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Marine Impressed Current Cathodic Protection System

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Abstract: *The paper presents Marine Impressed Current Cathodic Protection system like a method of protection of the ship against corrosion. By installing and developing ICCP systems, we minimize the risk of failures or major renewals of hull structures, propeller and other still or iron parts of the vessel, which can be attacked by corrosion, during the ship's expected life time and like this also ship owners can cut down repair costs.*
This article major points are: how to design and choose the best Impressed Current Cathodic Protection system - ICCP for a ship, what are the main components and how it works an ICCP system, types of anodes, what parts of the ship the ICCP system can protect, installation of the system components and maintenance.

Keywords: *ICCP, ship, protection, corrosion, design*

1. Introduction

For improving the corrosion protection design and for extension of ship's life time, marine industry had given a great attention to modelling and understanding of electrochemistry-current distribution.
Because steel and iron are used as a shipbuilding material, corrosion of ship's hull was identified as a serious problem.
The area most affected is 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.
Some ship owners have a bad habit. In order to decrease dry dock stay costs, they cut anodes and put them away soon after the ship has been cleaned and inspected for repair, not thinking about the purpose of the anodes and about life and environment protection. They do not understand that in time expenses will be much higher, then the economy that they try to achieve now by cutting the anodes.
Cathodic Protection has been widely used for protecting structures from corrosion. The design of Cathodic Protection Systems normally relies on a combination of experience and experimental data.
Problems and failures of Cathodic Protection systems is not only an economic cost, but it can also present a threat to life and the environment.
Impressed Current Cathodic Protection (ICCP) systems can be installed on all types of ships:

- Cruise Ships
- Container Vessels
- VLCCs
- Ferries
- FPSOs
- Ice Class Vessels

Most operators recognize the need to combine modern hull coatings with a purpose designed Impressed Current Cathodic Protection system.

2. Computer modelling

Modelling is more than just a representation of the actual structure. It is a methodology for advancing the understanding of system performance. It is a methodology for determine relative importance of the many factors that have an influence on system performance.

Recent research in computer modelling, are using different programs like Ansys Fluid, AutoCAD 3D. They 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 (Figure 1).
These advances have been applied on offshore, marine installations and on ships.

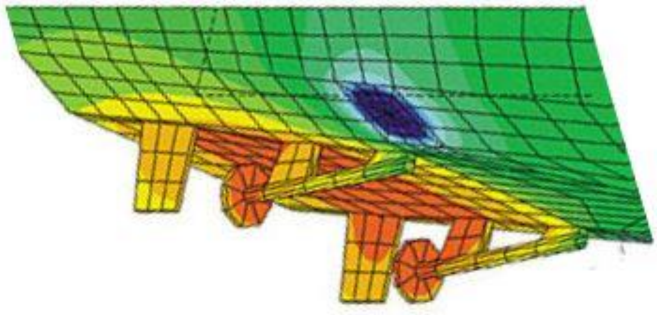

Fig. 1. Modelling of Cathodic Protection of ship

Predicting the Cathodic Protection systems in the marine environment is an important application area of computer modelling.
Using the software enables the designer to develop a full 3D virtual prototype of the vessel and its Cathodic Protection system.
Advantages of using a computer modelling program:

- The designer can assess the performance of ICCP system;
- Optimize the design by varying parameters such as anode location, reference electrode location and number of anodes;
- Investigate interference effects caused by nearby Cathodic Protection systems, electrical sources and metallic structures;
- Determine the protection potential, corrosion rates and the life of the Cathodic Protection system;
- Evaluate the effect of different operating environments and their impact on the effectiveness of the Cathodic Protection system;
- Evaluate the performance of the Cathodic Protection system under potential damage scenarios;
- Predict the ICCP Control system behaviour using the ICCP software which simulates its transient dynamic response under working condition
- Possibility of modelling any geometry including ships, platforms, pipelines, storage tanks and others.

The design process for Cathodic Protection of marine structures includes various necessary input parameters and the decisions, which must be made.
There are design considerations to take in account like:

- Determine the current density requirement, which is based largely upon environmental parameters.
- The net cathodic current is then calculated.

They are determined various aspects in the design like anode selection, sizing, number and placement [1][2].

3. Corrosion

In principle, the major factors that must be considered in protecting a hull from corrosion are:

- The nominal wetted surface area which requires protection;
- The material characteristics of metallic components exposed to the seawater

- The chemical aspects of the bulk electrolyte (seawater) under operational conditions (seawater conductivity, pH, dissolved oxygen and surface reactions).

These reactions are influenced by: the temperature, velocity and diffusion properties of the surfaces, both with and without Cathodic Protection applied.
The growth of calcareous deposits, on the ship hull, while cathodic ally protected, all surfaces may foul with marine organisms, resulting in a biological system that will further influence the surface properties of the metals involved.
The principle of Cathodic Protection is that, when 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 [3].
This corrosion process is caused by:

- Difference in natural potential, in galvanic 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.

Corrosion takes many forms in the marine environment. It can be seen as pitting on hull plates; in the disintegration of weld seams; around bow thrusters and on the surfaces of rudders and other vital components (Figure 2).

Fig. 2. Corrosion on hull plate

A well designed ICCP system can eliminate these problems, safeguarding the structural integrity of the vessel and significantly reducing maintenance costs throughout its operational life.
Metallic corrosion is an electro-chemical reaction in which the metal combines with a non-metal, such as oxygen, to form a metal oxide or other compound. This depends upon the nature of the environment.
Different metals have different tendencies to corrode, activity or potential. These potentials can be tabulated and form the electro-chemical series.
A more practical approach is the determination of the tendency of certain metals to corrode in a particular electrolyte, such as sea water [4][5].

