A New Protection Strategy of Impressed Current Cathodic Protection for Ship

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Corrosion is never avoided in the use of materials with various environments. The underwater hull is normally protected against rusting by several coatings of anti-corrosive paint. The purpose of ICCP (Impressed Current Cathodic Protection) system is to eliminate the rusting or corrosion, which occurs on metal immersed in seawater. The anode of ICCP system is controlled by an external DC source with converter. The function of anode is to conduct the protective current into seawater. The proposed algorithm includes the harmonic suppression control strategy and the optimum protection strategy and has tried to test the requirement current density for protection, the influence of voltage, the protection potential. This paper was studied the variation of potential and current density with environment factors, time and velocity, and the experimental results will be explained.

Key Words : Anode, ICCP, Corrosion, Control Strategy, Cathodic Protection

1. Introduction

Metallic corrosion is an electro-chemical relation in which the metal combines with a non metal, such as oxygen, to form a metal oxide or other compound. If two metals are placed in an electrolyte such as seawater, they are in direct electrical contact. A generating current will pass through the electrolyte from the more active metal onto the least active metal. The least active metal does not corrode and is termed the cathode. The more active metal, the anode, passes into solution or turns on an electric current.

Some metals and alloys have two positions in the series, marked "Active and Passive". If corrosion is occurring and approaches the electro-chemical series position for the material, it is the active position. The passive position relates to a non-corroding situation where the material is protected by a self-forming surface film.

The hull of ships potential has to change from the corrosion position to cathodic protection position for preventing corrosion by ICCP system. An external current source is employed in the ICCP system. The main power units of the ICCP system include a transformer and converter. The anode receives DC current from the main power units. The function of the anode is to conduct the DC protective current into the seawater.

This study was focused on the determination of optimum required current density for ICCP on the underwater hull in ship operating condition and marine environment. Also, we describe that the high efficiency of ICCP can be achieved by using the converter with harmonic suppression algorithm.

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2. ICCP System for Ship

Cathodic protection of an uncoated ship is practically not possible or is uneconomic due to the protection current requirement and current distribution. The complete protection of the ships with ICCP is becoming increasingly important since defects in the coating due to mechanical damage are more frequent on the underwater hull. The cathodic protection includes the ICCP method and SA (Sacrificial Anode) method. Fig. 1 shows a typical pH-potential for iron (Fe).

In this figure, the passivity region is stable and coats the iron surface. So, this region is protecting it from corrosion. The immunity region also is stable and will not corrode in this zone.

The ICCP system describes in this paper is designed to be applied to the exterior wetted hull of a ship. The iron potential has to change from the corrosion region to the anodic protection or cathodic protection for preventing corrosion by providing external DC source. The cathodic protection is a system of preventing corrosion by forcing all surfaces of an underwater hull to be cathodes by providing external anodes.

Generally, the ICCP system comprises several anodes, reference electrodes and a power control units. There are five components required in the basic ICCP system as shown in Fig. 2. A controller (A) is connected to the reference electrode. The controller delivers a control signal to one or more power supplies (B). The anode (C) is also mounted through the hull and electrically insulated from it. The reference electrode (E) is mounted through the hull (D) of the ship and is exposed to the seawater. The power supply creates a DC power which is connected to anode and hull.

Corrosion of a metal in water is protected by a current flowing from one area of the hull to another area. The one area where the current leaves the hull and enters the seawater is called "anodic" and another area where the current enters the hull from the seawater is called "cathodic". Corrosion occurs only at the anodic

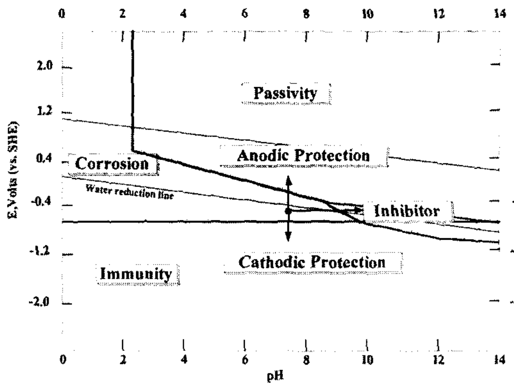

Fig. 1 Typical pH-potential for iron (Fe)

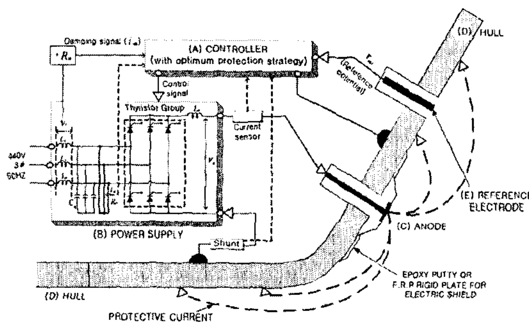

Fig. 2 Schematic of the ICCP system for ship

areas.

