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RECENT ADVANCES IN CATHODIC PROTECTION OF SHIPS

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RECENT ADVANCES IN CATHODIC PROTECTION OF SHIPS

By N.S. DEMPSTER B.Sc.

INTRODUCTION

This paper deals primarily with the cathodic protection systems currently in use on ships of the Royal Australian Navy Fleet. Many of these systems are based on recently developed materials on which performance data have now been accumulated but which have not yet found widespread introduction to the Merchant Navy in Australia.

The author's experience in this field arose from a joint project with Department of Navy engineers and scientific staff of Defence Standards Laboratories, Department of Supply, with the purpose of assessing the applicability of cathodic protection to the Navy in general and with the specific aim of developing effective systems for shipboard application.

The more recent and major inits of the Fleet are now equipped with impressed current systems and while some further development is proceeding on dielectric shields and underwater paint systems, the present systems are providing effective protection. It is envisaged that there will be a continuing requirement for refinement of these systems including the introduction of automatic control and the re-siting of anodes to provide improved current distribution.

It is proposed firstly to discuss general considerations such as principles, current density requirements, control methods and available systems and secondly to outline the cathodic protection systems currently in use in the R.A.N.

GENERAL CONSIDERATIONS

Principles

WHen a metal is in contact with an electrolyte there are, for a variety of reasons, areas formed on the metal surface which are at different potential levels. At some areas of high energy (called anodes) metal atoms can leave the crystal lattice and enter the electrolyte as positively charged ions. In so doing, electrons are freed at these metal sites. The anodic reaction for iron is then $Fe \rightarrow Fe^{++} + 2e$. While this reaction is proceeding at the anode sites, in other areas called cathodes, electrons are being consumed by a reaction such as $O_2 + 2H_2O + 4e \rightarrow 4OH'$. This is the predominant cathode reaction at neutral or near neutral pH conditions and involves the reduction of dissolved oxygen to hydroxyl ion. Since electrons are being produced at the anodes and consumed at the cathodes, a stream of electrons will flow through the metal from anodes to cathodes.

The anode and cathode reactions are proceeding at exactly the same rate and the resulting corrosion rate can be reduced by restricting either the anode reaction rate or the cathode reaction rate.

(Inhibition by chromate is an example of control by restriction of the anode reaction and the well know method of de-aeration of boiler feed water is an example of control by restriction of the cathode reaction.) In the process of cathodic protection, sufficient electrons are supplied from an external source to satisfy the local cell cathode reaction and consequently the anode reaction which was previously supplying the electrons for this purpose is stifled.

It is of interest to consider cathodic protection in terms of the influence on the anodic and cathodic polarisation curves of Fig. 1. This diagram is simply a graph of reaction potentials vs reaction rate (i.e. current) and shows how the potential of anodic and cathodic reactions change as the current changes. This change in potential with variation in current is called polarisation and it will be seen that anodic reactions polarise in the cathodic direction and cathodic reactions polarise in the anodic direction. The lines AB and CB therefore represent anodic and cathodic polarisation respectively and since the diagram shows that both the anodic and cathodic reactions are polarised we are dealing with an instance of mixed anodic and cathodic control.

The measured electrode potential of the corroding metal surface is given by E and the local action current by the intercept of the anodic and cathodic polarisation curves i.e. I_1. If sufficient current I_2 is applied from an external source, the potential of the local cathodes will be polarised to the open circuit potential of the local anodes, no local action current will flow and complete protection will be achieved. In this instance then, the protective current I_2 is greater than the corrosion current I_1, but if the system were to operate under solely cathodic control, i.e. no anodic polarisation, the corrosion current would be given by the intercept D i.e. I_2 which is equivalent to the protective current. This is a limiting case in which the protective current is equivalent to the corrosion current but in all other instances of mixed control or anodic control the protective current will be greater than the corrosion current.

Current Density Requirements and the Cathode Reaction.

The current density required to cathodically protect a structure in sea water will depend on many factors including the oxygen content of the water, the velocity of the water or structure, temperature, the presence of deposits, the type and condition of the paint system and the salinity of the water. Many of these factors alter the current density requirements by their effect on the cathode reaction.

As indicated earlier, cathodic protection is achieved if sufficient electrons are supplied from an external source to satisfy the local cell cathode reaction $O_2 + 2H_2O + 4e \rightarrow 4OH'$. The current density required for complete protection is therefore dependent on the availability of oxygen at the metal interface.

Since oxygen reaches the metal interface by diffusion through the electrolyte, any factor which will vary the diffusion rate will alter the current density requirement for protection. The need for higher current densities with increased water velocity and increased temperature is therefore appreciated. Conversely, lower current densities can be used when the metal is covered by deposits or paint coatings.

For example, the protection of bare steel may require an initial current density of 20 ma/ft^2 but this can be reduced to a small fraction of a milliampere by a 6 mil. coating of a vinyl paint system.

The U.S. Navy Department (1) has measured the increase in current requirement on a ship installation maintained at constant potential at various velocities; the current flow to the propellers has been shown to increase fourfold at 15 knots, whereas the current to the hull increases only slightly with increased velocity. This large difference between the current density requirement of the propeller and the hull is due essentially to the difference in oxygen availability at the respective metal interfaces. Whereas the surface of a moving bare metal propeller is highly oxygenated, the availability of oxygen to the hull metal interface is limited by the diffusion rate of oxygen through the paint film.

While a current density of 20 ma/ft^2 may be required initially tp protect bare steel in sea-water, this can be reduced in time to 4 ma/ft^2. This is due to the production of cathodic "chalk" (magnesium hydroxide and calcium carbonate) which is preecipitated from sea-water under the alkaline conditions at the cathode surface. While this increase in alkalinity at the protected metal interface produces some desirable effects such as above, it can be dangerous in the protection of an amphoteric metal such as aluminium unless the cathode potential is carefully controlled. Furthermore the alkaline conditions cause deterioration of oil-based paint films by saponification of the oil and in such instances great care must be taken to avoid over-protection of the structure. In general, vinyl and bituminous paint systems are being used on R.A.N. ships and both types have reasonable resistance to alkaline conditions.

