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LEAD INDUSTRIES ASSOCIATION

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CHEMICAL BULLETIN NO. 74

SUBJECT: "LEAD-SILVER ALLOY ANODES IN CATHODIC PROTECTION OF SHIPS"

To Members of the Lead Industries Association:

Attached for your interest is a reprint of "Lead-Silver Alloy Anodes in Cathodic Protection of Ships," which appeared recently in "Corrosion." It is thought to be useful information on this new use for lead.

Extra copies, up to 25, are available to members free of charge and above that quantity at our cost of $7.60 per hundred.

Very truly yours,

Robert L. Ziegfeld

Secretary.

Abstract

An alloy of lead-2% silver has been used experimentally as an improved current source for cathodic protection of an active destroyer. This paper describes the anodes and their associated equipment and method of fitting. Data are given on the performance of the system after one year's service and comparisons of performance and costs are made with existing impressed current and galvanic systems. 5.2.3

Service Experience With

Lead-Silver Alloy Anodes in Cathodic Protection of Ships*

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Introduction

THE POSSIBLE use of lead alloy anodes for the cathodic protection of ships was first suggested by Grennell and Wheeler.[1] They had conducted laboratory experiments on pure lead and lead alloys as anodes in sea water and their results indicated that lead alloyed with a small percentage of silver gave coulomb efficiencies equal to or better than the best grades of graphite anodes. This high coulomb efficiency is due to the formation of a protecting film on the lead alloy which slows the attack on the underlying metal. As the peroxide is electrically conducting, its presence does not markedly affect the anode resistance, provided it remains in contact with the metal substrate, i.e., no non-conducting compounds of lead are formed between the peroxide layer and the metal. Grennell and Wheeler had shown that, in sea water, pure lead was not a good anode material, due to the tendency to form the non-conducting compounds beneath the peroxide.

Confirmatory laboratory experiments were made at the Naval Research Establishment with a number of lead alloys, of which the alloys (lead 98%, silver 2%, and lead 98%, silver 1%, tin 1%) appeared the most satisfactory. One anode of each of these alloys was cast and fitted to an active tug early in 1955. In service, the alloy with the 2 percent silver gave the better performance and showed excellent promise of being a suitable inert anode for the cathodic protection of slow speed ships.

The suitability of the anodes for high speed ships, such as destroyers, was still open to question, because the peroxide layer under these conditions had to withstand the high water speed and vibration associated with such craft. To test the anodes on such ships ten anodes (lead 98%, silver 2%) were fitted to HMCS Crusader, a destroyer, in July 1956.

This report describes the method of installation of the anodes and associated equipment, discusses operational experience, and makes economic comparisons with other anode systems.

Components of the Cathodic Protection System

The cathodic protection system fitted to HMCS Crusader consisted of (1) two sizes of lead 2 percent silver anodes, Mark I for fitting under the ships counter and Mark II for fitting on bilge keels, (2) anode brackets of gum plastic sheeting, (3) current shields of polychloroprene, (4) rectifiers and appropriate wiring and glanding, and (5) hull mounted reference electrodes.

Manufacture and Fitting of Lead—2% Silver Anodes and Brackets

Manufacture: The anodes were cast from lead ingot and silver bar in the proportion 98:2. The resultant alloy after casting analysed well within the desired range of 2% silver ± 0.1%. (Subsequently, anodes have been cast from alloyed lead 2% silver ingots, obtained from a metal supplier, with negligible change in alloying content on casting.) The anodes were mechanically sound and free from blowholes, sand inclusions and hot tears. An exploded view of a Mark I anode assembly (of which two were fitted) is shown in Figure 1. The Mark II anode (of which eight were fitted) differs from this in overall length of exposed faces and cable connection.

