Design and Programming of Cathodic Protection for SHIPS

A. Mathiazhagan

Abstract—**In order to minimize the risk of failures or major renewals of hull structures during the ship's expected life span, it is imperative that the precaution must be taken with regard to an adequate margin of safety against any one or combination of failure modes including excessive yielding, buckling, brittle fracture, fatigue and corrosion. The most efficient system for combating underwater corrosion is 'cathodic protection'. The basic principle of this method is that the ship's structure is made cathodic, i.e. the anodic (corrosion) reactions are suppressed by the application of an opposing current and the ship is there by protected. This paper deals with state of art in cathodic protection and its programming in ship structure.**

I. INTRODUCTION

Cathodic protection was first practically applied in 1825 when soft iron anodes were installed to provide protection against corrosion of the copper cladding on the submerged hulls of sailing vessels. Later, in the early 1900's, when steel began to be used as a shipbuilding material in preference to naturally corrosion resistant iron on the grounds of economy and better mechanical properties, corrosion of ship's hull was identified as serious problem. The area worst affected was at the after end of a vessel - an area of high wave turbulence and adjacent to the bronze propeller which creates a galvanic couple causing pitting of the adjacent steel. This problem was alleviated by the installation of zinc anodes around the stern frame and on the rudder - a practice that continues even today. Initially results were varied because it was not appreciated at purity of the zinc in the finished anode is vital to its performance. Contamination of the zinc by iron or copper causes the anode to passivate and become useless. It is vitally important that anodes are acquired from a reputable supplier whose manufacturing techniques avoid any possibility of contamination and whose production methods include routine metallurgical analysis.

Just prior to the Second World War, the Canadian Navy conducted experiments with the use of magnesium as an anode metal on the underwater external hull plating of their destroyers. But nevertheless, use of this metal in cargo/ballast tanks has had to be abandoned due to its propensity to cause sparks on impact and to its property of evolving excessive quantities of potentially explosive hydrogen gas in operation (1).

Research then shifted to the development of new alloys of zinc and aluminium which have vastly increased the electrical capacity as well as achieving unproved reliability and more negative electrical potential which greatly improved their performance.

In parallel with the introduction of aluminum alloy sacrificial anodes in the late 1950's the idea was conceived that low voltage D.C. current could be applied to inert metals so as to save the cost of replacing sacrificial anodes at regular intervals and indeed, so-called impressed current systems are now in common use - not only for the external hulls of ships but also for the internal surface of cooling water systems at sea and ashore. Before a discussion of cathodic protection design, it is important that corrosion fundamentals and cathodic protection principles be understood (2).

Cathodic protection has been widely used for protecting structures from corrosion. The design of cathodic Protection systems normally relies on a combination of experience, experimental data. However, problems and failures of cathodic protection systems not only has an economic cost, it can also present a threat to life and the environment.

Recent advances in computer modeling have enabled the performance of cathodic protection systems in protecting metallic surfaces to be predicted by simulating the environment and the electrochemical processes on the metallic surfaces. These advances have been applied on offshore and marine installations such as offshore platforms and ships (3).
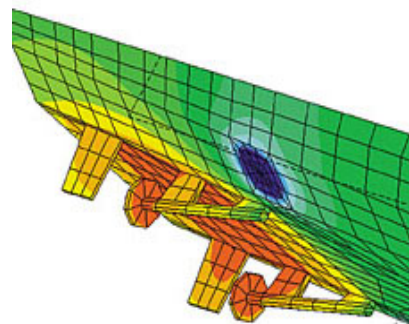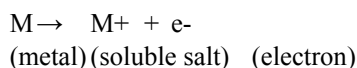

Fig. 1Modelling of cathodic protection of ship

Predicting the cathodic protection systems in the marine environment is a major application area of computer modeling. The design of a cathodic protection system is of great interest to defense organizations not only to ensure the integrity of the vessel, but because it contributes to the electric and magnetic signature of the vessel. Both sacrificial and impressed current cathodic protection (ICCP) systems on oil and gas structures, ships and boats can be modeled. The software enables the designer to quickly develop a full 3D virtual prototype of the vessel and its cathodic Protection systems.

