THE BLACKENING OF WHITE METAL BEARINGS

BY

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Introduction

In 1839 Isaac Babbit took out a patent for an alloy of tin, antimony and copper with excellent antifriction properties for use in bearing applications. This metal was so light in colour that it acquired the name of 'white metal', and it was so successful that it has provided the basis for the most widely used range of bearing alloys. Materials of this type are used at sea for bearings in turbines, gearboxes, main thrust blocks, plummer blocks and in a wide range of auxiliary equipments. After a period in service, these bearings are sometimes found to be black rather than white, with the previously soft surface covered by a very hard layer (FIG. 1). This blackening is typical of the surface produced by the corrosion of the tin phase of the white metal, a type of attack commonly associated with sea-water contamination of the lubricating oil. In 1974, a Type 81 frigate suffered a catastrophic failure of two small thrust bearings within the main gearing which was thought to have been caused by this type of corrosion. Less than six months later, similar blackening was discovered in the gearbox of a GMD after a journal bearing failure. These failures, together with reports of corrosion on high-speed thrust bearings in another vessel and in a shore test establishment, prompted the Ship Department to start an investigation into this problem.

Although the work is not yet complete, it is felt that an early article in the *Journal of Naval Engineering* would be of value. This article discusses the history of this type of bearing defect, particularly as it has affected the Royal Navy; describes the appearance, the nature and the hazards associated with the hard black film which is created; discusses the possible mechanisms by which the corrosion may proceed and from these derives various options which could reduce the chance of bearing failure to a more tolerable level. The results of some recent research work are discussed and a programme of further research is outlined. The work is directed towards main-gearing and thrust bearings but mention is made of corrosion in main engines and various auxiliaries.

Early History

This type of corrosion was first reported in 1957 during a routine examination of main-engine and gearbox bearings from the s.s. *Queen Mary*. A hard black scale was found to be covering a number of the journal bearings and samples of the white metal were cut and sent for analysis. The main thrust block associated with this engine had failed for no apparent reason some months previously and, less than a year after the inspection, the thrust block on another shaft in the same vessel failed during passage. Although most of the evidence was destroyed when the white metal melted, the failure was thought to have been caused when flakes of the hard scale broke away from the surface and were trapped between the thrust collar and the thrust pads.

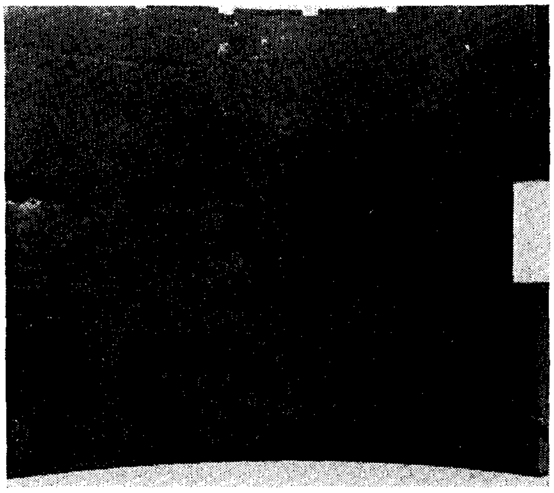

FIG. 1—SEVERELY CORRODED JOURNAL BEARING REMOVED FROM A TYPE 81 FRIGATE

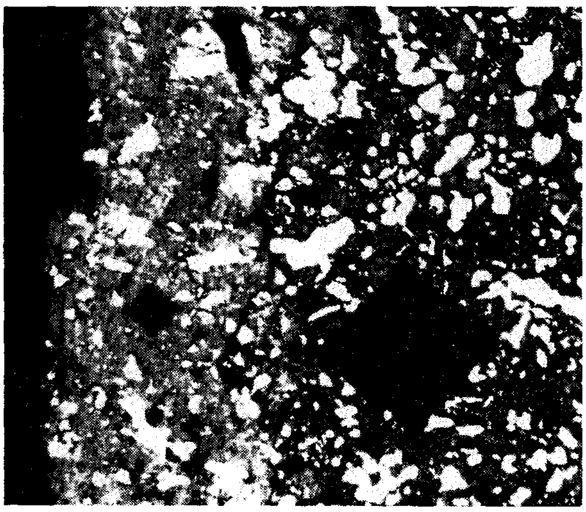

FIG. 2—SECTION THROUGH CORRODED SURFACE (× 200)

The most surprising feature of the corroded surface was its great hardness — some 7 to 10 times that of the base white metal. The Tin Research Institute expressed the view that the only substance likely to be present with such a hardness was stannic oxide (SnO_2). Further research revealed that the surface comprised a mixture of stannous and stannic oxides which had been formed by the corrosion of the tin in the white metal.

A journal bearing severely corroded in this manner is shown in FIG. 1. A magnified view of a cross section through an undisturbed region of corrosion is shown in FIG. 2. These photographs reveal many of the features of this type of attack and the cross section in particular warrants detailed attention. The photograph can be divided into three regions: the dark strip on the left which is the background; the lighter corroded layer extending for about 20 mm, and the rest of the picture to the right which shows the structure of the unaffected white metal. The difference in hardness of the two regions can be judged from the size of the diamond indentations made by the microhardness tests.

The major constituent of white metal is tin, which forms the dark background in the right-hand section. The tin is strengthened by two main alloying elements, antimony (Sb) and copper, (Cu) which combine together to form the intermetallic compounds (SbSn) and (Cu_6Sn_5) which show up as white spots. It can be seen from the presence of these white spots in the corroded layer that the attack takes the form of progressive corrosion of the tin to form tin oxides leaving the intermetallic compounds unaffected.

As a result of this and other attacks, a major investigation into this unknown phenomenon was launched in 1959. An excellent review of the work was given by Bryce and Roehner in 1961 (1). They reported that corrosion had been found in a number of vessels and in some shore-based power installations. The attack varied in intensity from a slight dulling of the normally bright white metal, through various intermediate stages where dark patches or bands appeared, to increasing thicknesses of hard black film covering the entire bearing surface. The partial films are typically 0·001 in. thick but full films ranged from about 0·0015 in. up to 0·020 in. in extreme cases. It was commonly observed that when the depth of corrosion was greater than about 0·005 in. flakes of corrosion product fell away from the surface. Isolated patches of corrosion were generally first observed in the unloaded areas near the horns of the bearing and only when the corrosion had developed did the loaded region become affected.