Control of Cathodic Protection

The degree of protection provided to a structure is assessed by its potential. Laboratory tests have established that the minimum protective potential for steel in sea-water is - 770mV. vs Ag/AgCl reference electrode, but it is common marine practice to adopt a potential of -800mV. Most painted steel structures in sea-water have a potential of 600 to650mV negative to Ag/AgCl and protection will therefore involve a movement of potential of up to 200mV. in a negative direction.

To date, R.A.N. practice has been to control this potential by manual adjustment of the current tocmaintain the ship's potential at the required value. The hull potential is determined by a number of reference electrodes mounted in appropriate positions on the underwater hull.

Various types of automatic control systems based on electro-mechanical or magnetic amplifier principles are at present under test by overseas Navies, but are not yet in use in the R.A.N. The most promising of these systems is one in which the hull potential is matched against a standard fixed potential and any out of balance is amplified to supply a transducer which will constantly vary the current supply until the hull potential matches the standard fixed potential.

Cathodic Protection Systems

There are two general methods of applying cathodic protection :-

(a) The Galvanic System in which metals less noble than the structure to be protected are joined directly to the structure. Active metals such as magnesium and zinc provide a source of electrons by virtue of the ease with which they corrode in electrolytes such as sea-water.

(b) The Impressed Current System in which electrons are supplied by connecting the structure to be protected to the negative side of a convenient low voltage D.C. source while the positive side is connected to an anode of suitable type.

GALVANIC SYSTEMS

1. Zinc Anodes

(a) Development of Effective Anodes

It is somewhat surprising to realise that although the use of zinc anodes was originally suggested by Sir Humphrey Davy in 1824 for the protection of copper sheathed hulls, there had been no significant development in this field until some 10 to 15 years ago. It had been common marine practice on steel hulled ships to fit commercial quality slab zinc anodes in corrosion-prone areas despite their apparent inability to protect the hull over extended periods due to the early formation of thick resistive films of corrosion product on the anode surface.

The discovery in 1946 that the presence of iron impurity caused anode stifling led to the final development of zinc alloy anodes which would maintain a high current output throughout their useful life. Initial work at Naval Research Laboratory, Washington, and research sponsored by the American Zinc Institute showed considerable improvement in anode performance by substantial reduction of the iron content, and in 1954 the U.S. Military Specification MIL-A-18001 limited the iron content to 0.0014%. In 1955 Anderson and Teel (2) confirmed the need to limit iron content to 0.0014% and showed that the addition of 0.1% aluminium to zinc containing 0.033% iron was effective in maintaining the same current output as theunalloyed zinc containing 0.0014% iron.

In United Kingdom in 1956 Crennell and Wheeler (3) showed that the ill effects of 0.02% iron could be largely overcome by alloying with 0.5 to 1% aluminium. An important further development by Reichard and Lennox (4) in U.S.A. showed that reduction of the iron limit to 0.0002% gave considerably higher current output than could be achieved at the 0.0014% level and that alloy additions of 0.1% aluminium plus 0.05% cadmium gave even higher current output than the 0.0002% iron limit or compositions containing aluminium additions alone.

In 1958 Crennell and Wheeler (5) reported that the performance of the zinc-aluminium alloy could be greatly improved by alloying with 0.5% aluminium plus 0.5% silicon and more recent tests have shown advantages in the addition of cadmium to this alloy.

A recent paper by Lennox (6) has given the following range of compositions of the zinc-aluminium-cadmium alloy which have been found to give reliable performance with maximum current output:-

Aluminium	0.1 - 0.3%
Cadmium	0.025 - 0.06%
Iron	0.005% max.

Special high grade zinc - balance.

In 1957 the R.A.N. Cathodic Protection Sub-Committee endeavoured to improve zinc anode performance by adopting the zinc-aluminium type composition investigated by Grennell and Wheeler of Admiralty. Initially the zinc alloy containing 0.8% aluminium, and later 0.3% aluminium, was introduced into service. In turbulent areas e.g. rudders, the performance of these anodes was moderately good but in main hull areas anode corrosion was irregular and performance was gnerally not satisfactory.

In view of the subsequently reported beneficial effects of silicon and cadmium additions to anode compositions containing aluminium, Defence Standards Laboratories undertook an extensive programme of tests to determine the optimum anode composition for service use by R.A.N. A brief outline of these tests will be presented at the forthcoming Annual Conference of the Australasian Corrosion Association, Adelaide, November, 1963. As a result of these tests R.A.N. has adopted a zinc anode composition containing 0.3% aluminium plus 0.05% cadmium with a limitation on iron impurity of 0.003%, although more recent tests indicate that a higher iron content may be acceptable. A second composition containing aluminium, cadmium and silicon was equivalent in performance to the above and anodes of this type are now manufactured commercially in Australia.

An indication of the comparative performance of some zinc anode compositions can be gained from Fig. 2 which shows the condition of anodes after comparable test conditions. It is of particular interest to note the poor performance and irregular corrosion pattern of the pure zinc anode (No. 4) although its iron content is only 0.0006%. Under the quiescent conditions of test the zinc - 0.5% aluminium composition (No.5) also performed poorly. The aluminium-cadmium and aluminium-silicon-cadmium zinc alloy anodes (Nos.1 and 3), not only maintained a high current output throughout their useful life but presented a very uniform pattern of corrosion.

(b) Advantages and Use of Zinc Alloy Anodes

Table 1 lists some comparative properties of various galvanic anodes. The low solution potential of zinc in sea-water (-1.05 V. vs Ag/AgCl) is a most important property of this material for marine service where electrolyte resistance presents no general problem. The low "driving voltage" of 0.25 volt, i.e. the potential difference between a protected structure at -0.8 volt and the open circuit anode potential of -1.05 volt, does provide a useful self-limitation on the current output which is not so marked with magnesium alloy anodes. While the low "driving voltage" does necessitate the maintenance of low resistance in the circuit This is readily achieved by casting the anodes around galvanised steel straps which can be welded or bolted to the structure.

