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Corrosion of Turbine Journals

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Corrosion in turbine lubricating systems is seldom severe enough to require a drastic remedy. On occasion, however, water of a corrosive nature, such as sea-water, has been known to gain access and to cause extensive damage to journals, gears, etc. During the 1939-45 war a number of ships, mostly vessels on anti-submarine duties, were out of commission for considerable periods owing to this type of mishap.

It has been found that corrosion-inhibiting turbine oils, effective in ordinary circumstances, cannot be relied upon to prevent corrosion by sea-water, and that owing to the persistent retention of salt by microscopic pits in the steel, sea-water corrosion, once established, is not easily arrested.

For the prevention of damage in these circumstances the author proposes the use of a water-miscible inhibitor consisting of sodium nitrite solution by circulating it with the oil until the measures necessary to eliminate sea-water from the oil system have been successfully applied, and any existing corrosion arrested.

The behaviour of sodium nitrite in contact with oil and with the constructional materials present in a turbine lubrication system has been examined by laboratory methods and no unacceptable reactions found to occur. Practical trials have been carried out at sea in the main engines of a destroyer, proving that sodium nitrite gives satisfactory protection against corrosion in presence of a large amount of added sea-water, and that corrosion already in progress can be stopped.

The method was applied in September 1947 to the main engines of another ship where rusting of gears and journals was in active progress. The need for a refit was obviated, and the ship returned to duty. No further trouble was experienced during six months service.

Sea-water was found in the oil system of one of the ships of the Fleet during the autumn cruise, 1948. Sodium nitrite was used to prevent corrosion, and at the end of the cruise no sign of damage could be found.*

INTRODUCTION

Normal corrosion risks in turbine lubricating systems are already well controlled. The measures herein described were devised for emergency use, rather than for continuous application, to deal with cases of intrusion of sea-water where the corrosion was so bad that machinery was being scrapped as a result. It remains to be seen whether there is any field for them in less extraordinary circumstances.

The infrequency of severe corrosion of turbine journals and gearing has resulted in a scarcity of co-ordinated information regarding it, the circumstances surrounding those cases which did arise often being obscure. When something approaching an epidemic occurred in ship's turbines at the crucial period of anti-submarine warfare, many different explanations were offered and some time passed before the situation became clear. An account of four cases arising in anti-submarine ships is given to illustrate this, and to establish the fundamental facts of a position which could easily recur in a future emergency. Consideration is then given to corrosion-inhibiting oils and to the water-soluble inhibitor, sodium nitrite, herein proposed. An account of the laboratory investigations and sea trials of sodium nitrite follows, with details of successful application of the proposals to the case of a ship where the gearing was already in an advanced state of corrosion.

WAR-TIME CASES OF CORROSION IN MARINE TURBINES

Case I

This ship was one of the fifty destroyers transferred to Britain by U.S.A. All her turbine and gearing journals had previously been stoned bright, but soon after she was commissioned in the Royal Navy large amounts of ferric oxide were noticed in the bowl of the centrifugal separator, and a main thrust bearing failed. All journals were found in a state of active corrosion, deeply etched and covered with black oxide which turned red on the surface after opening up. The whole forced lubrication system, including pumps, coolers, storage and drain tanks was dismantled and cleaned, and the journals stoned bright. After reassembly, oil was circulated for forty-eight hours. Inspection showed that journal corrosion had already begun again, but the operational need was such that no further delay could be tolerated and the ship went to sea. She remained in service for eight

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* Patent protection for this treatment has been applied for.

months, and at the end of that time the bearings showed approximately 0·020-inch wear-down and a further re-fit was ordered. Corrosion was even worse than before. The cleaning of the lubrication system was repeated and in addition extra handholes were cut in the turbine bearing sumps, which were then washed out with carbon tetrachloride. Most of the journals had to be re-machined, and the ship was in dock for three months. Only eight months later the trouble had recurred and all main journals had once more to be machined. Each time the ship made a short trial run the journals showed fresh rust and had to be cleaned up. At this point several independent opinions were called for and at least six different explanations were suggested. The eventual discovery and repair of a salt-water leak from the bilges into the oil system apparently cured the trouble, no further reports being received. As far as available information goes, a plain mineral lubricating oil was used throughout. Reports on its condition were satisfactory as might be expected from the fact that consumption was heavy enough to equal a complete fill-up in ten days steaming, but curiously enough there is only one mention of any test for salt water having been made prior to the last investigation. This occurs in a report by the Anglo-Iranian Oil Co. The general view appeared to be that such excessive corrosion could scarcely be attributable merely to sea water, and several experts continued to emphasize other explanations.

A very clear appreciation of the part played by salt water appears in a report by the Engineer Officer which includes an account of similar trouble which arose later in a new ship and was caused by connecting the sea water side of the oil coolers to the drain tanks when the ship was under construction.

Case II

This concerned another destroyer under refit. The condition of her machinery was described in terms which coincided closely with Case I, but the refit was nearing completion and no first hand investigation could be made. Two independent analyses of the emulsified oil and water from the circulation system had been carried out and each report indicated the presence of salt. Each report also showed contamination of the oil with fatty matter, and whilst ignoring the salt, expressed the view that the presence of fatty matter had caused the trouble. This view arose, no doubt, from the fact that the condition of the machinery first came to light through blockage of oil strainers ascribed by the engine-room staff to the sudden formation of an emulsion. The detection of fatty matter capable of acting as an emulsifier thus appeared to account for everything, the rusting being put down to the circulation of an abnormal proportion of water with the oil. In the light of the experiments recorded below it now appears likely that rusting occurred first, and that the blockage of strainers was due to solid rust. There was, however, no possibility of resolving doubts in either direction, owing to the speed with which repairs had gone forward and the lack of facilities for further investigation.

Case III

Within a week or two a third entirely similar case arose, again in a destroyer operating in the North Atlantic. The oil in use was in good condition and although emulsified with water in the turbine system, was found when clarified to have an Institute of Petroleum demulsification value of 120, which is quite satisfactory. Rust was present and the water contained 0·05 per cent NaCl, equal to about 20 grains of chlorine per gallon, or 1·5 per cent of sea-water.

This concentration of salt does not appear particularly alarming, but a more significant result was obtained by examining the rusty steel turnings removed when machining one of the journals. On analysis these turnings yielded approximately 1·6 per cent of water-soluble solids consisting of salt and ferric chloride, which leaves little room for doubt that the rust was produced by salt water. With regard to the low concentration of salt found on testing the water, it should be borne in mind that inward leakage of sea-water would usually be stopped by the outward oil pressure when the engines were started. Meanwhile any sea-water which entered whilst the engines were at rest would be removed by the separator and slowly replaced by fresh water from the turbine glands. Hence a salinity test made after several days of steaming might fail to indicate the seriousness of a leak, though the loss of oil ought to arouse suspicion.

The very similar conditions found in these three ships appeared to warrant the conclusion that salt water leakage lay at the root of most if not all cases of this type of rusting. The conclusion was reinforced by the descriptions of similar occurrences compiled by the Engineer in Chief's department, the presence of sea water being mentioned in a number of instances. It was considered, therefore, that a successful method of stopping salt-water corrosion would deal adequately with the trouble and a recommendation was made to the effect that periodical testing for salinity of the water discharged by the separator should become a routine precaution.

Case IV

This arose three years later, when the cause of the trouble was no longer in doubt. The ship was a recently built frigate and depthcharge concussions had so strained her hull that within her first year replacement of a large proportion of her underwater rivets had been necessary. After the war she was laid up for some months and when re-commissioned experienced engine trouble during her first full-power trial. The first sign was the blowing of a gland packing due to excessive wear-down of a turbine bearing. Then it was observed that the oil contained rust, and a test revealed that the water present in the oil system was 90 per cent sea-water. On opening up, heavy corrosion of gears and journals was discovered together with wear-down of bearings. Part of one of the main gear wheels is shown in Fig. 1, Plate 1. The most seriously damaged bearing had suffered 0·065 inch wear-down, which had resulted in rubbing of the turbine rotor against the casing. Although only three years old, the main gearing had to be scrapped. The intrusion of sea-water was traced to two split tubes in an oil cooler.

A point of interest is that for some months before the ship was laid up the oil in use was corrosion-inhibiting turbine oil to U.S. Navy Symbol 2190T. The corrosion therefore took place in spite of the protection of this oil, and it is fair to conclude that however valuable it may be in normal circumstances it is inadequate in presence of a serious sea-water leakage. This was confirmed by trials described on p. 63.

EXPLANATIONS PUT FORWARD DURING DISCUSSION OF CORROSION OF TURBINE BEARINGS

Before leaving these typical cases it will perhaps be of interest to mention some of the alternative explanations offered, and then to give reasons for regarding salt intrusion as the main factor. The following four explanations of the corrosion (or variations of them) were advanced from one quarter or another.

(1) Introduction of emulsifying agents in error or by saboteurs

There is no clear evidence that the presence of fresh water, even when emulsified with the oil in large amounts, causes rusting to the extent found, and some at least of the bad cases arose with oil of good demulsification properties.

(2) War conditions

These included the necessity for closing engine-room hatches at night (thus creating an exceptionally hot moist atmosphere), the use of high speeds and sudden changes of course in all weathers (bringing sea-water in at fan intakes), curtailment of opportunities for maintenance work and other adverse circumstances.

These conditions were, however, widely experienced; and cases of excessive rusting were isolated. It did not appear logical to accept them as sufficient to account for the troubles in question.

(3) De-gaussing

This war-time measure involved the presence of a magnetic field which, it was suggested, might induce currents in the turbine shafting sufficient to set up galvanic corrosion. Calculation of the maximum potentials generated by the field in question showed that they would be of an order less than the ordinary contact potentials of the different metals, and incapable of producing any marked galvanic effect. Moreover, de-gaussing was universal, and heavy corrosion relatively infrequent.

(4) Detergent effects of new oil supplies

The suggestion here was that oils of the naphthenic type sometimes supplied in U.S.A. and Canada, were likely to bring into circulation rust and oil sludges previously adhering harmlessly to casings, thus emulsifying an excessive quantity of water into the oil, which water would in turn cause fresh corrosion. The absence of records of oil supplied made it impossible to secure evidence in support of this explanation but the trouble-free experience of most ships known to have made the change of oil tended to discount it. Laboratory attempts to produce the sequence of effects described were unsuccessful.

Reasons for regarding salt intrusion as the most frequent cause of heavy corrosion

(1) Although no more than a trace of salt is usually present in turbine lubrication systems, significant amounts were found in each case of severe corrosion investigated, and no case has so far been heard of where salt could not be found.

(2) Salt water is a more potent corrosive agent than distilled water, which is commonly present in turbine systems and does not cause corrosion on the scale investigated.

(3) A very close reproduction of the heavy corrosion investigated was twice obtained by adding sea-water to engines previously in good condition. (See pp. 62 and 63.)

(4) The number of salt-water leakages into machinery increased during the war owing to underwater concussion. This coincided with an outbreak of corrosion trouble, not generally, but in a limited number of ships, nearly all being types making extensive use of depth charges.

PREVENTIVE MEASURES

(1) Corrosion-inhibiting oils

A very important contribution to the solution of corrosion problems is the development of corrosion-inhibiting oils. In a turbine system the oil necessarily has a great part in rust prevention—that is to say, the moisture ordinarily present would play havoc if it were not, in the main, held out of contact with the steel of the system by the much larger volume of oil. In general, water droplets in contact with working surfaces are mechanically displaced by oil whilst the turbine is running, but other surfaces on which water can rest as it settles out of the oil are liable to corrosion, the risk being greater the less the degree of turbulence. When the turbine is not running, the relative immunity enjoyed by working surfaces disappears, and "water-marks" on journals, etc. result from the presence of any considerable proportion of water in the oil. The protective efficiency of an oil can be greatly increased by the addition of polar materials which form a molecular film on the steel, so hindering the contact between steel and water. Figs. 2 and 3, Plate 1 illustrate the effect of the polar material. Disks of nickel steel were submerged to a depth of ⅜ inch in (a) plain mineral oil SMLO; (b) corrosion-inhibiting oil 2190T. Water was added in droplets which sank through the oil and rested on the steel, as happens with machinery after shutting down. The photographs were taken after four days standing at room temperature. It will be seen that the corrosion-inhibiting oil 2190T prevented corrosion by distilled water whereas the plain mineral oil SMLO did not. This lasted for twenty days, after which all the droplets showed rust.

Unfortunately the results are not nearly so good if salt be present in the water. The condition of the salt-water droplets shows that, although oil 2190T delays rust-formation, especially by water not too heavily contaminated with sea-water, it cannot prevent rusting even for the short space of four days. It was observed further that, whilst each droplet remained unattached to the steel and would move freely with movement of the oil so long as no rust was apparent, it became attached to the steel with the beginning of rusting and if forcibly disturbed would break up, leaving behind a wet rust-patch to which another droplet would readily adhere.

It may therefore be concluded that salt water causes disruption of the protective oil film far more readily than does fresh water and, once corrosion has begun, the re-establishment of a protective film of oil may be prevented, even after the turbine has been started up. Hence it is unsafe to rely on corrosion-inhibiting oils to ensure protection after contaminated water has entered the system. This is apparent from Case IV cited above and from the practical trial described on p. 7. With pure distilled water, the protection afforded by corrosion-inhibiting oils is good but, even so, the liability of the protective film to break down if unrenewed, for example during a prolonged shut-down, should be taken into account and the amount of water kept to a minimum. The difficulty in providing more effective inhibitors lies, largely, in the fact that most suitable polar materials are also emulsifying agents, and on that account cannot be tolerated in so large a proportion as would otherwise be desirable. It is found also in the fact that when the supernatant oil is locally displaced by water the protective film (necessarily very thin) is deprived of its source of material for replacement. Thus the slightest discontinuity, however caused, enables corrosion to gain a foothold from which it can spread and undercut the neighbouring film.

(2) Water-soluble corrosion inhibitors

The possibility of dissolving a corrosion inhibitor in the water in the system has hitherto been neglected, doubtless on account of several obvious objections. There are not many water-soluble inhibitors which do not react either with lubricating oil or with one of the non-ferrous metals used in a forced lubrication system, and apart from this the wastage of inhibitor due to continual extraction of the water by centrifugal saparators could entail considerable expense and difficulty.

The war-time epidemic of heavy corrosion, however, provided an incentive to explore this line of attack in the assurance that, even if the drawbacks could not be eliminated altogether, they would need to be serious indeed to outweigh the consequences of inaction.

Although cases have been known in which sea-water was present almost undiluted in lubrication systems, there did not appear to be any need to employ the full strength of inhibitor solution necessary to combat this concentration of salt, since it is always possible to extract the bulk at least of the water from the system and by adding distilled water to dilute what remains. Indeed, after the ingress of sea-water has been stopped, the system can be cleared of salt by repeating this flushing process a sufficient number of times. It is during the interim period between the occurrence of a leak and the complete elimination of salt that the inhibitor is most needed, and it was considered that most attention should be given to the dosage necessary to counteract the effect of sea-water diluted with distilled water to one in four or weaker.

LABORATORY WORK

General consideration of the possibilities pointed to sodium nitrite as the most promising inhibitor. It was known to be highly efficient in distilled water and with low concentration of salt[*], and there was no obvious reason to expect reactions with oil or non-ferrous constructional metals. It had, moreover, been used successfully to prevent rusting of steel by soluble oil emulsions[†].

As already remarked, rusting in forced lubrication systems is controlled to a large extent by the presence of oil but the effectiveness of the control depends on the various circumstances which determine how much of the steel shall be oil-wet and how much water-wet and for how long.

It was therefore decided to make two investigations (a) a purely metallurgical one, no oil being present, and (b) a simulation of practical conditions, with oil, air and aqueous solutions circulated over the metals.

The proportions of nitrite required to protect steel against different concentrations of sea-water in absence of oil could then be taken as adequate in practice, and if such proportions had no ill effect when used under simulated practical conditions it was considered that the way would be open for a full-scale trial.

The metallurgical work was arranged with Dr. Hoar of the Corrosion Section, Metallurgical Laboratories, Cambridge Univer-

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[*] U.S. Patents 1,940,041; 2,054,282

[†] German Patent 680,884.

sity, under an existing research contract with the Ministry of Supply, and the tests in presence of oil were made by the author.

(1) Metallurgical Investigation

Dr. Hoar's work will be published in detail elsewhere. The principal conclusions reached were:—

(a) Any distilled-water/sea-water moisture (up to 50 per cent sea-water) can be rendered completely non-corrosive to steel at 25 deg. C. and at 60 deg. C. by the addition of a percentage of sodium nitrite equal to one-fifth of the sea-water percentage, except that for low sea-water concentrations at 60 deg. C. rather more nitrite in proportion is required.

(b) Smaller amounts of nitrite, not giving complete protection, convert general rusting into local pitting which, in the case of the machinery in question, is probably less dangerous than general rusting.

(c) The amounts of nitrite needed for steel protection have a decidedly beneficial influence on the corrosion of white metal, a slightly beneficial influence on the corrosion of copper, and no appreciable influence on the corrosion of brass.

(d) Sodium nitrite is effective only in neutral or alkaline solution. The *p*H value of the solution should preferably be about 8 and should not fall below 7.

Dr. Hoar's results for mild steel are given in further detail in Fig. 4.

A comprehensive series of tests was later carried out by Dr. D. Wyllie of the Chemical Department H.M. Dockyard, Portsmouth. In this the effect of varying proportions of sea-water on the corrosion of steel is studied, and it is shown that the percentage of sodium nitrite required to inhibit corrosion can be reduced by adding quite small amounts of other substances. These results also will be published elsewhere.

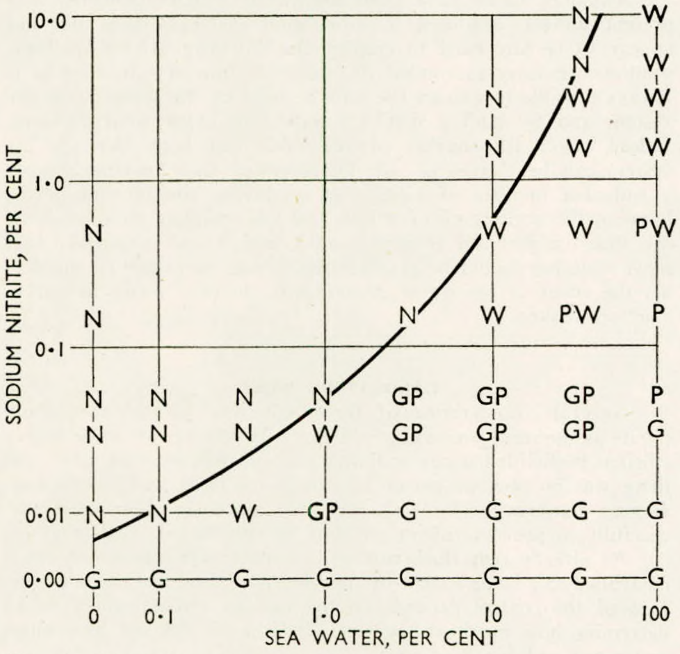

FIG. 4.—*Corrosion of mild steel in mixtures of sea water, distilled water and sodium nitrite*

N = no corrosion
W = water-line pitting
P = pitting over the whole surface
G = general attack over most of the surface

(2) Simulation of Working Conditions

For the tests under simulated practical conditions the author used a cast-iron gear pump fitted with steel gears and copper and brass connecting tubes, arranged to circulate oil and water over specimens of white metal, copper, aluminium bronze, aluminium and mild steel sheet. The charge of oil and water was circulated ten times per minute and air was admitted to the suction side of the pump to maintain the liquid in a thoroughly aerated condition.

It was found that, with sufficient heat applied to the delivery pipe to maintain the temperature in the reservoir at 80-85 deg. C. Admiralty Special Mineral Lubricating Oil (SMLO)* and distilled water rapidly formed a dense emulsion, and there was considerable frothing. The water evaporated quickly despite the addition of a vent tube as a reflux condenser to the reservoir, and within twelve hours the oil became noticeably oxidized. It appeared, therefore, that the conditions were severe although the temperature of the bulk of the oil was much lower than the temperatures ordinarily used in laboratory oxidation tests. Probably the intense aeration and the presence of water and metal dust from the pump contributed to the acceleration of oxidation, but the local rather than general application of heat to the system is likely to have been the principal factor. This local heating, however, is in conformity with conditions in practice, where the shearing of the oil film generates a large amount of heat in a very small volume of oil.

Table 1. Effect on metals of (a) distilled water, (b) salt water, (c) salt water plus sodium nitrite mixed with oil, in a twelve-hour circulation test at 70 deg. C.

Circulating mixture	Corrosion of metal specimens			
	Steel	Copper and aluminium bronze	White metal	Aluminium
180 ml. oil (SMLO) 40 ml. distilled water	None	Slight stain	None	None
180 ml. oil (SMLO) 30 ml. distilled water 10 ml. artificial sea water	Considerably pitted	Slight stain	None	None
180 ml. oil (SMLO) 30 ml. distilled water 10 ml. artificial sea water 2·8 gm. sodium nitrite (=7 per cent of the water)	None	Slight stain	None	Slight whitening

The apparatus was next run at the lower reservoir temperature of 50 deg. C. with SMLO and 18 per cent of distilled water. In twelve hours there was little change in the oil and no corrosion of the metals, though an emulsion which did not completely separate for some hours was formed. In view of these results, a temperature of about 70 deg. C. was thought suitable for further tests.

Table 2. Effect on metals of undiluted sea water plus (a) 7 per cent sodium nitrite (b) 14 per cent sodium nitrite in a thirty-four hour circulation test at 65 deg. C.

Mixture	Corrosion of metal specimens			
	Steel	Copper and gun-metal	White metal	Aluminium
180 ml. oil (SMLO) 40 ml. artificial sea water 2·8 gm. sodium nitrite (=7 per cent of the water)	Slight local pitting	Slight stain	Dulled and very slightly pitted	25 per cent of area corroded
180 ml. oil (SMLO) 40 ml. artificial sea water 5·6 gm. sodium nitrite (=14 per cent of the water)	None	Slight stain	Slightly dulled	80 per cent of area corroded

The three twelve-hour tests recorded in Table 1 gave no indication of interaction between sodium nitrite and lubricating oil, but it was found that the nitrite emulsion took somewhat longer to separate. Copper and white metal were practically

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* A "straight" Penna type turbine lubricating oil without chemical additives which has been standard in the Royal Navy for many years.

unaffected but aluminium showed definite signs of attack. Steel was fully protected, although considerable rusting occurred in presence of salt water without nitrite.

A further test was made over the longer period of 34 hours (see Table 2) and with full-strength sea water, using 7 per cent and 14 per cent of sodium nitrite. The latter high concentration was adopted to show up any unwanted effects as clearly as possible, rather than with the expectation of its being necessary in practice.

Again there was no indication of harmful interaction between nitrite and oil, and the corrosion effects were of the order to be expected from Dr. Hoar's results. Aluminium was included in these experiments in order to gain a rough idea of the intensity of attack to be expected. Normally in steam-turbine practice it is either not used at all, or is employed only in the form of robust castings such as gearbox covers of aluminium silicon. It was concluded that these would not suffer any harm unless the exposure were far more severe and prolonged than that contemplated.

(3) Effect of Sodium Nitrite on Demulsification of Oil

The slowing down of separation of emulsified oil and water when nitrite was present was noted repeatedly, and pointed to a possible difficulty in removing water by means of the centrifugal separator, especially from old, partially oxidized oil. Since the addition of nitrite is proposed only as an emergency measure to prevent serious damage to machinery, the possibility that a charge of emulsified oil might have to be set aside for special separation treatment, or discarded altogether, could doubtless be accepted. A few experiments were made, however, in order to assess the extent of the difficulty.

A partially oxidized charge of SMLO (I.P. demulsification value = 470) mixed with undiluted sea water containing 14 per cent of sodium nitrite, was taken as representing thorougly adverse conditions and the rate of breaking of the emulsion formed from this mixture was compared with the rate for the same oil when mixed (a) with distilled water and (b) with sea-water alone. Each oil-water mixture (200 ml.-80 ml.) was circulated in the pump apparatus for fifteen minutes, producing a close emulsion. This was quickly transferred to a graduated tube as used in the Institute of Petroleum test for demulsification, immersed in a water-bath at 200-203 deg. F., and the rate of decrease of the emulsion layer (as oil and water settled out) observed. The rates for the three mixtures are given by Fig. 5.