The bracket material was gum plastic sheeting used in two thicknesses: a

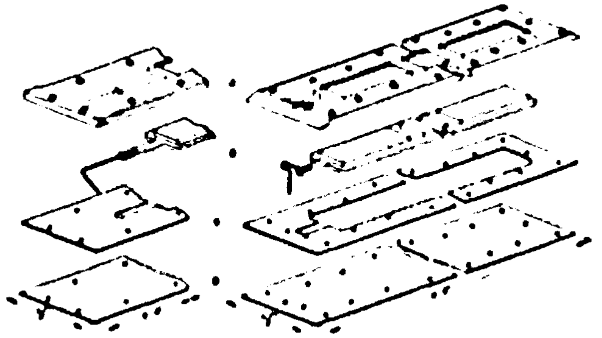

Figure 1—Exploded view of Mark I lead alloy anode. Cable connection for Mark II is at one end. A, Bracket; B, Anode; C, Polychloroprene gasket; D, Backing piece.

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1-inch thick sheet, which formed the main bracket or cover, and an ⅛ inch sheet, which served as extra insulation below the anode and was used to hold it in place in the main bracket for ease of handling prior to installation. The cutting and machining of the stock was carried out in such a way as to leave the cover and back in single lengths.

The brackets for the Mark II anodes were made in matching pairs with left and right hand grooves for the anode cable leads. This facilitated the mounting of the anodes in pairs and ensured that both cables would point towards the gland outlet for the pair. A sheet of polychloroprene (1/16 inch thick) was used as a gasket seal between the cover and backing pieces in all cases. The unexposed anode faces were coated with polychloroprene sheeting, 1/32 inch thick, using cold-bond solutions, to prevent corrosion on these faces and loosening of the anode in the bracket.

The conducting cable connection was made by soldering the wire in a slot cut into the lug cast on the end of the anode for this purpose. The joint was then wrapped with tape, the anode placed in the bracket with the cable placed inside the groove especially cut in the bracket. The cable was then covered with polychloroprene putty to ensure a water-tight joint. After these operations the backing plate was fastened to the main bracket with small counter-sunk brass screws.

Fitting of Anodes. Because hull plating at the stern is relatively thin, the Mark I anodes (Figure 2) were fastened to a ¾ inch mild steel (1×4-foot) backing plate welded to the hull. This plate was drilled and tapped to correspond with the anode bracket and gland opening. The Mark II anodes were mounted on the bilge keels in pairs, so that the ends with the cable connections butted together. The exact positions of the anodes were determined by the relative ease with which the gland, cofferdam and standpipe could be positioned inside the hull. The anodes were mounted with one pair towards the fore end and one towards the aft end of the bilge keel. The assemblies were secured in place with counter-sunk cap screws covered with polychloroprene putty.

Current Shields. Before installation of both Mark I and Mark II anodes the polychloroprene current shields were applied. These extended three feet in all directions from the anode. Later inspections showed that this should be increased to four feet. When it was necessary to lap sheets the vertical joint was made so that the forward lapped over the aft sheet in order to avoid possible lifting due to water action at the facing edge. The horizontal joint was made at the junction of the upper bilge keel surface to the hull plating. Previous experience had shown that when anodes are fitted to the topside of bilge keels, it is more important to provide a wider current shield on the hull immediately above the anodes than below. For this reason, the full width of the sheet was used above the bilge keel, whereas the lower sheet, starting from the hull junction, covered the top surface of the bilge keel and only about half of the bottom surface, from the edge in.