Dept of Ship Technology, Cochin University of Science and Technology, Kochi- 682022, Kerala, India. Corresponding author: alagan@cusat.ac.in

Using this computer model 1) the designer can assess the performance of both sacrificial and 'active' ICCP systems. 2) Optimize the design by varying parameters such as anode location, reference electrode location and number of anodes 3) investigate interference effects caused by nearby cathodic protection systems, electrical sources, docks, pipelines or other metallic structures 4) determine protection potential, corrosion rates and the life of the cathodic protection system 5) evaluate the effect of different operating environments and how they impact the effectiveness of the cathodic protection system 6) evaluate the performance of the cathodic Protection system under potential damage scenarios 7) predict the ICCP Control system behavior using the ICCP software which simulates its transient dynamic response under working condition 8)model any geometry including ships, boats, pipelines and storage tanks using the comprehensive element library.In this application, the protection potentials achieved on the ship by the cathodic protection system are predicted. The user can use the spreadsheet type interface to easily assess the effect of alternative cathodicprotection system designs, different operating environments and the condition of the hull on the protection provided by the cathodic protection system (4).

II. THE PRINCILPES OF CATHODIC PROTECTION

Metal that has been extracted from its primary ore (metal oxides or other free radicals) has a natural tendency to revert to that state under the action of oxygen and water. This action is called corrosion and the most common example is the rusting of steel.
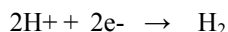
Corrosion is an electro-chemical process that involves the passage of electrical currents on a micro or macro scale. The change from the metallic to the combined form occurs by an "anodic" reaction:
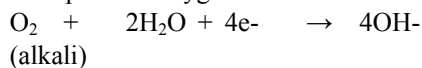
$$M \rightarrow M+ + e-$$

(metal)(soluble salt) (electron)

A common example is:

$$Fe \rightarrow Fe++ + 2e-$$

This reaction produces free electrons, which pass within the metal to another site on the metal surface (the cathode), where it is consumed by the cathodic reaction. In acid solutions the cathodic reaction is:

$$2H++ 2e- \rightarrow H_2$$

In neutral solutions the cathodic reaction involves the consumption of oxygen dissolved in the solution:

$$O_2 + 2H_2O + 4e- \rightarrow 4OH-$$

(alkali)

Corrosion thus occurs at the anode but not at the cathode (unless the metal of the cathode is attacked by alkali).

The anode and cathode in a corrosion process may be on two different metals connected together forming a bimetallic couple, or, as with rusting of steel, they may be close together on the same metal surface.

This corrosion process is initially caused by:

Differerence in natural potential in galvanic(bimetallic) couples. Metallurgical variations in the state of the metal at different points on the surface. Local differences in the environment, such as variations in the supply of oxygen at the surface (oxygen rich areas become the cathode and oxygen depleted areas become the anode).

The principle of cathodic protection is in connecting an external anode to the metal to be protected and the passing of an electrical dc current so that all areas of the metal surface become cathodic and therefore do not corrode. The external anode may be a galvanic anode, where the current is a result of the potential difference between the two metals, or it may be an impressed current anode, where the current is impressed from an external dc power source. In electro-chemical terms, the electrical potential between the metal and the electrolyte solution with which it is in contact is made more negative, by the supply of negative charged electrons, to a value at which the corroding (anodic) reactions are stifled and only cathodic reactions can take place. In the discussion that follows it is assumed that the metal to be protected is carbon steel, which is the most common material used in construction. The cathodic protection of reinforcing carbon steel in reinforced concrete structures can be applied in a similar manner (5).