4. Cathodic Protection

4.1 Introduction

Some metals and alloys have two positions in the series, marked Active and Passive.
The active position is equivalent to the position if corrosion is occurring and approaches the electro-chemical series position for the material.
The passive position relates to a non-corroding situation where the material is protected by a self-forming surface film.
If two metals are placed in an electrolyte (e.g. sea water or damp soil) and are in direct electrical contact, a current will pass through the electrolyte from the more active metal onto the least active metal (Figure 3). The least active metal does not corrode and is termed the cathode. The more active metal, the anode, passes into solution and the flow of electrical current increases. This is a metal ion and electron transfer process - corrodes.

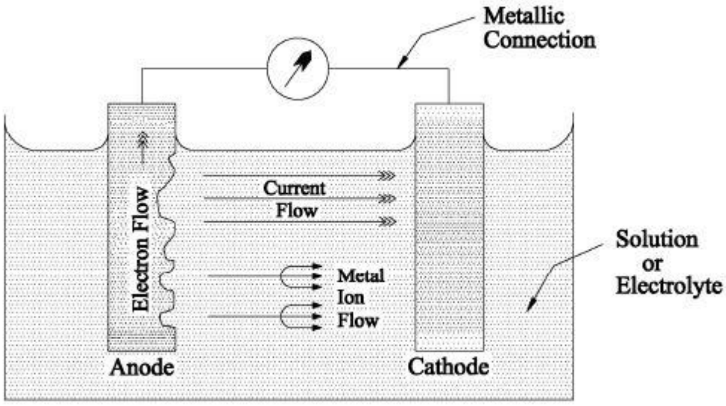

Fig. 3. Simple Corrosion Cell

The anodic and cathodic areas in a corrosion cell may be due to the electrical contact of two dissimilar metals, galvanic corrosion. Anodic and cathodic areas may be formed on a single metal surface as micro-cells for instance by rain drops on uncoated steel. Alternatively, they may be close but discrete cells found when accelerated corrosion occurs at uncoated anodic areas on a generally coated cathodic structure.
In addition, there are long line type cells that occur on pipelines that pass through aggressive low resistivity soils. These sections form anodic areas and corrode in preference to cathodic areas in less aggressive higher resistivity soils.
Large currents can occur at small anodic areas and lead to rapid corrosion of marine structures such as ship's internal tanks, external hull plates, sheet steel piling in harbors and tubular structures common in jetties and petrochemical drilling and production platforms.
Cathodic Protection is a system of preventing corrosion by forcing all surfaces of a structure to be cathodes by providing external anodes.
As described above, a galvanic corrosion cell occurs when dissimilar metals are in contact with each other within an electrolyte. Care should be taken in the construction of structures that will be buried or immersed in an electrolyte to ensure a galvanic cell is not created [6].

Galvanic cells can be:

- Steel or cast iron water boxes in contact with nonferrous (often copper based) tube plates in condenser water boxes in ships or generating plant. Rapid corrosion of the ferrous water box occurs close to the tube plate.
- Brass or bronze valves fitted to immerse steel buoyancy tanks or flooding chambers on marine petrochemical structures. Accelerated corrosion of the steel occurs near the valve.
- The connection of steel pipes into an otherwise cast iron system. Accelerated corrosion of the steel occurs near the cast iron sections.

Sacrificial anode Cathodic Protection achieves corrosion prevention on a particular structure or component by forming galvanic cell where an additional anode of zinc, magnesium or aluminium corrodes in preference to the structure. The galvanic corrosion current (see simple cell before) available from this anode/electrolyte/structure combination should be sufficient to overcome the local surface corrosion currents on the structure until no current flows from anodic areas of the structure. The structure is entirely cathodic or under complete Cathodic Protection [7][8].
The potential, or measure of activity, between the structure and the electrolyte is a relatively easily measured indication of whether the structure is anodic or cathodic.

For steel under normal non anaerobic conditions it can be shown theoretically, and is accepted practically, that a steel / electrolyte potential more negative than -0.85 volts measured against a standard copper / copper sulphate ref cell indicates that Cathodic Protection is achieved. This is equivalent to -0.80 volts measured against silver / silver chloride ref cell and + 0.24 volts against a zinc ref cell.

4.2 Sacrificial anode Cathodic Protection

As indicated previously, a metal can be made cathodic by electrically connecting it to a more anodic metal within the electrolyte. The most commonly used anodic metals are alloys of aluminium, zinc and magnesium. Anodes of these metals corrode preferentially, the corrosion current of the anode achieving cathodic protection of the structure to which they are connected. The anodes deteriorate as an essential part of their essential part of their function and they are therefore termed sacrificial.
Cathodic-protection systems can be monitored effectively by the measurement of structure-to-electrolyte potentials, with a high input impedance voltmeter and suitable half-cell (copper/copper sulphate, silver/silver chloride/seawater, silver/silver chloride/potassium chloride and zinc) [9].

4.3 Impressed current Cathodic Protection

Impressed Current Cathodic Protection system consists essentially of several anodes, reference electrodes and control units. All of them being inter-connected. Types, sizes, positions of the components are all around the hull, being specified according to design parameters.
A metal also can be made cathodic by electrically connecting it to another metallic component in the same electrolyte through a source of direct electric current and directing the current flow to occur off the surface of added metallic component (anode), into the electrolyte and onto the metal (cathode). This can easily be visualized by reference to the simple cell and assuming yet another ref cell with a power source is introduced and that the current flow from this ref cell is sufficient to overcome the natural corrosion current.
Because an external current source is employed, this type of protection is termed 'Impressed Current Cathodic Protection' – ICCP (Figure 4).