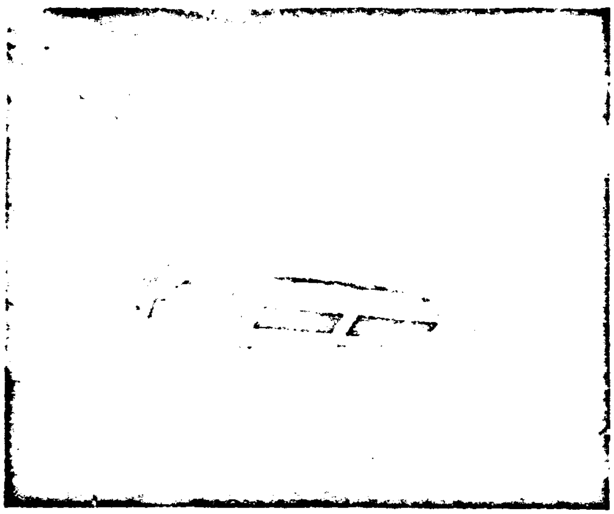

Figure 2—Mark I anode as fitted

Previous experience with polychloroprene sheeting bonded to steel hulls had shown that it was necessary to prevent water action at high speeds damaging the edges of the sheets, particularly at the leading edges. To accomplish this, steel strips were tack welded around the edges of all the sheets as shown in Figure 3. The cross-section of the steel strip was slightly cramped in order to give the edge over the plastic sheet a slight spring action when the strip was welded in place.

Glanding, Cofferdams and Standpipes. Single-holed glands, as shown in Figure 4 were used for the Mark I anode cable and the double holed glands were used for the Mark II anode cable pairs. A sponge-rated backing pad was used with each type of gland. The pads were held in place by continuous welding, both on the inside and outside, to prevent water seepage between pad and plating.

The cofferdams were as large in size as could be conveniently fitted, consistent with the space available and the possibility of making water-tight welds. A removable cover was fitted for access to the gland and anode cable. The waterproof connection between anode and supply cables (a straight splice covered with tape) was made inside the cofferdam. Standpipes were used to carry the cables from the cofferdam to two feet above the waterline.

Electrical Cables, Connections and Rectifiers. The anode lead was a short length of stranded single conductor 7/.064 polychloroprene cabtire cable.

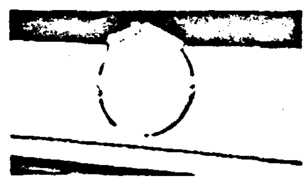

Figure 3—Polychloroprene sheeting as applied, showing securing strapping

This size of cable was the largest that could conveniently pass through the hull gland and fit a slot in the anode bracket in such a way as to make the water-tight seal previously described. Each anode had its own supply cable to give flexibility and reduce effects of lead breaks or shorts. The lengths of the electrical supply cables between rectifier and individual anodes varied, but the choice of diameter was fixed by the condition that the total resistance of any one cable should be less than 0.2 ohms.

Two rectifiers (each 440 v 3-phase AC to 0-12 V DC, 0-100 amp) were used, one on each side of the ship to serve the anodes on the corresponding sides. Terminal lugs and strips were used so that the individual anodes could be connected or disconnected at will. The rectifiers were mounted in the grating compartment of the ship and each had its own voltmeter, switches, ammeter and variac transformer for current control.

Reference Electrodes. Two silver-silver chloride reference electrodes were mounted on the hull at positions one quarter of the ship's length from the bow and on the keel just aft of the "A" brackets. The method of mounting these electrodes is shown in Figure 5. A standard

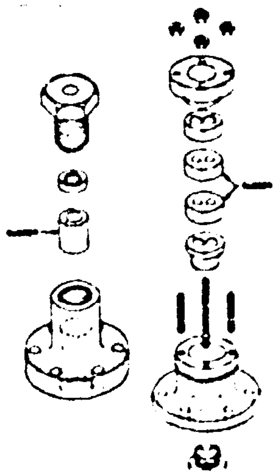

Figure 4—Shipside glands for anode cables

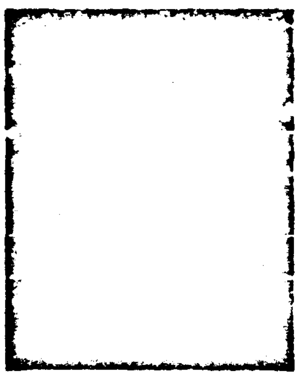

Figure 5—Hull mounted reference electrode

ship-side gland, cofferdam and standpipe were used and the electrode leads were brought to the same compartment in which the rectifier units were mounted. In addition to these the hull potential could also be measured with the standard over-the-side electrode and portable millivoltmeter. This meter and the mounted one at the rectifier panel had an internal resistance of 20,000 ohms volt.