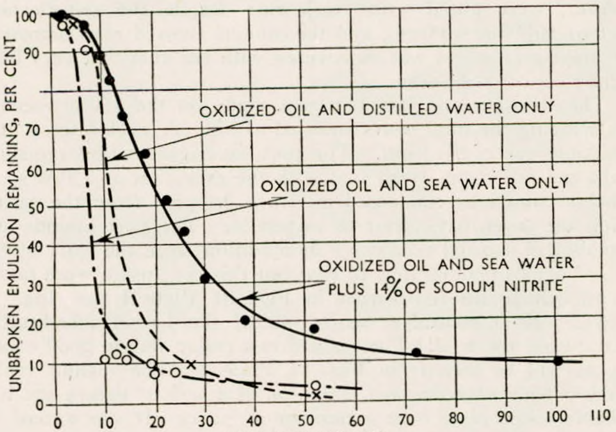

FIG. 5.—*Effect of sodium nitrite on the break-up of emulsions during settling at 200-203 deg. F.*

It will be seen that, whilst there is no very marked difference between the curves for distilled water and sea-water, the time required for the sea-water containing nitrite to separate out to any given extent is longer. In fact, during the sea trials to be described later, no difficulty arose.

(4) Tests for Salt and for Sodium Nitrite

It was thought desirable, before initiating practical trials, to have convenient methods of chemical control available for use in a ship.

The method of titration by silver nitrate used for determining salinity of boiler feed water is quite satisfactory when applied to water derived from a turbine oil system, the presence of traces of oil causing no difficulty. Similarly the approximate *p*H value of the water is ascertainable in a few moments by means of a universal indicator such as BDH 678.

If the oil is reasonably clean, its water content may be estimated by settling. The tube (Fig. 7) is filled with white spirit to B. A little sulphonated castor oil or similar "wetting agent", diluted half and half with water, may be added to assist separation of water and its volume at A noted after settling.

A representative sample of oil is drawn, preferably from a test cock whilst steaming and, without giving time for water in it to settle, 100 ml. is poured into the tube, reaching to mark C. It is then mixed with the white spirit by inverting and shaking. After completely settling in a warm place, droplets having been dislodged from the sides of the tube by spinning it about its axis and sharply reversing direction, the volume of the watery layer is again noted. Each ml. increase represents one per cent of water in the oil.

Methods for estimating water in dirty oil need not be described here.

Since an over-dose of sodium nitrite will do no harm it is seldom necessary to determine its concentration analytically. A method suitable for engine-room use was, however, worked out and may be of interest. It proved satisfactory during sea trials. The method is based on the reaction of nitrite with sulphamic acid, suggested by the Chemical Inspection Department, Ministry of Supply :—

$$NaNO_2 + NH_2HSO_3 = NaHSO_4 + N_2 + H_2O.$$

The determination is carried out as follows (Fig. 6) :—
Exactly 1·00 ml. of the water is delivered from a 1 ml. pipette into the bottle A, which is half-filled with distilled water. The stopper is inserted, and water poured into C (the water levels should remain steady, indicating absence of air-leaks). With the stopper removed, and C adjusted to bring the water-level in B near to the zero mark, a filter-paper packet containing about

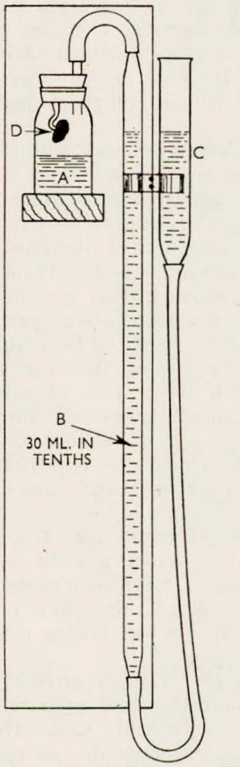

FIG. 6.—*Apparatus for determining the sodium nitrite concentration.*

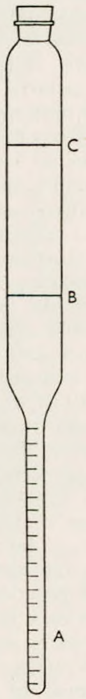

FIG. 7.—*Tube for estimation for water content.*

0·25 gm. of sulphamic acid is attached to hook D and the stopper firmly replaced. The level in B having been noted, A is swirled to detach the packet and open it up in the water.

Evolution of nitrogen gas will occur, and C is readjusted to equalize the water levels in B and C. The volume of nitrogen is then read off from the graduations on B.

Since 1 gm. of sodium nitrite yields 350 ml. of nitrogen gas at 67 deg. F. and normal pressure, the percentage present in the sample is $\frac{\text{Volume of nitrogen evolved (ml.)}}{3{\cdot}5}$

Results are generally correct within a tenth of the percentage of nitrite present.

TRIALS IN SHIPS' MAIN ENGINES

(1) Use of Sodium Nitrite to prevent Corrosion by Sea Water

Through the interest taken in the author's proposals by the Engineer-in-Chief's Department at the Admiralty it became possible to carry out practical trials.

Full-scale tests were begun cautiously with the daily introduction of small quantities of sodium nitrite into the forced lubrication system of a destroyer's turbines, the quantities being adjusted to 0·2 per cent of the water entering from the steam glands, which amounted to 117 gallons during 160 hours continuous steaming. No salt was present. At the end of the trip the journals showed no perceptible change. Old markings due to corrosion before the last refit were visible; otherwise their condition was normal.

In order to secure a positive result, permission was next obtained to put sea-water into both engines of an old destroyer in order to create corrosive conditions, and to add sodium nitrite to one engine only.

The opportunity was found in a twelve-year old destroyer already marked for breaking up, but based for a few months on Portland for occasional anti-submarine exercises in the Channel. The intermittent use of her engines provided excellent conditions for a corrosion test, and the fact that the ship was never far from her base greatly reduced the risk of complications in the event of an unexpected breakdown.

Her previous record showed no trouble with the forced lubrication system, and in a preliminary examination the journals and gearing were found to be in good condition, smooth to touch but lightly pitted, with no signs of active corrosion. There was no noticeable difference in the condition of the port and starboard engines. This is illustrated by Figs. 8 and 9, Plate 1.

The old lubricating oil, which had so far circulated through both systems with the interconnecting valves open, was removed, and the drain tanks cleaned by hand. The port and starboard systems were then isolated by closing the cross-connexions and each drain tank charged with 180 gallons of new SMLO, plus 30 gallons of distilled water and 10 gallons of synthetic sea-water. The water present thus had a test salinity of 320 grains of chlorine per gallon. In the case of the port system only, 28lb. (equivalent to 7 per cent), of sodium nitrite was dissolved in the water.

The ship then continued her duties with the salt solution in the starboard forced lubrication system and the salt solution plus sodium nitrite in the port forced lubrication system. In accordance with normal practice the forced lubrication pumps were run for two hours on each occasion before starting main engines, and for half an hour after stopping.

In the early stages of the trial an attempt was made to estimate the quantity of condensed steam entering the system by taking float gauge readings on the drain tanks when in harbour. These readings proved erratic and unreliable, so recourse was had to sampling the mixed oil plus water from a bearing test cock whilst under way, and determining the percentage of water present by simple settling tests. The salinity and the sodium nitrite content of the water were also determined.

It was found that only 10 per cent of water was present instead of the 18 per cent expected, the balance having disappeared, possibly into pockets in the system. It was decided to operate the trials with this proportion rather than make any further addition. The salinity and nitrite content of samples of water from the two systems were also slightly below the concentrations intended, probably owing to the presence of condensed steam in the system at the start. As the trial proceeded, however, it was found that very little condensed steam was entering and that it would be unnecessary to extract water until the end of the run. In these circumstances fresh additions of sea-water or nitrite were not made, although the concentrations show a small progressive decrease with lapse of time (Table 3). A small percentage of sodium nitrite found its way from the port to the starboard system.

Table 3. Progressive decrease in concentrations of salt and sodium nitrite in the lapse of time

Hours steamed	Sodium chloride		Sodium nitrite		*p*H value	
	Starboard (without nitrite), per cent	Port (with nitrite), per cent	Starboard (without nitrite), per cent	Port (with nitrite), per cent	Starboard (without nitrite)	Port (with nitrite)
50 hours	0·6	0·7	0·2	6·0	8·8	8·8
116 hours	0·6	0·7	0·2	5·0	8·8	8·8
158 hours (end of trial)	0·4	0·6	0·3	4·0	8·8	8·8

A first inspection of the main gear wheels was carried out fourteen days after the start of the trial. The ship had made nine trips totalling fifty hours steaming during that time. The port wheel showed no change in appearance, but the starboard wheel was unmistakeably rusty.

Thirty days later the Engineer Officer of the ship reported that the starboard "Autokleen" oil strainer had become choked with rust, the self-cleaning mechanism being found immovable. A new element was fitted but this seized up soon afterwards and the strainer had to be by-passed.

A second inspection of the gears was made on the forty-ninth day from the start, the ship having been at sea on twenty-one days and completed 110 hours steaming. There was still no change in the nitrite-protected port engine, the journals being in excellent condition except for old water marks, and the gearing showing no signs of new corrosion. The starboard journals, however, were pitted with fresh rust despite the self-cleaning effect of rubbing surfaces, and the pinions showed new corrosion. The main gear wheel was so covered with red rust that very little bright steel could be seen.

The thirtieth and last trip was made on the seventy-second day, bringing the total hours steamed to 158. A week later a final inspection was carried out. The port main gear wheel remained bright and free from fresh rust with the exception of a few spots probably caused by condensed moisture dripping from the casing during the seven days prior to inspection. The port pinions and journals still showed no change in condition since the start of the trial. Various photographs to bear out this conclusion were taken, two of which are reproduced in Fig. 10, Plate 1 and Fig. 12, Plate 2. No measurable wear-down of the bearings had taken place during the trial. The main thrust collar was in good condition, as will be seen from Fig. 14, Plate 2. The rusting visible on the outside edge was not active or of a serious nature and had probably taken place over a number of years. It was agreed by all concerned that the salt water had been prevented from having any adverse effect and the engine was in normal condition. It could be turned freely by the hand turning gear.

The starboard engine, on the other hand, was not far from breakdown. The main gear wheel was very badly corroded and covered with active red rust. The pinions were likewise badly corroded, though not quite to the same extent as the main wheel. The journals showed an average wear-down of 0·026 inch during the trial against approximately 0·003 inch during the whole previous life of the engine. Journal corrosion was very bad, and the white metal had started to pick up. The engine could not be turned by hand. It was found that during standing the suction line to the starboard forced lubrication pump had become choked with rust, and both pump and pipe had to be dismantled and cleaned. It was clear that the engine could not have run much longer. Fig. 11, Plate 1 and Figs. 13 and 14, Plate 2 illustrate its condition and should be compared with the corresponding views of the port engine in Fig. 10, Plate 1 and Figs. 12 and 14, Plate 2, keeping in mind that the engines were alike at the start of the trial, and that photographs in black and white, though clear enough when closely examined, cannot reproduce the strong contrast between the two engines which was immediately apparent on inspection.

The non-ferrous metals in each engine were free from marked corrosion with the exception of the aluminium silicon gearbox covers. These showed signs of attack, though not to a damaging extent.

It was agreed that this trial had shown the use of sodium nitrite to be satisfactory for the purpose in view.

(2) Use of Sodium Nitrite to Arrest Existing Corrosion

Experience in other ships having shown that salt-water corrosion, once started, is very persistent even after removal of the salt water from the oil-circulation system, it was considered to be of interest to discover whether the corrosion of the starboard engine could be arrested by circulating sodium nitrite, and since the ship had to remain in service for a time the opportunity was taken to make this further experiment.

The starboard forced lubrication system was emptied and cleaned by circulating two proprietory cleaning fluids in succession, flushing with water after each. This removed most of the loose rust. The system was then re-charged with new oil (SMLO) plus thirty gallons of a 2 per cent solution of sodium nitrite, and the ship returned to sea.

After four days at sea, this solution, containing more rust detached by the movement of the machinery, was discharged by centrifuging and replaced by a second thirty gallons.

After fourteen days there was no sign of active corrosion, the rubbing surfaces of the gear teeth being bright and the rest covered with old hard rust of dark appearance. The sodium nitrite solution was next removed by the separator and replaced by thirty gallons of distilled water. The ship continued in service for three weeks, and final examination prior to her departure for breaking up showed the condition of the gears to be unchanged, with no indication of corrosion having recommenced. The journals, though covered with non-active rust, had become comparatively smooth, and wear-down over the period dating from the introduction of nitrite was 0·003 inch, as compared with 0·026 inch for the previous trial. This experiment gave a clear indication that if the mechanical condition (degree of wear and tear) of the machinery permits, a system which has been severely corroded may be cleaned up and rendered fit for further service by the treatment described. without the expense and delay of mechanical overhaul, and that corrosion which has been checked by the use of sodium nitrite will not recommence in the presence of fresh water. Further confirmation has since been obtained from a practical application of the treatment (p. 65).

(3) Use of Corrosion-inhibiting Oil

Whilst the experiment just described was being carried out in the starboard engine, the port engine was used to confirm the conclusion (already arrived at from laboratory work and from Case 4, p. 58), that a corrosion-inhibiting turbine oil to meet U.S. Navy Symbol 2190T does not ensure immunity from corrosion by salt water. The port forced lubrication system was cleaned in the same way as the starboard, but was recharged with 180 gallons of oil 2190T. To remove any residual solids the separator was kept in action for several days. 7½ gallons of synthetic sea-water and 22½ gallons of distilled water were then added, and the ship proceeded on her normal duties. After fourteen days the gears which of course were bright and practically corrosion-free at the outset, were found to be speckled with patches of dark, hard rust, and with areas of active corrosion. The salt water was removed by the separator, and 40 gallons of distilled water containing 7 per cent of sodium nitrite were then added to arrest the action. A final examination three weeks later revealed no active corrosion. Wear-down of journals was 0·007 inch. This experiment therefore confirmed that oil 2190T cannot be relied upon for protection against sea-water, when present to the extent of one part in four of the total amount of water, and again showed that existing corrosion can be arrested by the use of sodium nitrite.

RECOMMENDATIONS

(1) Routine Precautions against Sea Water Corrosion

It has already been mentioned that the salinity test used for boiler feed water can be applied to the slightly oily water extracted from a turbine oil system. In practice, it is important to carry out this test at the time when the amount of salt water, if any, is at a maximum. Entrance of sea-water is most likely to occur when there is no oil pressure on the system, and the test should therefore be made on water separated when in harbour as well as at sea. The possibility of intake of bilge water on the suction side of the lubricating oil pumps, on the other hand, renders it desirable to test at intervals of, say, one week in all circumstances. Naval practice is to test once a week in harbour and daily at sea.

(2) Action in Cases of Slight Contamination by Salt Water

With plain lubricating oils in use the tendency to cause corrosion increases with the concentration of salt from zero upwards, and it is advisable to resort to flushing operations if ever the concentration exceeds 10 grains chlorine per gallon. (The salinity of sea-water is about 1,400 grains per gallon). Flushing is carried out by repeatedly introducing distilled water, circulating it with the oil whilst the engines are running, and removing it by centrifugal separation. Provided the amount of water is not excessive and it is mixed with the oil by running the circulating pumps before starting the engines, or by adding it slowly while steaming, there need be no fear of damage by failure of lubrication. Mixtures of more than one gallon of water to nine of oil have been used for long periods without any harm, though so large a quantity should not be present if the engines are to be run at full power. Up to 3 per cent is considered quite safe.

(3) Action in Cases of Heavier Contamination by Salt Water

It is taken for granted that when a serious amount of sea-water is detected, prompt steps will be taken to locate and remedy the leakage. In such circumstances, when the salinity exceeds, say, 30 grains chlorine per gallon, the danger of corrosion will be considerable, and flushing with sodium nitrite solution should be employed. A solution containing 7 per cent of nitrite is suitable and a stronger solution should be unnecessary, since the salinity, if excessively high, can be brought to a moderate figure by the first flushing operation. When repeated extractions and replenishments of nitrite solution have sufficiently reduced the salinity of the water, a few days steaming should elapse to give the nitrite time to arrest all corrosion before the last charge of solution is finally flushed away with distilled water and normal operation resumed.

SALVAGE OF MACHINERY IN A STATE OF ADVANCED CORROSION

When the presence of salt water has remained undetected and

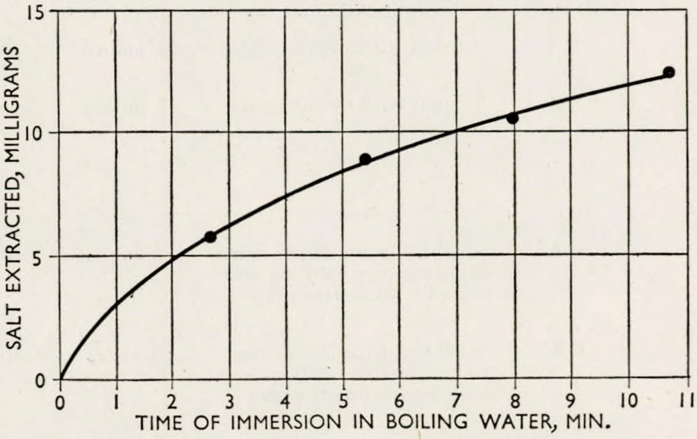

FIG. 16.—*Effectiveness of water washing*

Table 4. Arrest of corrosion showing effect of various treatments applied to heavily rusted bolts from gear wheels (see Case IV above) after degreasing and filing bright.

Treatment	Standing period	Condition	Further standing period	Condition
None	6 hours	Beads of wet rust over the corrosion-pits	7 days	Surface 100 per cent rusty
Washed several times with hot water	1 day	Rust formed over most pits but in smaller volume	7 days	Surface 70 per cent rusty
Plastered with nitrite paste; wiped off after four days	1 day	Rust formed over a few pits only	16 days	Surface 30 per cent rusty
Washed with hot water and plastered with nitrite paste; wiped off after eight days	1 day	No rust	20 days	No rust
Plastered with nitrite paste (about 1/20th inch thick)	7 months in damp atmosphere with occasional slight condensation of moisture	On wiping the surface clean, no rust was apparent	—	—

repair work is necessary, it is important to prevent further corrosion during and after the refit. The best method is that recommended above, since circulation of the nitrite ensures that every centre of corrosion will be reached. However, it is not always possible to run the machinery, and some alternative is then necessary.

In Case IV, described on p. 58, various unsuccessful efforts were made to save the corroded gearing by cleaning away the rust, and further experiments were carried out with one of the condemned gear wheels after it had been put ashore. A number of large heavily rusted bolts were taken from the flange, and used for small-scale tests. When one of these was simply filed bright, hundreds of corrosion pits remained dotted about the surface and within a few hours an eruption of moist black oxide formed over each pit, slowly turning red and spreading until within a week the surface was again completely rusty.

Immersion in boiling water extracted salt, but only slowly. Fig. 15 shows that water-washing is not effective quickly enough to be useful when rusty machinery is being cleaned by hand.

Scrubbing with a solution of sodium nitrite, and coating with rust-inhibiting oil or water-displacing fluid were likewise ineffective, clearly because the sub-surface centres of activity, full of salt water and corrosion products, were not reached by such means.

It seemed likely that if a solution of sodium nitrite could be

Table 5. Effect of various treatments applied to parts of heavily rusted main gear wheels (see Case IV above) after degreasing and cleaning with carborundum cloth.

Test Ref.	Rust-arresting treatment	Standing period	Condition	Subsequent treatment	Standing period	Condition
On wheel teeth						
A.1	Coated with plain mineral lubricating oil	1 month	Slight rusting	Wiped clean	7 months	About 80 per cent of area rusted
A.2	Coated with corrosion-inhibiting oil	1 month	Slight rusting	Wiped clean	7 months	About 40 per cent of area rusted
A.3	Coated with nitrite paste	1 month	No rust	Wiped clean	7 months	About 15 per cent of area rusted
On journal surface						
B.1	None	—	—	—	7 months	Rusty
B.2	Coated with plain mineral lubricating oil	—	—	—	7 months	Rusty, but slightly less so than B.1
B.3	Coated with nitrite paste	1 month	No rust	Paste wiped off	7 months	About 10 per cent of area rusted
B.4	Coated with nitrite paste	1 month	No rust	Paste wiped off and plain mineral lubricating oil applied	7 months	No rust
On wheel teeth						
C.1	Scrubbed with 20 per cent sodium nitrite solution and coated with nitrite paste	3 weeks	No rust	Paste wiped off	7 months	No rust except small patches on tops of teeth about 1 per cent of total area
C.2	Scrubbed with 20 per cent sodium nitrite solution and coated with nitrite paste	3 weeks	No rust	Paste wiped off and plain mineral lubricating oil applied	7 months	No rust

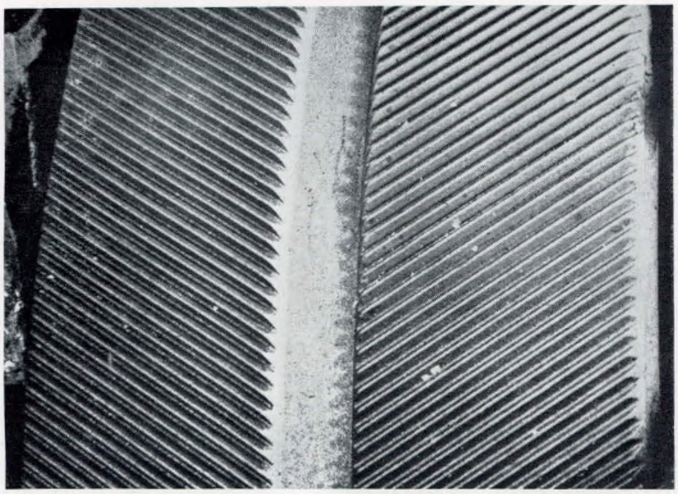

FIG. 1.—*Heavily corroded main gear wheel*

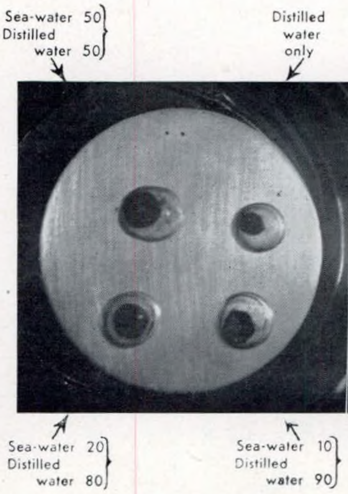

FIG. 2.—*Plain mineral oil*

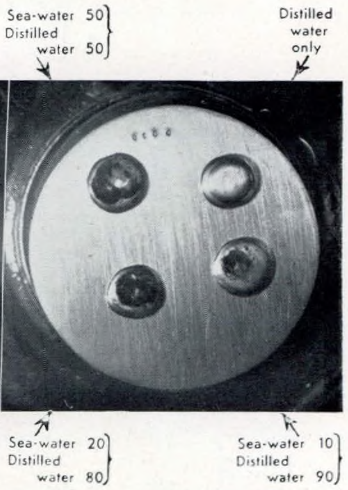

FIG. 3.—*Corrosion inhibiting oil 2190T*

FIG. 8.—*Port engine pinion at start of experiment*

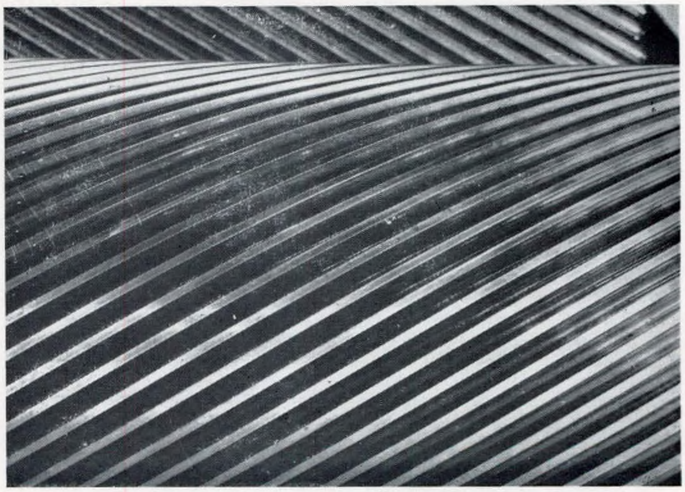

FIG. 9.—*Starboard engine pinion at start of experiment (no difference)*

FIG. 10.—*Protected port engine surfaces smooth and bright*

FIG. 11.—*Unprotected starboard engine surfaces rusty*

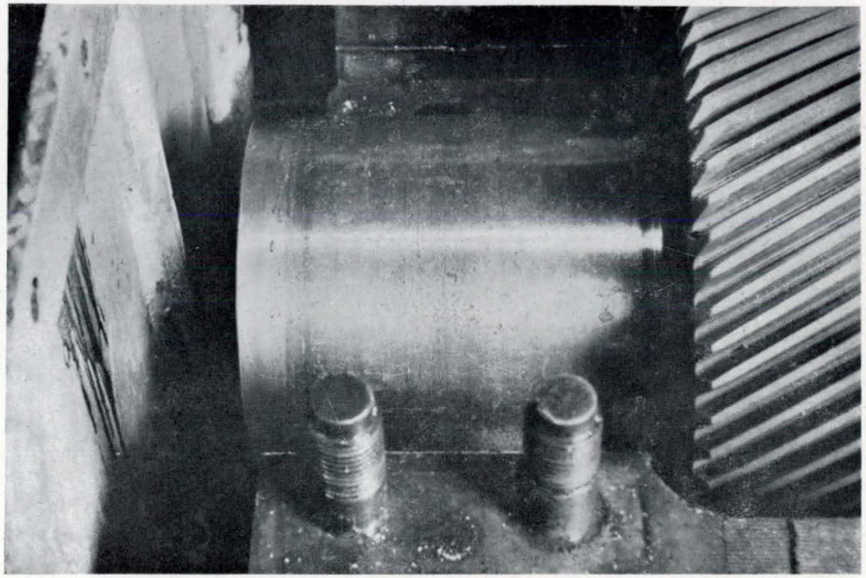

FIG. 12.—*Protected port engine journal with no wear down and surface smooth and bright apart from old water marks*