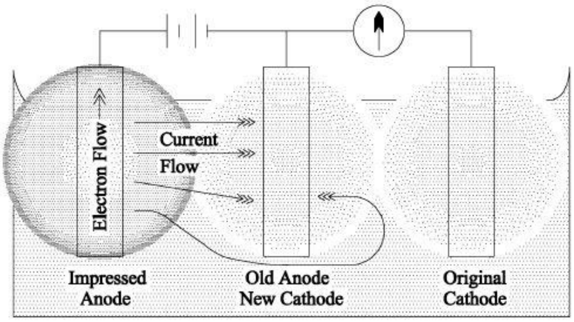

Fig. 4. Cathodic Protection Applied to a Simple Corrosion Cell

A source of direct current is required. This is generally obtained from mains power units that contain a transformer and rectifier.
The magnitude of this current may be automatically controlled in response to a continuous monitor of the cathode/electrolyte potential or may be manually controlled after intermittent measurement.
The impressed current anode material is ideally non-consumed by the passage of current from it into the electrolyte, in practice the materials used are a compromise between this ideal and the cost and physical properties of available materials. Impressed current anodes are made from graphite, silicon iron, lead alloys some with platinum di-electrodes, platinized titanium or more exotic combinations such as platinum clad niobium. The selection of the correct anode material is critical in the formulation of an effective and economic Cathodic Protection scheme [10].
Generally, for a given current demand, less impressed current anodes than sacrificial anodes are required for protection, as high anode currents are feasible (Figure 5).
Impressed current systems of cathodic protection are more sophisticated in design than sacrificial systems (Figure 5, Figure 7).

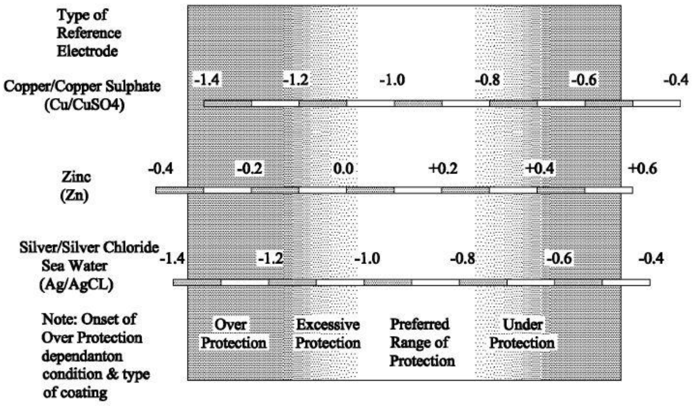

Fig. 5. Comparison of Reference Electrodes and Interpretation

Attention must be given to the propeller, any exposed shafting and to the rudder with the main hull structure protected. The propeller and the exposed shaft are protected by grounding the shaft to the hull structure with a shaft slip ring to make this appendage electrically common with ship's hull. Bonding rudder stock to ship's hull grounds the rudder and in this way the rudder is also protected by the digital system (Figure 6).

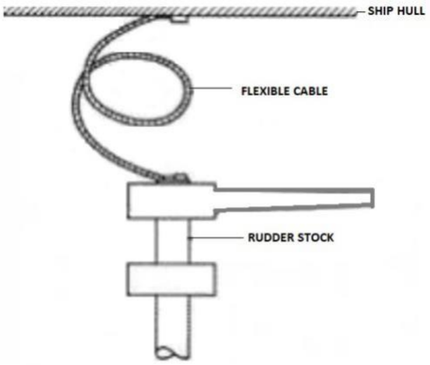

Fig. 6. Rudder stock bond

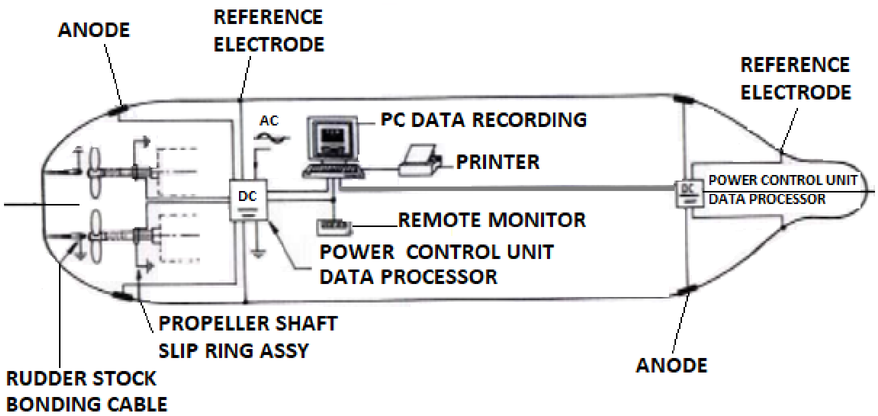

Fig. 7. Impressed Current system for ship

4.4 Marine Impressed Current system components

The Marine Impressed Current system comprises the following components (Figure 8):

- Rudder bonding;
- Linear loop anode;
- Remote monitoring unit;
- Shaft earthing assembly;

- Control panel;
- Reference cell.