Of some 900 vessels lubricated by the oils with which the authors of Ref. (1) were concerned, only four cases were reported where the corrosion was sufficiently advanced to warrant bearing replacement. Forty-eight ships were critically examined and of these, sixteen had some corrosion. Vessels which spent longer with the machinery at rest, such as passenger liners and dry-cargo ships, appeared to suffer more than vessels running continuously, and thrust bearings were more often attacked than journal bearings.

A number of theories were put forward to explain the pattern of evidence. Unfortunately a repeatable laboratory technique for reproducing the corrosion could not be found and the exact mechanism of attack was not discovered. Such results as were obtained suggested that the process was electrolytic in nature and that both oil and water were essential for the hard type of scale to form. Although reports on the nature of the two forms of oxide are somewhat conflicting it appeared that stannous oxide (SnO) is generally associated with soft crumbling films and although both oxides will be present it is the stannic oxide (SnO_2) which forms the basis of the very hard corroded layer found in ships' bearings.

The chemistry of tin is complex and the element is able to form a large range of compounds, especially salts. Bryce and Rochner identified the following factors as being of particular significance:

(*a*) Tin oxide is always present on the surface white metal but is usually restricted to microscopic thickness. At high temperatures thicker films can form directly without electrolytic action.

(*b*) Tin is anodic to tin oxide by 35 mV. In the presence of an electrolyte the tin will be progressively corroded with the sustained release of electrons.

(*c*) Tin oxide is a semiconductor, thus permitting electrolytic corrosion to continue underneath the corroded layer.

(*d*) Rust (Fe_2O_3) can function as a supplier of oxygen to tin in acidic conditions:

$$2\,Fe_2O_3 + Sn = SnO_2 + 4\,FeO.$$

(*e*) Iron is anodic to tin by 305 mV and would therefore corrode preferentially unless stray currents in excess of this value were able to reverse the polarity.

In the discussion of Bryce and Rochner's paper, reports of other laboratory work confirmed that tin oxides could be produced on the surface of white metal by four processes:

Electrolytic corrosion in the presence of oil and sea water.

Electrolytic corrosion in the presence of some oils and distilled water.

In dilute electrolytes with impressed currents.

Heating white metal to a temperature close to its melting point in dry air.

The nature of the films produced varied somewhat and the hard films containing a majority of stannic oxide were commonly found only when oil was present.

When the evidence is presented in this way it is difficult to see why corrosion is not much more widespread and why it was not reported during the hundred years before 1957 during which white metal had been in use. There is no simple answer. With most chemical reactions the rate of corrosion increases rapidly with temperature, and the need to reduce bearing sizes has led to a steady increase in allowable bearing temperatures. Thrust bearings generally operate with higher temperatures than journal bearings and this may be one of the reasons why they are attacked more readily. Lansdown and Hurricks (2) point out that copper, lead and iron salts can be powerful catalysts of corrosion reactions involving lubricating oils and it is perhaps significant that corrosion is more common in vessels over ten years old, particularly those with dirty lubricating oil systems containing sludges. These sludges are emulsions of chemical salts, oxidized oil, water and large quantities of iron oxides.

When all the evidence is compiled it can be seen that corrosion is possible with a very large number of oil and white metal combinations. No laboratory reported any variance between the different types of white metal used, but some evidence did accumulate which suggested that the oil type could influence the rate of attack. It was not however possible to isolate any one component or any one change in operating environment which could explain the distribution and range of severity of the corrosion observed in service.

Many people have suggested that the extreme pressure (ep) additives in the lubricating oil may aggravate the corrosion. These additives were introduced at about the time that corrosion first became a problem to provide additional protection against the gear teeth scuffing in highly-rated applications. Extreme pressure additives provide protection against the welding and subsequent tearing of the gear teeth surfaces by becoming chemically active as the local temperature rises in the very thin oil-films. They then combine with the steel to form iron salts which lower the coefficient of friction and prevent welding. The active component is usually a hydrocarbon containing a phosphorus, sulphur or, in the case of OEP69, a chlorine molecule. It was suggested that such chemical activity could disrupt the normally passive film of tin oxide on the bearings and initiate the corrosion. In the discussion following the presentation of Ref. (1), the authors were closely questioned on this aspect but they stated that no correlation was evident between the severity of corrosion and the use of this type of additive. Such a correlation, however, has now been firmly established by naval experience and research work is in hand to investigate the matter in more detail.

The solution recommended in Ref. (1) was the deliberate water washing of the oil. Water is always present in lubricating oil because of condensation and leakage past steam glands, neither of which can be entirely avoided. Because the corrosion process depends upon water acting as an electrolyte, the deliberate washing of the oil by distilled water should reduce the ion concentration of the remaining water to such a level as to prevent significant electrolytic action. This technique did appear to reduce the corrosion under laboratory conditions and was introduced as a shipboard routine. Together with the strenuous efforts to clean up affected systems, it appears to have been successful in reducing the problem in the merchant service to negligible proportions. Further work, carried out in 1969, is reported in (3) and reaches substantially the same conclusion.