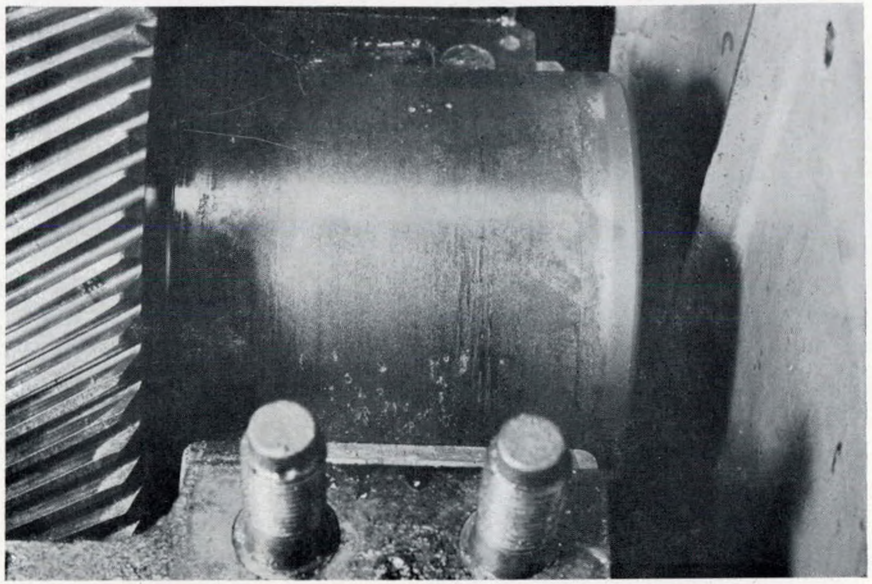

FIG. 13.—*Unprotected starboard engine with 0·026-inch wear down and old water marks obliterated by new corrosion*

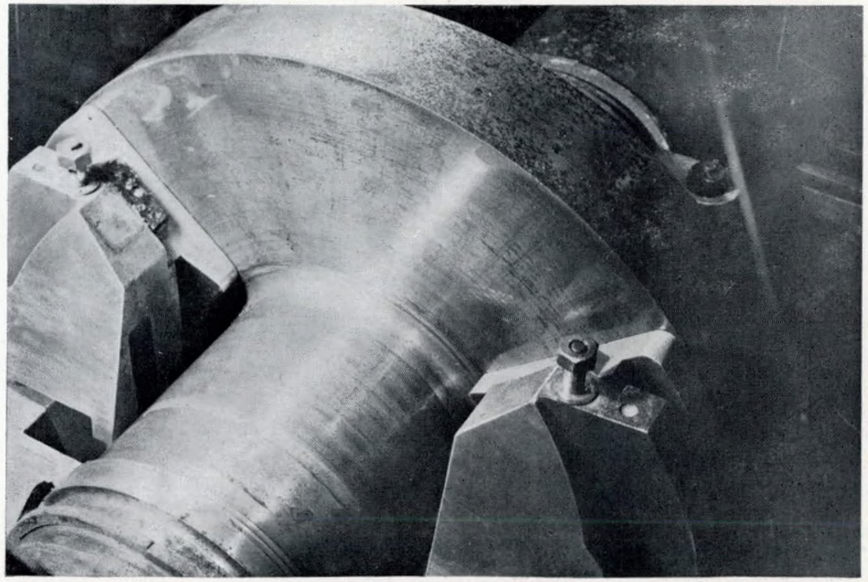

FIG. 14.—*Protected port engine after three months' operation with salt water present in the lubricating system*

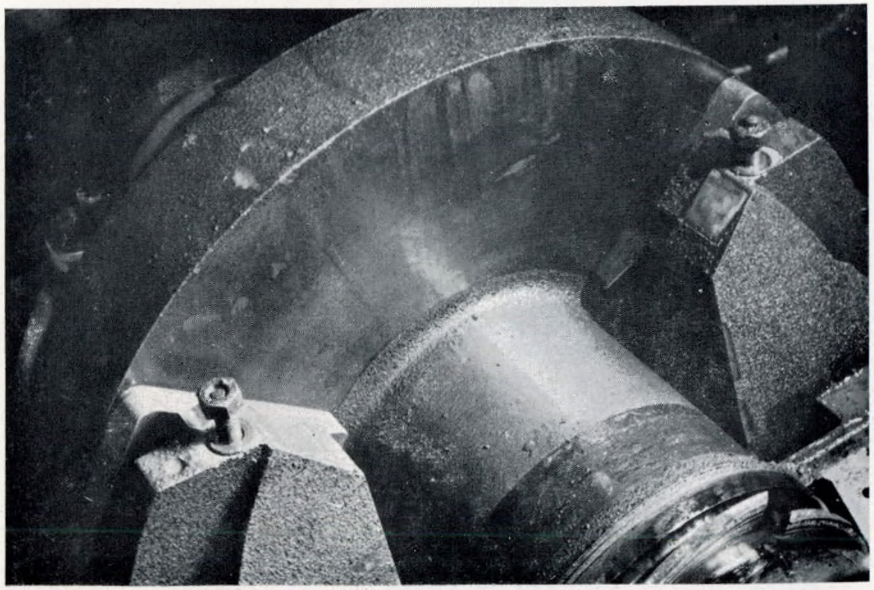

FIG. 15.—*Unprotected starboard engine after three months' operation with salt water present in the lubricating system*

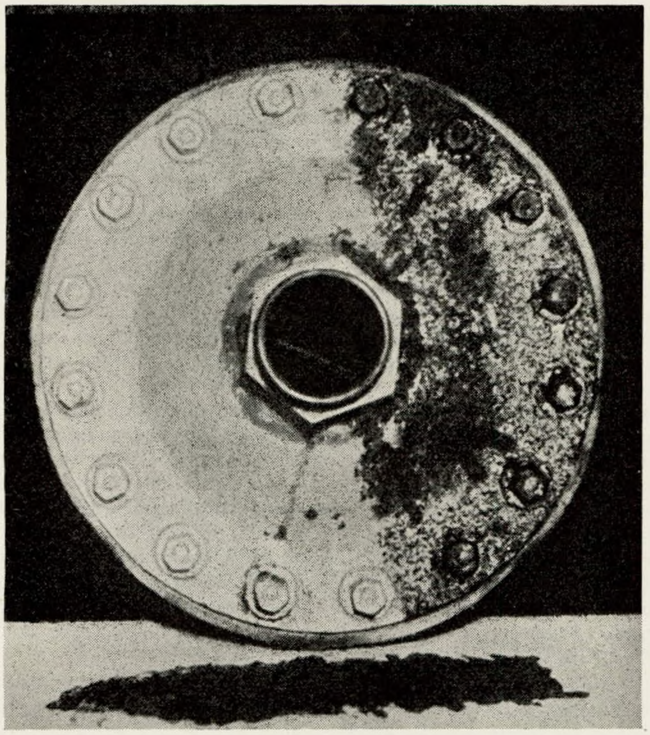

FIG. 17.—*Partially treated water softener cover*
14 oz. of rust were removed before the experiment was carried out.

made to penetrate these centres it would provide the remedy, and that the requirement was to keep such a solution in contact with the rusty surfaces for as long as might be necessary for it to diffuse into the pits and crevices. To this end a strong solution was made into a paste. The effect of the paste is shown by tests recorded in Table 4. Each bolt was degreased and filed bright before treatment.

Meanwhile similar trials were put in hand on areas of the journal and toothed rim of the wheel, which stood covered with sacking in a weather proof shed. The surfaces were first freed from grease with rag soaked in trichlorethylene and rubbed bright with carborundum cloth. The results were as shown in Table 5.

It will be seen that oils fail to stop rusting (A.1, A.2, B.2) though the corrosion inhibiting oil had more retarding effect than the plain mineral oil. Nitrite paste stopped rusting completely (A.3, B.3, C.1) and when oil was subsequently applied no rust formed for a further seven months at least (B.4, C.2). The corrosion-inhibiting effect of the paste continued after it was wiped off, and without subsequent oiling, to the extent that very little rust formed within seven months (C.1).

Another experiment, designed to test the treatment under extreme conditions, was carried out on the cover of a water softenning unit which had been in use for fifteen years. During this time nothing had been done to counteract the effect of continual spilling of salt (used in the softener) over the cover, and excessive rusting had resulted. By scraping and scratch-brushing some 14oz. of rust scale was first removed. The surface, approximately one square foot in area, was next thoroughly scrubbed with water and allowed to dry. One half was coated with nitrite paste and left for thirty-eight days, the paste being renewed once during that time. The whole surface was then again scrubbed with water, allowed to dry, and painted with cellulose varnish pigmented with aluminium powder. Within eight days the portion not treated with nitrite paste became dotted with beads of moist red rust erupting through the paint. These increased until fifty days later the cover presented the appearance shown in Fig. 17, one half rusty, the other with paint intact. It was then once more scrubbed with water and re-painted all over, but within fifteen days rust was again breaking through the paint on the untreated section thus showing the persistent character of deep-seated salt corrosion.

From these experiments it was concluded that nitrite paste could be employed to stop the progress of corrosion during a refit.

EXPERIENCE WITH SODIUM NITRITE TREATMENT IN THE ROYAL NAVY

Since the completion of the work described above, the nitrite treatment has been used in two ships.

In September 1947 the turbine oil system of a minesweeper was found to contain a quantity of almost pure sea-water, which has caused extensive rusting of gears and journals. The entry of sea-water was traced to split tubes in an oil cooler.

The method adopted was as follows:—

(1) The surfaces of journals and gear teeth were cleaned with white spirit and rag, surface rust rubbed off with emery cloth, and the whole scrubbed with 5 per cent sodium nitrite solution. Nitrite paste was applied as a temporary protective to the journals until these operations were completed.

(2) The paste was removed and 2½ gallons of a 3 per cent solution of sodium nitrite added to each hundred gallons of oil in circulation. The ship then proceeded to sea.

(3) After six hours steaming the solution was withdrawn by by means of the centrifugal separator.

(4) More nitrite solution was added and the procedure repeated until the salinity of the solution discharged was less than 10 grains of chlorine per gallon.

(5) Processes (2) to (4) were repeated using distilled water in place of nitrite solution.

(b) The oil system was emptied and re-charged with new oil.

Beyond the re-metalling of one or two scuffed bearings and the replacement of split oil-cooler tubes no repair action was necessary.

The ship returned to duty after this treatment, which had involved 2½ days steaming.

On examination four months later no sign of active corrosion could be found. The working surfaces were smooth and bright and no lubrication trouble had been experienced. A major refit was thus obviated.

During the autumn cruise of the Home Fleet a considerable amount of salt water was found in the forced lubrication system of a destroyer's engines soon after leaving Bermuda. The recommendations on p. 63 were followed (they now form part of a Fleet Order) and on the ship's arrival in home waters fourteen days later not only was the system free from salt, but there was no sign of any corrosion or damage. Without these precautions damage would undoubtedly have occurred.

ACKNOWLEDGMENTS

This paper is published with the approval of the Lords Commissioners of the Admiralty but the responsibility for any statements of facts or opinions expressed remains solely with the author.

The author's thanks are due to Dr. D. Clayton, formerly head of the Joint Advisory Service on Lubrication, for helpful discussion and encouragement at all stages of the work, especially when there seemed small prospect of securing practical trials, and to the team of engineers under Com'r(E) E. Tyrrell, R.N., who carried out the sea trials and gave practical effect to the proposals.

MINUTES OF PROCEEDINGS OF THE ORDINARY MEETING HELD AT THE INSTITUTE ON 8TH FEBRUARY 1949

An ordinary meeting was held at the Institute on Tuesday, 8th February 1949 at 5.30 p.m. R. K. Craig (Chairman of Council) was in the Chair. A paper entitled "Corrosion of Turbine Journals" by S. E. Bowrey, B.Sc. (published in this issue of the TRANSACTIONS) was read and discussed. Fifty-six members and visitors were present and six speakers took part in the discussion.

A. F. C. Timpson, M.B.E. proposed a vote of thanks to the author which was accorded with acclamation.

The meeting terminated at 7.35 p.m.

Discussion

Com'r (E) E. Tyrrell, R.N. (Visitor) said that as a result of the author's recommendations, an Admiralty Fleet Order had been issued, calling for the chlorine content of the water discharged from the centrifugal separator to be determined daily at sea and once a week in harbour. The chlorine content was determined by titration against a standard silver nitrate solution. It might be contended by many people that titration was too complicated and that glass-ware was too fragile to be of any use to the sea-going engineer. His experience however showed that with a little ingenuity it was possible to develop a compact and robust apparatus which could be packed in a box the size of a small suitcase, and that apparatus was now part of the standard equipment of all steam-driven H.M. ships.

One of the main difficulties was the unreliability of the belt-driven centrifugal separators fitted in many ships. Here he would say that separator manufacturers would do well to improve the reliability of their products.

The proposal to introduce water into a forced lubrication system was, of course, greeted with very considerable opposition. Investigation showed, however, that water in comparatively large quantities was often contained in turbine lubrication systems, particularly if the gland packing was in poor condition and if the centrifugal separators were not working correctly or not working at all. The loading on both bearings and gearing in marine practice was often unnecessarily and lamentably low. Hence very considerable contamination of the oil could be experienced without the slightest danger of breakdown. Practical trials in a destroyer with 10 per cent of water content in the lubricating oil showed that full power produced no damage. It had, however, been ordered that if water was contained in the system deliberately, then the maximum power available should be limited to 75 per cent. If water washing were to be accepted in the Merchant Service there would not, he thought, be any reduction in power whatsoever as loadings on machinery were very much lower than was the case in Admiralty practice. Such failures as had occurred —in gearing in particular—had been traced in nearly every case to excessive errors in machining rather than to a breakdown in lubrication. That was one of the points which shipbuilders might study rather more carefully—how to improve machining practice for their gearing.

The author had shown the way towards longer life and lack of troubles in turbine lubrication systems. It must be assumed that anyone who was up with modern practice was using a corrosion inhibiting oil of the 2190 T type, but much required to be done to improve present practice. Filtration was at present almost non-existent in practice. The present type of wire or spaced disk strainer merely served to keep out large impurities, and could not be regarded as providing adequate filtration from the point of view of reducing wear or safeguarding the life of lubricating oil.

Further, it had been shown that on the average if 10 per cent of old oil were left behind in a system this reduced the life of a new charge of oil by some 75 per cent. Yet, in a lubrication system it was often extremely difficult, sometimes impossible, to ensure that all the old oil was drained. Here again, shipbuilders might give more consideration to the adequate drainage of their turbine systems in the future.

Dr. D. Wyllie (Visitor) said that as reported by Dr. Hoar of Cambridge, sodium nitrite functioned as an anodic inhibitor, probably by virtue of its oxidizing properties. Some people held that in extreme cases ammonia might be formed, but he had not found any trace of ammonia in experiments, nor had he found any appreciable change in the ratio of the nitrite and nitrate concentrations. It was therefore considered that the reaction mechanism was more probably a catalytic one in which nitrite was reformed.

By experiments with a divided cell it had been possible to confirm that nitrite did function at the anode. These experiments had been carried out with a steel anode and a platinum cathode. 2 per cent of sodium nitrite added to sea water reduced the corrosion current to negligible dimensions, but a considerable increase in nitrite up to the order of 30 per cent did not completely stop all the corrosion current. Under conditions such as those described by the author 7 per cent of nitrite should therefore give ample protection. In corrosion tests at room temperature in which mild steel specimens were suspended in sea water containing various concentrations of nitrite—sometimes with a covering of oil and sometimes without—it was observed that the higher concentrations of nitrite prevented all signs of serious corrosion, but brown discoloration appeared in large patches which slowly spread over most of the surface of the metal. This was most severe at a nitrite concentration of about 10 per cent and did not entirely disappear until upwards of 25 per cent was added. Eventually, after periods of the order of twenty-eight days, each area of tarnish started to develop small pits at the centre. It was considered that the protective film of oxide was not completely impermeable and that very slow corrosion was in fact taking place, eventually changing into mild pitting. Attempts were therefore made to add other inhibitors to 5 per cent sodium nitrite in sea water in the hope of getting rid of this form of attack, and also to find inhibitors which yielded insoluble ferric salts to give a protective film and at the same time soluble calcium and magnesium compounds which would not give unwanted precipitates. Mono- and di-hydrogen phosphates answered this requirement in a narrow range of concentrations but the conditions were more easily complied with if metaphosphate was employed.

An interesting series of results were obtained when zinc salts were added to nitrite in the hope that the cathode inhibition of the zinc would reinforce the anodic action of the nitrite. Comparatively large amounts of zinc salts were required, but it was worthy of note that 5 per cent of sodium nitrite and 2 per cent of zinc acetate completely protected steel for 112 days. Experiments with the divided cell showed that the contribution of the zinc to corrosion inhibition was much less than that of the nitrite. The anodic action of the nitrite almost completely swamped the cathodic action of the zinc.

An interesting inhibitor of another type was sulphite.

Small additions of sulphites to nitrite completely stopped the corrosion current but only for a limited period, the sulphite eventually becoming exhausted. As was to be expected, the action of the sulphite was very marked at the cathode and was generally considered to consist in removal of the oxygen from the cathode reaction.

On the point raised by the author regarding possible emulsification with sea water of solutions containing nitrite, experiments had been carried out on the Herschel emulsification apparatus, and it was possible to make an assessment of the rates of separation of emulsions containing nitrite as compared with plain emulsifications in sea water. The presence of nitrite in the water made no great difference to the stability of emulsions made from either new or used turbine oil. The addition of some of the other inhibitors mentioned did not have any very marked effect, with the exception of zinc which, as would be expected, adversely affected the rate of separation.

If sea water was stirred for a prolonged period in the presence of steel and of uninhibited oils, the advantages of nitrite were very marked. Tests in the apparatus used in the ASTM salt water corrosion test for turbine oils resulted in the oil developing an acid value of 4·5 after fourteen days of stirring. Rather large amounts of water were used—equal amounts of oil and water—a larger amount than was normally employed, when only 10 per cent was added. When corrosion was prevented by the addition of nitrite or nitrite mixtures, the highest acid value obtained in fourteen days was 0·9. Hence, any adverse effect nitrite might have on demulsification was more than offset by the increase in oil stability owing to the prevention of corrosion and the formation of catalists in the oil. Under these severe conditions, no inhibitor gave complete protection, and it was not possible to make firm distinctions.

Finally, an interesting demonstration of the point that oil soluble corrosion inhibitors could in certain circumstances be detached from metal surfaces and not replaced was afforded by the simple device of dipping steel plates in some efficiently inhibited turbine oils, and leaving the test pieces exposed to condensation in a humidity cabinet. In these conditions corrosion soon set in, there being no means by which the inhibitors could be reattached to the metal once they had been detached.

He was not free to discuss the efficiency of different types of oil soluble inhibitors, but he would like to close by drawing attention to a recent paper by Baker and Zisman in ***Industrial and Engineering Chemistry*** in which the relation between the absorption of polar rust inhibitors at metal surfaces and in emulsified water was discussed.

Dr. F. Wormwell (Visitor) said he had been interested in the description of the various reasons suggested for this corrosion. In cases of this kind all manner of obscure reasons were often suggested to account for serious corrosion when fairly obvious reasons were overlooked. In the present instance, of course, the emphasis was on the access of salt water. Little had been said about aeration, but salt water did normally contain oxygen and presumably oxygen corrosion was being dealt with here, stimulated by the presence of chloride, which was the arch enemy of all protective methods.

He had been interested also in the statement that "Smaller amounts of nitrite, not giving complete protection, convert general rusting into local pitting which, in the case of the machinery in question, is probably less dangerous than general rusting." This was very interesting because it was exactly the converse of what was usually found. Usually the most dangerous forms of corrosion were of the localized type, but in this particular instance apparently a little localized attack was not so dangerous as general corrosion.

The author also stated: "Sodium nitrite is effective only in neutral or alkaline solution. The *p*H value of the solution should preferably be about 8 and should not fall below 7."

That was a limitation, but apparently in these conditions it was not a serious one because—as had been seen—practical trials had shown the value of the nitrite treatment.

He must confess he had had very little personal experience of the use of sodium nitrite as an inhibitor. What evidence he had, however, fully confirmed what the author had shown—that it could be a most useful inhibitor, at any rate for steel, in certain conditions. The paper illustrated the principle of choosing the right type of inhibitor for the particular conditions. Unfortunately there were at present no corrosion inhibitors which could freely be recommended for all possible applications. One always had to consider the particular conditions—chloride content, aeration, and so on. Once the inhibitor was decided upon, it was important to decide what concentration was effective.

There was a reference in the third paragraph of p. 61 to other metals. He was anxious to obtain as much information as possible, and perhaps the author could give him any further references to systematic work on the use of sodium nitrite. One would like to know to what extent it was reliable in the case of other metals. He gathered that with aluminium alloys it did not necessarily always give complete protection in the presence of chlorides.

The only reference in the paper to other work would appear to be to U.S. patents and a German patent. He would like to draw attention to a paper in an American Symposium in 1945 on corrosion inhibitors. It contained an article on the use of sodium nitrite by Mr. Wachter of the Shell Development Co. Apart from that, he had failed to find any really systematic study other than the present one.

He looked forward to seeing the detailed results of the work carried out by Dr. Wyllie. He supported the plea that engineers should consider whether corrosion inhibitive treatment or modifications of design or environment could help. Very often one was asked to stop corrosion in 100 per cent of sea water by the addition of 0·01 per cent of inhibitor. He did not think anyone could do it at present, but provided one was willing to pay the price—in this case perhaps 5 or 7 per cent of nitrite—one could get a great saving not only in material but in ease of operation.

Dr. D. Clayton (Visitor) said that as he had been associated with Mr. Bowrey he would not say very much about the technical details in the paper, but he had a few points to make as regards the background. He wished to emphasize first the confusion that originally existed as to the cause of this trouble, and then the importance of a systematic approach to solving problems of that kind. Much of the confusion had arisen through trying to pin the trouble to the oil. Oil was a happy hunting ground for faults, and perhaps the oil industry was not without blame in fostering a certain mystery about oil. But engineers did not always co-operate with oil technologists in providing the data on which a sound survey could be built; for example, it was very often difficult to get samples so that an examination could be made and real evidence produced.