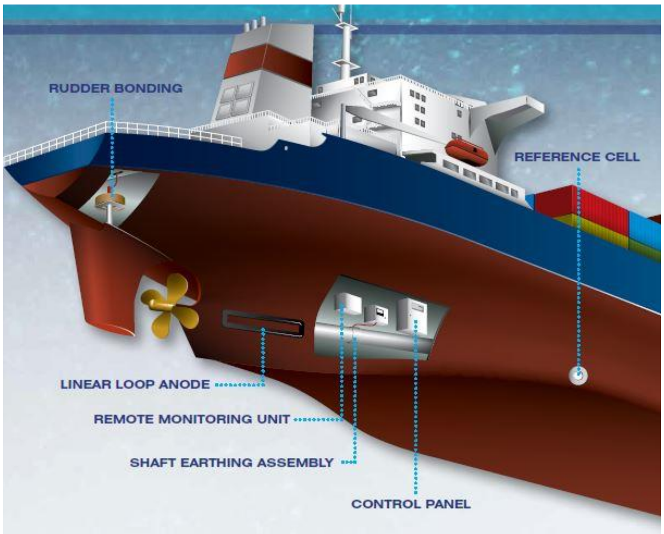

Fig. 8. Marine Impressed Current system

4.4.1 Impressed Current anodes

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 have no consequences. In this case also the type of anode is important for an effective and efficient operation.

Anodes can be:

- Linear loop anodes (Figure 9);
- Circular anodes (Figure 10);
- Elliptical anodes (Figure 11).

Linear Loop Anodes

Produce a powerful output from a relatively small surface area. Light weight and easy to install.

Fig. 9. Linear Loop Anodes

Ideally suited to vessels where a smooth hull profile is required. Can be flush mounted in areas where space is limited.

Fig. 10. Circular Anodes

Elliptical Anodes

The elliptical shape enhances current distribution. Provides the flexibility to fit into complex hull profiles.

Fig. 11. Elliptical Anodes

It is necessary that anode must be surrounded with a protective shield to avoid very high cathodic current density in the immediate vicinity of the anode, like enclosing anode with neoprene shield. 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.
The function of the anode is to conduct the DC protective current into the sea water. Anodes have been designed to perform this function whilst maintaining a low electrical resistance contact with the sea water. Standard surface mounted anodes are available with from 50 to 300 Ampere ratings. For forward mounted systems and for special applications 50 ~ 175 Ampere recessed anodes are available.
Materials now used by Anodes have now gone beyond lead alloy with specialist coated titanium based Anodes now available. All anode designs utilize a tough, chlorine resistant, but slightly flexible plastic carrier.
The use of a 24-volt system reduces the number and length of the anodes from that required with a 12-volt system. The increased anode / sea water resistance resulting from this decrease in anode size is overcome by the additional voltage.
The potential of the hull steel to the sea water is unaffected by this increase in driving voltage, as the resistive effects are local to the anode and the hull/sea potential is a function of the current flow, the sea water and the coating condition, not the driving voltage.
The electrical connections to the active surface are made at the back of the anode and are fully encapsulated and protected by the hull penetration. Recessed anodes of essentially similar construction are provided for bow section applications.
All hull penetrations are provided with substantial double plates and cofferdams. The penetrations themselves are made watertight with heavy duty packing glands, the cofferdams are full sealed and provided with watertight cable glands, all conforming to the requirements of Classifications Societies [11].

4.4.2 Impressed current reference electrode

The high purity, high stability, zinc ref cells are designed to give a stable reference against which the hull/sea potentials can be measured and a small current flow that is used in the closed loop circuit to maintain the present levels of protection. The construction and the quantity of zinc employed within the electrodes are such that a minimum life of ten years is available without maintenance or replacement.
The minimum number of ref cell per power supply is one although normally two will be fitted. Ideally, these should be located a minimum of 7.5 meters distant from the anodes. In the case of a stern only installation with the anodes more than 200 meters from the bows, one ref cell may be located in the bows.
A novel feature of the closed circuit is that additional reference cells may be placed at areas that may be susceptible to over-protection such as adjacent to the anode dielectric shields. These additional reference cells provide a permanent check, thus preventing any coating damage due to

over-protection if conditions of operation change from those anticipated. This feature is offered as an optional extra to the standard schemes.
All hull penetrations are provided with substantial cofferdams. The penetrations themselves are made watertight with heavy duty packing glands. The cofferdams are fully sealed and provided with watertight cable glands [12][13].

4.4.3 Bonding

To enable the rudder to receive protection it is provided with a dedicated electrical bond in the form of a flexible cable from the top of the rudder stock to the main ship structure. In the same way any stabilizers are bonded to allow protective current to these surfaces.
To allow protection of the bare propeller and any exposed shafting and to prevent electrical arcing between shaft and bearings the propeller shaft is fitted with a slip ring assembly as optional items. A set of brushes provide the completion of a low resistance path to allow current to flow to the propeller blades along the shaft and back to the hull.
The slip ring track is silver plated as standard and in addition silver graphite brushes are used to minimize contact resistance [14][15][16].