It is evident from the cathodic polarisation curve for steel (Fig. 3), that at potentials more positive than -1.1 volt the cathode reaction is limited to the reduction of oxygen and the cathode current density will be controlled by the availability of oxygen at the interface or by the diffusion rate of oxygen. Using zinc anodes it is therefore impossible for the cathode potential to exceed the hydrogen discharge potential and the cathode reaction can only be the reduction of oxygen.

There is no necessity to fit dielectric shields around zinc anodes as is required with magnesium, since the cathode potential even in areas close to the anode cannot be excessive and current distribution on the cathode surface is controlled by the availability of oxygen at the metal interface.

The further advantage of zinc anodes is in cost and as Table 1 shows, the cost per ampere year of zinc alloy anodes in Australia is approximately half that of magnesium.

Zinc alloy anodes are mainly used in the R.A.N. for the hull protection of the smaller and slower-moving ships and for the aft end protection of older active destroyers which have a limited future life. Where noise reduction and hull resistance considerations are important, recent overseas practice is to mount the anodes in groups in line parallel to the direction of water flow. This effectively reduces the resistance of the group of anodes to the frontal resistance of the first anode but the current per anode will be reduced to less than half its output under ideal spacing conditions. This may be compensated for by additional anodes which involves a weight penalty. Zinc alloy anodes are also employed in the R.A.N. for the protection of recessed areas such as main condenser inlets and outlets.

2. Magnesium Alloy Anodes

A magnesium alloy anode in sea-water has a potential of -1.5 volt, which gives it a driving voltage of 700mV. to a cathodically protected steel structure; this higher voltage is an advantage compared with zinc when dealing with high resistivity waters.

Within the R.A.N., magnesium anodes have not been used for hull protection of active ships for the following reasons :- (a) it is necessary to fit dielectric shields around the anodes to prevent local high current density and consequent damage to the paint film. (b) their higher driving voltage does not permit effective self-limitation of current output, which makes it difficult to produce a design which will not give overprotection under stationary conditions, and (c) magnesium anodes are expensive in Australia.

Magnesium anodes of the following approximate composition (Al 6%, Zn 3%, remainder Mg) are used by the R.A.N. for the protection of reserve ships and stationary ships and structures, mainly in situations in which the supply of shore-based power is difficult or there is danger of stray current interference with adjoining structures if impressed current systems were employed. In these instances the anodes are suspended a minimum of 10 feet from the structure, which gives a reasonably uniform current distribution.

IMPRESSED CURRENT SYSTEMS

The impressed current system is preferred for the overall hull protection of active ships because of the greater flexibility in control of the current and incidentally, because the current demand is known, it can form a useful guide to the condition of the underwater paint. The current density required for protection of a ship's hull can vary considerably depending on whether the ship is moving or stationary, the condition of the paint system, the salinity of the water etc. These variations in current density can be achieved most effectively by an impressed current system.

The components of the system are :- (1) a D.C. source (2) means of controlling and measuring current (3) a suitable anode (4) dielectric shielding (required only for hull mounted systems).

Current Supply

In earlier D.C. equipped ships, the low volyage D.C. supply for cathodic protection was provided by motor generator sets, the current being controlled by field control of the generators and by variable resistors. In the more recent A.C. equipped ships the control is simplified by the use of transformer-rectifier units, each supplying a pair of anodes located port and starboard at a particular frame position. The recent destroyers are fitted with 8 anodes (4 transformer-rectifier sets) and the frigates with 4 anodes (2 transformer-rectifier sets).

Anode Materials

Materials used on R.A.N. ships have included mild steel, silicon iron, lead alloy, and platinum electroplated titanium. Graphite and platinum base alloys appear to have been preferred in U.S.A. Some properties of impressed current anodes are given in Table 2.

Mild steel is an expendable anode while the remainder of the materials may be classed as "insoluble" anodes. Mild steel anodes are normally operated at low current densities, where the anode efficiency is 100%, the anode reaction being $Fe - Fe^{++} + 2e$. The supply of electrons to the structure is therefore accompanied by an equivalent electrochemical loss of iron from the anode. For the "insoluble" anodes however, the anode reaction is essentially the discharge of oxygen and chlorine, in addition to which there may be some small loss of the anode material. Anode consumption varies with the material and the current density, and with platinum anodes it is virtually zero.

Steel: The initial installation of mild steel anodes on destroyers was not entirely satisfactory. These anodes were mounted on wooden fairings on the bilge keels but difficulty was experienced in obtaining satisfactory current distribution to the for'd and aft areas. The wooden mountings did not provide satisfactory insulation and the whole fitting was cumbersome and difficult to maintain.

It was envisaged that a better current distribution could be achieved by using several small anodes placed at designed spacings around the hull. This design would preclude the use of mild steel anodes because of their high consumption rate. "Insoluble" anodes were therefore adopted and mild steel is at present used only for the ground bed installation at one dockyard to provide protection of ships during fitting out.

Silicon Iron: (14.3% silicon minimum). This was used as a dome form anode 12" base diameter, 3" high with a cast-in stainless steel stud protruding from the flat base. This stud passed through the hull in insulated bushings and was used for securing the anode and for electrical connection of the D.C. supply. Although initial difficulties were experienced in casting techniques, silicon iron proved a reasonably satisfactory anode material but it has now been replaced by the lead alloys for use on active ships. The consumption rate of 0.5 lb./ampere year quoted in Table 2 is based on overseas data obtained from laboratory tests conducted under satisfactory conditions. Service trials on one R.A.N. ship over a period of 3 years have given an average consumption rate of 1.4 lbs./ampere year. This discrepancy may be due to velocity effects.

Silicon iron is still used in rod form anodes for the protection of ships during fitting out at one dockyard.

Lead Alloys: A lead alloy containing 1% silver and 6% antimony is used as the standard anode for hull mounted impressed current systems on the more recent ships of the fleet. These anodes are in the form of a flattened dome 10" base diameter. While they are subject to a form of passivity at current densities of 15-20 amp/ft^2, operational experience with this type of anode over a period of 4 years has been entirely satisfactory. The consumption rate in operational service is only of the order of 0.2 lb./ampere year.