The author had already mentioned the number of explanations of the troubles offered, and he himself would like to stress the enormous amount of time devoted to the subject at a critical stage of the war. The oil industry put hours and hours of time into the examination of samples and into speculation as to the cause. A great debt was owed to the author for ultimately demonstrating that salt water was the source of the trouble in all of these cases.

Here was a very good example of the necessity to try out ideas on full-scale plant. It might seem that to take machinery that was going to be scrapped and to use it as a "guinea pig" was a perfectly straightforward, sensible thing to do, but it was actually extremely difficult to persuade people, even in such circumstances, to put their machinery at the disposal of experimenters so that information could be obtained which would inevitably react to their own benefit.

One wondered how many other ideas of a similar kind would ultimately come to fruition if they could have the same opportunities of trial. No-one would dispute that an engineer in charge of turbines had a most expensive and valuable piece of equipment on his hands; everybody would sympathize with his reluctance to experiment with it. But there was no doubt whatever that its state—in Commander Tyrrell's words—was in some respects still lamentable. That should be put right, and the only way was by experiment. The nation was very dependent on ideas at present, and would soon have keen competition on its hands, so it was necessary to rectify faults and inadequacies as quickly as possible. Of course, the greatest care should be taken so see that any idea was put through all its paces in the laboratory or in small scale apparatus first. But once it had reached the stage of seeming to be practicable to everybody concerned, it was absolutely vital to take the next step—an enterprising, perhaps a bold step—and to try it out in full scale. Machinery reaching the end of its life was an obvious choice for such experiment. As many people as possible should watch the experiment, so that the maximum benefit was gained. Often such work could best be done co-operatively; the financial scale being large, sharing of cost and responsibility was desirable.

The author had not only exercized patience and persistence in carrying out the original process of disentangling the story. Having recognized that sodium nitrite might be the answer, there was the gruelling process of making it a practical proposition—testing for possible difficulties with metals, with the oil; working out practical details such as strength of solution, apparatus for ship testing; considering whether to use it all the time or only in emergency, and so on; even deciding how much one dare put up to the Admiralty in one go!

One or two technical points were of particular interest. The question of rust stabilizing emulsion had been mentioned. This was by now well known in academic circles, but perhaps practical people did not realize sufficiently how easy it was to get a stabilized emulsion due to rust in a perfectly good oil. Then there was the question of the preferential wetting of a surface that was slightly rusty. A matter all too often neglected in this country was the protection of surfaces during manufacture so that they were assembled in the final machinery free from rust. If rusty surfaces were particularly prone to water-wetting, this was a still further reason for preventing rusting in machinery during manufacture and assembly.

It was not relevant to the main theme of the paper but the author had hinted at it, so perhaps he might mention the benefits to be derived from corrosion-inhibitors in all sorts of industrial problems. People looking for protection of a temporary character always thought in terms of oil and greases, but there were many cases where an aqueous corrosion preventer could be very useful.

Com'r Le Bailly (Visitor) said that on the previous evening a message had been received from one of the dockyards saying they were proposing to use the author's treatment once again, on a minesweeper that had just been brought forward from reserve, to arrest the corrosion found.

He would like to suggest that Commander Tyrrell had been perhaps less than just to separator manufacturers. In his own experience it was not always the manufacturer by any means who was at fault, for until lately, whether by accident or design it seemed to be the habit to place separators in the hottest and most humid corner of the engine room, and if possible under a salt water main prone to leaks. Any machinery would perhaps have cause for complaint under that treatment. Until the separator was treated as an integral part of the lubrication system—perhaps just as much as the pump—there could be little justification blaming the manufacturers alone. He was glad to say he believed that that was now the policy.

Mr. Henry T. Meadows, D.S.C. (Member) said that from the paper on "The Lubrication of Steam Turbines" by Lt. Col. S. J. M. Auld and C. Lawrie read before the Institute on 30th April 1946, it appeared

(1) that the factors influencing the rate of oxidation of a turbine lubricating oil were (a) aeration and heating, and (b) intrusion of water and formation of stable emulsions;

(2) some oxidation inhibitors might be water soluble.

In view of these, it would appear that the life of the oil might be expected to be curtailed after either the flushing, or nitriting treatment recommended by the author. It might be that it was the author's intention that the oil be renewed at a convenient opportunity after such treatment. If such was the case then its application in ships of the merchant service, with their very much larger circulatory systems than H.M. ships, would appear to be limited. The author might envisage the re-inoculation of the oil with inhibitor, but from the previously mentioned paper it was learned that "Measurement of the amount of active inhibitors remaining in the oil was not always a simple matter nor was re-inoculation invariably effective. The response of used oil to inhibitor varied amongst oils and amongst inhibitors. The nature, behaviour and past history of both should therefore be known before re-inoculation was attempted. In the majority of cases deterioration once it sets in was very rapid and quickly passed beyond the point at which the oil would respond". It would seem therefore that the cost of the arresting of corrosing would be a possible shortening of the life of the turbine oil. He would be glad to have the author's views on this question.

Although the application of the nitriting treatment to the turbine lubricating oils of merchantmen would appear to be limited, it seemed to him that there could be a great future for its use on board ship, on the lines indicated in the water softener cover experiment. Spare gear immediately came to his mind. To remove the grease or paint from a spare machined part to find it as it left the machine would indeed be an advantage. Many, like himself, must have been concerned on opening up some well-greased spare part, to find that active corrosion had been going on underneath the grease. While it was known by some that all greases were not ideal preservatives, to others, grease was grease, and as such could be used for all purposes. It would seem that the nitriting treatment would be the answer to rusty spare gear. Thinking along similar lines, would the author give his ideas on the possibility of protecting the lubricating oil sump tanks of new ships by the nitriting treatment? If he approved of such treatment would a final wiping over of the plates with lubricating oil be satisfactory or would an oil resistant lacquer be necessary?

The first speaker had said that centrifuges were inefficient. From his experience he could not agree with that, and thought that as far as the Admiralty was concerned, a better word would be "inadequate". He had served in one of H.M. ships which had three turbine units of about 30,000 h.p. each. Only in the centre engine room was there a centrifuge fitted and this only a very tiny one of about 50 gallons per hour capacity. Obviously such a small machine was hopelessly inadequate to deal with the author's flushing or nitriting treatment. Possibly it was in trying to make such a small centrifuge do such a large job that the first speaker had formed his low and unjust opinion of centrifuge manufacturers.

Mr. S. P. Smith (Member) wrote that he was one of the engineer officers on board the ship quoted in case 1. He joined this ship in the second refit at Messrs. Cammell Laird and he would like in fairness to the great number of people who worked so hard to overcome their troubles to point out that the leakage from the bilges referred to in the paper could not have had anything to do with the corrosion problem. This leakage was from a pipe joint on the lubricating oil system which had not been properly tightened up during the last refit. It was well above bilge water level but he did not think it was high enough "to clear a yardarm".

In these ships it was, if he remembered rightly, impossible to run with both engine rooms connected. There were, however, emergency valves which had always been kept closed. The leakage was in the forward engine room and the corrosion occurred equally on all sets of turbine bearings and gearing. He thought the reason why sea-water leakage was not emphasized in the investigations was because all oil pipes, coolers, drain tanks and the systems throughout had been very thoroughly hydraulically tested on several occasions and were found to be perfectly tight.

There was no doubt that the cause of this repeated corrosion was due to the fact that these ships had an unsatisfactory sea-water cooling arrangement for the turbine bearings which were blanked off before they were taken over, but sea-water had probably been left lying in the bearing sumps during the whole time these destroyers were laid up in America. As a consequence there was very heavy corrosion in these sumps which it was impossible to clean out, although attempts were made by using carbon tetrachloride and afterwards by sand blasting.

When they were in Birkenhead a chemist from the Liverpool University suggested that after thoroughly cleaning, the sumps should be coated with an oil resisting enamel, but this suggestion was not approved by the Admiralty. The idea was, of course, to seal the deep rust pores and this might well have proved a satisfactory solution.

Success was finally achieved by flushing the system with distilled water.

It was to be hoped that a very valuable lesson had been learnt from the author's work and that in future when these troubles occurred, there would be no hesitation in calling in people best fitted to deal with them and no pains spared in carrying out any worthwhile experiments.

Mr. S. E. Laxton (Associate) wrote that he regretted that the author's work was not extended to the inhibition of corrosion sometimes met with in Diesel engines as the result of the combination of the products of combustion with salt water. One imagined that a sodium nitrite solution would be equally efficacious and hoped that the author might find it possible to carry the investigations that much further.

Perhaps in the future some, if not all, turbine and perhaps Diesel vessels would be equipped for testing for salinity in the water effluent from the separators which would always by then be made accessible and well lighted. In the meantime, the lubricating oil suppliers with a chain of laboratories all over the world would continue to help by analysing samples and reporting on their condition, a service which was still not as well used as it might be. Thanks were due to the author also for demonstrating so clearly that the best of the Pennsylvanian oils S.M.L.O. was markedly inferior to the modern corrosion inhibited oils, such as 2190T.

The author indicated that oxidation inhibitors were removed by water washing. This might have been true of some of the earlier oxidation inhibitors, but there was at least one range of turbine oils available today in which the oxidation inhibitor was insoluble in water.

During the discussion on the paper it was mentioned that the demulsification number of a turbine oil jumped when the oil people started putting things into it and this was not quite true.

Additives did tend to increase the demulsification test number taken on an unused oil, but if the correct additives were used in consort with a compatible mineral oil, the demulsification numbers determined after, say, 500 hours and greater periods throughout the life of the oil, would actually be less than those obtained from the same oil untreated and when tested at similar periods. Furthermore the useful life of the oil was extended considerably.

Dr. Allen Wolf (Visitor) wrote that since corrosion in steam turbines due to the entry of water into the oil was by no means confined to the journals, but might be suffered by all ferrous metal surfaces in contact with the oil, the scope of the title of the paper might well have been enlarged accordingly. On the other hand, since the author had confined himself to the salt water corrosion of ferrous metal surfaces this might perhaps also have been indicated in the title, since sodium nitrite treatment would probably prove of little or no avail in dealing with the other type of corrosion which mainly attacked the surfaces which were above the oil level in the reservoirs etc., and consequently out of reach of the sodium nitrite solution.

The latter type of corrosion was particularly marked on the ceilings of oil reservoirs and on the walls thereof above the oil level and might be very severe even when no sea water entered the lubrication system at all (as in most land installations) and when the amount of fresh water which leaked into the system was comparatively small. This super oil level corrosion (which might conveniently be termed "secondary corrosion", since it never occurred with new oil or with oil in good condition, no matter how much salt water leaked into the oiling system) was due to the formation of volatile water-soluble highly corrosive organic acids as a result of aeration and oxidation of the oil at "hot spots" on the turbine bearings etc.

The only way to avoid this type of corrosion was to use oils containing a small proportion of an efficient water insoluble oxidation inhibitor. It was important to note that the addition of an oxidation inhibitor to used oil which had already reached an advanced stage of oxidation was quite useless, since so much iron soap would have formed in the oil that the oxidation catalysis effect of this impurity completely outweighed the retarding effect of the inhibitor. On the other hand, if an inhibitor was added at a very early stage of oxidation, before the iron had picked up much iron soap, the situation might be caught in time and further oxidation of the oil arrested. In this connexion the quantitative determination of the iron content of the oil (particularly after filtration) was a very useful guide, and colorometric methods had been developed by means of which the iron content of the oil could be determined with an accuracy of the order of one part of iron per million of oil. A few parts of iron per million of oil might be tolerated, but when the figure reached 20 or 30, it was a danger signal that catalytic oxidation of the oil might be about to begin in earnest. In badly oxidized oils which were already causing severe secondary corrosion and sticking of the hydraulically operated speed governing mechanism, the iron content might be as high as 200 to 300 and in severe cases even over 600 parts per million.

He thought it should perhaps be pointed out that the practice of using corrosion inhibitors in turbine oils was started about 1940 in the United States, not so much for the purpose of preventing salt water corrosion in all turbines, as inhibiting the rusting which was very common in new turbines, even when the water entering the lubrication system contained no salt. It was observed that after the turbine had been in use for some time, this initial or "primary" rusting was usually arrested, and this was attributed to the development of polar oxidation products in the oil and the adsorption of these substances by the ferrous surfaces with formation of a protective film.

This line of reasoning led to the common practice adopted in the United States up to about 1941 of adding some 15 to 20 per cent of old oxidized used turbine oil to the charge of new oil for the initial fill-up of new turbines, a practice which was undesirable due to the frequency with which the old oxidized oil catalytically accelerated the oxidation of the new. Moreover, the growing use of oxidation inhibitors rendered it increasingly difficult to obtain used turbine oils in which oxidation had proceeded far enough to impart to them the necessary degree of polarity.

The static corrosion tests described by the author showed that although corrosion inhibited turbine oils such as 2190 prevented rusting of steel surfaces submerged in oil for a few days by fresh water, the period protection under static conditions was limited. He suggested that where water settled out from the oil in pockets in the lubrication system, active rusting might occur even in the absence of salt water. This actually sometimes occurred in practice and indicated strongly the desirability of so designing turbine lubrication systems that pockets in which wet oil could stagnate were as far as possible avoided. Where the presence of such pockets was unavoidable, they should at least be provided with drain-cocks, or preferably automatic water discharge syphons. Corrosion due to water (whether fresh or salt) separating oil from the wet oil in parts of the oiling system was particularly objectionable in certain parts of the hydraulic speed governing mechanism where rusting might interfere with the operation of the oil operated pistons in hydraulic cylinders, or with valves submerged in separated water. Such corrosion might be sufficiently severe to render weekly dismantling and cleaning or renewal of the parts necessary, even when the oil contained an efficient corrosion inhibitor, and in the absence of drainaways for the separated water, the author's sodium nitrite treatment appeared to be the only one likely to offer any remedy. He thought it might be taken as a fundamental principle that corrosion inhibited oil could offer no permanent protection from rusting by separated water if, as was almost invariably the case (and in fact required by the OM88 specification) the corrosion inhibitor was insoluble in water. In this connexion it might be remarked that efficient corrosion inhibitors which were soluble both in oil and in water were apparently very rare, and interest therefore attached to British Patent Specification 585,643 which described the use of lubricating oils which contained 0·01 to 0·1 per cent weight of lithium nitrite. The advantage of this particular nitrite over sodium nitrite lay in the much higher solubility in certain organic solvents, such as arryl alcohol, which in turn could be dissolved in lubricating oils. Presumably when oils containing saturated solutions of lithium nitrite were brought into contact with water, sufficient of the nitrite was dissolved out by the water to inhibit corrosion under static conditions. Where considerable amounts of water leaked into the lubricating system and were subsequently removed by drawing off from sump tanks and by centrifuging of the oil, a steady loss of lithium nitrite might therefore be expected to occur and it would therefore be advisable for the corrosion inhibiting effect of the nitrite to be supplemented by the presence of a second corrosion inhibitor dissolved in the oil, the latter inhibitor being of the insoluble type. A similar precaution might well be advisable when sodium nitrite (in aqueous solution) was added to the lubricating system.

In the footnote on p. 59, reference was made to two United States Patent Specifications describing the use of sodium nitrite (in conjunction with other chemicals) for preventing the corrosion in the cooling systems of internal combustion engines. It might be of interest that the earliest patent describing the use of sodium nitrite alone (or with alkaline salts) for preventing the corrosion of ferrous metals was apparently U.S. Specification 1,565,043. The British Patent Specification corresponding with the German Patent 880,884 was 465,704. Some of the matters dealt with above were discussed in greater detail in a series of articles on turbine lubrication problems and their solutions published in *Petroleum* during 1946 and 1947.

Since, according to the paper, sodium nitrite was effective only in neutral or alkaline solution, the preferred *p*H value being preferably about 8 and not below 7, due account should apparently be taken of the fact that aqueous extracts of used turbine oils and turbine oil sludges were often distinctly acid (*p*H for example between 5·0 and 6·0). This was very common where the oil had become badly oxidized and had developed a relatively high total acidity and might be pronounced even where the neutralization number of the oil was only moderate. It would therefore appear desirable to determine the *p*H value or acidity of an aqueous extract of the oil and to adjust the *p*H to about 8·0 by the use of a carefully calculated amount of a suitable alkali in conjunction with the sodium nitrite, or at least to near 7·0 by a preliminary water wash.

Presumably care would be necessary to avoid the use of excess alkali in order to prevent too great a reduction in the dissolubility of the oil. Borax had been suggested in connexion with the use of sodium nitrite for preventing the corrosion of steel surgical instruments in sterilizers, but possibly other alkalis would be preferred in turbine lubrication systems and the author's views on the point would be of interest.

The above precautions, incidentally, would only be necessary in the case of turbine oils which had not been inhibited against oxidation, and where the leakage of water from the oil cooler and, or alternatively the steam glands was not sufficient to wash out automatically from the oil the water soluble organic oil oxidation acids to which the aqueous acidity of oxidized turbine oils was presumably due.

Some contributors expressed surprise at its having been found possible to lubricate turbine bearings with oil admixed with relatively large proportions of dilute aqueous solutions of salts. However, in this connexion it might be recalled that early high-speed enclosed crank-chamber splash-lubricated steam engines such as the Westinghouse in U.S.A. and the Willans in this country had been successfully lubricated by means of oil-water mixtures in which the percentage of water was sometimes as high as 95 per cent, the viscosity of the oil-water emulsion being but little greater than that of water itself.

Commander Tyrrell had referred to the desirability of fitting efficient filters to turbine lubrication systems to supplement the centrifugal purifiers, and in this connexion the possibility of using the highly retentive paper-pack edge filters which had been found so satisfactory for cleaning internal combustion engine lubricating oils and transformer oils, would no doubt occur to many. However, as there was a limit to the amount of suspended water in the oil which such filters could tolerate without clogging, it was essential to install and operate the filter in such a manner that the oil fed to it was sufficiently dry. In other words, the filter should be operated in conjunction with an efficient centrifuge of ample capacity the centrifuge functioning as a dehydrator and primary by-pass unit for the removal of the coarser solids, while the paper pack filter functioned as a secondary by-pass unit for the removal of the finest solids, only dry oil discharged from the centrifuge being fed to the filter.

It was his experience that where a turbine lubrication system was suffering from severe sludging and corrosion troubles, continuous by-pass filters of the multiple textile fabric bag type had little if any effect in minimizing operational troubles, useful though they might be as an insurance against undue wear of frictional surfaces in land installations where there was ample space and the oil had not undergone marked oxidation.

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The Author's Reply to the Discussion

Mr. Bowrey in his reply wrote that although sodium nitrite had been known for a long time it had only recently been used much in engineering circles and a reference to the possibility of confusion might not be out of place. If a typist through excess of zeal were to alter the "i" to "a" on a supply order one might find sodium nitrate being used. This would be a misfortune because sodium nitrate accelerated corrosion. He therefore recommended emphasis on the distinction, such as "Sodium nitrite, NOT Sodium nitrate" when ordering supplies. The two substances were similar in appearance but only the nitrite (used for inhibiting corrosion) effervesced generating reddish fumes when treated with battery sulphuric acid, so it was easy to distinguish if in doubt.

With regard to the points raised by Com'r Tyrrell and Com'r Le Bailly concerning centrifugal purifiers and oil filters he agreed that efficient working of these units would have avoided many troubles in the past.. They could not, of course, function properly under corrosive conditions. Until corrosion had been stopped it was impossible to have clean oil. After it was stopped, if the purifying equipment was unequal to the task, there might still be no alternative to discarding the oil. The difficulty of cleaning contaminated oil was greatly increased by the presence of pockets where water and solids could stagnate, and the demand which had been voiced for attention to this point was in his experience widespread.

The important work carried out by Dr. Wyllie on the addition of various substances to ensure the effectiveness of sodium nitrite at concentrations of 5 per cent or less in undiluted sea water was completed after the earlier experiments described in the paper, and there was reluctance to make a change in the policy of using a straight solution of nitrite, which might invalidate the results obtained. Also, with nitrite at a low price, there was no particular inducement to do so, although in other applications the additions could obviously be of great value.

The behaviour of sodium nitrite towards non-ferrous metals, regarding which Dr. Wormwell had asked for information had not, to his knowledge, been fully investigated although the patent literature relating to the use of sodium nitrite in automobile engine cooling systems suggested that much unpublished work had been done. The fact that sodium nitrite was ineffective in acid solution had at first been regarded as a serious drawback, but it had caused no trouble. The frequent changes of solution designed to get rid of salt would also get rid of water-soluble acids if present.

The plea entered by Dr. Clayton against waste of the opportunities presented by old machinery capable of being used as a "guinea-pig" was one he would heartily support. It was all too seldom that those responsible for discarding worn out or redundant machinery were aware of, or ready to consider, the ways in which it might be used experimentally to further research and development.

Reference had been made by Mr. Meadows to the expense involved if it became necessary to discard oil which was in the system when the nitrite treatment was applied. There was perhaps an implication that the oil was rendered unfit for service in the account of procedure adopted for a minesweeper on p. 65. This was not intended. The minesweeper's oil was not changed because it had been injured by the nitrite treatment, and on no occasion so far had oil been changed for that reason. Certain oxidation inhibitors were slowly removed by water-washing, but at least one oil supplier had been ready to meet that contingency by adding more inhibitor and, as Mr. Laxton had pointed out, water-insoluble oxidation inhibitors were now in use. He agreed that an attempt to save oil already failing by giving it an extra dose of inhibitor would not succeed, but the replacement of inhibitor lost from good oil was generally practicable. To his mind, however, the question of oil replacement was secondary to the stopping of corrosion. If corrosion were not stopped the loss and damage would far exceed the value of a charge of oil and the oil itself would be spoiled by continued contamination with iron compounds which promoted both oxidation and emulsification. The uses of nitrite paste outside the field covered by the paper were, as Mr. Meadows suggested, no doubt considerable, but it would be a mistake to suppose that it formed a protective film comparable with the usual preservative coatings. All it did was to inactivate the corrosion which would otherwise disrupt a paint film. Nitrite paste could be used as a temporary protective and had certain advantages over grease, but it must itself be protected against washing off by rain, condensation and the like.

Regarding the origin of the salt water in Case I he welcomed Mr. Smith's correction. This further information emphasized the influence of design on the ease or difficulty of keeping oil in good condition. Oil-resisting enamels were of great value in preventing corrosion of non- wearing surfaces, provided the surfaces were properly prepared. The enamel had to be applied to a clean surface, free from active corrosion. Otherwise the corrosion would simply lift the coating off and the last state would be worse than the first.

Mr. Laxton's suggestion regarding the use of sodium nitrite to combat salt water corrosion in Diesel engines was intriguing, but there were many difficulties which did not arise with steam turbines. He would welcome an opportunity to discuss the proposal, especially in relation to a specific instance of corrosion trouble.

The "secondary" or "overhead" corrosion due to acid vapours mentioned by Dr. Wolf was a form of trouble more likely to attack installations where the oil was changed less frequently than in H.M. ships, and he had not so far discovered it in conjunction with salt water corrosion. There was therefore no experience of the effect of nitrite treatment on it, but he agreed that a different line of attack would be necessary. The first step would doubtless have to be elimination of the acids. He had considered the addition of alkali to ensure a sufficiently high pH value when using nitrite, but so far this had been unnecessary. The practice of repeatedly centrifuging out and replacing the nitrite solution seemed preferable, for it removed impurities of many kinds and introduced no complications. The advantages of a water-soluble corrosion inhibitor such as lithium nitrite would be considerable in some circumstances; in a given turbine oil system one had to estimate the rate of loss of inhibitor due to entry and extraction of water to decide whether its use would be worthwhile. An alternative would be to make periodic small additions of sodium nitrite, sufficient to keep, say, 0·5 per cent always present in the water in the system.

Latest Developments in Reversible Propellers

PROFESSOR L. C. BURRILL, M.Sc., Ph.D. (Member)

Further Discussion

Mr. R. W. L. Gawn (Visitor) wrote that the author well covered in general terms the advantages and disadvantages of controllable propellers and the specific classes of vessel both warship and merchant ship for which controllable propellers could be usefully considered. He wisely refrained from claiming that propellers of this type could be usefully considered for ships generally. The case presented for the adoption of controllable propellers was functional or operational in merchant ships, a striking example was compliance with the dual purpose requirements of tugs.