III. MONITORING AND MAINTENANCE OF CATHODIC PROTECTION

Cathodic-protection systems may be monitored effectively by the measurement of structure-to-electrolyte potentials, using a high input impedance voltmeter and suitable half-cell. The standard practical half-cells are copper/copper sulphate, silver/silver chloride/seawater, silver/silver chloride/ potassium chloride and zinc.

Adjustments are made to the cathodic-protection current output to ensure that protective potentials are maintained at a sufficiently negative level as defined by the project specification. The level of protection in water is accepted at steel potentials of minus 850 mV (wrt Cu/CuSO4) or minus 800 mV (wrt Ag/AgCl/seawater).

Transformer rectifier outputs may be displayed by telemetry at central control stations. Many cathodic protection systems are increasingly being controlled and monitored by remote computers and modem links. Other communication systems that enable, for example, pipe-to-soil potentials to be monitored from a helicopter or light aeroplane, are available. Galvanic-anode outputs may also be monitored, as can currents in electrical bonds between structures. Tests to measure interaction are usually conducted annually where areas are at risk or after adjustments to cathodic-protection current output.

Maintenance includes the mechanical maintenance of power-supply equipment and the maintenance of painted surfaces of equipment.It is good practice to inform all owners of cathodic protection systems and infrastructure in the area of influence of any new cathodic protection systems, or of significant changes to existing systems, so that the effect on these facilities may be assessed(6).

IV. CATHODIC PROTECTION CRITERIA

This is apparent from the practical point of view that the value of -0.85 V Vs a saturated calomel copper - copper sulphate reference cell generally accepted as a criterion for

the cathodic protection of steel. Unprotected bare steel in seawater will exhibit an electrical potential of about -0.52 V Vs saturated calomel half-cell. When the potential of steel is shifted by 0.33 V in negative direction then the corrosion of steel in seawater is stilled.

In accordance with Farad * s law the rate of metal weight loss is directly proportional to current density. In case of steel in seawater, the average corrosion rate of about 25 mg/dm2 (day) is equivalent to an anodic current density, of about 15 MA/ft2. This has been found to be the current density to protect the steel in quite seawater during the early period of current application. As the corrosivity of the water is increased by environmental factors such as higher velocities oxygen concentration, temperature, and bacterial metabolic process, leading to higher rate of corrosion, the current required for cathodic protection also increases. The cathodic protection systems for ships and other large complex or critical structures involve much careful study and engineering; this is likely to require the services of specialists in this field for designing it (7, 8).

V.   DESIGN OF CATHODIC PROTECTION SYSTEMS

The design process for cathodic protection of marine structures includes the various necessary input parameters and the decisions, which must be made. This is based upon a listing of design considerations. Thus the initial step is to determine the current density requirement, which is based largely upon environmental parameters (water velocity, wave height, temperature, dissolved oxygen etc.) from this and physical features of the structure the net cathodic current is then calculated. Based upon this and other considerations a choice is made regarding the type of cathodic protection system - sacrificial Eg: anode or impressed current. This is followed by various aspects in the design of either of these including anode selection, sizing, number and placement.

VI.   SACRIFICAIAL ANODE

A sacrificial anode can be any metal but it should be substantially anodic to the metal to be protected. A sacrificial anode can be described as a metal which itself corrodes instead of another anode (metal). Sacrificial anodes are pure zinc, magnesium or aluminum. These anodes must be electrically connected to the surface to be cathodically protected and must be in contact with the conducting environment. A voltage can be measured between the sacrificial anode and metal to be protected. Sacrificial anode system is used to protect the ship hull, ballast tanks, heat exchanger underground tanks and submerged pipelines network. Before a satisfactory cathodic protection design can be made using sacrificial anodes, the following information has to be available or decided upon, 1)Information on the area of die steel work to be protected, 2)the type of coating, if any, that is to be used,3)the length and frequency of time me steel work is in contact with the electrolyte. In ships, certain ballast tanks are only full of ballast water for certain periods of time and it is only in these periods of time mat the sacrificial anodes operate, 4) the life required from me

cathodic protection system, 5) the current density to be used to protect the structure has to be chosen and different situations require different current densities. These current densities in practice are in the range of 20 mA/m2 - 4000 mA/m2 6) the resistivity of the electrolyte must be determined in order that die right anode material is chosen.