4.4.4 Shaft earthing

4.4.4.1 Introduction

A turning propeller shaft on a ship becomes electrically insulated from the hull by the lubricating oil film in the bearings and by the use of non-metallic bearing materials in the tail shaft. When the shaft is insulated in this way an electrical potential can be measured between the shaft and the hull and this can accelerate corrosion in the ship. If the ship has a system of cathodic protection, whether it is sacrificial anode or an impressed current system, the shaft insulation will prevent the propeller and the boss from receiving protection.
The electrical potential between the shaft and the hull can also cause a heavy current to flow in bearings when the oil film breaks down or is contaminated with seawater. This current can cause deep pitting of the bearing surface. Excessive wear on the shaft bearings can often be traced to this cause.
Now in addition it's necessary to reduce the spark erosion causing the excessive wear on main engine metal bearings and this shaft earthing is the most appropriate method. All the troubles can be avoided and cathodic protection can be extended to the propeller if the shaft is properly earthed with a propeller shaft slip ring. The effectiveness of the shaft earthing system should ensure a maximum contact resistance of no greater than 0.001 ohms for a water filled bearing and 0.01 ohms for an oil filled bearing.
Our own tests indicate that high silver content brushes running on a silver track have repeatable low conductivity that can maintain these limits and ensure a low resistance contact is maintained even under dirty conditions.
The shaft earthing assembly comprises a pair of high silver content/graphite compound brushes mounted in balanced brush holder, running on a silver alloy slip ring.
Each brush holder has an adjustable spring tensioner which is supplied present to the minimum [17][18].
At this pressure the expected life of the brush is approximatively one year.

4.4.4.2 Design base

- Intermediate shaft diameter: Ø 655 mm

4.4.4.3 Installation work by shipyard

- Assembling the intermediate shaft earthing assembly;
- Attaching the intermediate shaft monitoring millivolt meter & wiring;
- Welding the brush holder support bar and assembling the brush holder.

4.4.4.4 Installation

- Weld the mounting post(s) nearby shaft where slip ring is installed (Figure 12).
- Weld the support bar(s) carefully on mounting post according to the drawing.

- Slip ring.

It is strictly required to install slip ring correctly according to following procedure for the good performance of shaft earthing and longer life time of brushes.

- Make clean the area where slip ring is positioned.

The area should be cleaned and prepared for bright bare steel.

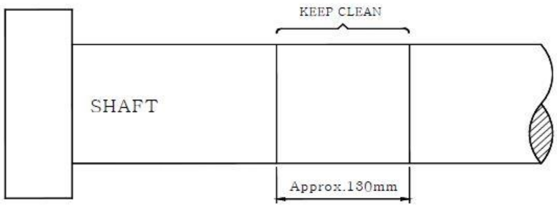

Fig. 12. Slip ring position

- Fasten stainless steel bands (A & B) temporarily (Figure 13).

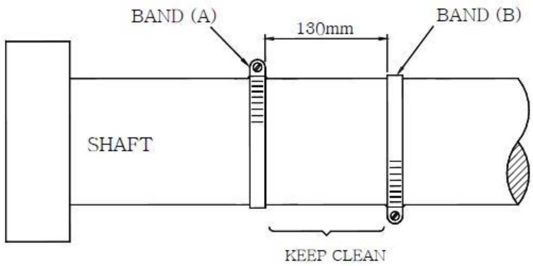

Fig. 13. Fasten stainless steel bands

- Put the slip ring around the shaft and mark the overlapped part. Cut the overlapped part at an angle of 45 Ø carefully (Figure 14).

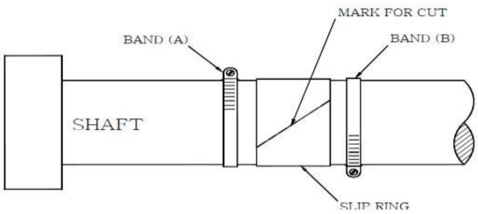

Fig. 14. Slip ring around the shaft

After cutting properly rub the both edges of inner surface of slip ring with a fine-mesh file or sand paper as below. Then secure slip ring very tightness around shaft (Figure 15).

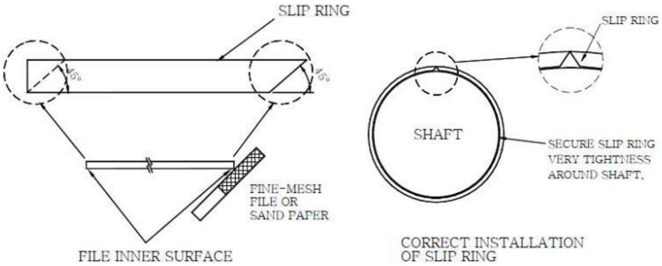

Fig. 15. Inner surface of slip ring

- Fasten the slip ring around the shaft by the tightening stainless steel band (B) (Figure 16). When the slip ring is tightly installed no protrusion or gap is found. In case there happens with protrusion or gap smoothly rub the protrusion with sand paper.

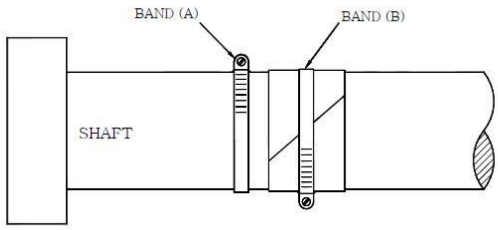

Fig. 16. Fasten the slip ring around the shaft

- Fasten the both edges of slip ring with 3/4” (19mm) pressure tape for a preparation of tight fastening of stainless steel band (Figure 17). Apply the tape to the slip ring five times at the opposite direction of the shaft rotation.

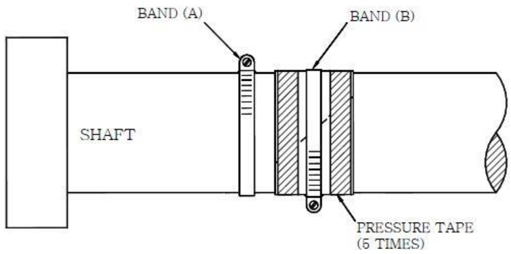

Fig. 17. Fasten the both edges of slip ring

- Fasten the stainless steel band (A) over the pressure tape tightly by tightening fixing bolt around the edge of slip ring (Figure 18).