Two classes of warship were considered in the paper, namely motor torpedo boats and submarines. In each the reason proposed for fitting controllable propellers was inherent in the type of machinery fitted. In the former, supercharged engines at fast shaft speeds were the determining factor. The advantage was that the pitch could be adjusted to suit the limiting boost pressure of the machinery at any condition of loading of the vessel. This was of importance having regard to the change of loading of service.

As regards the submarine the case for the controllable propellers rested on adjustments of pitch to suit the revolutions and power curve of electric drive and the greater resistance in submerged trim as compared with Diesel drive and reduced resistance in surface trim. If the design of the hull or machinery was modified it would not follow that there was a general case for the controllable propellers, but there might well be a field for a dual setting propeller as the author indicated.

The author brought out in (6) on p. 6 the advantage of the controllable propeller for reversing. This could lead to economy by the omission of astern drive, e.g., astern turbine in some classes of ship and was of more general application.

Compared with the fixed propeller there were two inherent disadvantages of controllable propellers at present from the efficiency point of view. One was the large boss required for the control arrangements of the propeller. This was more noticeable if the machinery was fast running since in a fixed propeller the boss was generally of small size. The earlier designs of propellers of this type first investigated eight years ago were less efficient than fixed propellers because of this feature. Some advance has since been made in reduction of size of boss to overcome this defect.

The root sections of the blades of the controllable propellers were also unsatisfactory since the blade must terminate in some form of spigot recessed into the boss to be connected to the control gear. This circumscribes the shape of the root sections. Advance had been made with experience including ship tank and cavitation tests and ship trials. There was still, however, scope for improvement in these two respects in order that the efficiency of controllable propellers might be as favourable as that of fixed propellers.

It should be mentioned, however, that there might be operational advantages of controllable propellers particularly at low speed. The author referred to the saving of fuel consumption at cruising speeds with motor torpedo boats fitted with controllable propellers. In the case of a boat fitted with a number of shafts, the controllable propellers facilitated fuel economy in permitting of a drive on say two shafts only of a quadruple arrangement the propellers on the inactive shafts being adjusted in pitch to reduce the blade resistance well below that of fixed propellers if dragged.

Mr. A. C. Walker, B.Sc. (Visitor) wrote that the following three main points emerged from the paper, upon which he wished to comment.

Firstly, as regards reliability by following simple fundamental principles in the choice of materials, and paying careful attention to the rigorous operational requirements of marine propellers the leading manufacturers had evolved designs which had proved their reliability in some hundreds of installations.

Materials were used which combine a high tensile strength with good resistance to erosion and corrosion, and where any two adjacent components of the propeller were in contact with sea water their potentials were balanced to avoid electrolytic action. All component parts aft of the stern gland were made very robust and were designed to work at quite low stresses. This enabled propellers to survive the many unpredictable loads resulting from fouling. Damage which did occur from this cause was always local to the blades, and propellers were completely serviceable again when the blades were either repaired or replaced.

Lubrication was adequate and reliable. In general the hydraulic medium used for operation was a good lubricating oil and the pressure under which it was supplied to the hub was always sufficient to ensure good lubrication and to exceed the external water pressure. Seals, both for the inclusion of oil and the exclusion of water had reached a high degree of perfection and could be relied upon to operate successfully over long periods.

With regard to the conditions existing at any desired combination of rotational speeds and power independent of the speed of the vessel the author had pointed out that in all but the high-speed planing craft hull e.h.p. was proportional to (speed)^3. It could also be shown that for a given fixed value of the ratio J = ship speed ÷ (propeller r.p.m. × diameter) the propeller b.h.p. absorbed was proportional to (propeller r.p.m.)^3 the constant of proportionality depending upon the propeller pitch and the cavitation number. Hence, provided propeller loading was sufficiently low for cavitation effects to be neglected, the fixed-pitch propeller working at a constant value of J and pitch diameter ratio gave a constant efficiency over the ship's speed range, the order of this efficiency varying only with resistance due to fouling, load, or adverse weather.

It was of some interest to consider an example illustrating the comparative flexibility of the variable-pitch propeller and the following was based on a typical modern cargo ship. Fig. 22 showed the speed resistance curves for a ship of 410-feet length and 55-feet beam. Line (a) referred to the ballast condition at which the displacement was 5,000 tons, line (b) referred to the normal maximum displacement condition of 12,260 tons, and line (c) was the resistance curve for a fouled ship in adverse weather conditions with maximum displacement. Line (b) represented the condition near to which the greater part of the working time would be spent, but conditions (a) and (c) would both be frequently met with and it was important to analyse the propeller performance at these extremes.

The engine in this case was a Diesel engine giving 2,000 b.h.p. at a maximum of 110 r.p.m. and capable of running at constant torque down to 50 or 60 r.p.m. The single propeller was 14ft. 9in. diameter having three blades with an area of 80 sq. ft. As a fixed-pitch propeller the boss would be 2ft. 8in. diameter and as a

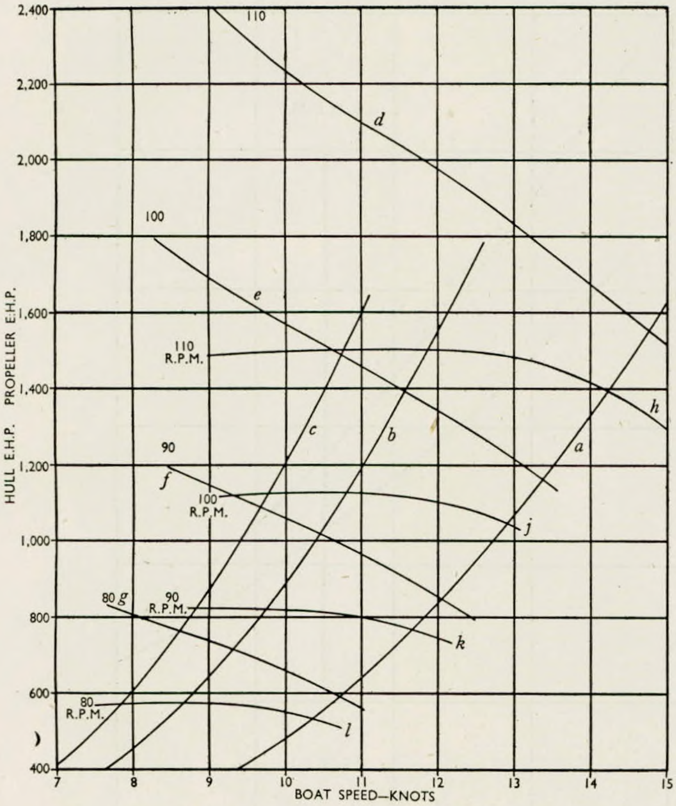

FIG. 22.—*Speed resistance curves for a ship 410-feet long and 55-feet beam with a fixed pitch propeller*

variable-pitch propeller this would be 4ft. 6in. The loss of efficiency in the latter case due to this larger boss and the necessarily inferior blade root sections would be of the order of 4 per cent. This deduction has been made in the subsequent comparisons.

Lines (d), (e), (f) and (g) on Fig. 22 showed the b.h.p. absorbed by the fixed-pitch propeller when running at 110, 100, 90 and 80 r.p.m. respectively, and lines (h), (j), (k) and (l) showed the delivered e.h.p. The intersection of line (h) with (a), (b) and (c) therefore gave the speeds which could be attained at 110 r.p.m. for each ship condition. The intersection of lines (j), (k) and (l) showed the corresponding speeds attainable at 100, 90 and 80 r.p.m. respectively.

Fig. 23 showed the same ship resistance curves as used in Fig. 22 and in this case lines (h), (j), (k) and (l) gave the e.h.p. delivered by the variable-pitch propellers at 110, 100, 90 and 80 r.p.m. respectively, based on full engine torque. It would be noticed that in general these lines intersected the ship lines at higher speeds due to the ability of the variable-pitch propeller to absorb to full torque at any particular rotational speed.

Fig. 24 showed a comparison of speeds attainable with fixed-pitch and variable-pitch propellers over a range of ship resistance for four values of engine speed, and careful consideration of this figure clearly indicated the value of the variable-pitch propeller as a means of maintaining high cruising speed without running the engine at maximum speed.

Figs. 24(a), (b), (c) and (d) have been obtained by cross-plotting Figs. 22 and 23, and Fig. 24(a) showed that, when running at the design speed of 110 r.p.m. and at the design displacement of 12,260 tons the fixed-pitch propeller gave an extra 0·2 knot due to its lower hub losses. Over most of the displacement range however, the variable-pitch propeller gave the highest boat speed due to its ability to absorb full engine power, the fixed-pitch propeller being limited at the extremes by overloading and over-speeding. Fig. 24(b) showed that at 100 r.p.m. the variable-pitch propeller was superior over the whole range of resistance, and Figs. 24(c) and (d) showed the increasing extent of this superiority as engine speed was reduced.

Fig. 25 showed the engine fuel characteristics and Fig. 26 gave the b.h.p.-r.p.m. combination for maximum economy. Lines (a), (b) and (c) showed the power r.p.m. combination necessitated by the use of a fixed-pitch propeller and it would be noted that over the lower r.p.m. range the propeller was running too fast for maximum economy and over the upper range too slowly. The variable-pitch propeller could be run at the correct r.p.m. for each power, and over the lower r.p.m. range this would mean increased propeller efficiency in addition to improved fuel economy. The result of running the propeller faster to achieve fuel economy would however result in a reduced propeller efficiency which would partially offset the engine gain.

This analysis referred to a single-screw ship, but the results would be similar for two or four screws, in which case the effects of running with one engine out of commission would be similar to effects of increased resistance. It would appear therefore that even in the case of the average cargo vessel the use of a variable-pitch propeller offered many advantages—enabling the operators to make full use of the engine torque where desirable to attain high ship speeds, or permitting the use of low engine speed without undue sacrifice of ship's speed. In addition to these advantages to be obtained at sea were the very real improvements in handling in port areas and docks. Reversal of propeller pitch could be achieved in 15 seconds and full engine power in reverse was available in the same time.

It was probably not fully appreciated that full power when a ship was stationary would mean about 60 per cent increase of thrust over what was available from a fixed-pitch propeller, and there were many emergencies in which this increase would be a very material help. Further, the time delay in the passage of the orders from bridge to engine room was eliminated by bridge control.

Reversing mechanism on main engines became unnecessary and initial cost and maintenance was thereby reduced considerably. Where starting was by compressed air this was only necessary in sufficient quantity for the first start of the engine and need not be sufficient to cover several re-starts after reversal. The dangers of failure due to re-starting a hot engine with cold compressed air was also avoided since the engine once started continued to rotate in its correct direction until shut down.

The author's statement that the variable-pitch propeller was less efficient than its fixed-pitch counterpart was entirely misleading since it conveyed the impression that loss of efficiency automatically resulted from the use of a variable-pitch propeller. In fact, when considered over the whole useful range of displacement and resistance the variable-pitch propeller was generally the

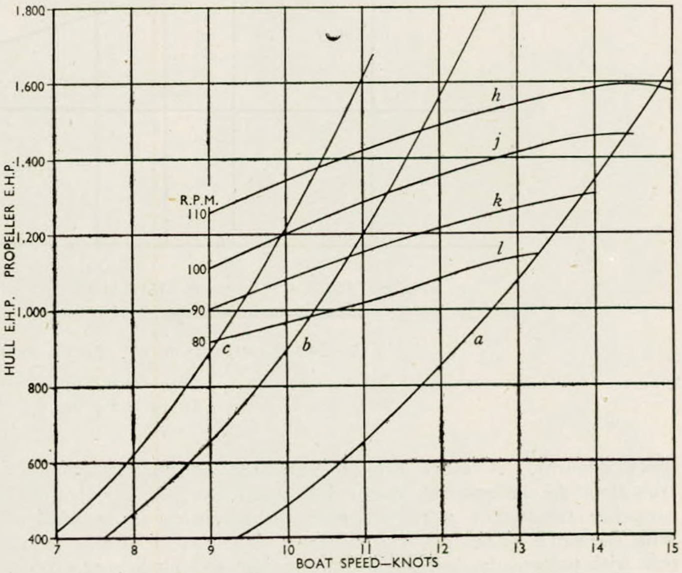

FIG. 23.—*Ship resistance curves for the same ship as in Fig. 22 but with a variable pitch propeller*

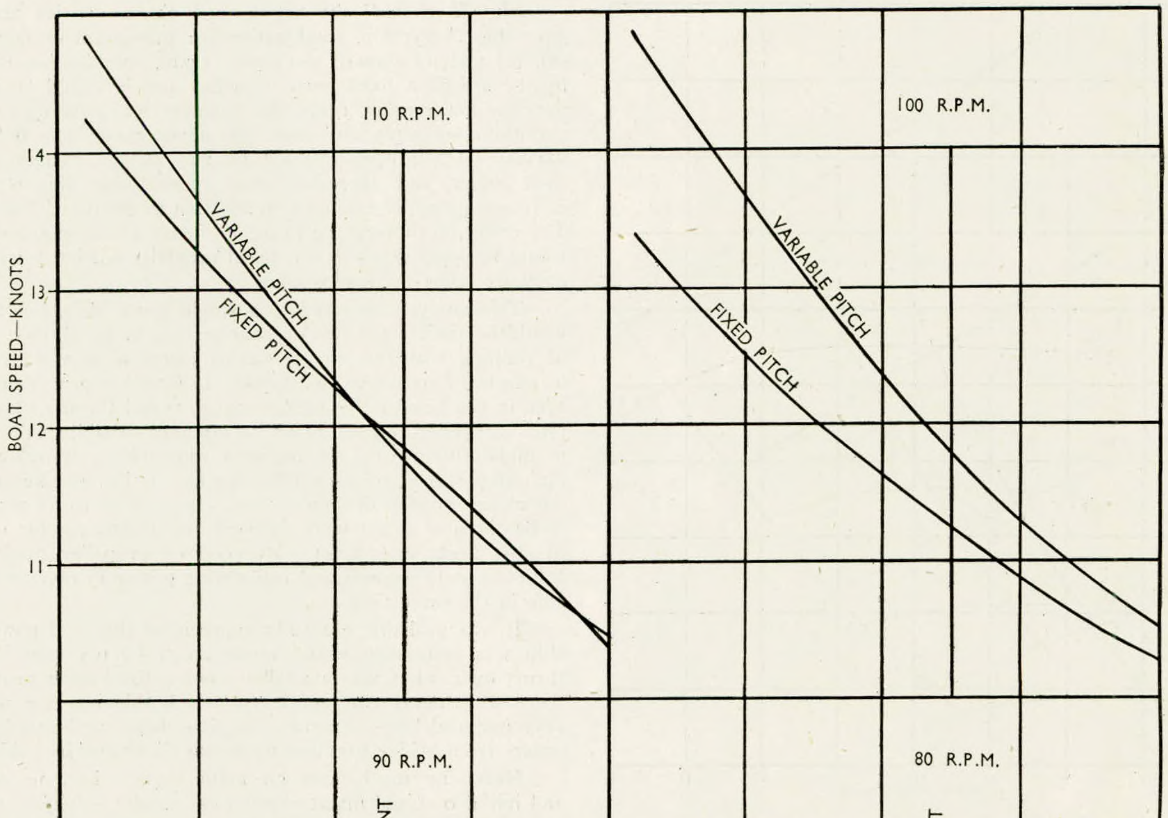

FIG. 24.—*Comparison of speeds attainable fixed and variable pitch propellers*

(*a*) *80 r.p.m.*
(*b*) *100 r.p.m.*
(*c*) *90 r.p.m.*
(*d*) *110 r.p.m.*

more efficient. A more precise statement of relative efficiency was that the necessarily larger hub used for the variable-pitch propeller resulted in a reduction in the efficiency to be attained with the same blades and a small hub. The extent of this reduction with present day hub shapes, dimensions and blade root profiles was difficult to assess, but analysis of the scanty model and full-scale data available indicated a figure between 4 and 5 per cent.

It was instructive at this stage to consider the above sources of loss in more detail in order to obtain a more accurate idea of their probable order, and discover what steps were necessary to reduce this loss.

As regards hub shapes and dimensions the first effect of increased hub size for a given propeller diameter was to reduce the effective disk area. Thus, for a given thrust, i.e., a given total momentum change, the mass of water passing through the disk in unit time was reduced and induced velocities both rotational

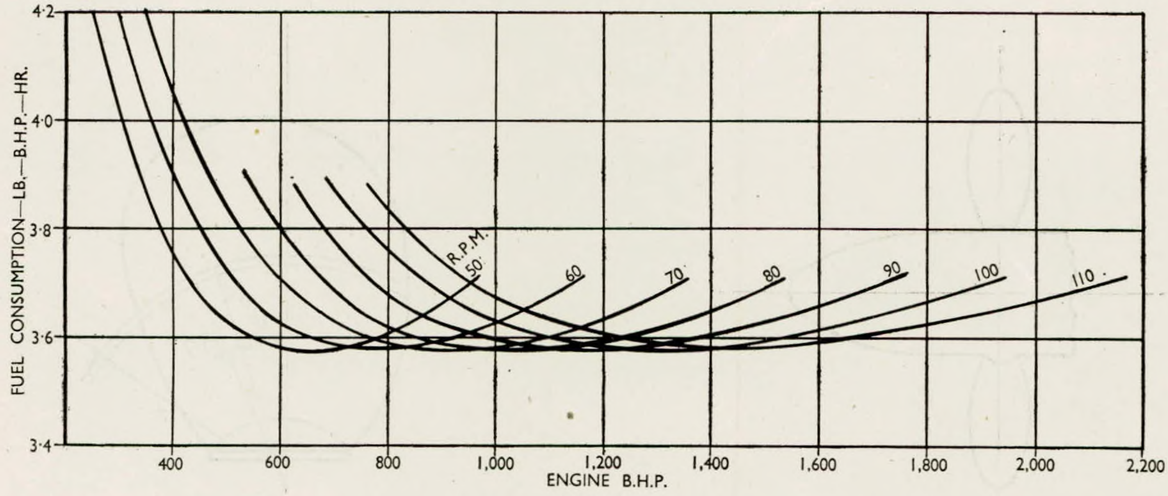

FIG. 25.—*Engine fuel characteristics*

and axial were increased. The increase of loss due to this effect had been calculated for the 14ft. 9in. propeller used in the foregoing example, and amounted to about 1·25 per cent.

The second effect of size was to increase the area of non-working surface and hence to increase friction drag. This effect was however small and amounted to about 0·5 per cent.

The third effect of size was to increase the projected area of the hub in the wake downstream of the propeller disk, and the author had argued that this necessarily meant an increase of drag resulting from the low pressure core of the downstream vortex. Now it was obvious that pressure must fall as the streamline adjacent to the hub approached the tail of the rear fairing cone. It was by no means obvious however that it would everywhere be less than the static pressure surrounding the propeller, since immediately in rear of the disk the pressure had been considerably increased. Fig. 27(a) indicated a typical pressure distribution in a single propeller slipstream and Fig. 27(b) was the corresponding diagram for a contra-rotating propeller which left no rotation in the slipstream aft of the propeller disks. It would be apparent from these diagrams that excess area between points (x) and (y) could only have a forward component of thrust. It was therefore very uncertain whether increase of hub size would produce extra drag from this cause alone and it was suggested that this effect might be neglected on large propellers where there was no danger of producing a cavity core to the downstream vortex.

Fig. 9 showed a completely developed cavity core in the downstream vortex, but he would ask the author to state if this was a propeller in which there was increased pressure in the immediate wake, or was it in fact a turbine runner which had a drop of pressure downstream. Further, was the author certain that this vortex was entirely due to the rotation of the slipstream, or was it due to the combining of the trailing vortices leaving the blade roots?

As regards blade root profiles the major reason for losses occurring over blade root profiles lay in the incomplete knowledge of flow velocity and direction in this locality. It was considered therefore that in view of the very small proportion of work done