Operational Procedure

Previous experience with lead-alloy anodes had indicated that the anode current density should exceed a minimum of 3 amp/sq ft to form a tight peroxide film that would prevent attack on the underlying metal and resultant shortening of the 10-year life expectancy of the anode. It was also known that the current density requirement of a freshly painted hull is low. For these reasons, some of the anodes were left unconnected on undocking the ship and a prepared schedule for making the connections was drawn up, so that the anodes in use were always delivering more than 3 amp/sq ft. Additional considerations in drafting the schedule were (1) maintenance of even current distribution over the hull with variations in current demand, (2) the maintenance of the optimum hull potential, (3) maintenance of the minimum supply voltage that would be compatible with other requirements, and (4) the current-voltage relationship of each anode as found immediately after undocking. Typical values for the latter are given in Figure 6.

Daily readings of the hull potential with both the portable and hull-mounted electrode systems and of the anode current and voltage were scheduled when the ship was in a steady state, either at rest or in motion and the current adjusted to hold the hull potential at the designated value, 850-900 millivolts.

When, for example, the ship started to move, a current increase was scheduled. The suggested increase was 20 percent until experience with the particular ship dictated otherwise. When a change in current had been made, the hull potentials were to be checked a half hour after such change to determine if the change had the desired effect. Variations in hull current and measurements of potential would then be made at intervals thereafter as required, until the optimum hull potential was reached.

In order to avoid frequent coupling and uncoupling of anodes due to current demand changes with motion, the schedule was made broader than minimum anode current density and power considerations would dictate, i.e., some sacrifice of power was made in the interests of convenience.

The over-the-side reference electrode readings were scheduled as the standard value for the hull potential, until it had been established that the hull-mounted electrodes gave comparable readings.

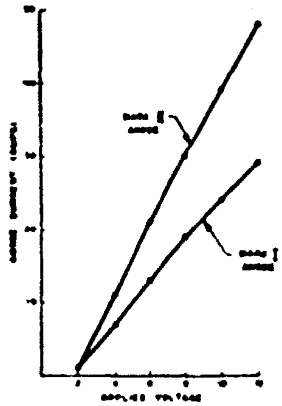

Figure 6—Current-voltage relationship for Mark I and Mark II anodes

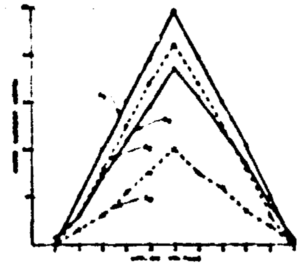

Figure 7—Current-voltage relationship showing recovery when unused anodes are connected to the system.

When this happened, the over-the-side readings could be taken once a week as a check or, if erratic readings were obtained from the hull-mounted electrodes at any time. Daily readings with the hull-mounted electrodes were scheduled, first with the anode current on and then with the anode current off momentarily.

Operational Experience

On undocking in July 1956, the current-voltage relationship for each anode was obtained and the typical results shown in Figure 7 were used for scheduling of the anode connections.

Unfortunately, the available AC supply with the ship berthed was overloaded and it was not possible to provide power to the system from this source. A junction box for shore power was planned for the system, but . not installed until some seven months after the ship had been undocked. When at sea, power was taken from a generator used to run special equipment needed only at sea. Thus, for the first seven months, the anodes were activated only while the ship was underway and the plot of current demand against time during this period is not continuous and the potential time curve shows wide fluctuations. Furthermore, the number of anodes in use was increased above the normal requirement to allow reasonably quick buildup of protection during the time the ship was underway.