The power supply performs two functions. It converts the shipboard AC power to a low voltage-high current DC and controls this DC over a wide range by the controller. The anode of ICCP system is connected to the DC, it will deliver a current to the hull which suppresses current flow from the anodic area and makes the entire hull "cathodic" and stops the corrosion on the hull.

The DC voltage developed between the reference electrode and the hull is connected to the controller. The controller compares the level of cathodic protection of the hull as determined from the reference electrode with the desired level of protection as set by the operator.

The reference electrode is insulated from the hull and does not receive any anode current. The controller uses the reference electrode signal to determine whether the power supply and anode should deliver more or less current.

3. Proposed Control Algorithm

3.1 Dynamic condition

There was very little understanding of the performance of ICCP under dynamic conditions as ship operating condition. Much of the published research reports data obtained in static conditions, apparently because of the difficulties of obtaining consistent results in flowing environments. The dynamic condition was performed to rotate the electrode. The velocity of the electrode was calculated using the equation (1).

$$V_{speed}=\omega r \quad (1)$$

where ω represents the angular velocity in radians/second and r is the radius of the electrode in meters.

3.2 Harmonic suppression algorithm

The converter consists of phase-controlled thyristors. This converter has the inherent drawbacks that their power factor decreases when the firing angle increase and that harmonics of the line current are relatively high. Good power factor of the power circuit can be achieved by using the converter with the harmonic suppression algorithm. The main circuit of the converter is shown in Fig. 2.

If damping resistance R_{dr} is connected to the AC side of the converter, the quality factor Q_0 of LC filter for the harmonic components is reduced, and the steady-state waveform distortion due to the amplification effects of the LC filter will be suppressed effectively. The current component i_{dc} in R_{dr} is generated by the bridge circuit of the converter. The reference value i_{rdc} to generate the current i_{dc} is given by

$$i_{rdc}=v_{ch}/R_{dr} \quad (2)$$

Where, v_{ch} is the harmonic component of the filter capacitor voltage. This reference value i_{rdc} can be obtained by detecting v_{ch}. The approximate value of v_{ch} can be obtained by detecting the voltage v_l across the filter inductor L_s :

$$v_h=v_l\left(=-L_s\frac{di_s}{dt}+r_s i_s\right) \quad (3)$$

Where, r_s is the total resistance of the filter inductor and AC line. i_s and L_s are the supply current and the inductance of the LC filter. The controller has to generate the control signals for DC output voltage V_d according to both i_{rdc} and the potential of reference electrode V_{ref}.

3.3 Protection strategy

Experience has shown that a potential of 0.80 V (SSCE) on steel hulls as indicated by this same reference cell will provide adequate protection from corrosion. This holds true for hulls protected cathodically impressed current anode. This protection strategy includes the important factors such as the protection potential, the density of protection current, and total requirement current.

The protection potential V_P can be expressed as

$$V_P=(V_a-V_c)+I(R_l+R_m) \quad (4)$$

Where, I is the requirement current, V_a is the polarization positive potential, V_c is the protection potential of hull, R_l is the resistance of electrolyte part and R_m is the resistance of metal part. The output current of anode is given by

$$I=\Delta V/(R_l+R_m) \quad (5)$$

Where, ΔV is the effectiveness potential. The density of protection current varies widely for different metals, seawater salinity, velocity of flow past the surface of underwater hull, type of protective coating applied to the surface, temperature, etc. It is known that a value of 0.01 A/ft^2 will protect bare steel in quiet seawater, while bronze would require 0.05 A/ft^2 or higher under same conditions. A painted hull of a ship, however, might require only 0.001 A/ft^2 or even less under ideal conditions. Total requirement current for protection is obtained by multiplying the current density by the wetted area. The total protection current requirement I_T is calculated as :

$$I_T=\sum_i J_i\cdot S_i \quad (6)$$

Where, J_i is the protection current density, S_i is the individual surfaces.

The harmonic influence can be apprehended

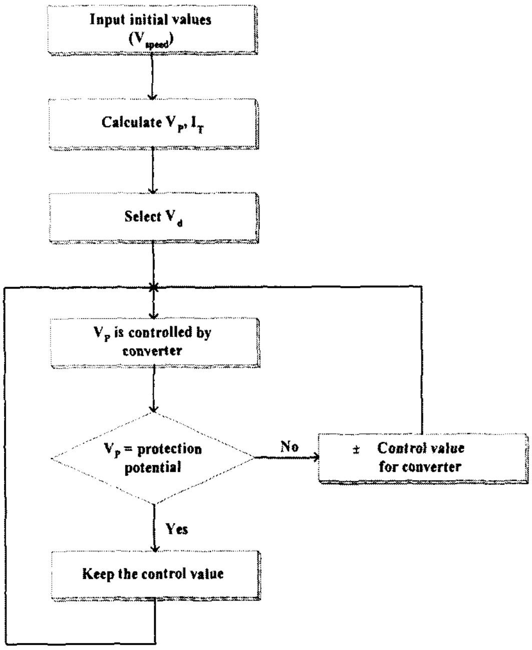

Fig. 3 Flow chart of the proposed control algorithm

from equations (2) and (3). The DC output voltage V_d can be controlled with α (turn on) angle. The α angle be decided by the reference potential, the protection current and i_{rdc}. The density of protection current is to be controlled according to a kind of metal and total protection current is calculated with the wetted area of ship and the density of protection current.