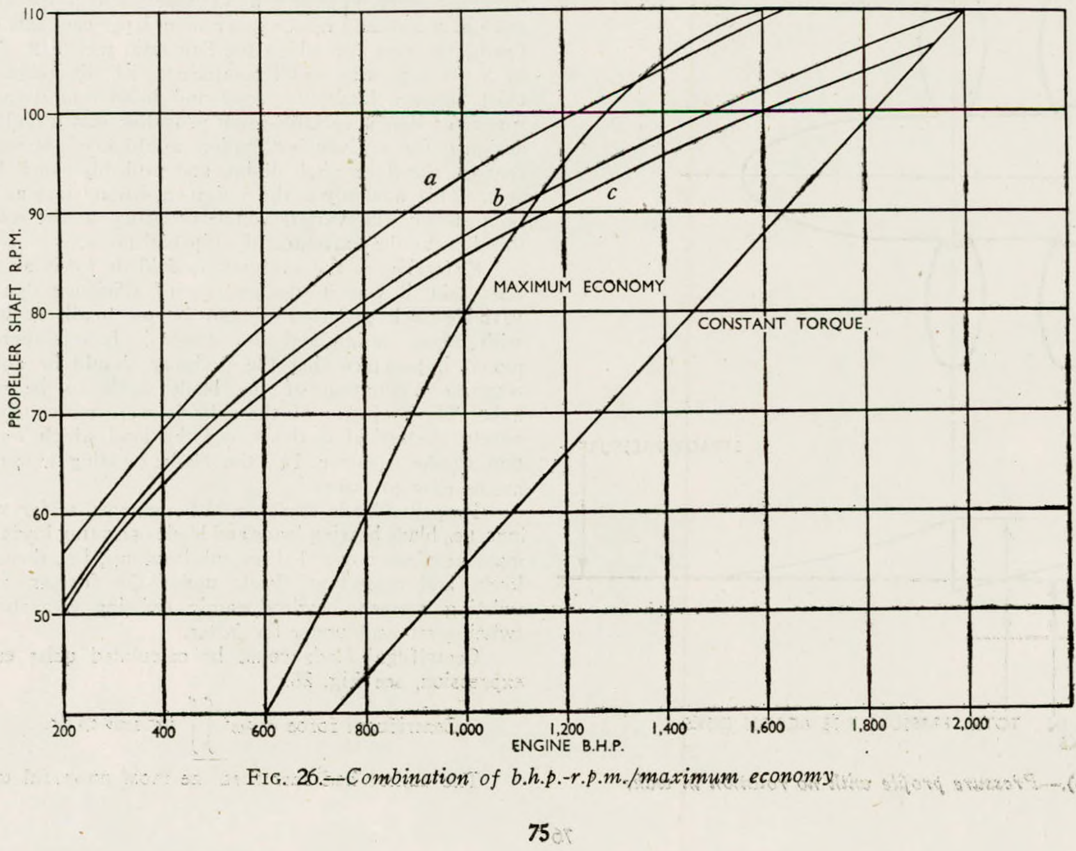

FIG. 26.—*Combination of b.h.p.-r.p.m./maximum economy*

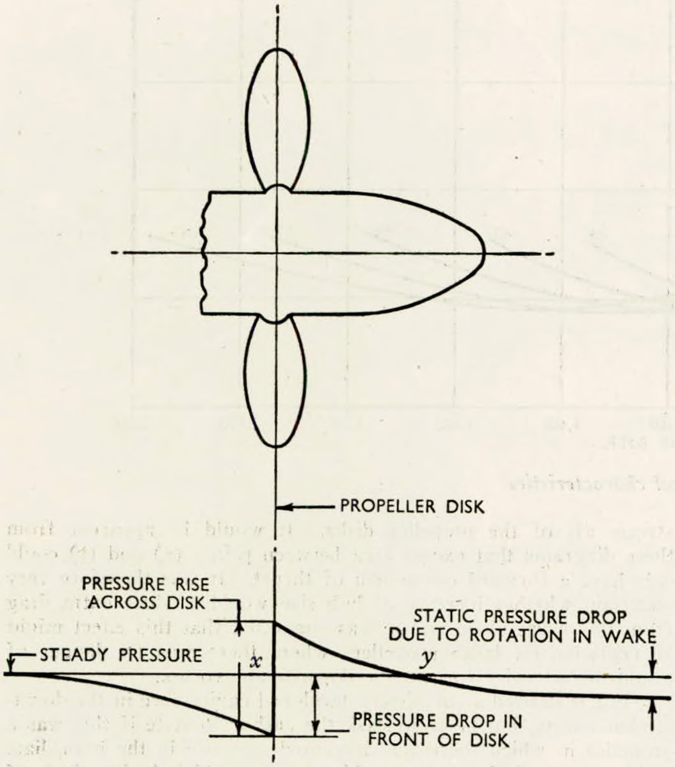

FIG. 27 (a).—*Pressure profile with rotation in wake*

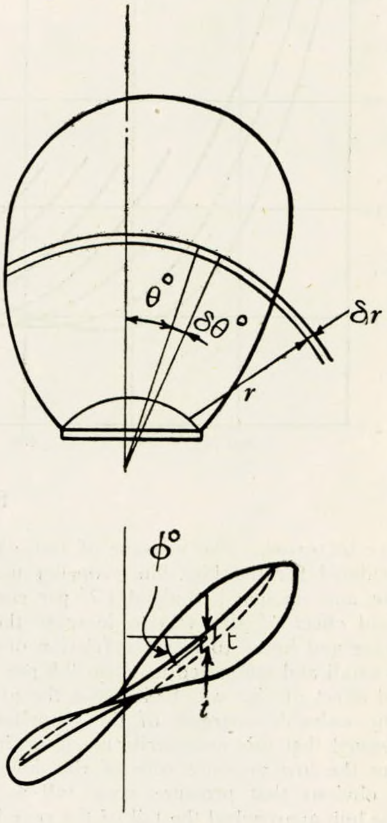

FIG. 28

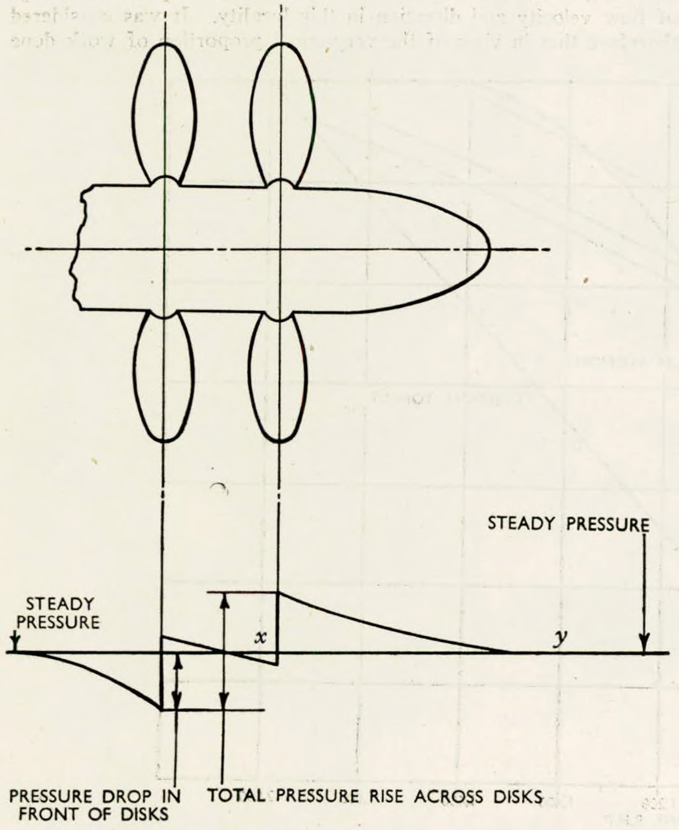

FIG. 27 (b).—*Pressure profile with no rotation in wake*

over the inner portion of the blade, the efficiency loss should be very small when section profiles and pitch were correctly set. Comparative strip analysis suggested that the loss due to this cause was not more than 1 per cent. It would seem therefore that when properly designed a variable-pitch propeller with a hub ratio of 0·3 should not be more than 3 per cent less efficient than a fixed-pitch type for which the hub ratio was 0·18. This difference of 3 per cent was small compared with differences which might exist between blades of good and indifferent design, and it was suggested that a variable-pitch propeller which had been carefully designed for a given installation would lose not more than 3 per cent on the fixed pitch design and probably much less than 3 per cent. This was only at the design condition, since as had previously been shown, the variable-pitch propeller would more than offset this loss at the extremes of ship resistance.

Referring to the evaluation of blade loads as had previously been said, it was in the interest of efficiency that the hub of a variable-pitch propeller should be as small as was compatible with robust design and loss stresses. It was therefore of paramount importance that the designer should be able to make an accurate evaluation of the blade loads to be carried by the hub. The majority of these loads were accurately calculable by purely theoretical methods, but the load which was most important to the designer, i.e., the blade twisting moment, was by no means easy to assess.

Propeller blade loads could be grouped under two main headings, i.e., blade bearing loads and blade operating loads. Each of these main headings covered three sub-headings, i.e., thrust loads, torque loads, and centrifugal loads under the former, and centrifugal twisting moment, hydrodynamic twisting moment, and friction twisting moment under the latter.

Centrifugal loads could be calculated quite easily from the expression, see Fig. 28.

$$\text{Centrifugal force} = \rho\omega^2 \iint t\, r^2 \sin\theta \, d\theta \, dr \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The author had furnished the most powerful tool for evaluating thrust and torque moments, i.e., the strip analysis method.* Using this method the blade loads could be evaluated in the axial and rotational directions and subsequent double integration from the blade tip towards the axis gave the component bending moments at any radius along the blade.

Referring again to Fig. 28 it would be seen that centrifugal twisting moment was given by the expression

$$\rho\omega^2 \iint tr^3 \cos^2 \theta \tan \phi \, d\theta \, dr \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

which for any given blade resolved to $K \sin^2 2(\phi+\alpha)$ where α is approximately 10 deg. and K was the maximum value of expression (2).

Friction twisting moment could readily be assessed by evaluating the normal reactions at the bearing surfaces, and by using the coefficient of rolling or sliding friction (for roller or plain bearings) converting these to moments about the vertical axis.

Hydrodynamic twisting moment could not in general be calculated accurately by use of the two dimensional theory as suggested by the author. This method assumed the pressure distribution over any particular profile to behave as it would in infinite aspect ratio two dimensional flow. For very narrow blades operating at their design pitch these assumptions were reasonably valid, but for a wide blade operating at zero pitch they gave moments that were very much less than measured values. The reasons for this discrepancy were not yet thoroughly understood, but it seemed probable that there was a strong mutual interference effect between adjacent blades at low pitch angles which modified considerably the pressure distribution, to produce large moments with little or no resultant propeller thrust.

Until data was available from scheduled research on this subject, recourse had been taken to analyse carefully results from a wide range of full scale propellers. These results could be generalized into the following expression:—

Maximum hydrodynamic twisting moment = $K\,C^2D^3N^2$

where C = maximum blade width
D = propeller diameter
N = propeller r.p.m.

K was a constant depending to a first order on propeller pitch and to a second order on blade shape and distribution about a vertical axis. The form of K was shown in Fig. 29 and it seemed reasonable that this curve was a tangent to a series of curves such as those shown dotted representing various fixed values of incidence or slip. Thus by using accurate and detailed methods for evaluating blade loads it was possible to reduce hub sizes to a minimum necessary to meet the working conditions. Many variable-pitch propellers were made for very arduous duty with a hub ratio of 0·25 and this ratio could in many instances be reduced to 0·2. Reduction of the ratio beyond this limit would be neither practicable nor advisable because hub size and shape losses were then diminishing very slowly, but blade root losses due to the necessarily thick roots began to increase.

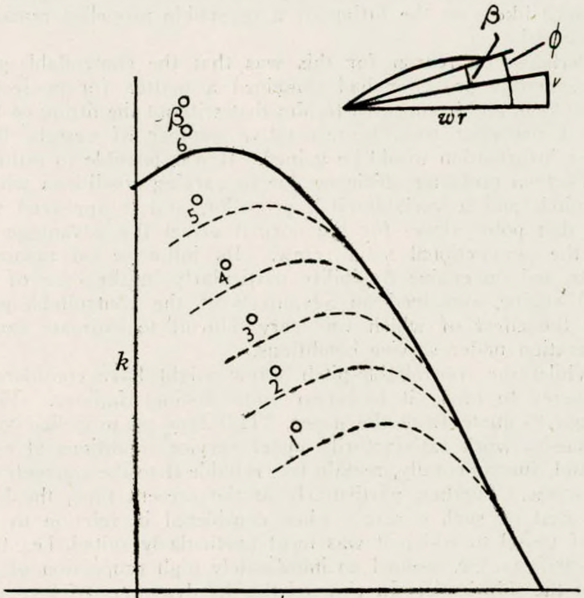

FIG. 29.—*Form of* K

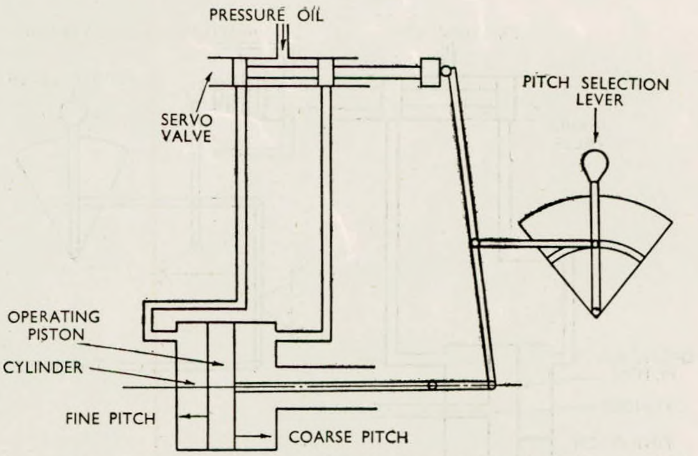

FIG. 30.—*The principle used in selecting and maintaining a pitch*

Since the paper was chiefly of a comparative nature, little was said on the subject of propeller controls. Although the only importance of controls in any comparative argument was the fact of their necessity with a variable-pitch propeller, it was however useful to know the fundamental aspects of their design, and also to realize to what extent they could be developed.

The principles used in selecting and maintaining a pitch were simple, consisting generally of a hydraulic servo-mechanism similar to that used for rudders, etc. (see Fig. 30). It was however by no means sufficient to use a simple separate pitch control lever having no interconnexion with engine throttle or fuel control.

A little consideration would show that a propeller which was capable of efficiently absorbing some 2,000 b.h.p. as in the earlier example was also capable of delivering power of the same order should the pitch be quickly reduced when the ship was proceeding at full speed. The result of such an action would inevitably result in serious overspeeding of the engines if the throttle were not closed first. Even with the engine shut down rapid reduction of pitch at high speed produced overspeeding since engine motoring horse-power was (except in the case of direct coupled gas turbines) very much less than their maximum rated power.

There were many alternative devices which would overcome this difficulty. The engine overspeed governor where such was fitted helped to reduce the unbalancing accelerating torques, and

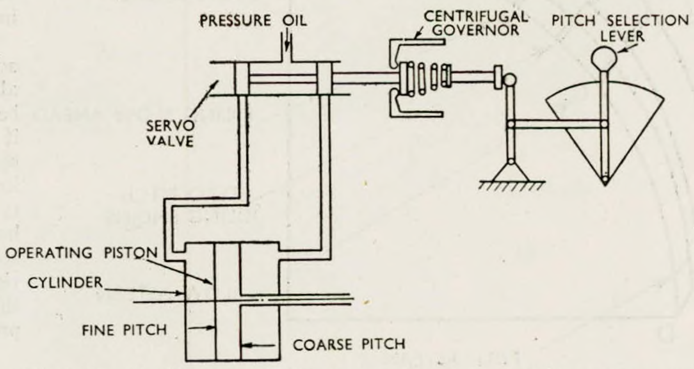

FIG. 31.—*Positioning of the servo-valve by a centrifugal governor*

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* Burrill, L. C. 1944 Trans. N.E.C., Vol. 60, p. 269, "Calculation of Marine Propeller Performance Characteristics"

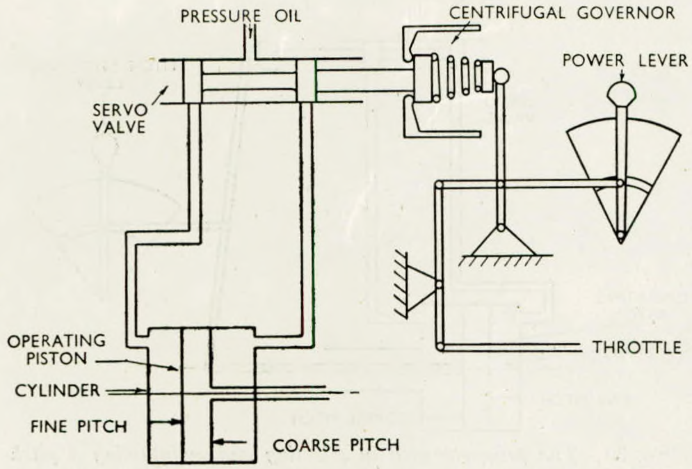

FIG. 32.—*Engine throttle and propeller speed control interconnected*

artificial time delays would prevent the too rapid reduction of pitch. The most complete answer to these problems was however to use a constant speeding control. In this method the positioning of the servo-valve was controlled by a centrifugal governor (see Fig. 31). The selection of any given propeller speed preset the speed at which the flow of oil to the operating cylinder would be cut off, and hence instead of the pitch being selected and maintained, propeller speed was selected and maintained. This type of control had been used on aircraft for many years, and here the above possibilities of overspeeding were far more acute and the results would be quite disastrous.

Thus by the introduction of a simple and well-tried mechanism, i.e., the centrifugal governor, the danger of overspeeding was removed. More important, however, it was now possible to select and maintain the optimum engine speed for any given ship speed independent of changing displacement and resistance. Proceeding a little further it was possible by analysis of Figs. 23 and 25 to predetermine engine speed for any given throttle setting to give the most economical running in terms of gallons per sea mile for all ship speeds. If now engine throttle and propeller speed control were interconnected as in Fig. 32, to maintain this optimum combination of power and speed, the result was a single lever by which the ship speed was controlled. This "power lever" was arranged as shown in Fig. 33. Over the ahead range from A to B the power and r.p.m. increased from idling to full power, and the system was constant speeding. Over the range from A to C the throttle setting was maintained at idling and pitch was selected between low ahead and astern values. This range covered most of the low speed manœuvring requirements. Over the range C to D the pitch increased to its maximum reverse value and the throttle opening to full astern power. Actual operating experience had been obtained with this simple type of control, and it appeared to be applicable to any type of marine engine.

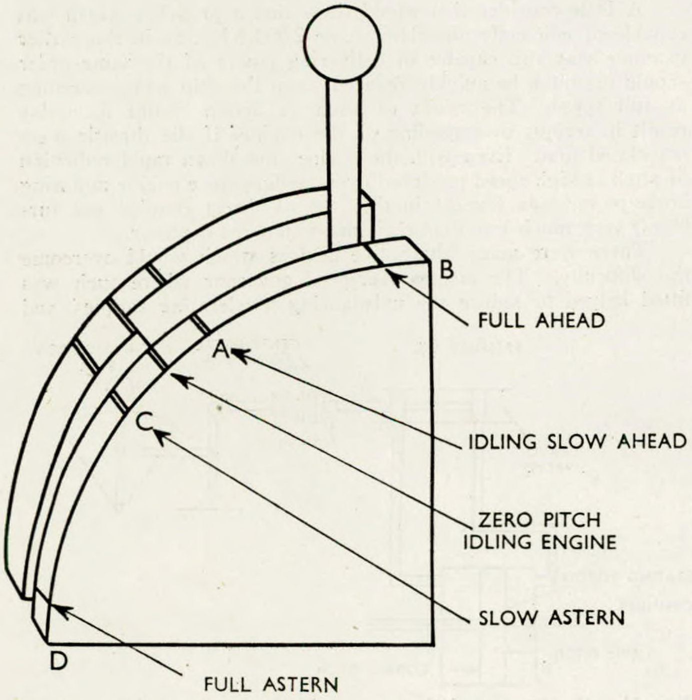

FIG. 33.—*Diagrammatic arrangement of power lever*

It was therefore quite practicable to control the fore and aft speed of the ship from a single lever, the movements of which were correctly sensed, i.e., full forward for full ahead speed and full back for full astern. This lever could be placed on the ship's bridge and control could be effected from there for operation in confined waters. When at sea, or wherever it was desirable, control can be effected by the engineer.

He would conclude therefore that the variable-pitch propeller should be considered very seriously in any new designs which were being laid down, since the overall performance of a ship would in the great majority of cases be better, and when full advantage was taken of the possible control system the handling would be immeasurably improved.

It was inevitable that in the course of progress one established system was overtaken and replaced by a new and better one, but at the period of change before the new methods were thoroughly developed and the old ones were becoming over-developed there appeared equal justification for either. At such a stage in propeller design one should examine the parallel progress being made in propelling machinery, and it was felt that the arrival of the gas turbine with its peculiar propeller requirements gave a sure pointer to types of propellers which would be required in the near future.

Mr. L. Sinclair (Visitor) wrote that the author had assembled together details of the most successful controllable-pitch propellers to date, and had also summarized the general advantages and disadvantages likely to be encountered on fitting such a screw to a particular type of vessel. On the other hand many questions related to the operational advantages and the effect on engine performance likely on the fitting of a reversible propeller remained unanswered.

Perhaps the reason for this was that the controllable-pitch and reversible propeller had remained a matter for conjecture far too long, and it appeared to him that without the fitting of that type of propeller to a representative number of vessels, little further information would be gained. It was possible to estimate the effect on propeller efficiency due to varying conditions with a fixed-pitch and a variable-pitch propeller, and it appeared that from that point alone, for the normal vessel the advantage lay with the conventional solid screw. Its influence on manœuvrability and on engine flexibility particularly in the case of the Diesel engine, remained an advantage of the controllable-pitch screw the effect of which was very difficult to estimate except in operation under service conditions.

Whilst the controllable-pitch screw might have considerable advantages to offer, it had two quite distinct failings. First, although to quote from the paper, "This type of propeller could be made to work satisfactorily under service conditions at sea", it should, fundamentally, remain less reliable than the conventional solid screw. Further, particularly at the present time, the high initial cost of such a screw when considered in relation to the type of vessel to which it was most particularly suited, i.e., tugboats, drifters, etc. seemed an inordinately high proportion of the cost of the ship itself. In view of the disadvantages of increased risk, maintenance and first cost, very marked improvements in ship economy would be required to make the controllable-pitch propeller an attractive proposition to the shipowner.

It seemed from the paper that vessels fell into three classes, as far as the controllable-pitch propeller was concerned:—

(a) Normal vessels which spent the larger part of their working life at fixed speeds under average conditions with conventional engines.

(b) The above type of vessel having non-reversing engines, such as the gas turbine.

(c) The tugboat class, where high manœuvrability was required, and a very wide range of loading had to be accommodated by the propeller.

In the case of (a) (which comprised the bulk of shipping at sea today) there seemed no advantage to be gained from the point of view of performance as represented by saving in fuel or power, by the use of a controllable-pitch propeller. On the other hand, the maintenance of a Diesel engine could possibly be reduced by a controllable-pitch propeller avoiding the necessity for frequent stopping and reversing of the engines when manœuvring in port in restricted water ways.

In the second class, there seemed an undoubted field for the controllable-pitch screw, but in his view, a good reversing gear inside the hull would appeal much more strongly to the marine engineer unless the controllable-pitch propeller had other attractive advantages.

The third group was therefore the obvious field at the present moment for the reversing screw. As far as the propeller manufacturer was concerned the tonnage represented by this class was in a relatively small proportion of his output, and furthermore, due to the disadvantages mentioned above, particularly that of cost, there was, at present, no real demand for controllable-pitch propellers from the owners of this class of ship.

With regard to the advantages listed in the paper, it was noted that item 1 referred to the reduction in time required for the stopping and reversing of the ship. This appeared to give the impression that the saving was due solely to the elimination of the passage of messages to the engine room staff. This saving was, however, surely due to the fact that it would be unnecessary to stop the shaft, and furthermore, by adopting the correct pitch setting for the propeller, maximum astern thrust could be obtained immediately.

Item 5 of the advantages was, as the author pointed out, open to criticism, as the controllable-pitch propeller would probably be arranged to work at constant revolutions, and if not, there was a greater likelihood of this type of propeller running, at some time, through a torsional critical region. The problem of designing the most suitable shafting to suit the engine and propeller whilst avoiding torsional criticals, would thus still have to be faced.

The detailed examination of the various vessels for which controllable-pitch propellers were more likely to be successful were most interesting, and covered fully the various aspects of the problem. The case of the submarine, however, seemed one in which the controllable pitch screw would offer even more marked advantages than suggested. In this case not only was the displacement and wetted surface area of the vessel entirely different when submerged, but also a different engine was used. A controllable-pitch propeller under those circumstances might offer important savings in the size of the underwater engine, and thus afford increased space in the submarine.

In the final pages of the paper were contained notes which would certainly be of use to propeller designers, the calculation of hydrodynamic and centrifugal twisting moments being of particular interest. Such calculations were most laborious and to make a complete examination of all the conditions likely to be met at every blade setting and speed of advance, entailed a considerable amount of design office work. Whilst the average shipyard and engineering works technical office could, with a fair degree of accuracy, determine the scantlings of a normal fixed-pitch propeller, it was evident that in the case of the controllable-pitch screw, propeller design would be largely in the hands of the specialist.

A further item of considerable interest was the photograph which showed the formation of the vortex core abaft the propeller. As this photograph showed a boss of good stream line form, it illustrated the importance of the special attention which should be given to the design of boss and blade root sections. It also led one to speculate as to the conditions existing behind many ill designed "built" propellers still in service, and suggested a reason for the almost unbelievable improvements which had been obtained by replacing such propellers by modern solid screws.

It would appear that it was the effect of the controllable-pitch propeller on engine performance which had been least discussed when considering this type of screw. He also looked forward to the day when, having two similar vessels, one with the fixed pitch and the other with a controllable pitch screw, some ship owner would be prepared to publish parallel results obtained in service.

Mr. Lennart Pehrsson (Visitor) wrote that the manufacturers of the Kamewa propeller had had much service experience on the use of controllable-pitch propellers and these remarks were for the most part based on that experience.

A controllable-pitch propeller should necessarily be designed to have the same strength as a fixed-blade one. Therefore it was of the greatest importance that with a given boss diameter, the blade flange was made as big as possible, thus enabling one to provide the root section of the blade with sufficient length and the flange bolts with sufficient area, without excessive stresses in the material of either the blade or the bolts. The blade thickness ratio Si/d used for various Kamewa propellers was within the range 0·04-0·05, i.e., within the same range as was usual for fixed-blade propellers. The maximum stresses allowed in the Kamewa propellers were quite normal. As the stresses in a propeller could not be calculated for all the hard treatment which might occur, practical experience should say whether a construction was satisfactory. That knowledge had been received from the following ships fitted with Kamewa propellers which had come into contact with the ground:—M.S. *Hadsel,* pilot ship *Gavle,* M.S. *Dalanas* (hull, propeller shaft and propeller blades damaged by being jammed with ice), M.S. *Suecia,* M.S. *Hoken* and mine sweepers. On all these ships with the exception of the *Gavle,* propeller blades and propeller shaft were bent in spite of the shaft being made considerably stronger than stipulated by the classification society. In all cases it had been possible to operate the propeller blades although the propeller shaft had been very bent (on *Hoken* the shaft was bent 1·5 deg.).

Thus experience had shown that the blades and operating mechanisms were sufficiently strong, and since the flange was large enough, the root section of the blade could be given sufficient strength without involving a thickness which would lead to root cavitation. The material used in the blades was stainless steel, and when inspecting Kamewa blades he had not yet observed any pitting from cavitation. Blades of propellers for ships with speeds up to 17 knots had been inspected. The most recent propellers, those built for M.S. *Los Angeles* (19·5 knots), had not yet been inspected, but the cavitation tests in the cavitation tunnel showed that the model propeller was free from cavitation.

Thus strength and cavitation had not been a difficult problem when designing the Kamewa propeller for merchant ships.

From service experience it was found unnecessary to have a spare propeller. Only spare blades should be carried and if a further spare was wanted, a spare propeller shaft (which also applied to fixed blade propellers).