It was soon observed that the hull potential as read by the hull-mounted electrodes was within 10 mV of that given by the over-the-side reference electrode. This is believed to be fortuitous for the case of the stern reference electrode as the stern anodes and two large cathodes (the propellers) were close by, and it indicates that by strategic placement of the reference electrode, it is possible to obtain "hull potentials" that are useful in the stern area. It was also noted that the response of the stern electrode to a current change was much quicker than for the forward electrode, a not unexpected effect but one that may prove important in automatic current control. The response of two reference electrodes (one near the field of an anode and one at a distance from it) can give better sensing of the effects of current changes than can be obtained from distant electrodes because the rate of polarization of large structure is rather slow.

The graph of the current-hull potential relationship is shown in Figure 8. The current demand for protection of this ship was rather less than that required for similar destroyers using magnesium and steel anodes, because there was no large wastage of current near the anode, the plastic current shield had the effect of moving the anode array from the hull and, the energized stern anodes close to the propellers were used.

Because current demand was relatively light most of the time only four, or at the most five, anodes were energized in order to maintain the hull potential and to meet the minimum current density requirement. As a result, some of the anodes were not used before the ship was drydocked in July 1957. Just prior to this drydocking, tests were made to determine whether there had been any change in the current-voltage relationship of the anodes with time, i.e. if the peroxide layer formed during the year changed the metal anode resistance. All anodes used and unused were tested with the results given in Figure 7, 9-10. Here the designations "P" and "S" refer to the side of the ship and the anodes are numbered from fore to aft thus P5 and S5 are the Mark I anodes at the stern.

The ampere-volts readings were taken with the voltage both increasing and decreasing in uniform steps as shown by the graphs.

The anodes in use at the time the readings were taken (June 29, 1957) were P, P, S, and S, and the current-voltage relationship was very close to that for the original readings taken shortly after fitting, indicating a negligible resistance change. The five anodes, P, P, S, S and S, that had not been used during the year showed distinctly lower amperes per volt (Figure 10). In order to determine if they would recover from the effect of disuse, two of the anodes, P, and S, were substituted for P, and S. Three days later, the current-voltage relationship was again found for these anodes with the results shown in Figure 7.

From this figure, it can be seen that the anodes quickly recovered from the effect of disuse. This was partly indicated by the increase in current output for corresponding voltages in Figure 10 for the unused anodes as the voltage was decreased from the maximum of 12 volts. The change in resistance was probably due to the formation of a corrosion film over the anode surface more resistant than the peroxide film. From Figures 7 and 10, the effect of the longer cable runs to the forward anodes, P, P, S, and S, compared to those for P, P, S and S, can be seen in spite of the fact that quite low resistance cables were used as conductors.

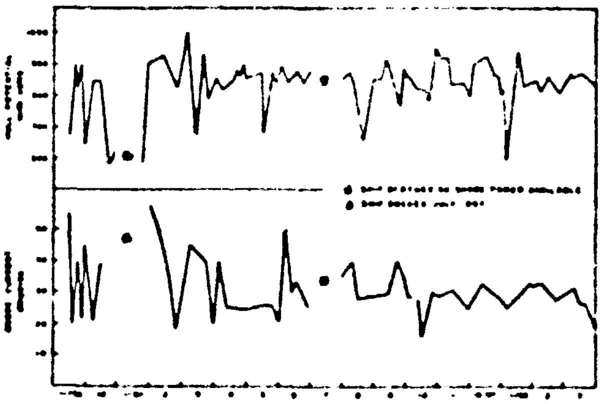

Figure 8—Relationship of anode current and hull potential with time.