The mechanism of operation of lead alloy anodes, and particularly their passivation with increase of current density, is being investigated at D.S.L. It has been established, inter alia, that high consumption rates are experienced in 1:10 dilution of sea-water such as may be experienced in estuarine waters and it is known that they exhibit an extremely high consumption rate if used as ground bed anodes on the sea floor.

Platinum Anodes: The United States Navy has used platinum alloy anodes for hull protection. The anodes have been constructed from silver or copper wire clad with an alloy of 90% platinum, 10% palladium. More recently an 80:20 and later a 50:50 platinum-palladium foil has been mounted on a glass reinforced polyester backing of disc shape. While the later designs of anode have given satisfactory service, the initial cost is high.

In the United Kingdom, Imperial Chemical Industries Ltd. have patented a platinum-electroplated titanium anode which possesses many advantages compared with clad anodes and is considerably cheaper. With platinum clad silver or copper anodes any defect in the cladding will result in rapid solution of the base metal. On the other hand, bare titanium will effectively passivate under anodic treatment by the formation of stable oxides. Porosity of the plating is therefore not important and damage to the coating will not result in the destruction of the basis metal.

The platinised titanium anode has certain advantages for naval ship application; its small size minimises underwater noise and the cost per annum is low. Two anodes of this type are at present on trial on an R.A.N. destroyer. The design of the anode is shown in Fig. 4; dimensions of the disc are 6 inch diameter, 5/16 inch thick. The entire anode including stud is manufactured from titanium and the working surfaces are coated with 0.0001 inch platinum. Within the range of current density 5-50 amp/ft^2 the determined electrochemical loss of platinum in sea-water amounts to 5 x 10^{-6} inch/year, which would give this anode a theoretical life of 20 years. These anodes have been on trial for only one year and while one is showing no defects, the other has lost a small amount of platinum from near the centre of the anode. These areas can be seen in Fig. 5 as the small dark areas; the two larger crescent-shaped areas were present initially and are associated with the original welding of the stud. This anode has been operating at an average current density of 28 amp/ft^2 and the maximum and minimum current densities have been respectively 70 amp/ft^2 and 6 amp/ft^2.

[illegible] anodes used by R.A.N. have all had the form of a dome or disc with a securing stud on the back face. This general form has proved most successful for ease of fitting and electrical wiring and has permitted simple but adequate sealing. A further advantage of this form of anode is the limited area of dielectric shield required compared with the long anode favoured by some overseas authorities.

Trailing Anode.

The U.S.N. has developed an impressed current system based on a platinum rod anode towed behind the ship(7). Provided that the distance between anode and hull exceeds about 20 feet, a suitable uniformity of hull potential is achieved. Some difficulties were experienced in designing a suitably robust anode and cable but a recent Dutch design has overcome these problems by trailing aluminium wire from a spool which is connected to the D.C. supply. The trailing anode system overcomes the necessity for dielectric shields which can be a troublesome and moderately expensive feature of hull mounted impressed current systems. A disadvantage of this system is that uniform protection cannot be provided under stationary conditions but it is nevertheless a very desirable method for protection of liners and some cargo ships which operate on a fast turn around.

Current Distribution

The satisfactory protection of an underwater hull requires a uniform potential to be achieved over the whole of the underwater surface. This is dependent on the uniformity of current distribution. While this aim may be approached with a remote anode system as used on reserve ships or ships fitting out, it is more difficult when the anodes have to be fitted to the hull as on an active ship.

With galvanic zinc anode systems a large number of anodes can be distributed around the hull and a reasonable uniformity of current can be achieved. With the higher speed frigates and destroyers however, the effect of these anodes on resistance to movement and the development of underwater noise becomes important.

The number of anodes used in an impressed current system must be restricted because of the complexity of power distribution within the ship. On the other hand, it is more difficult to achieve uniformity of potential with a limited number of anodes. The Daring class destroyers are fitted with eight anodes and the type 12 frigates with four. To assist in the spread of current from the anode, and to overcome local damage to the paint film, it is necessary to use a dielectric shield around the anodes. These shields are thick coatings of heavy duty organic materials; Fig. 6 shows a typical installation.

The size of shield depends on the anode current output and the type of paint system. Vinyl paints are capable of withstanding a hull potential of -1000 mV. for a period of 12 months, so that shield dimensions can be determined to give a potential at the edge of the shield no more negative than -1000 mV. for the desired current output.

Wheeler(8) has prepared a mathematical treatment which permits calculation of the dielectric shield dimensions for certain shape anodes. For the dome form anode a dielectric shield radius of 5 ft. will limit the potential at the edge of the shield to -1000 mV. when the anode current is approximately

9 amp. It should therefore be possible to operate the cathodic protection system on Daring class destroyers at up to 72 amperes without paint deterioration around the dielectric shields. This current is well above that required if the overall paint system is in reasonable condition. For an oil based paint system, shield sizes would need to be extremely large to limit the potential at the edge of the shield to the desirable maximum of say -850 mV. Hull mounted impressed current systems are hardly practicable on ships coated with oil-based paint systems but the trailing wire impressed current system should be suitable.

Fig. 7 shows the results of a longitudinal underwater hull potential survey undertaken on a Daring class destroyer with the assistance of divers. Traverse 1 shows the potential distribution with a current of 6 amp. solely on No. 1 anode and traverse 2 the distribution with a current of 9 amp. on No. 2 anode. Traverse 3 (the continuous line) shows the potential distribution when anodes 1 and 2 were both operating with respective currents of 6 and 9 amps. (Anode No. 3 was not operating during this trial). The dielectric shields around anodes 1 and 2 were 5 ft. in radius and the observed potentials at the edge of the shields were of the order of -840mV. vs Ag/AgCl. It is interesting to note that within an inter-anode distance of some 89 ft. the potential is uniform, within 20mV., over a distance of 65 ft; this is a reasonably good potential distribution for a hull mounted impressed current system.