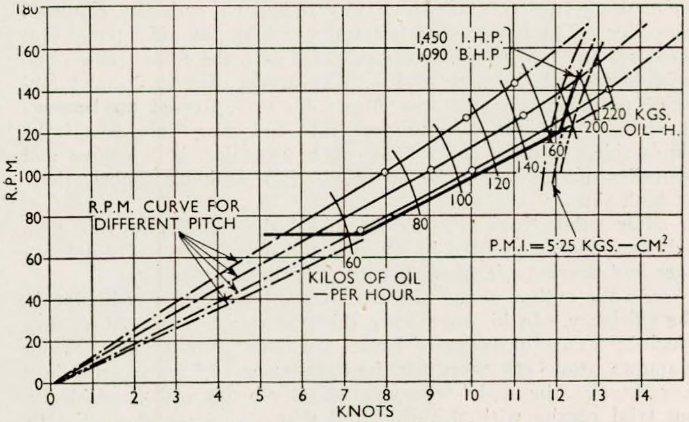

FIG. 34.—*Result of trials with M.S.* Corvus

In regard to the advantages and disadvantages of controllable-pitch propeller installations, the following remarks could be made to the author's points concerning advantages :—

(1) The manœuvrability, as stated by the author, was better with the controllable-pitch propeller. This depended also upon the arrangement of the control devices. With the Kamewa propeller, all operations except starting the engine could be carried out from the bridge, i.e., adjusting the pitch, regulating the engine speed and stopping the engine. By repeated operation of the propeller ahead and astern a ship could be made to turn round on the spot, clockwise with a left-hand propeller and counter-clockwise with a right-hand propeller.

(2) The possibility of keeping the propeller running at constant speed could be of advantage with steam and gas-turbines since the inflow angle to the turbine blades would then be constant even when the turbine was only partly loaded. With steam turbines the elimination of the astern turbine increased the efficiency by some 2-3 per cent.

(3) The advantage of running an engine with higher torque than that which was taken up by a fixed blade propeller was illustrated by Fig. 34. The middle pitch line in the diagram gave r.p.m. and fuel consumption for designed pitch, i.e., the same pitch for which a fixed blade propeller for this ship would have been designed. The thick line was the operating line for the controllable-pitch propeller. The diagram showed that near the top speed the gain in fuel oil was in the order of 5-7 per cent with the controllable-pitch propeller operating in the most suitable manner.

By a mechanical device (the "combinator"), pitch and revolutions of the Kamewa propeller were varied so that the propeller automatically operated along the thick line, the line for smallest oil consumption, in Fig. 1. When full mean pressure was reached, a red lamp on the operating pillar on the bridge was lighted. Naturally this occurred at different engine speeds, depending upon the actual conditions of ship and sea. The deck officer therefore had the possibility of adjusting the combinator in order to get the correct end point of the operating line, i.e., full revolutions at full mean pressure. This adjustment was simply made with the help of an adjusting handle and the red indicating lamp. The combinator arrangement had proved to be necessary to ensure economy. From the economical point of view it was quite wrong to run a Diesel engine at constant speed and regulate only by adjusting the pitch.

With regard to the disadvantages of the controllable-pitch propeller, some remarks concerning points 3 and 4 had been made above. With regard to (6) the problem of the adjusting forces for the Kamewa propeller did not give any basic difficulty : it was only a question of having sufficient oil-pressure. For merchant ships the pressure was very moderate.

A type of ship with controllable-pitch propellers from which Swedish engineers had had extremely good experience was the icebreaking tug, two of which were equipped with the Kamewa propeller. The power absorbed was 665 b.h.p. at 375 r.p.m. But also as a forward propeller on an icebreaker, the controllable-pitch propeller should be very useful. The action of a right-hand forward propeller was that the slipstream was pressed up between the hull and the ice on the port side and thus "lubricated" the ship's side. With a controllable-pitch propeller, both engine and propeller blades might be reversed, thus enabling "lubrication" of both sides of the ship.

For submarines, it could be added that singing of the propellers might be avoided by varying the pitch. He had not however had any experience with such propellers.

As the author stated, the size of the boss gave a reduction in the efficiency. In his experience this loss could be cut down very much by a careful design of blades and boss. For the most recent Kamewa propellers, those for the twin-screw 19·5 knot cargo liner *Los Angeles,* the model tests were slightly better with fixed blades, but trial results with this ship and with the sister ships *Seattle* and *Golden Gate* which had fixed blade propellers showed very little difference, and that difference was rather in favour of *Los Angeles.*

Regarding the vortex core behind the boss, attention was drawn to the fact that with a turbine runner the vortex core was dangerous since it affected the pressure in the draft tube and thus produced oscillations in the speed of the runner. For a propeller in open water, the influence on pressure and revolutions was probably very small even with 28 per cent boss.

This vortex core was also formed behind a fixed-blade propeller. In the cavitation tunnel he had observed such a vortex core in a special test with a fixed blade propeller, the diameter of the core being about 7 per cent of the propeller diameter.

In model experiments for determination of the turning moments of the blade, he had arrived at the same conclusions as the author obtained theoretically.

A dimensionless constant for the turning moment could easily be derived :—

$$K_m = \frac{M}{\rho D^5 n^2}$$

where M = turning moment
ρ = density of water
D = diameter
n = revolutions.

The constant had exactly the same form as the torque-constant used in propeller experiments, only that instead of shaft-torque there was turning moment. It was plotted on the usual base of advance coefficient

$$J = \frac{V}{nD}$$

With $K_M > 0$ the pitch tended to increase, and decreased when $K_M < 0$. For a given pitch setting, K_M was very near 0 at $J = 0$, and with increasing J, K_M increased to a maximum and then fell passing 0 to negative values. A cross curve at constant J and different pitch settings showed that K_M increased with increasing pitch.

Mr. F. J. Tector, B.Eng. (Visitor) wrote that there was, however, obviously some reluctance on the part of shipbuilders to adopt the controllable-pitch propeller in preference to other well-established methods of obtaining reversal and control of thrust and, although Professor Burrill in his synopsis made it clear that he was concerned more with the propeller designer's angle than that of the operational engineer, it was the latter, he would submit, who remained to be convinced of the reliability of the installation and of its economic advantages when weighed against its much greater capital cost, and somewhat lower propulsive efficiency. There was also its vulnerability to be taken into account and the fact that it would occupy the unenviable position of becoming a piece of mechanism which could only be serviced when the ship was docked. Those considerations should, therefore, be carefully assessed before the controllable-pitch propeller finally moved from the drawing board stage to actual installation.

There were several practical issues in connexion with the fitting of controllable-pitch propellers on which he would like to have some further information, and perhaps the author could, in replying to the discussion, comment on some of those aspects. The first of these was the question of the attachment of controllable-pitch propellers to the tail shaft. It would appear that the most straightforward method was the flange mounting type which, however, entailed the withdrawal of the tail shaft outboard with its consequent repercussions in the case of the single screw ship. Some remarks on methods of obviating this difficulty would, therefore, be welcome.

Another point was the desirability of some forms of "hunting" or "self-adjusting" mechanism which would appear to be essential in all hydraulically operated mechanisms, but which was apparently only fitted in the Escher Wyss type. As it was most desirable in all conrollable-pitch installations to reduce the complication of the mechanism as much as possible, refinements of that nature should be avoided as much as possible, and the author's opinion was requested on that matter.

An opinion was also sought as to whether satisfactory arrangements could be made if the ordinary lignum vitæ type of tail shaft bearing was retained. This question appeared to be outside the general scope of controllable-pitch propellers but it was considered that if the oil-lubricated type of stern bearing was preferred by the controllable-pitch propeller manufacturers, the cost and complication of the installation was further increased in comparison with normally acceptable practice.

In conclusion, he was of the opinion that the development of the controllable-pitch propeller was being retarded at the present time principally on account of its complication and the high initial capital cost, not ony of the propeller itself but also resulting from the changes in design which would have to be made to otherwise well-established components, such as rudders, stern tubes, shafting, etc.

Mr. James F. Allan (Visitor) wrote that the paper gave an up-to-date picture of the position regarding the application of controllable-pitch propellers in marine work. It was perhaps unfortunate that the author had entitled the paper "Latest Developments in Reversible Propellers", as this definition was inclined to be misleading.

Referring to the author's remarks on the advantages of controllable-pitch propellers, it might be of interest to note that many of these could be achieved in using electric transmission arrangements between the prime mover and the propeller. He did not propose to discuss the relative merits of those two systems as regards economy and reliability, but merely to mention the point in passing. Item 3 of the list was rather obscure and probably because of that its practical importance was not clear to him.

The disadvantages of the controllable-pitch propeller were clearly stated, but in spite of the author's statement regarding reliability one must add a certain feeling of reluctance to accept a system of propulsion which involved carrying most of the control mechanism inside the propeller boss and cone.

The question of loss in performance due to excessive propeller boss diameter was clearly of great importance in connexion with those propellers. Experience with built propellers as compared with loose bladed propellers indicated that in practice a boss size of the order of 0·26 to 0·28 D compared to 0·18 to 0·20 D would cause a loss in performance of the order of 5 per cent. This loss arose partly from the relatively narrow and thick root sections employed in a loose bladed propeller but he also thought partly from losses behind the boss. Enlarging the shaft bossing in front of the propeller did not give any improvement compared to a well-faired rope-guide. In a single screw ship it was not possible to fit an adequate cone abaft the propeller because of the rudder position. In a twin-screw ship, the length of cone necessary to fair adequately a 30 per cent boss diameter became a very substantial dimension.

As mentioned by the author, the losses arising from the thick root sections and the vortex formation behind the large boss could be minimized by suitable pitch reduction and the use of strut shaped sections at the root. This was a treatment which had been used effectively in propeller design by himself since the early thirties, and it had the added advantage of avoiding root cavitation troubles to a large extent.

However, the application of this principle to controllable-pitch propellers which had a boss diameter of 0·3 or more of the propeller diameter, required special consideration in view of the necessity of making the maximum use of the 0·70 of the diameter which remained for effective thrusting.

Referring to the various categories discussed on p. 7, it was clear that the application of the controllable-pitch propeller was favourable where there was a power/revolution demand departing violently from the natural power/revolution characteristic of a fixed blade propeller, which took cavitation into account where necessary.

The M.T.B. was a case in point and the gain at the cruising speed was substantial. However, a loss of a knot at top speed was a high price to pay. It might be that further development would lead to a reduction of that loss.

In the case of tugs, trawlers and similar craft, a practical problem arose in the considerable risk of damage to blades. Cast-iron propellers were used in many such cases in order to reduce the cost of replacing damaged propellers, so that the enormously increased cost of controllable-pitch propellers would appear to be a ruling factor. In other words, there would have to be very special advantages before controllable-pitch propellers would be adopted in the classes of vessel just mentioned.

The balancing of centrifugal and hydrodynamic moments on the blade mountings was a delicate matter involving the careful assessment of the various moments and the selection of a suitable compromise. There would appear to be some advantage in using section shapes with constant position of centre of pressure over a wide range of incidence.

On the question of blade section shapes, the author advocated the use of constant velocity type sections. These were rather similar to laminar flow sections, and the point to bear in mind was that a section could only be designed effectively in this way for a given narrow range of lift coefficient or angle of incidence. As propeller blade sections had inevitably to work over a wide range of incidence, great care should be taken to shape the leading edge of such sections so that excessive suction peaks were not created when the section was working well away from the designed incidence. This could be achieved to some extent by suitably rounding the leading edge.

The Author's Reply to the Discussion

Professor L. C. Burrill wrote in reply that Mr. Gawn's contribution was very valuable, as it represented the result of considerable experience and it was very correct to draw attention to the need for considerable experimentation in order to improve the shape of the root sections of the blades of controllable propellers. One interesting point mentioned was that the ratio of propeller boss to diameter was usually smaller in the case of high loaded fast-running propellers than in the case of moderately loaded slow-running propellers, thus imposing a severe limitation on the controllable-pitch designs. One advantage of the controllable-pitch propeller for quadruple screw arrangements was that at low speeds the power required could be developed on two engines, while the other propellers were adjusted in pitch to reduce the blade resistance to a very low value. This resulted, of course, in the saving of considerable quantities of fuel at cruising speeds. Mr. Gawn also referred to the limiting boost pressure as being the criterion which governed the design of propellers for M.T.B. machinery.

He was very interested in Mr. Walker's diagrams showing the flexibility of the controllable-pitch propeller drive for a typical modern cargo ship. These diagrams showed quite clearly that with the controllable-pitch propeller higher speeds could be obtained for various constant values of the engine speed, excepting at the full speed of 110 r.p.m., where the efficiency loss due to the large boss caused a diminution in speed. It must, however, be realized that these higher speeds which could be obtained at, say, 90 or 100 r.p.m., were associated with an increase in engine power. The diagram, Fig. 26, appeared to show that the normal engine revolutions with a fixed propeller were very different from those for maximum economy, excepting in the region of about 1,200 b.h.p. The hatched area in Fig. 35 superimposed on Fig. 26 showed variation in r.p.m. for +1 per cent above minimum fuel consumption. He had added a number of points in Fig. 25 (Fig. 36) showing the positions at which the fixed-pitch propeller would work for various brake horse-powers, and it would be seen that very little improvement in fuel economy could be achieved in the range between 1,000 and 2,000 b.h.p. In fact, the fixed-pitch propeller appeared to enable the engine to work very close to the minimum lb. per b.h.p.-hr. throughout the whole range from 1,000 to 2,000 b.h.p.

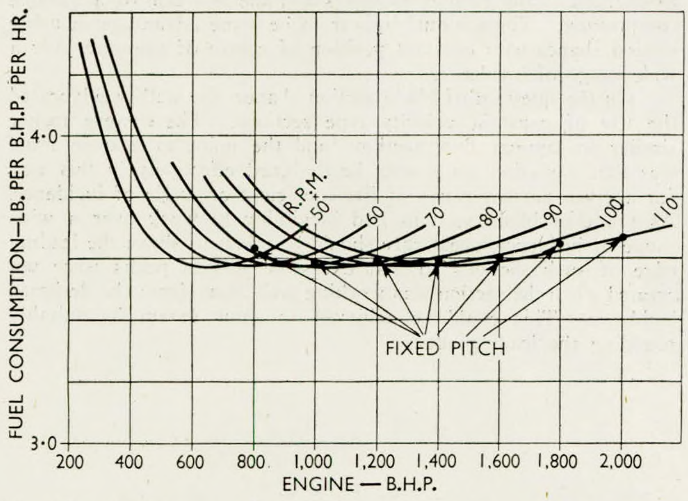

FIG. 35.—*Fuel consumption characteristics. Spots marked "Fixed Pitch" correspond to normal working r.p.m. with fixed-pitch propeller*

The figures which Mr. Walker gave for the losses due to the decreased effective disk area with a large boss, and also due to the increased friction drag, were very valuable, and it was interesting to note that the total loss in efficiency was put as somewhere between 4 and 5 per cent. Fig. 30 did refer to a turbine runner but similar circumstances obtained in the case of a propeller and it appeared very likely that vortex cores had been present behind some propellers with large bosses. This was confirmed by the remarks in Mr. Pehrsson's contribution where it was stated that such a vortex core had in fact been observed in the cavitation tunnel with a model propeller. He was not certain whether the vortex in question was due to the rotation of the slip-stream or due to the combination of the trailing vortices leaving the blade roots, but he was inclined to think that these two effects in a marine propeller were more or less one and the same. That was to say, the propeller acted as a complete unit and the vortex core formed at the centreline was due to a combination of the separate effects of the blades and of the rotation of the slip-stream as a whole. It was unfortunate that in the usual cavitation tunnel arrangement the shaft occupied the position which would be taken up by this central core, as this was a matter which would appear to be worthy of very close examination on the model scale. It was true that the inner portion of the blades provided only a very small proportion of the total thrust, but the drag losses due to breakdown of flow at the blade roots could be very considerable, as had been shown by Dr. Baker. There was also the possibility of erosion of these inner sections and of the surface of the boss, which must be avoided. The information about blade operating loads and the slightly different methods of calculating centrifugal twisting moments and hydraulic twisting moments given by Mr. Walker were a welcome addition to the information given in the paper, and these would be very helpful to designers of controllable-pitch screws.

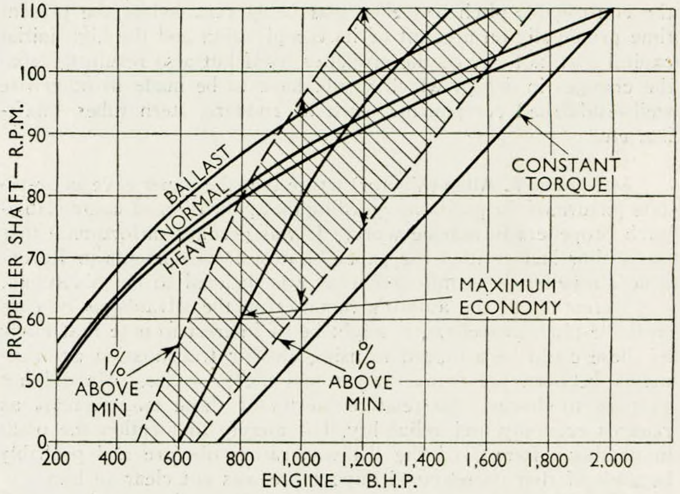

FIG. 36.—*Comparison of engine and propeller characteristics. The hatched area shows variation in r.p.m. for +1 per cent above minimum fuel consumption*

He agreed with Mr. Sinclair that the real test of a new device was its performance in service on actual ships, and that engineers who were prepared to experiment with controllable-pitch screws could be assured that the propeller manufacturers would be very keen to assist. It would, for example, be of great value in connexion with the development of such propellers for use with the gas turbine to observe the performance of controllable-pitch propellers on a vessel fitted with fast-running Diesel engines, so that working experience could be gained from actual sea trials. The remarks about the avoidance of torsional criticals were in agreement with his own views, as the presence of a critical within the normal working range of speeds could be very dangerous with a controllable-pitch propeller unless steps were taken to make it impossible to set the propeller at such a pitch that the engine was caused to run at these critical revolutions for any length of time.

One of the distinct merits of the controllable-pitch propeller arrangement was the extreme ease with which the propeller could be put astern, and this would no doubt be of considerable advantage to a submarine, as at present the arrangements for reversal were rather complicated in such vessels. No doubt other practical advantages could be mentioned for controllable-pitch propellers for such vessels. Mr. Sinclair's point about the comparison between the conditions obtaining abaft the boss of a controllable pitch propeller and those corresponding to a built propeller with large boss was a very good one, and he had no doubt one of the large sources of loss with badly designed built propellers was the possibility of forming a large core of this kind, and this might, as Mr. Sinclair suggested, account for some of the very large gains which had been obtained on numerous occasions by replacing built propellers with solid propellers having small carefully streamlined bosses.

It was of considerable interest to note the great care taken by Messrs. Kamewa to obtain low blade-thickness fractions within the normal range of from 0·04 - 0·05, and to note that this was achieved by the adoption of a large flange and, in some cases, by allowing the blades to extend beyond the flange and thus overlap the boss. The experience with the M.S. *Suecia* and the several other vessels appeared to indicate that in the event of damage due to fouling of the propeller the blades would bend before the mechanism was affected. It was probable that this was due to the particular form given to the blades and the thicknesses adopted, as no doubt Messrs. Kamewa would prefer the blades to be damaged rather than the pitch adjusting mechanism. The trial results for the M.S. *Corvus* illustrated the flexibility achieved with the controllable-pitch propeller. In this case the full-speed condition of the engines appeared to correspond to a condition above that for minimum fuel consumption and Mr. Pehrsson suggested the use of a constant mean indicated pressure between 12·15 knots and 12·5 knots. It would appear, therefore, that the value of the adjustable pitch was limited to a very small range of speed and it would appear that for maximum economy in service, the ship could have been fitted with a fixed-pitch propeller having a slightly increased pitch. Alternatively, the results given here would appear to suggest the adoption of a dual-pitch propeller, as the higher pitch setting would probably be used almost continuously in service. No doubt the controllable-pitch propeller did enable the speed power correlation to be adjusted to suit the actual fuel consumption figures obtained from the ship after she was put into service, and in some cases this might prove to be of considerable advantage, but a similar result could sometimes be achieved by fitting a new fixed-pitch propeller having a slightly increased pitch after the vessel had been in service for some time. He was indebted to Mr. Pehrsson for his description of the new mechanical device—the "combinator"—which enabled the propeller to work automatically along the thick line in Fig. 34 and it would be very interesting at a later date to have some account of the performance of the M.S. *Los Angeles* in service, since this ship was, presumably, fitted with a device of this kind.

He was very pleased to learn that Mr. Pehrsson had been able to observe the existence of a vortex core, having a diameter about 7 per cent of the propeller diameter in the cavitation tunnel. Unfortunately the presence of the shaft abaft the working propeller did not usually enable this phenomenon to be studied, and in the case of a propeller having a large boss it might be that the tunnel results, particularly for the root sections, had been influenced adversely by this fact, and it might also happen that the extent of cavitation in way of the root sections, as indicated by the tunnel tests, was different from that which would obtain in the actual ship. This was a matter which was worthy of careful study and it would be interesting to follow the results obtained by Mr. Pehrsson when these became available. It was interesting also to note that the model experiments for the determination of the turning moments on the blade confirmed the results of theoretical calculations, and that these experimental results could be plotted in the form of a suitable dimensionless constant to a base of $J = \frac{V}{nd}$. It appeared to him that the results of such experiments should be very valuable in reducing the turning moments required for adjusting the blade pitches, and that the results of such research work could improve the performance of future controllable-pitch propellers.

Mr. Tector approached controllable-pitch propellers from the practical engineering angle. Mounting the propeller on a flange was not favoured by marine engineers, as compared with the normal arrangement, and every effort should be made to improve the fitting of such propellers. In this connexion, it would be noted that the recent Escher Wyss propeller shown in Fig. 1 did indicate a short tapered portion at the end of the shaft fitted with two keys, and this would appear to be very desirable. Other controllable-pitch mechanisms had been devised which would enable the propeller to be fitted in the normal way with a tapered portion extending completely through the boss, and it remained to be seen whether these would be found to be more advantageous when the use of such propellers became more general. One ordinary lignum vitæ type of tail shaft bearing should be able to be retained with this arrangement, and no doubt this would be favoured. If, eventually, the principle of designing a controllable-pitch propeller giving an adjustable pitch over a small range of angles, rather than complete reversibility, was followed up, then it would appear that the adjusting mechanism and the method of attachment could be considerably simplified, with advantage to the general working of the ship. It was true that the principal deterrent to the development of the controllable-pitch propeller was the high first cost and the attendant hull alterations, and for the normal cargo ship it would appear that the advantages did not at present justify this expenditure. No doubt this position would improve when more propellers had been fitted, and for the gas turbine the extra cost was small in relation to fitting an internal reverse gear.

Dr. Allan stated from experience that the efficiency loss to be expected with a boss size from about 0·26 - 0·28 would be of the order of 5 per cent, and it was interesting to note that in Dr. Allan's view the enlargement of the shaft bossing in front of the propeller would not give any improvement as compared with a well faired rope guard. This was in accordance with his views, but recent experience tended to show that with special care in designing the loss could possibly be reduced to about 3 per cent. The principle of the "Aquadal" propeller for which Dr. Allen was responsible was the adoption of a pitch-reduction which reduced the lift of the root sections to zero, and this was combined with the use of strut-shaped symmetrical profiles. No doubt Dr. Allen would now agree that owing to the curvature of the stream lines, due to cascade effect, these sections would require a slight centreline camber, but generally speaking, this treatment was in accordance with the principles mentioned on p. 9, whereby the circulation was reduced to zero at the crown of boss. It was agreed that the conditions at 0·7 radius of the propeller were most critical in determining the efficiency, and that the loading should be so arranged as to give optimum drag/lift conditions at this radius, but he did not think this would conflict with the above principle. Constant-moment sections usually had a reflex centreline camber, which was not favourable to high efficiency, particularly in the outer parts of a marine propeller blade, and in view of the wide variations in angles of incidence, which occurred in a controllable-pitch propeller, he did not favour adoption of this type of section. There was, however, some justification for the use of strut-shaped sections throughout, particularly in the case of tugs, where the astern pull could sometimes be as important as the ahead thrust. No doubt the constant-velocity type sections could only be expected to give a uniform distribution of suction over a small range of lift coefficient, but such sections were intrinsically superior to those having a parabolic or approximately triangular distribution of thrust, under conditions where cavitation could hardly be avoided. This had been confirmed by experience with full-size propellers and he believed that sections of this type would eventually be adopted almost universally under such onerous conditions. It would be seen from the section given in Fig. 11 that the condition for uniform suction did not necessarily require a sharp leading edge, but he believed that the type shown in Fig. 10 would be found to be more suitable for use near the hub. The design of the most suitable sections for controllable-pitch propellers was now being studied in various cavitation tunnels, and it was urgent that very careful research be made, in view of the possible increase in the speed of rotation of controllable-pitch propellers, should they be fitted in conjunction with gas turbine installations.