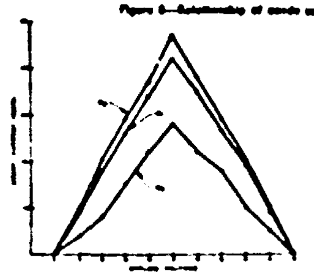

Figure 9—Current-voltage relationship for anodes in continuous use

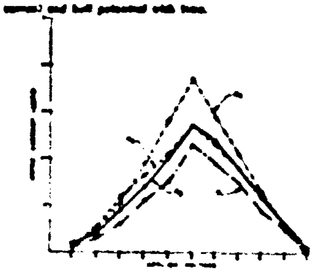

Figure 10—Current-voltage relationship for anodes not in use

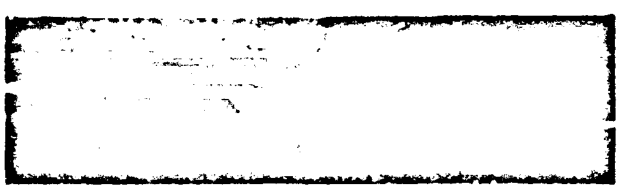

Figure 11—Adjacent anodes in use one year (left) and three days (right). [illegible]

Inspection of Ship After One Year

An inspection of the ship, carried out early in July 1957, showed very little evidence of anode consumption on those anodes that had been in use continuously. The anodes that had been in use for the three days prior to docking, P, and S, showed very little difference from those in continuous use. For the active anodes, the peroxide film was intact and very thin and the height of the surface of these anodes was approximately the same as that of the unused ones, i.e., the anode surface was still about ⅛ inch above the surface of the bracket material.

In Figure 11, the adjacent parts of an anode used three days and a continuously used anode are shown. From this photograph, it may be seen that, in addition to the small anode loss mentioned above (a), there is cathodic deposit at the heads of many of the retaining screws, (b) the sheeting above the forward anode had come away from the hull as can be seen by the wrinkling, (c) there was no noticeable deterioration of the bracket material, (d) the steel straps around the edges of the neoprene sheeting had held the edges securely, and (e) the paint was in poor condition.

In regard to (a), the face of the brackets was not covered with sheet during installation as originally intended, and the need for such a covering in addition to the putty is indicated. The loosening of the sheeting (b) is a more serious defect. In applying the polychloroprene, it is part of the technique to remove the air from blisters with a hypodermic needle and roll the sheet flat. This procedure leaves a hole in the sheet, which is partly taken care of by overcoating with cold bond solution, but the resulting film is susceptible to hydrogen blistering and, in some instances this will lift the sheeting away from the hull. When the

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TABLE 1—Principal Characteristics of Alternative Installations

Anode System	Reported Life Time Years	Streamlining	Ruggedness	Maximum Current Density	Ease of Fitting
Lead 2% Silver	10 +	Good. Bracket 1" thick. Total thickness overall thickness may be halved.	More than graphite or platinum; less than steel and magnesium. Conforms to contours of ship. Excellent shock resistance.	Depends on power considerations rather than anode. Better than graphite; slightly less than platinum.	Requires current shield and special bracket as do graphite and platinum. Easier to fit and cheaper than graphite bracket. More expensive than platinum bracket. Labor for fitting less than steel, more than magnesium.
Steel	3 (renewable every three years)	Fair, not as good as lead silver, thicker bracket.	Anode rugged but wooden bracket susceptible to mechanical damage and subsequent loss of anode.	Depends on power considerations and expected life time of anodes.	Does not require current shield. Wooden bracket must be fastened to conform to contour of bilge keel. Steel anode sections difficult to handle and to adapt to contour of bilge keel.
Platinum 90-10 Pt-Ir alloy 10 mils thick	10 + (indefinite if not damaged and remaining intact)	Good, same as present lead silver. Bracket at leading 1" thick.	Thin foil platinum anode susceptible to tearing. Platinum clad on less noble substrate more rugged but still susceptible to puncture and corrosion attack on substrate.	Limited only by power considerations.	Requires current shield and special bracket. Bracket less expensive than for other permanent current systems. Fitting labor same as for lead-alloy.
Graphite	10 years	Poor. Requires 3" thick, short streamline bracket.	Poor. Graphite fragile, susceptible to cracking and shocks.	Limited to 10 amps per sq ft to maintain 10 yrs life. Less than lead or platinum.	Requires current shield and costly bracket. Difficult to adapt to hull contours. Must be used in short, thick sections only.
Magnesium	2 years	Poor due to irregular corrosion pattern and decreasing thickness of anode areas.	Very good. Poor corrosion pattern resulting in necking or dropping of caps. [illegible] and loss of portions of an anode necessitating earlier replacement.	Current may be limited further by circuit resistance.	Easily fitted, no current shield required. Can be adapted to mild changes in hull contour.

