, the speed and depth requirements of the Royal Navy's submarines are unlike anything used commercially, and the test rigs have been designed to test to maximum conditions. Though mostly used for testing at conditions particular to Royal Navy requirements, the rigs can also operate under conditions found in commercial shipping.

There are five main test rigs

- Two bearing test rigs capable of testing 200 mm (FIG.1) and 514mm diameter bearings (Fig.2).
- Three seals test rigs which are capable of testing shaft seals for the current classes of nuclear submarines.

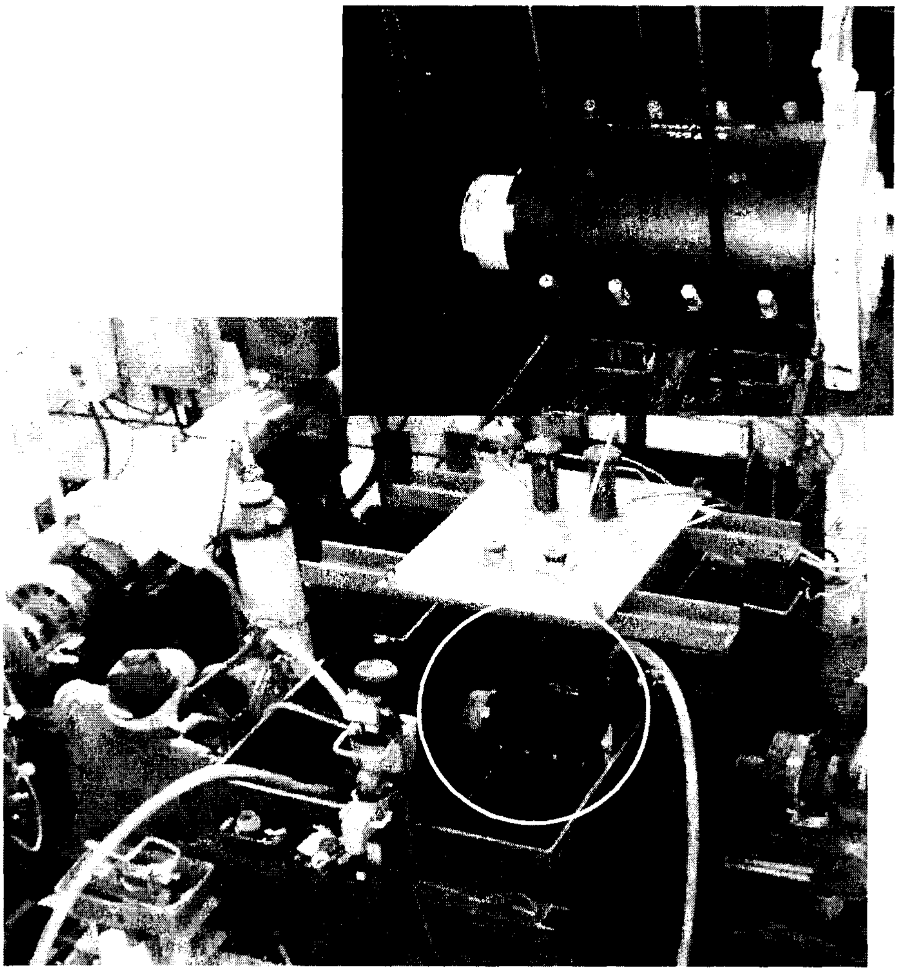

FIG.1 – 200mm TEST RIG

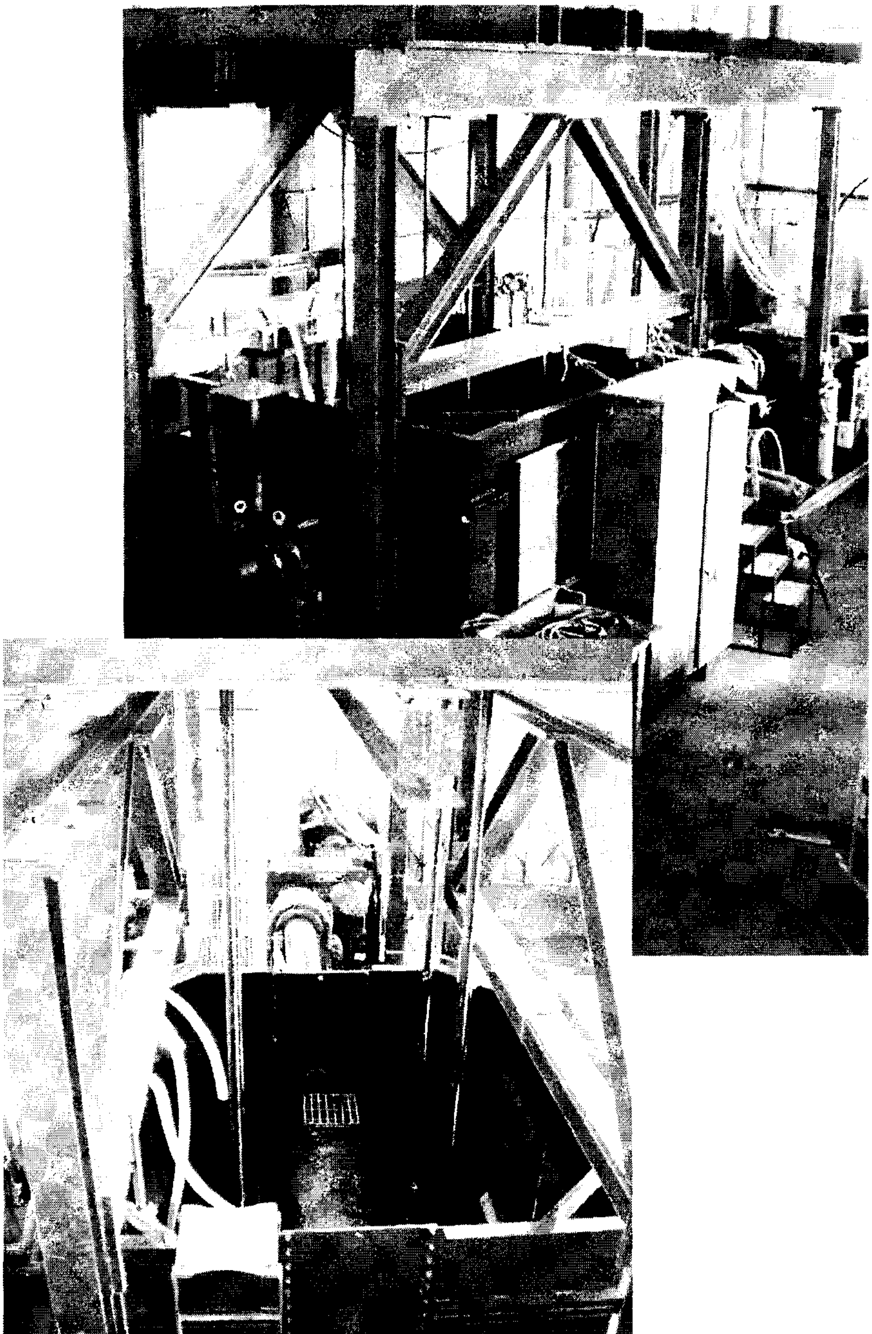

FIG.2 – FRIGATE (514mm) TEST RIG

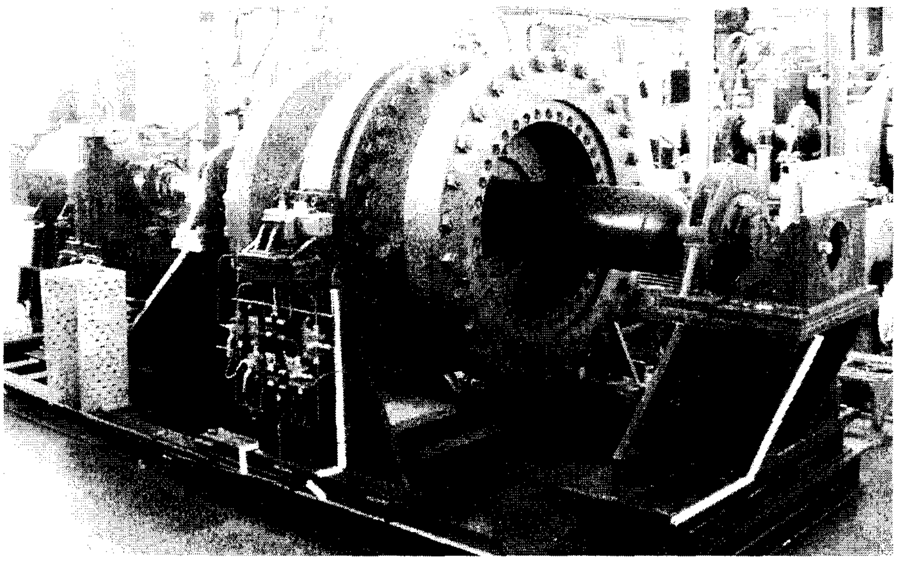

FIG.3 – SUBMARINE SEAL TEST RIG

Seals Test Rigs (FIG.3)