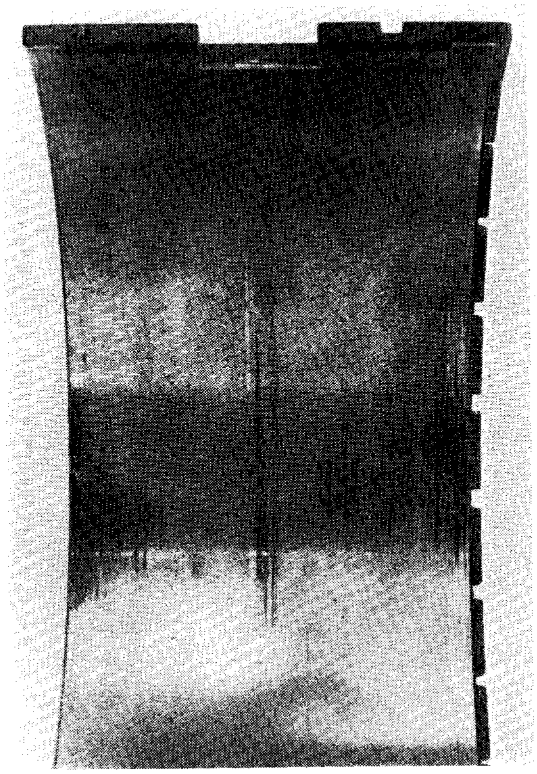

FIG. 3—LIGHT POLISHING OF LOADED REGION

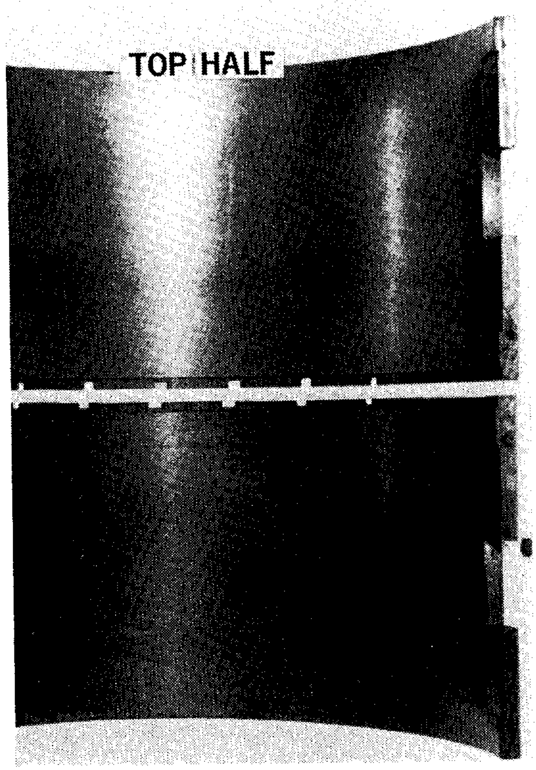

FIG. 4—EARLY STAGES OF CORROSION ON BEARING REMOVED FROM A GMD AFTER 5400 HOURS RUNNING

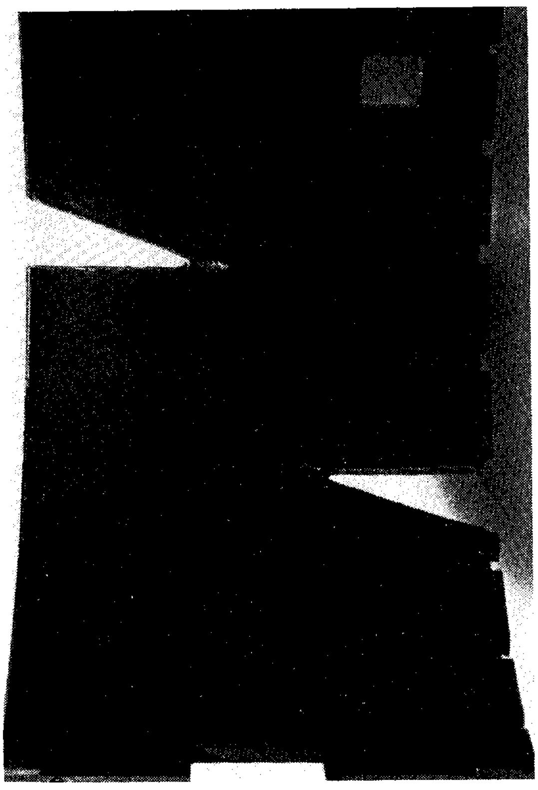

FIG. 5—TYPICAL SMOOTH BLACK SURFACE CAUSED BY CORROSION TO DEPTH OF ABOUT 0·003 INCHES

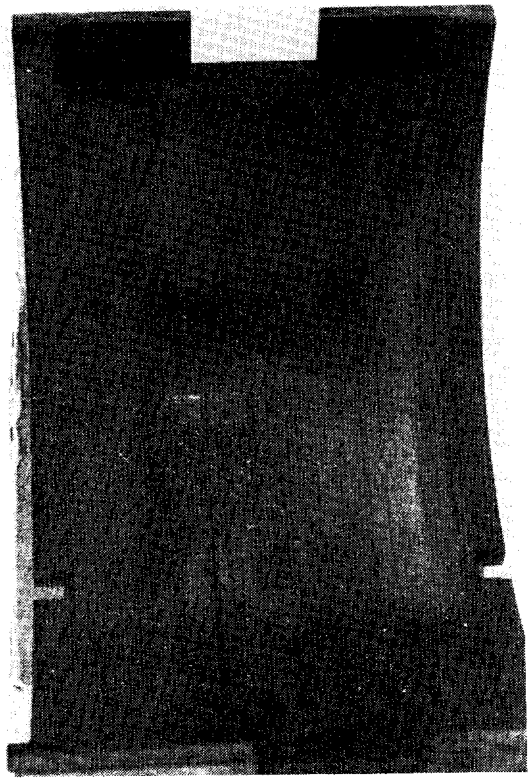

FIG. 6—LIGHTER CORROSION PRODUCTS ON A BEARING FROM A 'LEANDER' CLASS FRIGATE

Naval Experience

This form of corrosion has been affecting the Royal Navy since 1959 when a turbo-alternator bearing in a Type 14 frigate was found blackened after a fatigue failure (FIG. 8). After several other attacks, a D.C.I. on the subject was issued in 1963 and later revised in 1966. This revision forms the basis of the current instructions in BR3001 (Art. 1316). Although the problem continued to affect the fleet, it faded from prominence in the Ship Department and, when the two bearing failures were reported in 1975, the problem was at first thought to be a new one.

The first action taken during the current investigation was to visit two of the ships affected by corrosion and to discuss the problem with the dockyard and naval personnel involved. It was obvious from these discussions that bearing discolouration was not thought to be unusual. This was particularly the case with GMDs and Type 81 frigates refitting at Portsmouth. In order to quantify the problem, all ships were asked to forward reports of known cases of bearing blackening. Although the response to this enquiry was limited, it did provide clear evidence that, although stannic-oxide corrosion affected only a small proportion of the fleet, it was far more common than the Ship Department has realized. TABLE I gives the results of the survey.