Dielectric Shields

A wide range of organic materials has been tested for suitability as dielectric shields, but the choice of reasonably suitable materials is still small. Since the anode reaction of the "insoluble" anodes involves the discharge of oxygen and chlorine, the shield materials must be resistant to these gases at quite moderate concentration.

Any defects which occur in service will be subject to a high current density with consequent development of highly alkaline conditions at the metal interface. The shield material must therefore be alkali resistant, particularly at the metal-interface bond. Other necessary characteristics are:- low water transmission rate, good adhesion to steel, resistance to shock, vibration and flexing, compatability with anti-fouling paints, and ease of application.

The standard material used by U.S.N. is neoprene sheet, which is secured to the hull by adhesives. R.A.N. has adopted a unique approach in the use of plastic resins for dielectric shields and although some adhesion problems have been experienced, service trials of epoxyfibre glass and epoxy-polyester-fibre glass have been successful for periods in excess of 3 years. There has been no evidence of chemical deterioration of these resins in service and the adhesion is likely to be greatly improved with the introduction of steel grit blasting in place of wet sand blasting for hull preparation. The aim is to achieve a service life of at least 5 years. At present these shields are applied by a lay-up technique to a thickness of 50 mils and they extend to a 6 ft. radius around the anode. Hot spray application methods are at present under consideration, as this technique would make a substantial reduction in application time.

UNDERWATER PAINTS

Cathodic protection must be regarded as a method of supplementing the protection provided by paints and an insurance against serious pitting which can occur in the event of paint damage. Strategic considerations impose demands such as the maintenance of a smooth hull to ensure maximum design speeds and the extension of the inter-docking period [redacted] The design of the cathodic protection system must therefore be integrated with the performance of underwater paints and the plastic resins used for dielectric shields. Improvements in paint performance will limit the current requirements, with an ensuing reduction in size of anodes and dielectric shields. The number of anodes and shields in an installation may also be reduced.

In past years the R.A.N. used oil modified alkyd paint systems with a mercurial anti-fouling coating. The anti-fouling properties of this system in Australian and Far-Eastern waters were not sufficiently good to permit an extension of the docking interval beyond 6 months. Because of the better anti-fouling performance of the cuprous oxide pigmented vinyl paints, an entirely vinyl paint system was introduced. From anti-fouling considerations this permitted an extension of the docking interval to 12 months, but the risk of corrosion with any paint failure was increased. Cathodic protection was initially introduced primarily for this reason.

The vinyl paint system was applied by brush and roller, which produced comparatively thin films per coat and made it difficult to achieve the desired minimum total film thickness of 10 mil. Film thickness was commonly of the order of 6-7 mil, and in some instances considerably less, and paint performance was below expectation. It cannot be too strongly stressed that the specified thickness of paint should be applied in the first instance, as failure to do so cannot be rectified by subsequent re-coating. While these difficulties with the vinyl paints might have been overcome by the introduction of hot or airless spraying, R.A.N. introduced an aluminium pigmented bituminous anti-corrosive (A.C.) paint system which could be readily built to the requisite film thickness. For ships equipped with cathodic protection a vinyl anti-fouling (A.F.) system is used. The performance of the bituminous A.C. paint appears satisfactory to date and the cathodic protection current requirement has been reduced significantly.

The Navy Department is sponsoring research by the Commonwealth Scientific and Industrial Research Organisation and Defence Standards Laboratories, Department of Supply, on the development of improved toxins and anti-fouling paints, and also on the development of improved anti-corrosive paints, in which initial background information is being obtained on the electrical properties and ionic diffusion characteristics of anti-corrosive paints.

SUMMARY AND FUTURE DEVELOPMENTS

Of the available galvanic anode systems, there is little doubt that the zinc alloy anodes are most suitable for hull protection of active ships, and within this type, the R.A.N. is using one of the most effective compositions known to date. Furthermore it is highly improbable that further improvements can be made to the zinc alloy composition without departing from the desirable solution potential characteristics of zinc based materials. There have been some recent developments in aluminium alloy anodes which will be of interest as these low potential anodes will be competitive with zinc on a price basis if they have sufficiently high current efficiency.

A major difficulty which exists with all galvanic systems is that the number of anodes required must be estimated at the time of docking from the condition of the existing paint system and the proposed re-painting or touch-up schedule.

Adjustment of the number of anodes after flooding the dock is not usually practicable and resistance control of the anode current output is extremely troublesome and wasteful of current. A simple solution to this problem has not been presented and it perhaps serves to emphasise the convenience of impressed current systems in this regard.

The design, control and hardware of present impressed current installations on R.A.N. ships are adequate to provide satisfactory protection but further developments is required in the following fields :-

(1) The assessment of the value of automatic control.

(2) The further assessment, under laboratory and service conditions, of plastic resins for dielectric shields.

(3) A study of the process of deterioration of paint films under cathodic protection conditions and the development of paints capable of providing an extended service life.

Francis and Cook (8) of the Bureau of Ships, Washington, have recently analysed the maintenance costs of 10 destroyers before and after installation of galvanic cathodic protection systems and have concluded that savings of from $10,000 to $20,000 per destroyer per overhaul can be expected from the use of cathodic protection. A graphic representation of their findings is given in Fig. 3. The maintenance costs included in this analysis involved solely those associated with rudders, struts and strut barrels, sea chests and hull plating and did not include consideration of propellers, propeller shafts or sonar domes or the influence of cathodic protection on reduction of fuel costs or extension of time between overhauls.

While a similar analysis of comparitive maintenance costs has not been undertaken by R.A.N., the evidence from the above survey would indicate that the introduction of adequately controlled cathodic protection systems should bring about substantial savings in hull maintenance costs.

