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A Review Paper on Impressed Current Cathodic Protection to Reinforcement

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ABSTRACT: This paper aims to describe the study of the ICCP and range of cathodic protection systems and hardware in current practice, with reference to the treatments applied to port and structures all over world. The technology available for repair and maintenance of reinforced concrete structures has grown in recent years and electrochemical treatments, such as impressed current cathodic protection, are now becoming common.

Keywords — Corrosion, Anode, Impressed Current Cathodic Protection (ICCP), Rectifier.

I. INTRODUCTION

Cathodic protection was first for all intents and purposes connected in 1825 when delicate iron anodes were introduced to give protection against consumption of the copper cladding on the underwater part of cruising vessels. Afterward, in the mid 1900's when steel started to be utilized as a shipbuilding material in inclination to normally erosion safe iron on the grounds of economy and better mechanical properties, consumption of ship's body was recognized as significant issue.

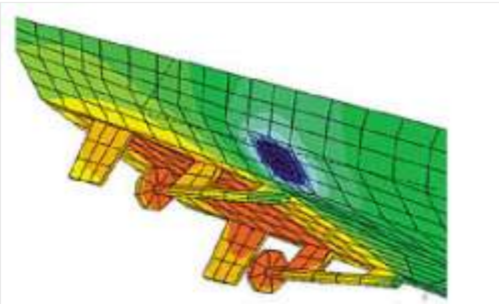

Fig. 1.1 Modelling of CP of Ships

Cathodic protection has been largely used for shielding structures from deterioration due to corrosion. The structure of cathodic Protection frameworks typically depends on a blend of understanding, exploratory information. Be that as it may, issues and disappointments of cathodic protection frameworks not just has a monetary cost, it can likewise introduce a risk to life and the earth. On-going advances demonstrating have empowered the execution of cathodic protection frameworks in ensuring metallic surfaces to be anticipated by recreating nature and the electrochemical procedures on the metallic surfaces. These advances have been connected on seaward and marine establishments, for example, seaward stages and ships. Refer fig. 1.1

Cathodic protection is one of the methods of preventing corrosion and is widely applied in Naval and Underground piping system. This technique can be useful on steel reinforcement in concrete to contain corrosion within the limit. This method can be applied to any metallic structure in contact with electrolyte and its main use is to shield steel structures buried in soil or immersed in water. The metal surface is protected by making it the cathode of an electrochemical circuit. It is a simple technique of protection where the metal to be protected is linked to a more easily rusted "sacrificial metal" to act as the anode. The sacrificial metal then gets corroded instead of the protected metal.

Through applied electric current i.e., Impressed Current Cathodic Protection (ICCP), corrosion can be reduced virtually to zero, and a metal surface can be kept in a corrosive environment without being damaged for an indefinite time. Application: its application can be found in water or fuel pipelines and steel storage tanks, ship and boat hulls, offshore oil platforms and onshore oil well casing, etc. It is sometimes more economically feasible to protect a pipeline using sacrificial anodes and this is often the situation on smaller diameter and length pipelines. Anodes to be selected depends upon the galvanic series potential of the metals to drive internal current from the anode to the structure being protected. The purpose of this work was to simplify design complexity in a step-by-step approach and detailed methodologies involved in impressed current cathodic protection projects with a view to broadening the understanding and optimizing design.

II. PRINCIPLE OF CATHODIC PROTRECTION

The principle of cathodic protection is based on the idea to reverse the electrochemical nature of the structure to be protected by supporting a cathodic reduction on its level, and by deferring the reaction of oxidation on another structure which receives the deterioration.

This corrosion process is initiated by difference in natural potential of metal and metallurgical variations in the metal state at different points on the surface. Local differences in the environment, such as dissimilarities in the supply of oxygen at the surface i.e., oxygen rich areas convert to cathode and oxygen depleted zones convert to anode. In cathodic protection, the metal to be protected is connected to a external anode and an electrical dc current is impressed so that all areas of the metal surface become cathodic and therefore the metal does not rust. 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 immobilized and only cathodic reactions can take place.[1]

III. IMPRESSED CURRENT CATHODIC PROTRECTION

For large structures or where simply cathodic protection cannot be applied and galvanic anodes cannot economically deliver enough current to provide protection impressed current cathodic protection (ICCP) systems are used. ICCP system involves anodes connected to an external DC power supply source, generally a transformer-rectifier connected to AC power. In the absence of power supply, alternatives such as solar panels, wind power or gas-powered thermoelectric generators are used. Anodes essential for ICCP systems are accessible in a variety of shapes and sizes.