It can be seen that the majority of cases reported occurred in guided-missile destroyers and Type 81 frigates, both of which have very similar reversing gearboxes. The two other cases occurred in Y.100 machinery and were both quite severe, the most recent leading to the failure of the main thrust block. It is also interesting that all instances of blackening reported were in systems using OEP69, except for one plummer bearing using OM100.

TABLE I—*Result of survey to establish the extent of stannic oxide in the surface fleet*

Ship Class	*No. in Class*	*Replies received (11.1.76)*	*Additional reports from other sources*	*No. of cases of corrosion*	*Comments*
Type 12 and 14	6	2	0	1	Salt-water contamination probably responsible.
Leander Class	26	7	1	1	A main thrust block failed due to flaking corrosion. Corrosion was unusual in colour: light grey not black.
GMDs and Type 82	9	5	2	6	Generally mild and covering only loaded region of bearing. Some corrosion in auxiliaries, especially STAs.
GP frigates	7	0	4	4	Most significant problem area. Corrosion widespread and heavy. Some positive action probably needed.
Large ships	8	5	0	1	Use OM100. No problems in main machinery. Corrosion suspected in one plummer bearing.
Type 41 and 61	8	3	0	0	Use OMD112/113. No problems
Totals	64	22	7	13	

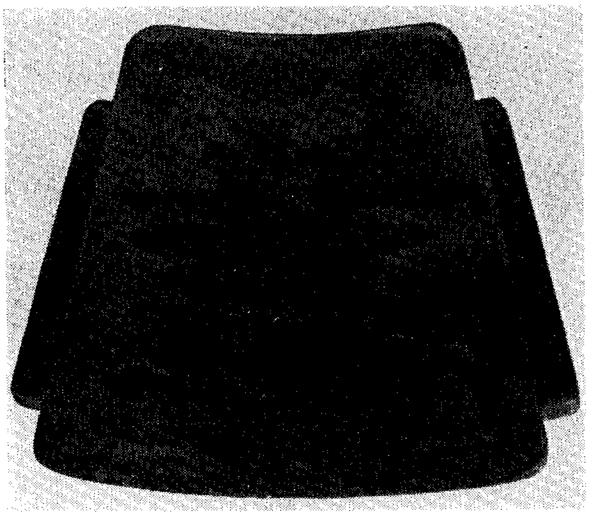

FIG. 7—PATCHY CORROSION ON MAIN THRUST PAD

The depth and appearance of the corrosion varied significantly, as can be seen from FIGS. 3–7. The first of these is not corrosion but shows the typical polishing marks where the shaft has rubbed during start-up and shut-down. FIG. 4 shows the early stages of corrosion, typical of that found in GMDs, which has caused a dulling of the surface of the bottom half of the bearing with some regions showing obvious blackening due to corrosion to a depth of about 0·001 in. The speckling at the edge of the dark region is typical, and it can be seen that the corrosion in this example is confined to the bottom half of the bearing: the top half still retaining an unmarked surface despite nearly 6000 hours in service. A more advanced stage is depicted in FIG. 5, a bearing which had been in service for less than two years. Here the corrosion has covered the entire surface of the bearing to a depth of about 0·003 in. with an even and surprisingly smooth black layer. A small square of white metal, revealed by scraping off the corrosion product, gives a good contrast. FIG. 6 shows a bearing removed from a *Leander* Class frigate. The colour of this bearing was most unusual for such an advanced state of corrosion, being a mottled light grey rather than the more common matt black. This layer was found to vary in thickness between 0·005 and 0·008 in. and another bearing from the same gearbox, in otherwise similar condition, was showing signs of flaking. FIG. 7 shows a main thrust pad on which patches of hard black tin oxide had started to form.

In most of the gearboxes examined by the author, the corrosion has been spread widely and fairly evenly throughout the bearings, those with highest running temperatures usually showing the most severe attack. Widely different degrees of corrosion can occur within a single gearbox but this is usually because some bearings have been replaced at recent inspection, whereas others may not have been examined throughout the life of the ship.

Although the appearance of the corrosion is variable, the hardness of the tin oxides makes identification relatively easy. The best simple test is to scratch the surface of the bearing, preferably away from the loaded region, with a pin or sharp knife. A clear difference in resistance to penetration will be apparent between corroded areas and the soft white metal. Scraping the black surface with a sharp knife feels similar to sharpening the graphite lead of a hard pencil. It is also helpful to know that the presence of stannic oxide has been confirmed in the great majority of cases where blackening has been found during the course of this enquiry although, in a few cases, the blackening has been due to carbon from the oil and to sulphur corrosion products.

A search of various records held by the Ship Department was also made. This revealed the history of the problem and many references to stannic oxide corrosion were found, spread fairly evenly right back to 1959. The findings are summarized in TABLE II. Although this survey was neither exhaustive nor really random, it does support the evidence from the Fleet, the only major difference being the early reports of corrosion in OM100 systems. The bearing failures reported in the TABLE are discussed in more detail under the heading 'Assessment of Hazards'.

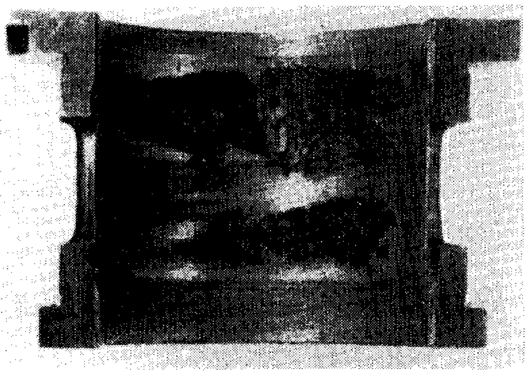

FIG. 8—BLACKENING THOUGHT TO HAVE FOLLOWED FATIGUE FAILURE—TYPE 14 TURBO ALTERNATOR 1959

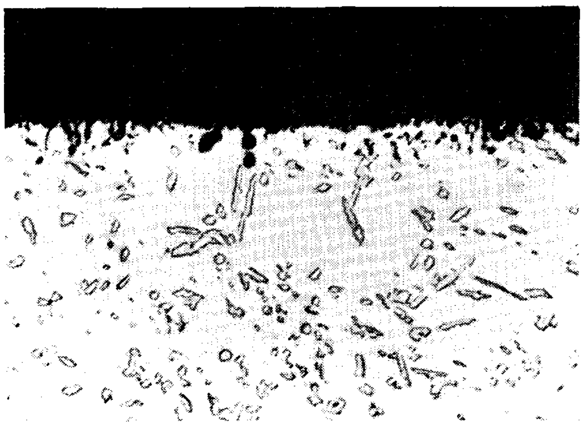

FIG. 9—PITS FORMED BY CORROSION OF HIGH-SPEED THRUST BEARING AFTER 800 HOURS (× 120)

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The records also revealed that corrosion had often been reported on bearings which had suffered damage through fatigue. In some cases it is clear that the corrosion has been aggravated by the conditions of high local temperature generated by the fatigue failure (FIG. 8). In other cases the order of occurrence is less clear and the possibility that the presence of a corrosion pit may reduce the fatigue resistance of the bearing cannot be ignored (FIG. 9).