Use of the seals test rigs has declined over the past few years, very much because there have been few problems experienced with current seal designs used in RN surface ships and submarines. A low technology seal, which had a number of potential advantages over the more traditional seal, was developed and all but proved, but final development was not completed when the UK Company involved withdrew its basic seal design for commercial reasons. The seals test rigs are however maintained to ensure that independent testing can be carried out if required on submarine seals as they get older or if improvements are proposed.

Bearing Test Rigs

The two bearing test rigs can operate from very low shaft speeds to about 200 rpm top speed. Bearing load is applied by pulling up on the bearing in its housing with the test shaft supported by pedestal roller bearings. This does not exactly simulate the weight of the shaft and propeller applying a load to the A-bracket bearing, but it is not considered safe or feasible to have a dummy propeller load of several tonnes rotating in a test house at 200 rpm. Load is applied hydraulically and bearing pressure can be varied from zero to about 10 bar, though operation in the middle of the range is the norm. Water quality is also varied in the trials, using both clean sea water to simulate deep sea operation and 'gritted' water, to simulate operation in shallow water – a particular requirement of some RN ships such as the Assault Ships and Mine Countermeasures vessels.

For many years after the war, the rubber stave design bearings were utilized in underwater bearings, and these were successfully used, up to the era of the LEANDER class frigates in the '70's and '80's. These rubber staves were replaced by Asbestos reinforced resin materials which were able to accept higher loads, leading to shorter – and therefore cheaper – bearings. Much of the early trials work on the test rigs resulted from the need to avoid using Asbestos in the bearing materials, a decision which the Ministry of Defence made earlier than most. This hazardous fibre was used in most bearing materials and provided excellent wear and friction characteristics. Non-asbestos materials were developed by a number of commercial suppliers and these were independently tested on the test rigs and the best introduced into service fleet-wide.

In the Royal Navy's search for reduction in through-life costs, this research has continued. New bearing materials are being developed by the manufacturers both in the UK and abroad and these are considered and tested with the aim of identifying those where there is potential for longer life, while retaining the low wear and friction characteristics which the Royal Navy requires. The use of the rigs enables standard tests of new materials to be carried out, providing direct comparison with datum trials. It is acknowledged that no test rig can ever exactly mirror the conditions found in either the stem-tube bearing or the A-brackets, so after rig-testing, new bearing materials are subject to a Minor Trial in a warship before final approval is given for fitting in the fleet.

Gunmetal Liners

Shaft bearings consist of two parts - the bearing material located in the housing and the shaft itself. Traditionally, the Royal Navy has used steel shafts fitted with Gunmetal liners in way of the bearings and seals. These Gunmetal (LG4 - a Copper/Tin/Lead/Zinc alloy) liners have given reliable service and perform well as one half of the bearing combination. They are relatively easy to fit, being shrunk onto the shaft, have good friction qualities with the in-service bearing materials and, with their high thermal conductivity, ensure that the bearings run cool even when water flow is marginal. The one drawback that they have is that the metal is relatively soft and prone to wear. This wear is usually in the form of grooves along the contact section and is rarely constant along the length of the liner. Hence, when new bearing material is fitted in the housing, the optimum initial clearance cannot be achieved over the whole length of the bearing and a higher initial wear rate can be expected. Each shaft will be fitted with new liners at least once, but usually more, during the lifetime of the ship. As well as renewing the liner, this work also enables a check to be made that corrosion has not occurred between the liner and the steel shaft. This is a costly task, though normally undertaken as part of the routine overhaul of the shafts during dry-dockings.

Recovery of the diameter of Gunmetal liners has been attempted in the past by employing metal spraying techniques. This is proven technology for some applications, but in-service experience for shaft liners demonstrated that it could be potentially disastrous. In one instance, the surface layer of Gunmetal became detached in one area, providing a very sharp edge which cut through the bearing material, leading to immediate failure of the bearing and an emergency docking to renew it. Metal spraying of shaft liners has therefore been discontinued.

As part of the trial programmes, the test rigs have been used to try different types of liner. These have included hardened surface finishes and the use of novel surfaces, such as a 'dimpled' liner. This latter used shallow drillings over the bearing area to promote water flow between the bearing segments and the shaft.