For any specific situation, the total anode weight, the total current required and the number of anodes which Ij meet die current and weight requirement are calculated as follows. The wetted area of steel to be protected is calculated from drawing or direct measurement.

The total current I (A) needed is =

$$\frac{\text{Area (m}^2\text{) x current density mA/m}^2}{1000}$$

The following formula gives die weight of anode material required

$$\text{Anode weight (Kg)} = \frac{\text{Current (A) x life (y) x 8760}}{\text{Capacity of materials (A hrs /Kg)}}$$

where life is the design life in years (1 y = 8760h)

The minimum number of anodes required per structure is assessed from the following formula

Number of anodes = Weight of anodes required individual net weight

current required =individual anode current output

Note : The anode selection must satisfy both the total weight and total current output requirements as follows

Weight requirement = No of anodes x individual net weight

Current requirement=No. of anodes x individual anode current output.

All anodes are to be evenly distributed around me submerged hull near or just above bilge; an increase in number of anodes in the stern area is recommended due to high current density demand caused by propeller.

Recommended Practice for installation.
1) Anodes are equipped with east in brackets for direct welding to hull.
2) Anodes must be evenly distributed according to drawing (See fig. 4).
3) No anodes on flat bottom causing problems during dry locking.
4) Do not paint die anodes.

VII.   IMPRESSED CURRENT CATHODIC PROTECTION

Impressed current cathodic system consists essentially of several anodes, reference electrodes and control units. These are inter-connected.

Types and size of the components and their positions in and around the hull are specified according to design parameters. Consideration must be given to the propeller, any exposed shafting and the rudder with the main hull structure protected. The propeller and exposed shaft are protected by grounding the shaft to the hull structure with a shaft slip ring to make these appendage electrically common with ship's hull. Bonding rudderstock to ship's hull grounds the rudder

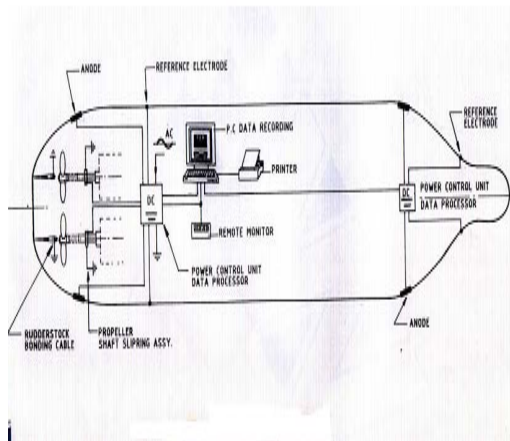and in this way the rudder is also protected by the digital system.

Fig. 2 Impressed current system for ship

The driving voltage for cathodic protection in this type of system is provided by an external power supply and so, inherent electrochemical potential difference between structure and anode are of no consequence. In this case also the type of anode is important to effective and efficient operation. Thus scrap iron or steel can be used but frequent replacement is necessary. Most recent construction has involved platinum coated niobium or titanium. The fact that these can pass current without significant weight loss due to their passive behavior.

Because of the large amount of current which can be provided by a single impressed current anode, relatively few anodes are required in comparison to the sacrificial case from the stand point of simplicity, this is advantageous, however, if a single anode fails, protection of a significant portion of the structure may be lost.

It is necessary that anode must be surrounded with protective shield to avoid very high cathodic current density in the immediate vicinity of the anode. Enclosing anode by neoprene shield can do this. An electrical control device automatically changes current required for cathodic protection. Reference electrodes are used to monitor the protection and to know whether all the structures are protected.