Although attention has been directed towards the main transmission system, corrosion does occur in other types of equipment. As the title of Ref. (1) suggests, main steam turbines have suffered in the past and in the course of this enquiry corrosion has also been reported in G6 gas turbines, in steam turbo alternators and in a fuel-pump gearbox. No failures have been reported in auxiliary equipments although the corrosion in the fuel pump was quite severe as can be seen from FIG. 10 where the two halves of the thick-walled brass-backed journal bearing and a small thrust pad from the pump are contrasted against an unused thin-walled gearbox bearing.

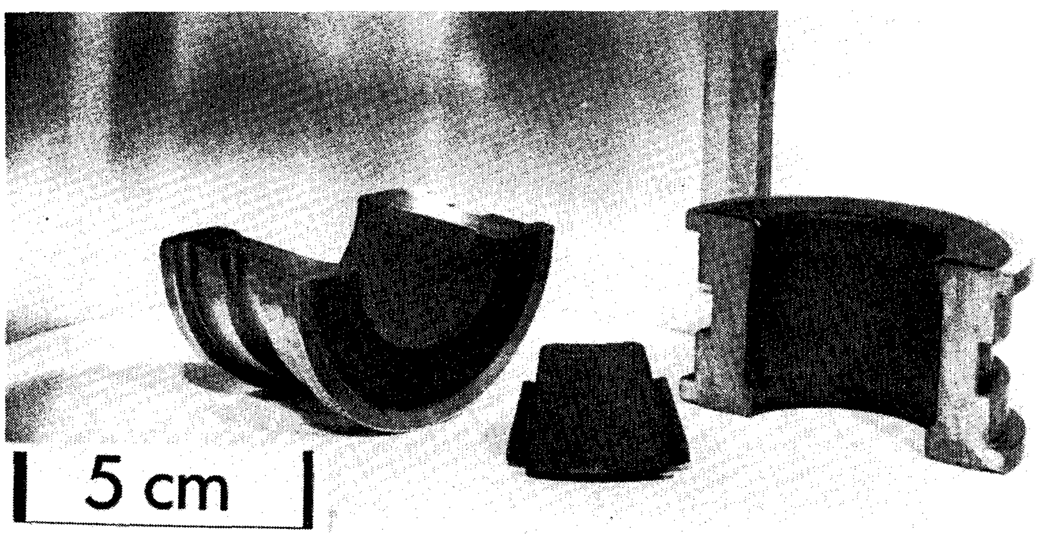

FIG. 10—CORRODED FUEL PUMP BEARING

TABLE II—*Cases of corrosion reported to the Ship Department before the survey in October 1975*

Year	*Ship Class*	*Equipment*	*Details*	*Max/Aver. Thickness (thou.)*
1959	*Type 14*	Turbo Alternator	Black patch near area of fatigue failure (FIG. 8). OEP90 oil.	1/·5
1960	*Victorious*	Main turbine	All main engine bearings. Salt-water contamination. OM100 oil.	7/5
1963	*Albion*	Main turbine	All main engine bearings. Salt-water contamination. OM100 oil.	8/3
	Type 12	Main gearing	Most gearbox bearings in both boxes. OEP69 oil.	4/3
1965	Type 81	Main gearing	Hard scale on thrust pads.	NK
1966	Type 81	Main gearing	Hard scale on thrust pads. Sludging of oil.	NK
	Type 81	Main gearing	Patches of oxide on thrust bearings	NK
1968	*Type 81	Main gearing	Astern pinion thrust bearing failure	NK
1969	*GMD	Main gearing	Astern pinion thrust bearing failure. Partial loss of lub. oil plus hard corrosion layer.	NK
1970	*Type 81	Main gearing and Gas turbine	All gearbox bearings corroded. Thrusts failed. Gas-generator bearings flaking. Some cracks.	8/3
	*GMD	Main gearing	Corrosion found after astern pinion thrust had failed.	NK
1971	*GMD	Main gearing	Corrosion found after astern pinion thrust had failed. Iron shot debris in lub. oil system.	NK
1972	GMD	Main gearing	All bearings photographed during refit. Most showed mild corrosion (FIG. 4).	1/·5
	*Type 14	Main engine	Blackening evident on turbine thrust pads after failure involving machining of thrust collar. Abrasive grit in system.	NK
1973	GMD	Main gearing	Partial blackening of many bearings.	1/·5
	Type 82	Main gearing	High-speed line thrust bearings blackened especially at trailing edge (hottest)	2/1
1974	Type 81	Main gearing	Majority of gearbox bearings black. Heavy sludging present.	NK
	*Type 81	Main gearing	Two thrusts failed. Heavy corrosion through-out gearbox (FIG. 1). Sea water present.	15/5
1975	Type 81	Main gearing	Widespread blackening (FIG. 5).	3/2
	Type 12	Main gearing	Widespread blackening. Journals of thick-wall design. Patchy main thrusts (FIG. 7).	3/1

TABLE II—*continued*

Year	*Ship Class*	*Equipment*	*Details*	*Max/Aver. Thickness (thou.)*
1975	**Leander Class*	Main gearing	Unusual light-grey corrosion found after failure of main thrust bearings. Journal bearing flaking.	7/4
	*GMD	Main gearing	Gearbox bearings found lightly corroded after journal bearing failure. Low lub. oil pressure. Sludging. Some bearings cracked.	2/·5

* Cases involving bearing failure.