TABLE 2—Relative Costs of Anode Installations for Destroyers

Item	Lead Alloy	Magnesium	Steel
Cost of fitting including overhead:			
Labor	[illegible]	[illegible]	[illegible]
Material	[illegible]	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]
CAPITAL COST			
Anodes complete	[illegible]	[illegible]	
Brackets and cable	[illegible]	Brackets not required	Included above
Plastic shield	[illegible]	Not required	Not required
GRAND TOTAL	[illegible]	[illegible]	[illegible]

Material cost includes anodes and brackets.
Eight Mark 11 anodes, Two Mark 1 anodes.
30 anodes.

sheet becomes large enough, the sheet either breaks or is torn by water action, thereby spoiling the current shield. Ease of application and effects of puncturing with the needle can be both improved by the use of two sheets of 1/32 inch material rather than the single 1/16 inch sheet. The paint, mostly the anti-fouling paint, failed close to the anode shield and at distances away from the anodes.

The failure of the undercoating was slightly worse near the edges of the shield, indicating that the width of the shield above the anode was a bare minimum for this paint. It is to be noted with interest that where the A/F paint was applied over the current shield, it was in better condition than on the hull plating, i.e., with an impermeable barrier under the paint alkaline attack was almost even though near the anode.

Discussion

Electrical and Mechanical Considerations

In view of the relatively short experience with the lead silver alloy anodes no specific coulomb efficiency can be quoted. From the results of the test to date, however, it can be said that provided the maximum anode current density of three amperes per square foot is maintained, the anode will have a life expectancy greater than 10 years.

The properties of this system such as streamlining, ruggedness, expected life, ease of fitting, maximum available current and density are compared in Table 1 with steel, platinum, graphite and magnesium anode systems.

It is seen from the table that lead 2% silver anodes without considering cost all economics are comparable in desirable properties to steel and magnesium on the overall picture and rate better than graphite or platinum because of their greater ruggedness.

Economic Considerations

The economic considerations can be broken down into three subheadings, capital costs of anodes and brackets, cost of fitting and cost of operating. The capital costs and fitting costs for lead alloy, magnesium and steel are given in Table 2.

The primary cost for the platinum alloy is the price of the platinum itself. Because no noticeable loss of the platinum alloy, 90% platinum, 10% iridium, has occurred on the anodes in use for over four years, it is assumed that there would be a high salvage value for the platinum and the capital cost in this case would be equivalent to the interest rate on the capital for the platinum.

The prime cost for the graphite anode assembly is its bracket because graphite is cheap. To give the graphite mounted on metal ships good protection against shock a special type of bracket is required. The bracket material used for the graphite was the same as for the lead-alloy anode brackets. However, for comparable area of anode working face, about three times the amount of bracket material is required for the former, with the result that for equivalent current per unit the graphite anode assembly costs almost twice that of the lead-silver anode assembly.

Because all permanent anode systems require shielding and the shields are distributed over the hull in the same way, cost of fitting will be the same in all cases. Considering this in view of the above remarks on capital costs for lead, platinum and graphite and the fact that for the lead anode the bracket cost is 58 percent of the assembled anode cost, it is concluded that the lead silver system would have the lowest capital cost. This statement assumes that over a 10-year period interest charges on the capital invested in platinum would exceed the cost of a lead silver anode and its bracket.