The flowchart of the control algorithm for ICCP system is shown Fig. 3.

The proposed control algorithm includes above facts, and the control program is made by the algorithm according to the flowchart in Fig. 3.

4. Experimental Investigation

The ICCP system of ships is always used in conjunction with protective coatings. The coatings are intended as the primary protection and ICCP is a backup in those areas where coating defects may be present.

The test system was implemented with the proposed control algorithm in the laboratory using anode, reference electrode, shunt and thyrister.

Figure 4 shows current density as a function of velocity at different pH. The current density

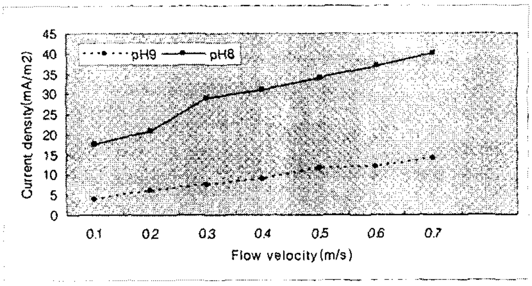

Fig. 4 Current density as a function of velocity at different pH

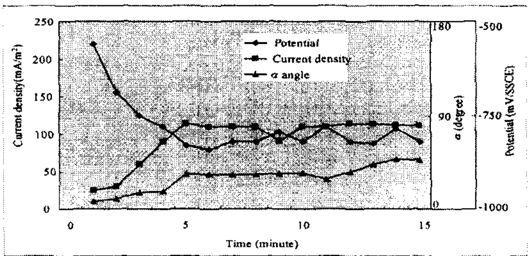

Fig. 5 Variation of potential, current density and α angle with time

increased with increasing velocity, but it decreased with increasing pH.

Figure 5 shows the variation of potential and current density with time. The potential was controlled with α to keep $-790\,\text{mV/SSCE}$.

The current density was $100\,\text{mA/m}^2$ after 5 minutes and the potential approached around $-790\,\text{mV/SSCE}$. The protection potential was kept about $-790\,\text{mV/SSCE}$ after 10 minutes, and it is maintained with controlling protection current by the switching angle below to 60 degree.

Figure 6 shows the variation of current with time and voltages (12 V, 24 V, 38 V). The protection potential was kept well with an error of less than 20 mV by using the proposed control algorithm. The requirement current is decreased with increasing the DC output voltage V_d (anode input voltage). It decreased continuously, and after 39 minutes, it approached to 4 A with 24 V and 38 V.

Figure 7 shows the experimental results of total harmonic distortion of the supply current in the steady state operation of the test system without and with the proposed control. In this case, the

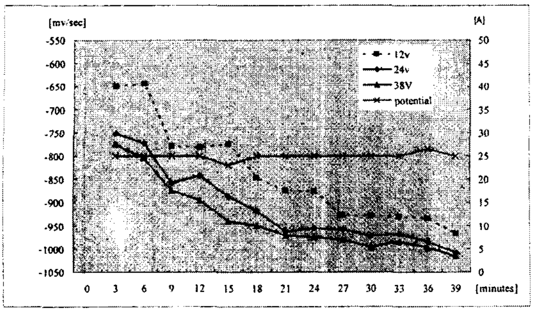

Fig. 6 Variation of current with time and voltages

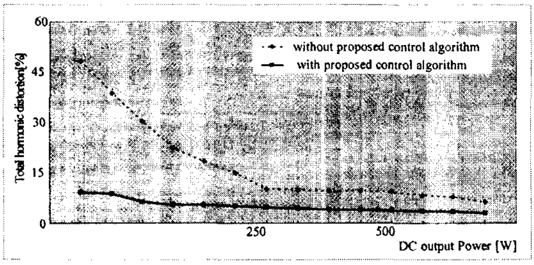

Fig. 7 Experimental result of total harmonic distortion

DC output voltage is 24 V. The total harmonic distortion is large especially when the DC output power is small.

The ICCP system contains additional current and potential measuring instruments for the individual impressed current anodes and measuring electrodes. An automatic current restriction of ICCP must be provided to protect against over-loading in low-resistance contacts to well-grounded installations.

5. Conclusion

In the design process of ICCP system, it is difficult to know the expected potential distribution over the underwater hull that leads to reliance on current density measurements as a means of assessment. The corrosion potential is influenced by the environmental factors such as velocity and pH. Accordingly, when the ICCP system is designed, various protection factors need to reflect in accord once with the marine environments.

In this paper, the proposed algorithm for ICCP includes the marine environment factors and the harmonic suppression algorithm.

The protection strategy is effective on the harmonic components and oscillating components in the transient condition and output power. The variation of current density with flow velocity and pH could be controlled by ICCP with the proposed algorithm.

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