Research Work

In 1973 surface blackening was reported on some high-speed thrust pads that had also suffered surface deformation of the white metal due to thermal cycling (*J.N.E.*, Vol. 21, No. 1, p. 96). Research into both problems was put in hand at Glacier Metals Ltd., one of the bearing manufacturers. The work on stannic oxide made use of a small high-speed thrust-bearing test rig which was able to simulate closely the conditions met in service. The results of this work have suggested the possibility of a further mechanism by which tin oxide corrosion can proceed.

The first objective of the research was to reproduce the corrosion that had been noticed on a small high-speed thrust bearing removed from H.M.S. *Bristol* (FIG. 9). The design duty of the bearing was 2·81 MN/m^2 (407 psi) at a mean sliding speed of 78 m/s (258 ft/s). The estimated maximum temperature on the surface of the pads was 134°C although the highest temperature in service was measured as 157°C. This discrepancy, which could be due to misalignment or to slight differences in pad height, was not thought to be remarkable by the bearing designers. The pads had run for some 800 hours in the ship at various conditions of load. A sample of oil drawn directly from the ship's system was used for the first series of runs, and the load on the test rig was adjusted to give surface temperatures equal to the maximum ship condition. The pads were inspected after just 12 hours of running and found to be already showing signs of blackening on the trailing edges (the hottest region). A photograph of the four pads is shown as FIG. 11 and contains two unused pads for comparison purposes. The test was terminated after a total of 80 hours by which time the entire surface was covered with a hard deposit.

Unfortunately the exact condition of the oil before the test was not established but a sample, analysed after 70 hours in the test rig, was found to contain only 207 ppm of water although the oil was slightly acidic. As the rig works only during office hours, the water content of the oil will in any case vary as condensation takes place and then is driven off.

In a second series of runs, fresh OEP 69 taken straight from the drum was used and exactly similar corrosion was produced. Again the importance of determining the exact condition of the oil was not appreciated and samples were not taken. After discussions with the Admiralty Oil Laboratory and the oil manufacturer, it is considered most unlikely that any significant water content or salt contamination was present and it is felt that the condition of the oil used in this test would have been equal to the very best which could be achieved in service.

Further tests were run with this same oil at progressively reduced bearing surface temperatures. Corrosion, albeit less severe, was still apparent at surface temperatures down to 110°C. As the maximum design surface metal

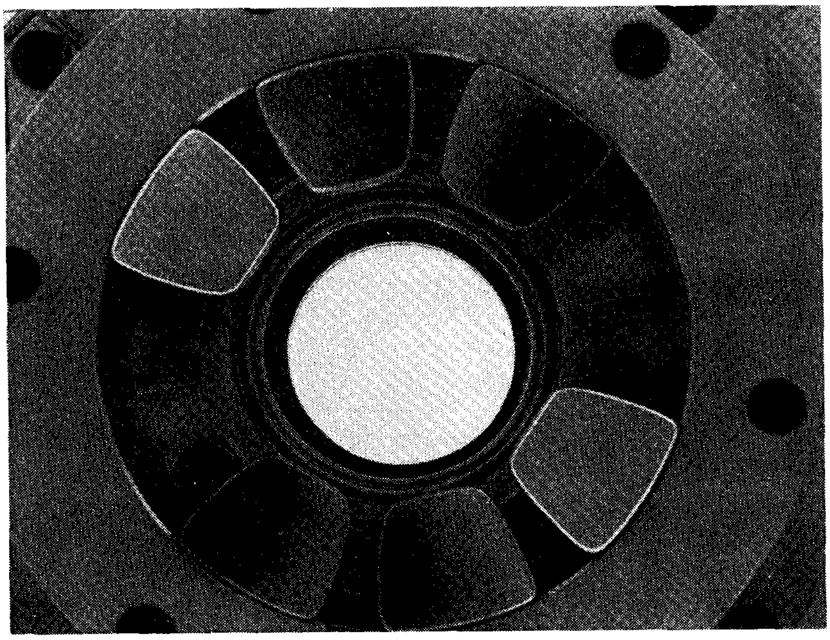

FIG. 11—ONSET OF CORROSION ON WHITE METAL TEST PADS AFTER 12 HOURS RUNNING
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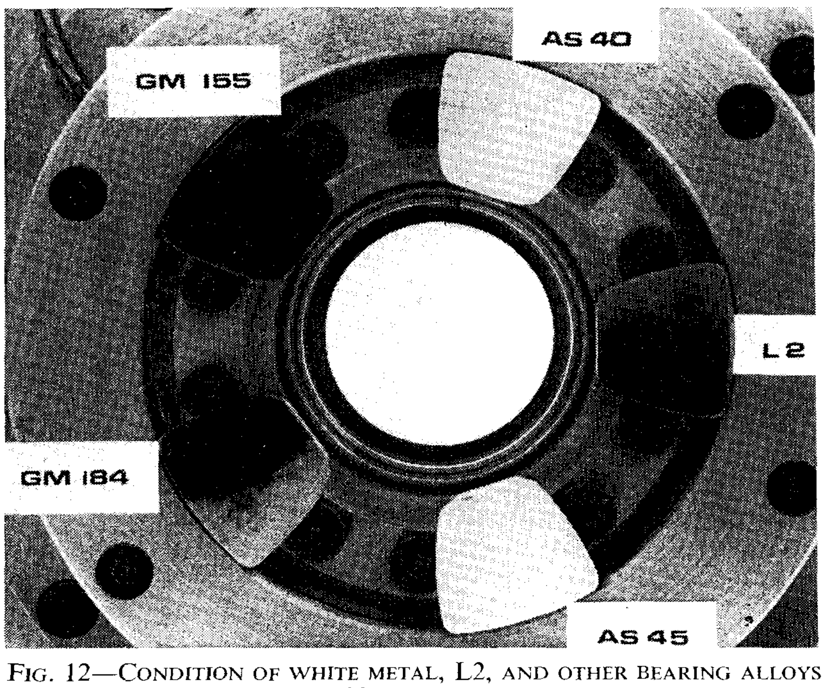

FIG. 12—CONDITION OF WHITE METAL, L2, AND OTHER BEARING ALLOYS AFTER 80 HOURS RUNNING
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temperature usually used for thrust bearings is 130°C, it was not considered feasible to reduce temperatures in service to a level at which corrosion would not occur.