Inconel Liners

Inconel 625 is an alloy of Nickel, Chrome and Iron. It is now being fitted as shaft liners more widely in commercial shipping – including some of the new cruise liners – and would appear to have potential for through-life cost reduction as it is very much tougher than Gunmetal. Initial costs are higher than for Gunmetal, but a through-life cost study has shown that savings will be made if just one liner change can be avoided during a ship's life. Inconel liner testing is now one part of the trial work being undertaken on the test rigs.

Many thousand of hours comparative testing have been completed on both the 200mm and 514mm test rigs, running Inconel 625 against both those bearing materials used by the Royal Navy and also against others which subsequently have not been recommended for adoption. Inconel has proved to be exceedingly hard wearing, with almost no detectable wear on the diameter, even with heavily 'gritted' water. Current trials include assessing the effect that different initial surface finishes have on the performance of the bearing, from a standard machined finish (0.8 μm Ra) to a fine polished finish of 0.2 μm Ra. Trials are also planned to assess whether cast/shrunk Inconel sleeves have any performance advantage over welded liner manufacture.

The one major drawback for Inconel when compared to Gunmetal is its very poor thermal conductivity, which is less than 10% that of Gunmetal. A-bracket bearing designs used in the Royal Navy utilize the natural flow of water past the shaft to provide a good water flow through the washways between the bearing segments. This is ensured by the design of the Rope Guards and the bearing housing. In the 'Pametrada' design of bearing which has been used in a number of Royal Navy ship classes, there are four washways, providing a total arc of about 160° of water in contact with the shaft liner. This provides for excellent heat removal from the bearing, particularly with Gunmetal liners, and overheating has never been a cause of failure. The wide arc (140° contact arc top and bottom) bearing design used the Type 23 frigate has a smaller washway arc, but is nevertheless performing extremely well.

The Stern Tube bearing is significantly different. Being effectively in a sealed tube, the bearing and the seal on the inboard side of it are dependent on a pumped water supply from inside the ship. This flows past the seal and through the bearing before exiting the stern tube to sea. Without this there is no natural water circulation through the bearing and overheating may easily result. Where an Inconel liner is fitted, this problem will be exacerbated, as the heat will not be conducted away through the shaft in the same way as it is for a Gunmetal liner. A short interruption in water supply may therefore be catastrophic leading to damage not only of the bearing, but possibly of the stern seal as well. Where proposals are made for using Inconel in the stern tube bearing, it is therefore essential that heat flow calculations are correctly carried out and the necessary flow of cooling water ensured. Flow meters with an alarm facility are considered essential.

In the trials that have been carried out over the years, one factor, which keeps appearing, is the inconsistency between small scale and full-scale tests. Laboratory trials using small test pieces do not always predict what will happen at full scale. Similarly, it has been found that the results of short tests should never be extrapolated and used in the prediction of performance over the long-term. Longer trials, where up to a year's shaft operating time is tested, have provided much better indication of likely performance at sea. The longer trials on the full-scale test rigs at Haslar are probably as realistic as they can be without excessive expenditure.

Commercial trials

The Ministry of Defence is keen that these unique and useful test facilities are used as much as possible and have encouraged BMT Defence Services Limited to hold talks with manufacturers who might wish to use them. A number of commercial trials have already been completed or are planned. Lengths and type of trial can be varied and changes can be made to the test equipment as needed. For instance, recent trials on these rigs have included the testing of commercial oil-lubricated bearings as well as those running in sea water. A recent upgrade to the instrumentation package enables data to be continuously recorded on up to 32 channels and this can be easily transferred into Excel spreadsheets for subsequent analysis.

Improved performance of RN bearings

In the mid '80's the Royal Navy was suffering from a significant number of underwater bearing failures. Since that time, much emphasis has been placed by BMT and MPS212 on testing the performance of the bearing materials and on emphasizing the care that needs to be taken in their renewal in the dock bottom. The compatibility of the bearing and liner materials are crucial to the longevity of the bearing, but the initial preparation and correct fitting of the bearing before the ship undocks is equally important. This is now appreciated in the dockyards, and Royal Navy bearing failures are almost things of the past.

The long-term aim of the test programme is to provide shaft bearings, which will last as long as necessary to avoid becoming the driver for docking the ship, whilst providing through-life cost savings. Dry docking remains a very expensive operation and a small but significant investment in identifying how to get the best out of existing bearing materials or to identify new and improved bearing and liner materials is considered to be very worthwhile.