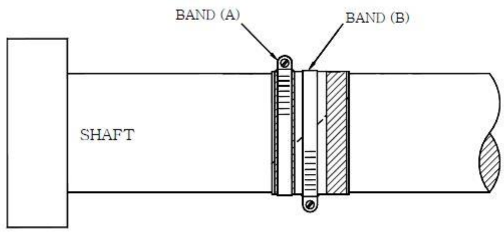

Fig. 18. Fasten the stainless steel band (A)

- Fasten the stainless steel band (B) over the pressure tape tightly by tightening fixing bolt around the edge of slip ring (Figure 19). After tightening bands (A, B), bend the end part of band to the opposite direction to prevent loosening when the shaft rotates.

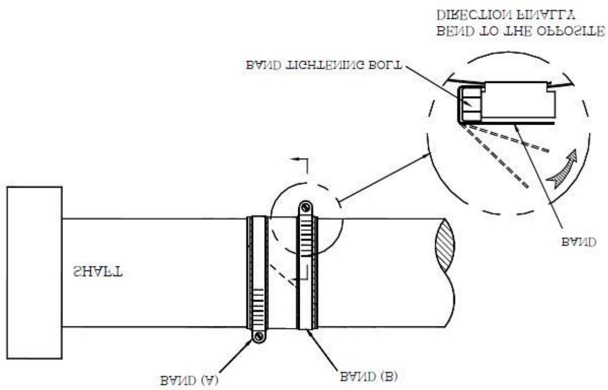

Fig. 19. Fasten the stainless steel band (B)

- Apply 2"(50mm) tape over both stainless steel bands (A & B) at the opposite direction of the shaft rotation finally (Figure 20). Keep the minimum 30 mm width of slip ring where brushes run.

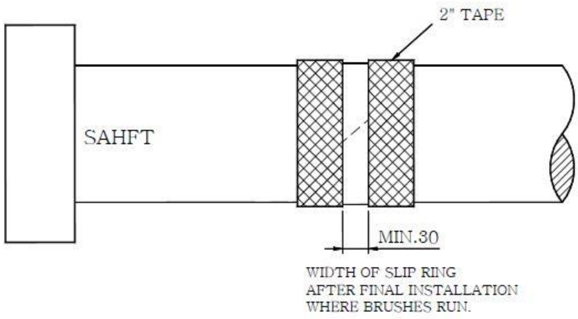

Fig. 20. Apply tape over both stainless steel bands (A & B)

➢ **Brush holder**

- Carefully study the drawing for correct installation and keep the distance of 3mm between bottom of brush holder and slip ring surface.
- Fit the brush holder to the support bar and align the assembly so that the brushes are able to run centrally on the slip ring, and the brush holders assembly is to be clear of the slip ring securing brackets when the shaft rotates.

Secure the assembly in this position by tightening the hexagon headed bolt at the top of the brush holder bod [19][20].

- The support bar for double brush holder should be connected to the hull electrically. So, the bracket(support) supplied by shipyard should be welded on the hull plate. The touched bracket surface should be galvanized to ensure metal touch in case the bracket will be installed by bolting.

➢ **Shaft monitoring millivolt meter (Digital type)**

- The system comprises a bulkhead mounted panel that incorporates terminals and a digital display meter.
- The meter has a high internal resistance that restricts current flow in the circuit to minimal levels and thus minimizes the volt drop between the slip ring and the monitor brush. The meter therefore accurately displays the potential difference between the shaft and hull.
- For ease of interpretation the display meter is scaled up to 250mV. As the meter reading rises above 80mV it is recommended that the slip ring and brushes to be checked and cleaned.
- The earthing cables of mV meter and double brush holder should be connected separately.

4.4.4.5 Operation

➢ The millivolt meter normally reads 250mV full scale.
➢ Reading of below 80mV when shaft is turning at sea indicate proper grounding. If readings are above 80mV, clean the faces of slip ring and brush with a clean cloth.
➢ The millivolt meter will read '0' when shaft is at rest because of the current entering the propeller will return to the hull through main engine bearings and engine foundation.
➢ Check according to troubleshooting in case the millivolt meter reading is '0' when shaft is turning at sea.

4.4.4.6 Maintenance and service

➢ This grounding assembly should be checked at least twice a week for cleanliness.
➢ If there has been a build-up of oil, dirt, scale and rust on the slip ring face or between slip ring and shaft, this should be removed with a degreaser, emery paper and clean cloth.
➢ Inspect and clean the brushes and brush holder to prevent their moving due to dirt build-up. Inspect the brush copper leads (pig tails) to ensure they have not become loose or corroded. The brush wear-down should be noted.

➢ At the time of every dry dock, disassemble the slip ring and clean the surface of the shaft right thereunder.

4.4.4.7 The life time of brushes

➢ The brushes are getting worn out by metal touch with slip ring.

Therefore, it's strictly required to keep clean and smooth surface of slip ring, also to carry out proper installation/alignment of brush holders as per our manual and drawing. Otherwise it's very hard to obtain the proper earthing and the proper life time of brushes.

➢ The brushes are consumable parts with wearing ratio approximately 2~3mm per 1,000 hours shaft rotation under proper installation. The replacement time is shown by engraving the line (15mm from the top) on the brushes.

Customer is requested to replace brushes with spares when the time comes.