These results call into question the role of water in the corrosion reaction. Even if small quantities of water were present in the fresh oil, it is highly improbable that it would have been present as an effective electrolyte when the bearing surface metal temperature was 157°C and the bulk oil temperature at exit from the flooded bearing was 130°C. Another significant feature of the tests was that only the load-bearing pads showed any evidence of corrosion—the unloaded pads on the 'astern' face of the rig which remained in place throughout the full series of tests showed no corrosion despite the high bulk oil temperature.

The final series of tests investigated the resistance to corrosion of four other bearing alloys, two, GM155 and GM184, based on lead and two aluminium-tin alloys AS40 and AS45. As can be seen from FIG. 12, the lead-based pads suffered even worse corrosion than the normal white metal (L2) but the aluminium tin (which had been developed for high-strength applications in diesel engines) suffered no corrosion in the eighty hours run. One of the materials (AS45) is currently undergoing further trials in a service application.

The temperatures now being reached within high-speed thrust bearings are sufficient to cause significant chemical activity of the chlorinated wax which forms the extreme pressure additive in OEP 69. It has been suggested that the chloride ions released by the ep additive react directly with the tin to form tin chloride. This is later converted to tin oxide, either by hydrolysis or by oxygen carried in as rust or oxidized oil. This theory received some support when a bearing blackened by corrosion was reported to have turned white overnight! The bearing in question had been removed from a gearbox immediately after a fluid coupling had suffered severe overheating. The bearing, which it was noticed had a blackened surface, was taken to an office and left on the windowsill during a damp weekend. By Monday morning, the bearing had developed a white crystalline deposit, similar in appearance to water stains on shoe leather. Chemical tests revealed this to be a mixture of hydrated stannic oxides and chlorates. The product was strongly acidic and was thought to have formed as a result of overheating the oil followed by the absorption of water.

How then do the various theories help to explain the pattern of occurrences in the Fleet? Why should the reversing gearboxes fitted to GMDs and GP frigates be so much more susceptible to attack? Further research has been put in hand to investigate the mechanism more closely but, even without this additional evidence, certain facts stand out that provide the basis for an explanation. The gearboxes fitted in these two classes of ships are the most highly rated in service and bearing temperatures are generally higher than in Y.100 and earlier designs. Furthermore, the gearboxes have been subject to a number of mechanical failures which have provided a generous source of iron oxide contamination. Considerable difficulty has been experienced in flushing the lubricating oil system to re-establish adequate standards of cleanliness. Rusting of the gearcase and the gear elements themselves has added to the problem with the production of further iron debris to act as an oxygen carrier thereby facilitating the corrosion.

The Present Situation

One further complication has been discovered recently which could explain the apparent increase in the frequency of attack: the formulation of OEP69 was changed by the manufacturer late in 1973. This change took the form of an additional additive package which was included in the base stock from which OEP69 is made. The new additive was requested by another customer of the oil company to improve the resistance of the oil to oxidation at high temperature. The revised formulation was tested at AOL and appeared to meet all the standard tests. As supplies to the previous formulation could not easily be made available the revision was accepted, and oil of the new formulation began to come into use early in 1974.

Since this change, not only does stannic oxide appear to have increased but also two other problems have been encountered: the silver nitrate test for sea-water in the oil has been affected and no longer gives repeatable results, and two severe cases of grooving of main turbine rotors have been discovered following the build-up of carbon deposits in the oil baffles. Several other oil and steam baffles have also been found to be full of carbon deposits. The effect on the salinity test can be linked directly to the change in oil formulation, but the other two phenomena cannot be linked to the new oil by experimental work and the connection is, at present, purely circumstantial. Further experiments are in progress.

The extreme difficulty of collecting reliable data about previous instances of corrosion makes it impossible to say whether the four cases reported in 1975 do represent a significant increase in the rate of attack. Fortunately the tests carried out by Glacier Metals Ltd. were done with the original formulation and so provide a comparison for further tests with the modified oil currently in use (Feb. 76). A series of further tests will be carried out during this year using four different oils. The first test will use a specially prepared batch of OEP69 which does not contain the chlorinated wax extreme pressure additive. This test should demonstrate clearly whether or not this particular additive has a special role to play in the corrosion process. A further test with OEP69 of the formulation currently in service will attempt to find out whether the corrosion proceeds more rapidly because of the changes to the oil. Tests with OM100 will investigate the effects of this less complex oil.

The precise role of OEP69 in the corrosion process has yet to be established, but the recent rise to prominence of stannic oxide together with the other problems mentioned above have all served to highlight the risks involved with such a chemically active oil. There have always been pressures to move back to OM100 which is far more easily available around the world. Recent problems have called into question the need for an oil of the extreme pressure type to protect gears from scuffing during the low-speed, high-torque condition encountered when manoeuvring. By an unhappy coincidence this is the one area of gear technology where analytical techniques are of least value. The Navy and Vickers Gearing Research Association (NAVGRA) has spent a lot of time trying to establish a theoretical routine or a simple rig test which will reliably predict the onset of scuffing in full-size gears, and some progress has been made. Some recent work has shown particular promise but is not yet sufficiently established for the results to be applied to equipment in service. Such analysis as has been done suggests that the majority of gearboxes in service that undergo reversal during manoeuvres would not suffer scuffing damage when running at constant speed but may be at risk during violent manoeuvres unless an extreme pressure oil is used. The problem will only be resolved by actual service experience and the possibility of carrying out a ship trial using OM100 is being investigated. It has also been decided to try to move away from such extreme pressure lubricants in future gear designs.

Assessment of Hazard

The significance of stannic oxide must be judged from the effect it has on ship availability. This is reduced directly by bearing failures and indirectly by an increase in the time spent by the ship in the hands of the maintainers. The evidence collected to date suggests that the number of bearing failures which can be attributed, even in part, to the presence of corrosion is small but the amount of work, not to mention the cost, involved in checking and replacing bearings so as to maintain maximum transmission system reliability is considerable.

The corrosion presents a hazard because:

(*a*) the hardened surface is less able to absorb dirt;

(*b*) hard debris may be generated within the bearing once the depth of corrosion is such as to cause flaking;

(*c*) after flaking, the effective bearing area is reduced;

(*d*) the presence of corrosion pits may make the bearing more prone to fatigue.