Table 2 gives comparative costs for lead, steel and magnesium anodes on destroyers. With a 10-year anode life for lead, and a two and three year life for magnesium and steel respectively it is seen that the lead-silver system is the more economical.

Cost of Operation

For equivalent capital cost of anode and bracket, the ratio of working areas of platinum alloy, graphite and lead alloy anodes would be 1:7.5:15 and hence the power costs per anode would be approximately in the reverse ratio. For a ship with its underwater hull in a given condition the minimum current demand for protection is more or less fixed, so that the power demand can be minimized only by using the least voltage required to produce the current. This again, is dependent on the geometry of the anode.

At the same equivalent cost per working anode, lead 2% silver alloy would show lower operating cost. However on the overall picture such a comparison cannot be used. For permanent anodes with plastic shields, power costs of a system in being would be the same for lead, graphite and platinum. Because of the better current distribution resulting from the use of shielding, the current required for protection with the lead-silver system described is less than that required for presently used steel systems.

However, because the steel anodes require less driving voltage these higher currents put out by steel systems result in the same power output. Thus actual power cost would be approximately the same for all the impressed current systems being compared and only a galvanic system such as magnesium would offer any substantial saving. It can be concluded from the properties tabulated in Table I and the economic analyses made above that lead-silver anodes compete very favorably with other presently used systems.

It should be stressed here that the order for the capital costs is based on a predicted performance for the lead alloy anode and the estimated costs of production of the anodes using the facilities available to date. If production was undertaken commercially, there is no doubt that costs would be radically altered, but it is still believed that they would favor the lead alloy system, particularly if further experience indicates that a life longer than 10 years can be expected, or that the thickness of the anode can be halved and still give a minimum 10-year life.

From the foregoing discussion it is seen that lead alloy anodes offer many advantages over competing platinum and graphite systems as a permanent steel anode and also a number of advantages over steel and magnesium anodes.

General Observations

In common with all permanent anode systems, a good, high-duty current shield must be used around the anode. To date, polychloroprene sheeting has proved to be the best available material for the shield, but a better material or improved ways of bonding it to the hull plating should be sought. It has been suggested that two thin sheets of material be used rather than a single thicker sheet. Cheaper substitutes also should be sought for this sheeting, because it constitutes a fairly large fraction of the fitting cost of permanent anode systems.

For permanent anode systems, those that require the least applied voltage are to be desired from point of view of shielding, because there would be less voltage applied across the shield material immediately adjacent to the anode. This means, in essence, that the permanent anode with the largest working face is to be preferred. The 4 x 54-inch working face of the Mark II is thought to be close to the practical maximum length for handling on a bilge keel. Such an anode weighs about 150 lb and until installed, reasonable care must be taken to prevent excessive flexure. As stated earlier, the 4 x 36-inch Mark I anode face is considered the practical maximum for mounting at the stern.

The use of energized stern anodes is evidently very worthwhile, because in this location they apparently reduce the total current requirement for protection.

Major disadvantage of the lead-alloy anode compared to platinum or graphite anodes is the dependence on the peroxide film to protect the underlying metal against corrosion and the maintenance of a minimum anode current density to form this film. However, provided this minimum anode current density is maintained, it would appear that the protective film is adequate even at high ship speeds and a long anode life can be expected. Moreover, if the film suffers damage, it is self-healing, a distinct advantage when compared with platinum clad anode.

The use of hull-mounted electrodes is more convenient for the measuring of hull potentials than the over-the-side electrodes. Because there appears to be very little difference between the readings obtained with either type when the former electrodes were out of the immediate field of the anodes, the use of over-the-side electrodes need only be resorted to for checking the hull-mounted electrodes.

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