- ➢ Brushes are consumable parts as stated above and they are often consumed earlier but it's not a matter of guarantee claim for supplying extra brushes.

➢ Use only our genuine silver graphite brushes for longer life and higher earthing efficiency [21].

4.4.5 How to select the best ICCP system for a ship

Designing steps for an ICCP system are as following:

- ➢ 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;
- ➢ Design the DC 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 [22][23][24].

4.4.6 Modern ICCP system C-Shield

4.4.6.1 Introduction

A modern ICCP system is C-Shield, which suppresses corrosion on the wetted surface of the hull using an arrangement of hull mounted anodes and reference cells connected to a control panel (Figure 21). This neutralizes 'corrosion cells' and eliminates problems that arise through dissimilar metals and the proximity of components such as propellers.

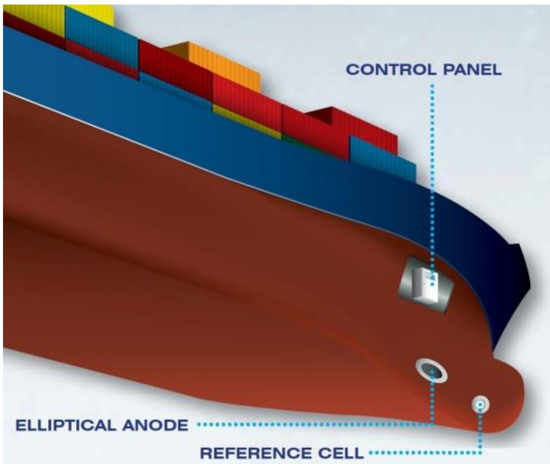

Fig. 21. C-Shield system

4.4.6.2 Thyristor control panels

C-Shield system is using thyristor control panels which combine cost effectiveness with rugged reliability that has been proved on vessels of all sizes worldwide. They also incorporate the latest computerized information systems enabling the status of the ICCP system to be monitored by ships' computers.
Thyristor control panels can be used for systems of up to 1,000 amps with 8 anodes and 4 reference cells being controlled by an individual panel. They are ideal for the requirements of cruise ships, VLCCs and many types of container and cargo vessels.
The popularity of these panels means that they can generally supplied within relatively short lead times.
Thyristor control panel characteristics:
- For ICCP systems of up to 1,000 amps.
- Reliable performance with minimum attention.
- Economical control for systems of all sizes.
- Combines computerised output displays, alarms and information systems.
- Can have up to 8 anodes and 4 reference cells per panel.
- Easily configured to clients' requirements.
- Relatively easy maintenance.

4.4.6.3 Maintenance

- Diver Change Anodes

Can be changed from the outside of the hull by a diver. Ideal for FPSOs and vessels with long intervals between dry docking (Figure 22).

Fig. 22. Anodes

- Reference Cell

Designed to measure the electrical 'potential' at the seawater/hull interface (Figure 23).

Fig. 23. Reference Cell

4.4.6.4 C-Shield modular control panels

Is based on advanced computerized electronics and is designed for installations of up to 350 amps. Extremely lightweight and compact in design, it can be easily installed in engine rooms and requires the minimum of attention from the crew. One of the major advantages of the unit is that the modules are interchangeable and can be quickly removed and replaced if necessary, thereby offering greater reliability.

C-Shield modular control panel characteristics (Figure 24)**:**
- For ICCP systems of up to 350 amps.
- Modular design for greater reliability and flexibility.
- Extremely lightweight and compact.
- Clear digital output displays.

- Incorporates 'under' and 'over' protection alarms
- Can be linked to bridge information systems

Fig. 24. C-Shield modular control panel

- **Minitek Panels**

The Minitek system has been designed to protect smaller steel hulled vessels against corrosion. It has been widely installed on tugs, fishing vessels and workboats where engine room space is at a premium.

Minitek Panels characteristics (Figure 25)**:**

- Operates from 230V AC electrical supply;
- Control panel measures 600mm x 600mm x 210mm;
- Far superior to sacrificial anode systems where output cannot be verified.

Fig. 25. Minitek Panel

- **Alutek Panels**

The Alutek system provides carefully controlled protection for aluminium hulls using an arrangement of flush mounted anodes, monitoring electrodes, controlling electrodes and di-electric shield sensors.

Alutek Panels characteristics:

- Operates from 230V or 115V AC electrical supply;
- Control panel measures 400mm x 500mm x 210mm;
- Lower yard installation cost than recessed sacrificial anode systems.

4.4.6.5 Shaft Earthing (Figure 26)

Even on ships fitted with ICCP or sacrificial anode systems, propeller shaft bearings are vulnerable to corrosion.

This is because turning propeller shafts are electrically insulated from the hull by the lubricating oil film in the bearings and by the use of non-metallic bearing materials in the tail shaft.

The problem can be eliminated if the shaft is earthed to the hull using a propeller shaft slip ring. A complete shaft earthing assembly is consisting of a pair of high silver content/ graphite compound brushes mounted in a balanced brush holder, running on a copper slip ring with a solid silver inlay track. This combination has been proved to give the optimum electrical continuity. The number of brushes depends on the size of the vessel. Smaller craft have a single brush holder [25] [26].

Fig. 26. Shaft Earthing

- **Installation**

Installation is simple. The shaft slip ring is supplied as two matched halves, complete with band and clamping arrangement.
The balanced brush holder is supplied ready for fitting to a shipyard-supplied 20mm diameter rod and mounting bracket.
Each brush holder has an adjustable tensioner to ensure good electrical contact and maximum brush utilization.