In order to assess the hazard, the known pattern of failure must be examined.

Stannic oxide corrosion has been affecting the Fleet since 1959. Its presence was not associated with bearing failure until 1968 when a spate of failures occurred in the small thrust bearings locating the single helical astern manoeuvring pinions in Y.111A and Y.102A gearboxes. These failures were caused by excessive end thrusts generated during arduous manoeuvres and, although stannic oxide was present in a number of such failures, the bearing was clearly inadequate for the duty being imposed even in the uncorroded condition. The problem was resolved by imposing tighter limitations on the manoeuvres that could be performed so reducing the bearing load.

Of the nine failures involving corrosion known to have occurred since 1968, four occurred in astern-pinion thrust bearings before the manoeuvring duty was reduced to its present level (Sept. 1970). In three other failures, adverse circumstances were identified that could have caused failures by themselves—in two, hard iron debris was found in the lubricating oil system, and in the other case, a journal bearing failed after the oil pressure had been at a marginal level for an extended period because of filter and pipework blockage due to sludge formation. Only in the two remaining cases were no additional factors found which could have explained the failure.

Only one of the nine failures involved a journal bearing; the other eight involved thrust bearings. This is somewhat surprising when conditions such as those in FIG. 1 are encountered in journal bearings, but the lack of failures taken with the number of running hours that must have been achieved by bearings in a substantially corroded condition is clear evidence that stannic oxide corrosion does not, by itself, pose a significant threat to bearings of this type. The presence of a very hard surface in close proximity to the shaft is inevitably a cause for concern and theoretically it must reduce the ability of the bearing to tolerate dirt, overload or misalignment, and must also increase the risk of damage to the journals themselves. However, the lack of failures, after what must amount to hundreds of thousands of bearing running hours in a corroded state, suggests that in practical terms the reduction in reliability is very small.

The position with thrust bearings is somewhat different. Not only are thrust bearings more prone to attack, probably because of higher operating temperatures, but also these bearings are more susceptible to dirt because of the smaller running clearances. The loading conditions are also more severe with high thrusts frequently encountered at slow rotational speed and in the stalled condition. In most of the known failures the depth of corrosion, as deduced from adjacent bearings, was substantial having usually proceeded to the state where flaking was occurring. It is probably fair to conclude that failure due to corrosion alone is not likely until the corroded region exceeds 0·005 in. in thickness. However, evidence of failure from the Royal Navy and from elsewhere shows that the reduction in operating margins caused by the presence of even a limited degree of corrosion on the thrust pads does result in significant reductions in service reliability.

Reducing the Hazard

For most of the Fleet, good lubricating oil hygiene, correct operation of centrifuges, regular checks of gearbox venting arrangements and the use of dehumidifiers or dessicant trays during periods of extended shut down will be adequate to prevent corrosion. If iron debris is introduced in unusual quantities either by a failure or by gearcase corrosion, every effort must be made to return the system to the proper standard of cleanliness. Recent evidence suggests that this should include the visual examination of selected pipe lengths where heavier debris and sludge may collect. Similarly, if sea-water contamination of the oil has occurred, the water washing procedure laid down in BR 3001, Art. 2006 must be followed to dilute the electrolyte so produced.

For Type 81 frigates, GMDs and possibly for a few other ships where bearing temperatures are higher than average, these measures alone may still not prevent corrosion, and further action may be needed. If it is decided that the risk cannot be contained by tighter inspection routines, three options are open: to change the oil, to change the bearing material or to change the operating environment by a technique such as water washing. Decisions on this must await the outcome of the current research and the build-up of further evidence from the Fleet.

The hazard can also be reduced by a more rigorous inspection and maintenance policy, with effort concentrated in ships known to be affected. Access to gearbox bearings is often difficult and when considering such a policy, the rapid increase in cost and time penalties has to be carefully weighed against the size of the hazard one is trying to eliminate. A suitable compromise between increasing the work load and reducing the risk of failure is currently being sought.

Concluding Remarks

Stannic oxide corrosion is one of a host of engineering problems that usually simmer gently in the background and only on rare occasions, due to a chance effect or to a small change in the environment, boil over into prominence. A balanced picture is starting to emerge, but clearly much work remains to be done and there is a continuing need for information from the Fleet to provide reliable data from which the rate of corrosion and the factors which influence it can be defined with greater certainty.

The information collected to date shows that stannic oxide corrosion is a long-standing problem and that the rate of corrosion in the past has been sufficient to cause a number of thrust bearing failures—about one a year. The research already completed suggests that OEP69 has a significant role to play in the corrosion process and this should be confirmed by work currently under way. Whether the changes made to OEP69 late in 1973 have increased the hazard remains to be seen and this more than anything else will dictate the kind of action required. The problem has emphasized yet again the importance of lubricating oil hygiene and careful attention to operating and maintenance routines which are so easily pushed aside by the urgency of day-to-day problems. Although the investigation is far from finished, many of the uncertainties expressed in this article should be resolved within the next twelve months and some firm conclusions can be drawn. The hard black surface on the white metal has been positively identified as the oxides produced by the corrosion of the tin phase. The corrosion may occur in several different ways, one of which appears to involve the extreme pressure additive in OEP69. The presence of a corroded surface does not produce a significant reduction in the reliability of journal bearings but does adversely affect thrust bearings and will lead to failure if pads are not changed. For the majority of ships, the risk can be contained by good husbandry and the current frequency of inspection. For Type 81 frigates and possibly GMDs further action may be required which would probably involve the regular water washing of the lubricating oil. If this is not sufficient, the use of aluminium tin in place of white metal appears to offer a permanent solution, albeit at greater cost. If the lubricating oil is modified, further corrosion tests will be needed to investigate the replacement oil.

Acknowledgement

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Ship Department Note: The decision has now been taken to revert to the original formulation for OEP 69 and supplies will become available towards the end of the year.

READERSHIP

As the *Journal of Naval Engineering* contains much information of interest and use to operators as well as to maintainers, it is suggested that Marine Engineer Officers of ships arrange for a wider circulation to appropriate officers and senior ratings of all branches.