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PROPERTY	ANODE		
	ALUMINIUM	MAGNESIUM	ZINC
Specific Gravity (lbs/in^3)	0.1	0.066	0.26
Solution Potential vs Ag/AgCl, (volts)	-1.00	-1.50	-1.05
Driving Voltage to Cathode at -0.30V, (volts)	0.20	0.70	0.25
Theoretical Consumption (lbs/amp.year)	6.5	8.7	23.5
Current Efficiency (per cent)	54	50	95
Actual Consumption (lbs/amp.year)	12.1	17.5	24.8
Cost/ampere year	-	@ 9/6 lb. -£8-5-0	@ 3/10 lb - £4-10-0 @ 3/4 lb - £4- 2-8

Table 1. Comparative Properties of Galvanic Anodes.

MATERIAL	ANODE CONSUMPTION (lb/amp.year)	DENSITY (lb/in^3)	REMARKS
Mild Steel	20 at c.d. of 1 amp/ft^2	0.28	
Silicon Iron	0.5 at c.d. of 5-10 amp/ft^2	0.25	
Lead-silver alloy	0.2 at c.d. of 5-10 amp/ft^2	0.4	Subject to "passivation" at c.ds.greater than 15-20 amp/ft^2
Graphite	1.2 at c.d. of 5-10 amp/ft^2	0.08	
Platinum-palladium alloy	negligible	0.77	
Platinum electroplated	negligible	0.16 approx.	

Table 2. Some Properties of Impressed Current Anodes.

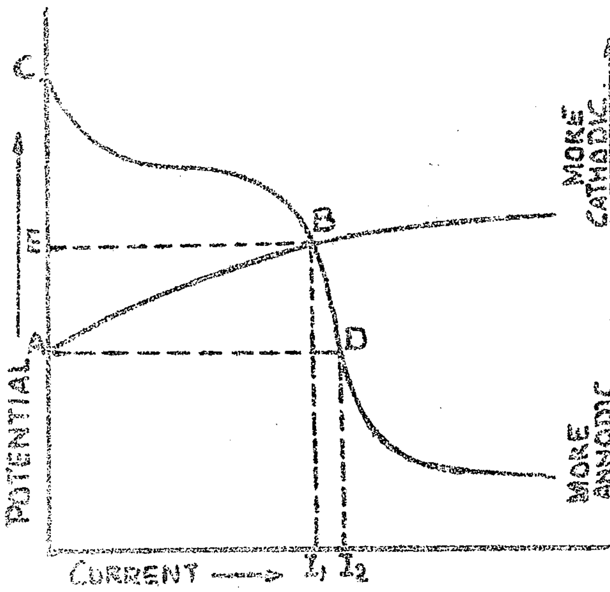

FIG. 1. SCHEMATIC REPRESENTATION OF ANODIC AND CATHODIC POLARISATION CURVES FOR STEEL IN SEAWATER.

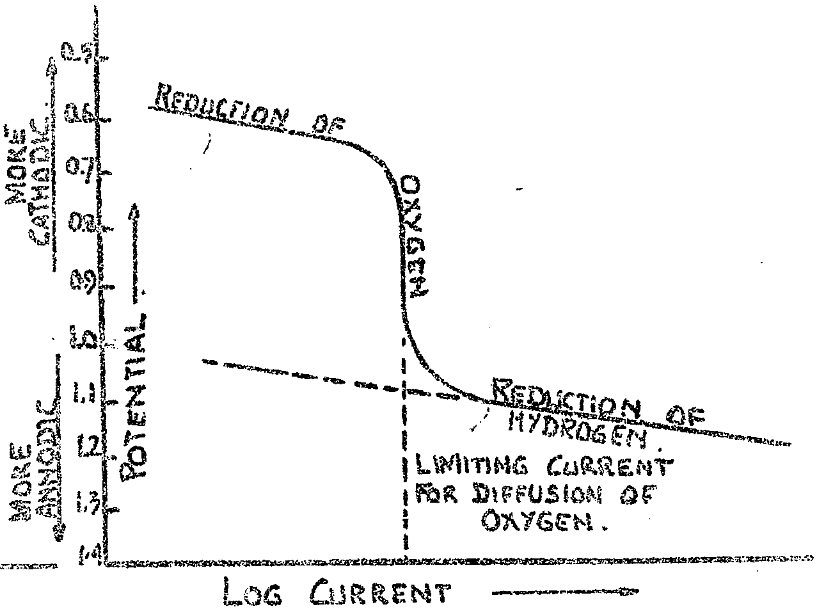

FIG. 3. CATHODIC POLARISATION CURVE FOR STEEL IN SEA WATER.

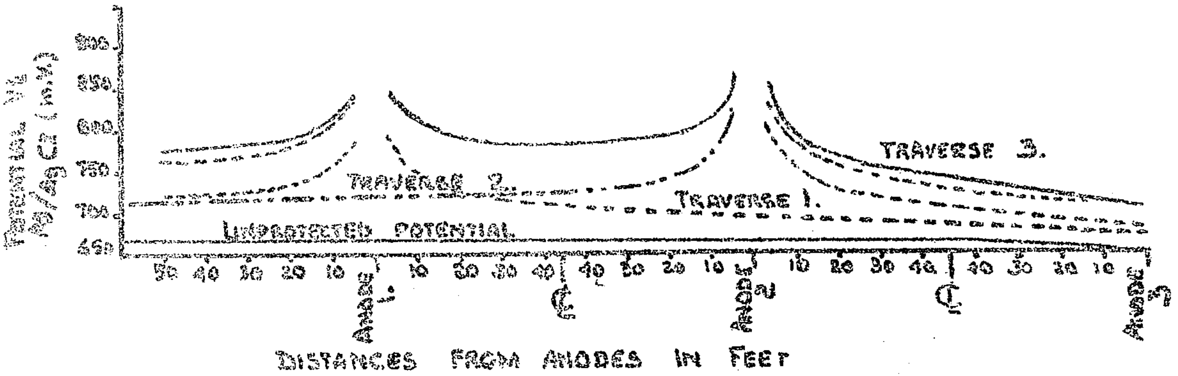

FIG. 7. LONGITUDINAL POTENTIAL SURVEY OF PORTION OF UNDERWATER HULL OF "DARING" CLASS DESTROYER.