4.4.6.6 Propeller shaft potential monitoring (Figure 27)

It has a compact millivolt meters to monitor the potential between the shaft and the hull and verify the effectiveness of the system.
The meters can be located in a convenient position for monitoring by the crew.

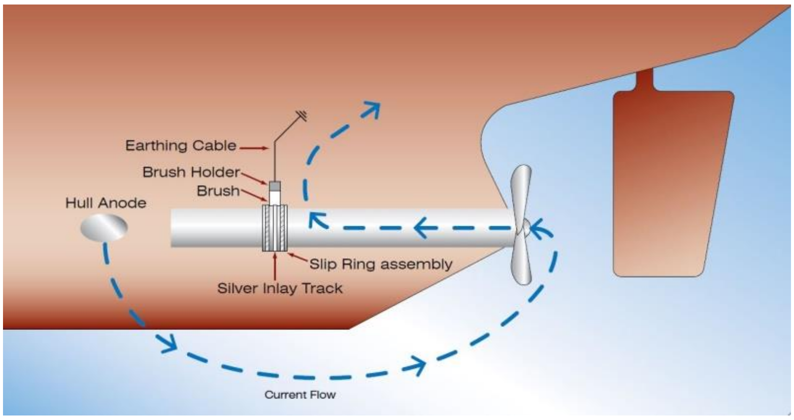

Fig. 27. Propeller shaft system

4.4.6.7 Large Thruster Tunnel ICCP Systems (Figure 28)

For bow and stern thruster protection there was developed a specialized system which is uniquely effective in providing corrosion protection.
Problems of corrosion arise because of the dissimilarity of the materials used in the hull and thruster tunnel construction and remain unchecked because they are outside the scope of conventional ICCP systems.
Specialized thruster tunnel systems are installed on ocean going vessels, harbor tugs and in offshore oil and gas applications.
The equipment consists of a power unit/controller and an arrangement of reference cells and anodes positioned on either side of the tunnel. The anodes and reference electrodes are flush mounted to maintain the optimum performance of the thrusters and reduce the effects of turbulence which can accelerate corrosion.
This has a number of advantages in comparison with sacrificial anode systems where anodes are much heavier, have to be checked at regular intervals and replaced at each dry docking. In contrast, this new specialized system for protection of bow and stern thruster provides carefully monitored, precisely delivered corrosion protection for a design life of up to 15 years (Figure 29).
The system operates continuously when the vessel is at sea, but when the impeller is activated during docking, the equipment is automatically shut down using a fail-safe switching system which

is installed by the shipyard. This prevents any stray current damage occurring to the bearings and seals [27][28][29].

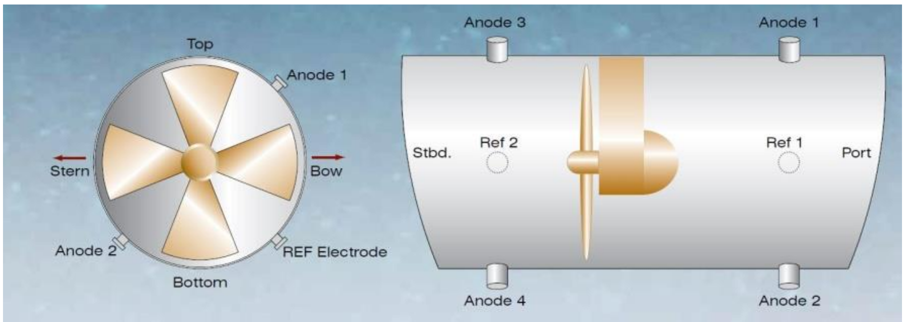

Fig. 28. Large Thruster Tunnel ICCP Systems

Fig. 29. Corrosion in and around thruster tunnel [30]

5. Conclusions

Cathodic Protection of steel in seawater is when a sufficient number of electrons from a preferred external source, are applied to the surface of the metal being protected. The electrons from external source, accommodate with the cathodic reaction such as hydrogen evolution or oxygen reduction. Without this protection, the electrons would react with oxygen at the cathodic surfaces and they would be covered by corrosion at the anodic areas. When additional electrons are supplied from an external source, they accommodate to the oxygen reduction reaction.
As a result, to the use of ICCP C-Shield, significant savings result had been demonstrated.
First time when they appeared ICCP systems had seem to be very expensive to install than sacrificial anode systems, but because of the escalating price of zinc, the differential cost between the two has been reduced, making ICCP systems competitive and even a more attractive proposition, from the economic point of view.
Sacrificial anodes have a lot of disadvantages. The main one is that they have to be renewed at periodic dry docking intervals as they become consumed, this resulting in on-going replacement costs for the ship owners.
By using a modern ICCP system like C-Shield, with special anodes, they can last for many years and achieve a more much reliable level of protection without the extra weight or drag which is inevitably associated with sacrificial methods.
Major operational savings result from the use of ICCP C-Shield. A smooth hull, free from corrosion ensures the lowest fuel consumption for the vessel that means more money saved by the ship owners.
Data collected in time, has shown that unprotected vessels, after as little as 2.5-3 years, can require an additional 30% increase in shaft power to maintain service speed, that means more money splendid on fuel, because of high consumption.
Throughout by using the ergonomic design of modern ICCP system like C-Shield, we can ensure the high reliability commensurate with minimal installation time. The lowest cost system may leave the installer with the highest work load.

By using a competitive ICCP system in combination with modern hull coatings, ship owners, can save money, protect life and environment.

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