VIII. IMPRESSED CURRENT INSTALLATION

Automatically regulated 3-phase rectifier (R) is connected to the anodes (PA), which are fitted in cofferdams facing outwards in the ship's side, the negative terminal is connected directly to the hull. From die anodes current is emitted into me seawater returning to hull and propeller. The current output from the rectifier is regulated automatically which is normal but inserting a special card in the control section can easily do manual regulation.

The reference electrodes (RE) have a dual mission. Finally, they must continuously monitor the hull's degree of polarization i.e. protection. Secondly they must effect on increase or decrease of the amount of current supplied to the platinized titanium anodes by regulation of the controller, following signals from monitoring unit (M). The rudderstock should be short circuited to the hull by a heavy flexible cable.

The amperage supplied to the anodes depends upon die voltage reading from the reference electrodes (RE) and resulting signal from the monitoring unit (M)
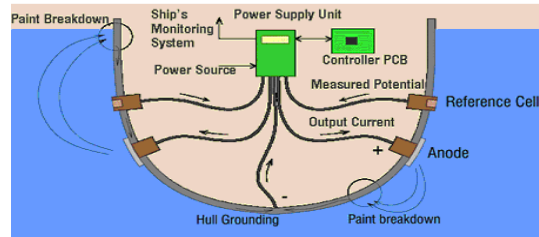

Fig. 3 Design of Impressed current system for ship

IX. IMPRESSED CURRENT DESIGN

Design steps are as follows

* Select the current density to be applied from the results of cathodic protection tests and from any available data

* Compute the total current requirement to achieve the required current density (total current) = current density x superficial surface area

* Design the d.c wiring systems for the most economical cable size in accordance with standard electrical practices and then calculate the total IR drop in the circuit

* Select rectifier voltage and current outputs

* Design the electrical circuits, fittings and switchgear in accordance with standard electrical practice

* Select the location of cathodic protection test station

* Prepare project drawing and specification

X. PROGRAMMING FOR POSITIONING OF ANODES

In the process of determining the position of sacrificial Anodes we need to divide the hull into different parts having same hull surface area. The algorithm for the division process is described below.

The input of the program is offsets

The output is the position of stations, which divide the ship into equal hull surface areas

XI. ALGORITHEM FOR THE POSITIONING OF SACRIFICIAL

1) Draw the body plan in autocad by just inputting offsets as spline.
2) Just measure the length of body plan at each station.
3) Simsonise or integrate that length to get hull suface area upto each stations starting from aft.
4) Draw the graph with length (x axis) *vs* hull surface area on the y-axis.
5) Divide the total curve into parts having same hull surface areas.

Note the position of each division on the curve and take the distance of each from the aft

XII. CONCLUSION

The most probable mechanism of cathodic Protection of steel in seawater is that a sufficient number of electrons from a preferred external source are applied to the surface of the metal being protected so that electrons from external source accommodate a cathodic reaction such as oxygen reduction or hydrogen evolution. Without cathodic protection the electrons reacting with oxygen at the cathodic surfaces must be supplied by corrosion at the anodic areas. As additional electrons are supplied from an external source these additional electrons accommodate the oxygen reduction reaction. Recently, increased attention has been given to hybrid cathodic protection system. These are a combination of both sacrificial anodes and impressed current and permit the advantages of each to be realized. A major disadvantage of impressed current systems has been lack of continuous operation. Using of hybrid system, protection would be available during these period, via the sacrificial anodes. While the impressed current is operative, however, the sacrificial anodes pass little current. Thus the weight of the anodes can be much less than is typical for a conventional sacrificial system. The search is presently in progress regarding the effect of intermittent operation upon sacrificial anode performance.

The successful operation of new generation marine structures will require that existing marine corrosion prevention practices be modified that new concepts in cathodic protection be developed.

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