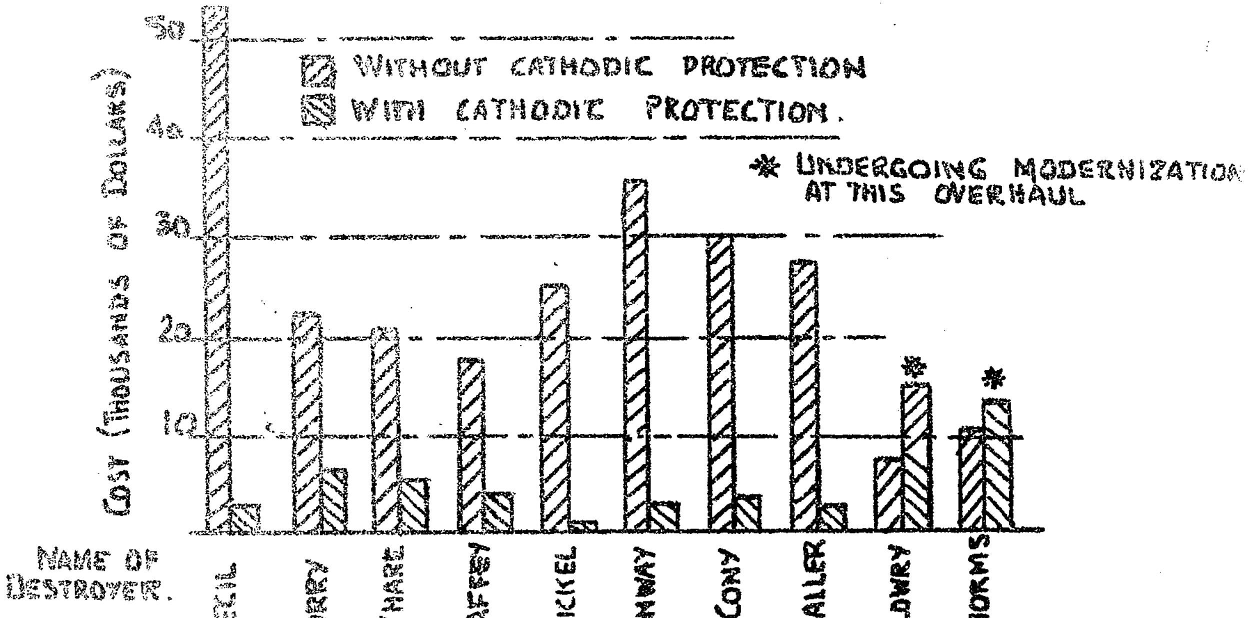

FIG. 8. COMPARISON OF MAINTENANCE COSTS, PER OVERHAUL (AFTER FRANCIS AND COOK REFERENCE 9)

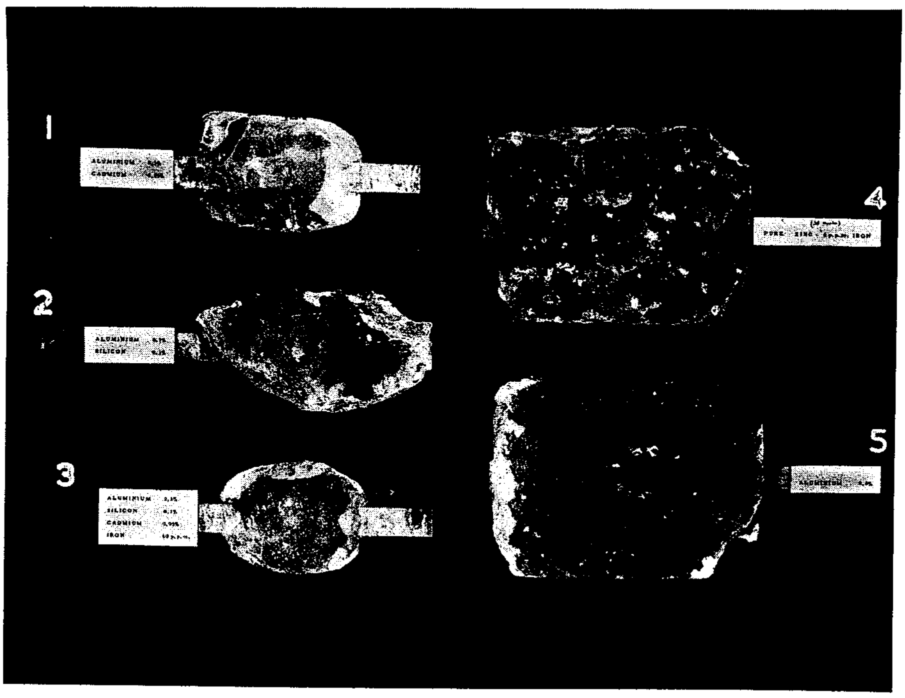

Fig. 2. Condition of various zinc alloy anodes after extensive test period.

Legend

Anode No.	Aluminium	Cadmium	Silicon	Iron		
				Nominal	Actual	Free
1	0.3%	0.05%	-	30 p.p.m	29 p.p.m	-
2	0.3%	-	0.1%	30 p.p.m	-	2.1 p.p.m
3	0.3%	0.05%	0.1%	60 p.p.m	-	1.6 p.p.m
4	-	-	-	-	6 p.p.m	-
5	0.5%	-	-	30 p.p.m	29.5p.p.m	-