Steam Gunboat Machinery—A Light-weight Steam Plant

Further Discussion

Mr. S. D. Lomas (Associate) wrote that as he was concerned with the shop tests and sea trials of the main propulsion turbines and gears he submitted a few points which might be of belated interest to the discussion.

In view of the absence of experimental work in the short time available for design and construction, remarkably little trouble was experienced on the tests of the prototype.

A modification was found necessary due to a tendency of the rotor of the turbine to make hard rubbing contact in the bottom half of the labyrinth glands of inter stage diaphragms, possibly due to differential expansion in the light structure.

An increase in the radial clearance in the lower arc of the diaphragm labyrinths prevented further rubbing at this point without appreciable loss in efficiency. After the usual care had been taken in the initial steaming and subsequent inspection it was found possible and even advisable to treat the units quite roughly on routine test runs. Quick accelerations and rapid reversal over a few hours followed by a steady load run for gear bedding formation became the order. Any tendency to vibrate due to labyrinth and shaft contact was usually eliminated by a short period of running at slightly reduced speed.

A puzzling feature experienced in the first pair of engines was some light surface scratching of the gear pinion bearing journals due to particles of grit embedded in the bearing metal although great care had been taken in cleaning the lubrication system. This was eventually traced to oil inlet holes drilled through the gear case fabrication passing through layers of metal in face contact, incorporated in the structure. Particles of scale possibly formed during welding operations were washed out of the small space between plate surfaces by the lubricating oil and carried to the bearings. Tubing of internal oilways in the fabrication prevented further trouble from this cause.

Some idea of the sturdiness of these units could be gained from the fact that in the course of a minor overhaul to engines that had been in operation for some months and had received battle scars, it was noted that, due to a discrepancy in the seatings an out of alignment error of approximately an eighth of an inch existed at the coupling between the turbine rotor and the pinion quill shaft. The flexibility of the drive had accommodated this very large alignment error and no trouble had been experienced in service, although in his experience the quill shaft type of drive was prone to heavy vibration if subjected to excessive malalignment.

In viewing the engine room layout with the number of steam driven auxiliaries, one was driven to speculate on the reason for the rejection of a scheme which it was understood was advanced by the main engine manufacturers. This was to incorporate two exceptionally light turbo-generators of 50 kW. output, previously developed and of proved reliability, to provide current for electrically driven auxiliaries.

The elimination of piping in the matter of weight and size of target for missiles entering the engine room space was surely in favour of such a scheme. The steam losses in so many small units must also have constituted a considerable item in overall consumption.

Finally, it was questionable whether the policy of minimum machinery weight and reduction of the safety margin by a layout which excluded any duplication of vital auxiliary machinery served any useful purpose.

The contradiction was a continual series of modifications which consisted of a considerable increase in armament and the bolting of heavy plating to the hulls in way of machinery spaces. How different this was from the special manufacture of manœuvring valve hand wheels made of bicycle frame tubing in order to save weight.

The resulting increase in draught with consequent loss of speed seemed to indicate a change in the employment of these ships from hit and run to stand and fight, no doubt dictated by conditions of service.

It was, however, disappointing to observe the overloading of the plant that inevitably followed and which it was understood eventually necessitated the fitting of modified propellers although he had lost contact with those fine little ships before this had been done.

The author's have no comments to make in reply.

The Non-Destructive Testing of Steel Castings and Forgings

Further Discussion

Mr. C. Croxson (Visitor) wrote that the following remarks were confined to radiographic methods. The authors stated that radiography "is very insensitive in the detection of small cracks", but did not this depend on what was meant by small cracks, and on other factors such as the thickness of the specimen under examination? In personal experience of over thirty years he could not recall a single instance in which failure occurred by cracking which had escaped detection by radiography. Stress corrosion cracks a few ten thousandths of an inch wide and $\frac{1}{16}$-inch deep had been found repeatedly in steel forgings, and also micro-cracks in welds, and it would give a better picture to say that X-rays were a valuable means of detecting cracks. There was less call for radiography of forgings than of castings largely because the former was usually only asked for when some surface mark aroused suspicion, and also because forgings were less prone to internal defects than castings.

Then again a discussion of intensifying screens seemed incomplete unless the other half of the combination—the photographic film—was mentioned. The advantages of metal screens were only fully realized when used with fine grain high contrast films. These films were somewhat slower than other types in common use but this was not an overriding disadvantage and they were greatly superior in the recording of fine detail. Generous exposures were necessary so that a density of at least 2·0 was attained on development. With such a technique the superiority of X-rays over gamma rays shown for a $\frac{1}{2}$-inch steel section in Fig. 22(b) would have been appreciably diminished.

The authors stated, in line with other writers, that with gamma rays "filtration became unnecessary . . . because little trouble was experienced with scattered radiation". In his experience however, the use of filters was almost of equal advantage in both X-ray and gamma ray technique, and as a rule even heavier filtration would be used for gamma rays than for X-rays.

With regard to Betatrons it was suggested that their disadvantage was not so much one of size (the magnetizing assembly of a synchrotron operating at 14MeV would go into a cubical box of 2ft. 6in. side), but difficulty of adjustment and low output of radiation coupled with a very unpleasant noise.

It was to be anticipated that radioactive isotopes for radiography might be of substantially smaller bulk than radium and of considerably longer life than radon. Radon sources prepared by the method due to Dawson* were however likely to be the sources

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* Dawson, J. A. T. 1946. Jl. Sci. Inst., Vol. 28, p. 138. "Radon—Its Properties and Preparation for Industrial Radiography"

par excellence for some time to come, as they approximate very closely to the ideal point source.

Mr. J. Rhodes wrote that Mr. Croxson's remarks were of exceptional interest. Those on the Betatron and radon sources were elaborations of the necessarily brief descriptions in the text of the paper.

The authors were well aware that in Mr. Croxson's own hands the X-ray technique had been used as a powerful tool for crack-detection. Had more time and space been available more justice would have been done to these interesting developments. For this brief review the authors would, however, tend to insist that in industrial radiography, as it was normally practised, the X-ray technique was not primarily used for the detection of small cracks. For this purpose the magnetic and ultrasonic methods within their own limitations were more reliable and economical.

A discussion of fine-grain high contrast films was omitted again for reasons of economy in space, but he was glad Mr. Croxson had referred to this subject. The reader should, however, not be given the impression that present day fine-grain films were only "somewhat slower than other types in common use". The relative speeds varied by a factor of about 2 to 3.

The relative advantage to be gained by filtration for X-ray and gamma ray photographs touched on a complex subject outside the scope of this brief review. Mr. Croxson might well have in mind some experiments and observations not known to the authors.

Metallizing in Relation to Marine Engineering

Further Discussion

Mr. F. R. Nicholls (Member) asked the author what would be the result of the subsequent wearing down of a shaft, after it had once been reclaimed by metal spraying, to the limit of the added new metal. Anticipating that the author would state that the position "would be disastrous" and that the wear should never be allowed to reach that limit, he hastened to add the following.

Since so little technical data on the subject of metal spraying was common knowledge and so few had practical experience to draw upon, should it not be the duty of the contractor, assuming that the work was not done by one's own staff using one's own equipment, to acquaint the customer with the fundamentals of the author's reply. His own experience was that no query was made on the expected wear or information given on the maximum permissible wear consistent with safety, following the repair as executed. He had in mind pump or piston rods where great diameter reductions were often permitted before repairs were put in hand, and if the result was as quoted, such repaired parts should be stamped for identification with other similar parts carried by the same vessel or firm. This was as equally true for a reciprocating rod as for a built up rotating shaft. There was one further point in connexion with reclaimed rotating shafts; it had been stated that the metal particles were deposited in the form of fish scales, following the lathe direction during the spraying process. Should not the lathe direction be made to be opposite in rotation to the normal direction of rotation of the working part, more especially when the bearing itself might be similarly reclaimed. This would seem to him to give better wearing qualities and, microscopically, better retention of the oil film.

He felt too that, for smaller repairs normally carried out without the customer's inspection or specification, too little attention was given to acquainting the customer with the amount of metal removed during the preparation, so that the ultimate effective area of the shaft or rod was known, as it was clear that the sprayed metal could play no part in restoring the tensile or torsional strength of the unit.

It was noticed that the shaft in Fig. 12 had been prepared with a square corner at the reduction in diameter and this caused the indicated hard spot against that shoulder. Surely the strength of the shaft and the elimination of that hard spot would both be assisted by tapering off that shoulder during preparation wherever possible.

The author has no comments to make in reply.

SWANSEA LOCAL SECTION

At the fourth meeting of the Swansea Local Section on the 24th March 1949, held at Swansea Technical College, Mr. K. C. Rockey, B.Sc. (Associate Member) read a paper on "Modern Methods of Stress Analysis" to a gathering of twenty-four members.

Mr. George Thompson introduced the speaker, who went on to give a very interesting address on strain recording by the electrical resistance method and also by the brittle lacquer process. There were two slides shown, of many, where the strain lines in lacquer could be clearly seen in the foot of a C.1 bedplate, and in the roots of teeth in a pinion wheel. They were also told about strain gauges fitted in boxes in various parts of the *Ocean Vulcan,* to find out hogging and sagging strains in a seaway. The method of adhesion of the lacquer to the specimen was gone into; the merits and demerits of a whole range of glues, cements and plastics were explained by Mr. Rockey. At the conclusion questions were put by Professor R. G. Isaacs who asked if the strain gauge could indicate fatigue, and also if it could be used on welded parts.

A hearty vote of thanks was proposed by Mr. Thompson and seconded by Mr. Cloudsdale and the meeting terminated at about 9 p.m.

JUNIOR SECTION

Lecture at the College of Technology, Belfast

On Wednesday, 30th March, Capt.(E) Gregson, M.Sc., R.N.R. (Member), delivered a lecture entitled "The Future of Steam for Marine Propulsion", in the Central Hall of the Municipal College of Technology, Belfast.

Capt. Gregson divided the whole range of ship types into: tramps, cargo-liners, passenger ships, cross-channel vessels, etc., and proceeded to enumerate the factors which should be considered in deciding upon steam machinery types. He spoke of the influence of unit size upon efficiency, and the effect of stand-by losses. Regenerative feed heating and air pre-heating were touched upon. Slides were shown to illustrate the effect of variations of boiler pressure and superheat temperature upon cycle efficiency; the relationship of the auxiliary load to the main propulsion load; and the all-round commercial factors of weight, space occupied, etc.

The meeting started at 7.45 p.m. and the lecturer spoke until 8.50 p.m. The meeting was immediately thrown open for discussion and there were many participants. At 10 p.m. the closure was put upon the discussion.

A vote of thanks was proposed by Mr. Stewart, a student of the College, and seconded by Mr. D. H. Alexander, the Principal. Mr. W. E. McConnell briefly explained the purpose of the meeting and invited interested young men to avail themselves of the Institute's pamphlet "How to Become a Marine Engineer". The meeting was well attended. The Chairman was Mr. C. C. Pounder (Vice-President).

Lecture at Barrow-in-Furness

A Junior Section lecture was given on the 8th April entitled "Operation of Marine Steam Turbines", by Dr. G. H. Forsyth, D.Sc. (Member), and W. Marsh, M.Sc.Tech (Manchester), B.Sc. (Durham), Wh.Sc. (Associate Member) at The Technical College, Barrow-in-Furness. The lecture was fully illustrated by the use of slides and a large collection of small scale models. The lecture covered design, selection of suitable materials and care and maintenance of small turbines and lasted two hours. A discussion of about half-hour followed and among the 130 visitors were many senior officials from Vickers-Armstrongs Works. The Principal of the College, Mr. Sandham, stated his pleasure at the success of the meeting and hoped further lectures by these authors would follow.

Mr. A. J. Berry, S.R., R.N.(ret), (Member), proposed a vote of thanks to the authors and delivered a short talk on the aims and objects of the Institute.

Cardiff Local Section

A lecture entitled "The Motor Liner *St. Essylt*" was given on Monday, the 4th April at 7.15 p.m. by Mr. John E. Church in the Lecture Theatre of the South Wales Institute of Engineers, Park Place, Cardiff.

In the absence of Mr. Ivor Thomas (Vice-President) the Chair was taken by Mr. Colin Moffatt, Committee Chairman of the Cardiff and District Section.

Mr. Church, addressing an audience of approximately a hundred, gave the reasons for the hull design, the type of main and auxiliary machinery and navigation safety devices installed in the vessel, together with information of the accommodation for passengers, officers and crew. The lecture was well received and the enthusiasm of the audience was shown in the numerous and varied questions the lecturer was called to answer.

Mr. J. M. Morton in proposing a vote of thanks to Mr. Church for his admirable lecture congratulated him and his owners for providing ample space in the engine room and for their courage in departing from standard designs and Mr. D. Skae in seconding the vote of thanks stated the owners and Mr. Church deserved the greatest possible success.

Mr. L. Blackmore proposed a vote of thanks to the Chairman, Mr. Colin Moffatt, paying tribute to his energy and enthusiasm for the Cardiff and District Section, which motion was seconded by Mr. T. G. Thomas. The meeting terminated at 9.15 p.m.

MEMBERSHIP ELECTIONS

Elected 7th March 1949

Members

Kenneth Abbey
Tara Berry
Arthur Leslie Brewer, Lieut.(E), R.N.
William Hepworth Clay
John Henry Evans, O.B.E.
Harold Graham Fawkes
Ian Eliott Smith Gordon
Leonard Walter Green, Lieut.(E), R.N.
George Hoskins Low
James Allan Milne
William Storey Pallan
Donald Pennell
John Mennie Sim
Archie Frederick Sinclair
Roderick John Stewart
Gordon Leslie Thomson
Lars Tveit
Denver Wood Wansey
George Williamson
William Edward Wood
Arthur Ernest Godden, Lieut.(E), R.N.
Joseph Benjamin Hayes
Robert Arthur Jancey
Raymond William Knapp
B. Nordan
William Pollock
Colin Reynolds, Lieut.(E), R.N.
Peter Antony Swager
Trevor Flint Tisdale
William Waddell
Alexander Carmichael Waugh
Arthur William James Yeandle

Associate Member

Allan David Pearson, Lieut.(E), R.N.(ret)

Associates

John Reginald Harry Silvester Atkinson
Stewart Rex Cairns
Jehangir Dadabhoy Daroga, M.Sc.
Leonard Dodd Derry
Thomas Dowell

Transfer from Associate to Member

Raymond Belcher
William Clark
John David Clarke, Lt.-Com'r(E), R.C.N.R.
Stanley Jones-Frank
James Keay, M.B.E.
Joseph McPherson
Robert Curle MacKellar Reid
Norman Carse Marr
Tirumalai Kumara Tolappa Srisailam
George Wyllie Steele
Arthur James Stewart

Transfer from Graduate to Associate Member

Hosny Mahmoud Hussein, Lieut.(E), R.E.N.

Transfer from Graduate to Associate

Stanislaw Waldemar Pappius

Elected 4th April 1949

Members

James Albert Anderson
Alistair Sutherland Brodie
Edward Brown
Ernest Burnett
Henry David Butterworth
Arthur James Cole
George Edward Dodds, Com'r(E), D.S.C., R.D., R.N.R.(ret)
Francis Xavier Fernandes
Victor George Fielden
Gilbert Stevenson Gibson, Lieut.(E), R.N.(ret)
Adam van Hasselt
Ernest John Hunter
John Gerald Irwin
Donald Henry Jones, Lieut.(E), R.N.
James Wilfred Kinsella
James Livingstone
Knud William Valdemar Lund
Alexander Herbert Rewi Macintosh
Eric Marlborough
Francis Henry Milsom
Charles Arthur Payne, M.B.E.

William Fergus Aird Rankin
Edward Henry Richardson
George Leslie Richardson Watkins
Charles Henry Westbury
Herbert Philip Weymouth
Hector Gordon Wickett, M.B.E.
Pieter Franciscus Willemse

Associate Members

William David Gervan Jordan
John Francis Preston
Alexander Stanley McFarlane

Associates

Harold Ernest Aldworth, B.Eng.
Ronald Cook
Leslie Finlay
Frederick James Robert Houghton
Ronald Kirkwood
Joseph William Lamb, Lieut.(E), R.N.
John Richard Lean
John Alfred Lightburn
James William Lough
Peter Frederick Martin, Lieut.(E), R.N.
Bharat D. Merchant
Henry Miller
Ramesh Chandra Mohan
John Richard Danford Nunn, Lieut.(E), R.N.
Vernon Walter Parker
Joseph Stanley Townsend
Alexander Miller Wilson

Graduates

Nazmy Guirguis Abib, B.Sc., S/Lt.(E), R.E.N.
Hassan Hussein Ezzo, B.Sc., S/Lt.(E), R.E.N.
James Brennan Neilson
Mohamed Salah El-Din Rida, B.Sc., S/Lt.(E), R.E.N.

Students

Begamudre Ananda
William Henry Eccleston

Transfer from Associate to Member

Edward James Coleman
Behram Darabsha Wadia
Frederick David Dickson
John Vincent Downing
Walter Garriock
Charles Stewart Hall
Thomas Kameen
Robert Andrew McCowatt
Kocherlakota Parthasarathy
Thomas Alfred Mansfield Searle
James Thompson

Transfer from Graduate to Associate Member

Ahmad Metwally Ahmad, Lieut.(E), R.E.N.
Saad Rizkalla Hanna, S/Lieut.(E), R.E.N.

Transfer from Student to Associate

Maurice John Booty

OBITUARY

Mr. Thomas Albert Cambourn (Associate 8780) was born in 1873 and was a native of Swindon. He served his apprenticeship with the Great Western Railway Engineering Shops and began his career with Messrs. Hudson, Scott and Co. of Carlisle, later transferring to Messrs. Carr and Co. In 1904 he joined the staff of the Carlisle Corporation Electricity Department and in 1938 became Mechanical Superintendent Engineer. He was with this company for thirty-eight years and retired in 1941. He was transferred to Associate in 1948. He was also a Member of the Electrical and Power Engineers Association. He leaves a widow and son.

Henry Trevor Crowther (Member 7111) was born in 1896 and served his apprenticeship with Cammell Laird at Birkenhead. War service in the Royal Engineers in the 1914-18 war interrupted his progress and he was invalided out of the service as a result of war wounds. He joined the staff of the Nelson Line as 6th engineer and rose to 3rd engineer before leaving for varied service with Shell Mex, the Harrison Line, and the Jamaica Direct Fruit Line. Whilst with the latter concern he obtained his chief's certificate with the *Jamaica Settler* and at the youthful age of thirty-two was chief engineer with the *Jamaica Pioneer*, which position he held for several years. He accepted a post with the Clan Line but sudden illness prevented him joining his ship and a subsequent operation rendered him unfit for further seagoing appointments. He accepted a shore post with the Westminster Ice Club and this was terminated by the 1939-45 war, when he was appointed as a sectional engineer at the Royal Ordnance Factory, Risley, under the auspices of the Ministry of Supply. At the end of the war he took up an appointment with Messrs. Halex, Ltd., as an engineer and after passing his civil service examinations finally joined the Ministry of Works as a permanent civil servant. He was in this position up to the time of his death on the 19th February 1949. He was elected a Member in 1932. He was 53.

Peter R. Fallows (Student No. 11162) was accidentally killed on the 21st March 1949 while serving in the aircraft carrier H.M.S. *Theseus*, during Fleet Exercises in the Mediterranean. He was the only son of the late Mr. W. E. Fallows, M.I.Mar.E. and Mrs. Fallows, of Whitley Bay. He had begun a marine engineering apprenticeship with the North Eastern Marine Engineering Co., Ltd., and in October 1947 he volunteered for national service fearing that he might not obtain admission into the Royal Navy if he awaited calling up.

He had already displayed outstanding character and ability, and his untimely death is deeply regretted by all who knew him.

Mr. Robert Gardner (Member 10762) was born in Glasgow in 1895 and served his apprenticeship with the Fairfield Shipbuilding and Engineering Co., Glasgow. During the 1914-18 war he saw service in the Royal Navy and was in H.M.S. *New Zealand* at the battle of Jutland. Mr. Gardner first went to New Zealand in the Union Co.'s vessel *Kaiwarra* since when he made rapid progress in the company's service and at the time of his death he was chief engineer of the T.E.V. *Rangatira*. He was elected a Member in 1946 and was also a Member of the Institute of Marine and Power Engineers. He died on the 18th February 1949.

Mr. John Courtney Vaughan Horton (Member 8101) was born in 1879 and joined the firm of Messrs. F. J. Trewent and Proctor, Ltd., London, consulting engineers, naval architects and surveyors, in 1895. With the exception of about two years spent in the Armstrong-Whitworth shipyard at Walker-on-Tyne and two and a half years in the Fairfield Shipbuilding and Engineering Co.'s yard at Govan, Mr. Horton's whole business career was spent with Messrs. F. J. Trewent and Proctor, Ltd., of which company he was elected a director in 1919 and managing director in 1930. This firm have specialized for a long time in the design, construction and maintenance of tankers. He was elected a Member in 1936 and was a Member of the Institution of Naval Architects. He died on the 24th February 1949.

Mr. Edward Philip Paxman (Member 8636) was born in 1901 and educated at Oundle School, and Cambridge University. He had a period of training with Metropolitan Vickers Electrical Co., Ltd., and then entered the employ of Blackstone and Co., Ltd., Stamford. He joined Davey, Paxman and Co., Ltd., in 1926, and shortly afterwards became chief engineer. After acting as director and then joint managing director, he became managing director on the association of the company with Ruston and Hornsby, Ltd., of which company he also became a director. He was a member of the council of B.I.C.E.M.A., a founder-member of B.I.C.E.R.A., and Chairman of the Council of this Association. He was also on the Grand Council of the F.B.I., a patron of the Engineering and Marine Exhibition, and in 1948 was elected master of the Worshipful Company of Farriers. He had many interests of a wide nature apart from his engineering and industrial associations, amongst which was his appointment in 1947 as a Justice of the Peace. His sudden death on 25th March 1949 at the early age of 47 will be a great national loss to the engineering industry as well as to his numerous personal friends in all parts of the world. He was elected a Member in 1938.

Mr. John Edward Roberts (Member 2027) died at his home at Caterham, Surrey, on 24th January 1949 at the age of 85 after he had been in failing health for about six months. As a very young man, Mr. Roberts joined the P. and O. Co. and served as an engineer for eighteen years, reaching the position of chief engineer. In 1895 he accepted a post which put him in charge of the ports and machinery in the harbours of Alexandria and Port Said. In recognition of his work which had led to benefit for Egypt, he was awarded the Insignia of the Fifth Class of the Imperial Ottoman Order of the Medjedieh. The decoration was bestowed by His Highness the Khedive of Egypt before the 1914-18 war. He was elected a Member in 1929. He leaves a widow, a daughter and a son.

Mr. Denver Wood Wansey (Member 12337) was born at Newcastle, New South Wales in 1892 and was educated at the Collegiate School, Newcastle. He served his apprenticeship with Messrs. J. and A. Brown at Hexham, New South Wales. His sea going career lasted over ten years in S.S. *Alice*, S.S. *Prophet*, S.S. *Amphion*, the greater time as second engineer in T.S.S. *Euripides*. During the 1914-18 war he served in the R.A.F. He was employed by Messrs. Howard Smith, Ltd., for twenty-two years and was assistant engineer superintendent for seven years. During this period he obtained his Extra First Class Certificate at Sydney. In December 1946 he was appointed to the Commonwealth Navigation Service at Sydney as Engineer and Ship Surveyor and held that distinction until his death on the 25th February 1949 after a short illness. He leaves a widow and two sons.