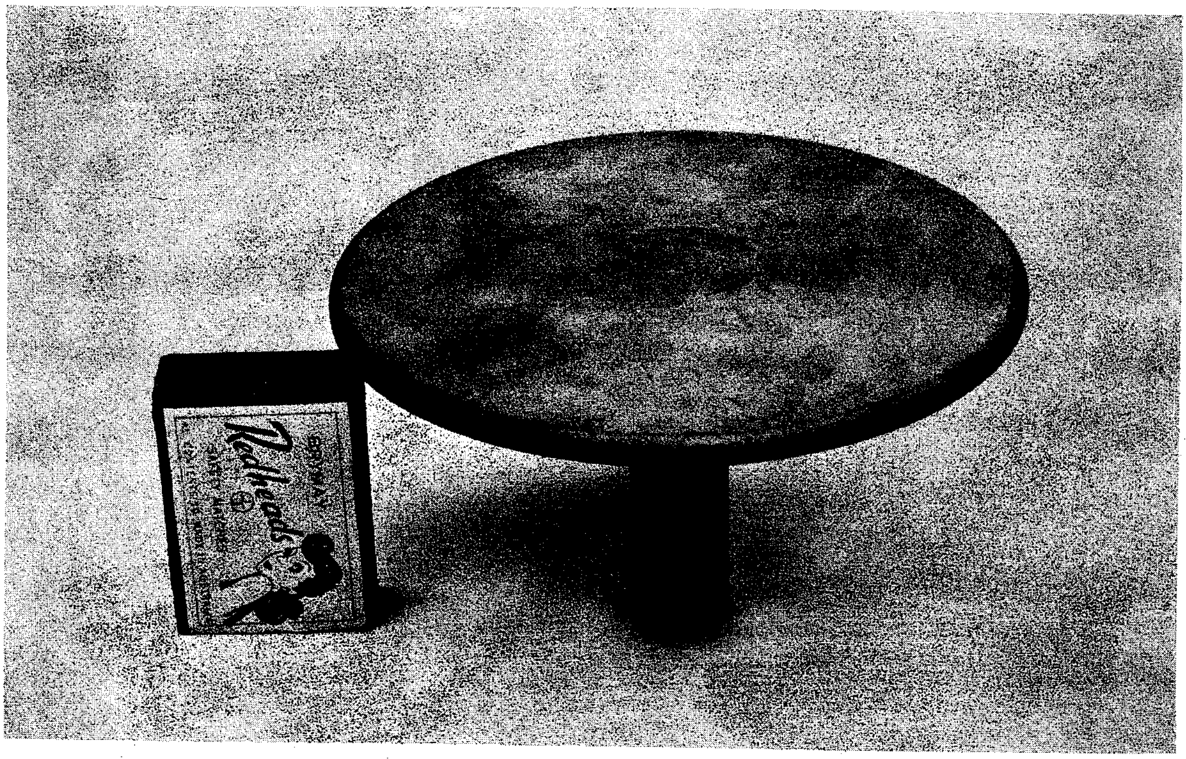

Fig. 4. Platinised titanium anode.

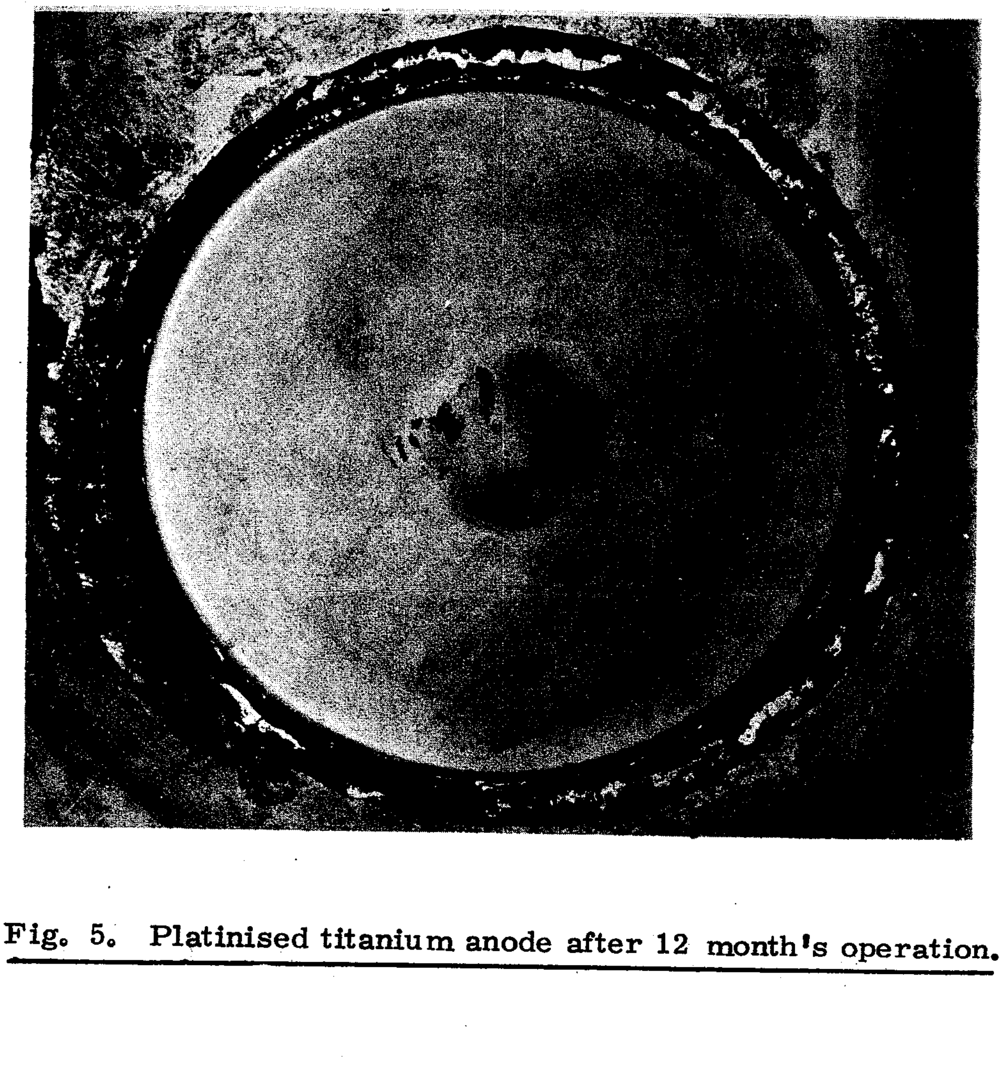

Fig. 5. Platinised titanium anode after 12 month's operation.