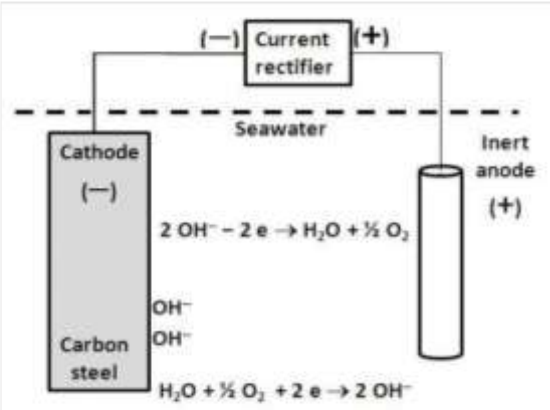

Fig. 1.2 ICCP Schematic Diagram

In an ICCP system, external current is impressed so that metal to be protected gets more electron and becomes anionic due to which further attack of environment does not affect the metal and thus, corrosion is prevented, refer fig 1.2. The steel is protected by supplying external direct current to the steel bars embedded in the concrete, which leads to cathodic polarization of the steel bars. It shifts the potential to a more negative level, where corrosion can neither initiate nor propagate.

Cathodic protection controls the corrosion procedure by altering the thermodynamics and kinetics of the affected steel and is achieved by establishing an electrical circuit with an introduced

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anode using the concrete as an electrolyte and the protected steel as the cathode. There are a number of different types of anodes that are available in varying geometric forms, but activated titanium or conductive ceramics anodes are most commonly used in marine applications.

Impressed current cathodic protection is a cost-effective alternative to patch repairs in chloride contaminated structures, not only because it provides a long-term solution but also because it avoids the need for massive removal and replacement of the contaminated concrete.

IV. PROGRESSION OF CORROSION OF STEEL REINFORCEMENT IN CONCRETE

Reinforcing steel in concrete initially protected from corrosion by the high alkalinity provided by the cement stabilizes the passive oxide layer on the surface of the steel. The passive layer can be destroyed by a reduction in alkalinity to below about pH 10, such as may be caused by carbonation from the atmosphere or by the presence of aggressive chloride ions. These ions may be present as a result of chloride contamination of the concrete materials at the time of placing, or by ingress from external sources such as a marine environment or de-icing salts.

Once the passive layer on the steel has been disrupted, an electrochemical cell can be formed in the presence of oxygen and moisture. The concrete provides the electrolyte in the cell, with the steel rebar completing the circuit and transmitting electrons from anode to cathode.

While oxygen is consumed at the cathode to release hydroxyl ions and thus to increase the local alkalinity, rust (iron oxides) and acid are formed at the anodic site. Rust occupies a far greater volume than its parent metal and the process led to a gradual buildup of bursting stresses within the cover concrete and, eventually, to spalling of parts of the concrete surface. [2]

V. ICCP TO REINFORCEMENT

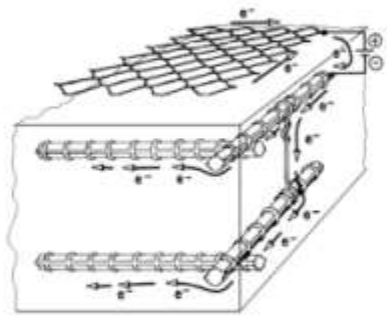

Fig 1.3- Cathodic Protection for Steel Reinforcement in Concrete.[8]

Cathodic protection involves the establishment of a small DC current from an external anode, through the concrete to the rebar. The current charges the steel negatively and it becomes cathodic, i.e., not corroding. By passing this very small current from a supplemental anode to embedded reinforcement, corrosion can be halted for an indefinite period. [2]

The supplemental anode transmits electrons which are consumed at the reinforcing steel. Other benefits of this process include the production of hydroxyl ions at the steel surface (thus reverting the pore water in the concrete to an alkaline state) and the gradual migration of the negatively charged chloride ions towards the new anode and away from the steel. [3,4]

VI. DEVELOPMENT OF ANODE SYSTEMS

The high resistivity of concrete as an electrolyte has been an obstacle to the use of ICCP of reinforcement until recent years. Throughout the years, the given anode resources have been utilized in impressed current frameworks.

Scrap Steel: Used in early framework because it is inexpensive and promptly accessible. Random corrosion patterns, high consumption rate and low operating current density make this a poor selection option.

High Silicon (14%) Cast Iron: Generally alloyed with 3-5% chromium for seawater application, the anode has good expected performance in seawater and mud yet the low operating current density, bulkiness and relatively fragile nature restrict its use to low current systems.

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Lead Silver: offers the benefit of practically high working current density combined with a genuinely low consumption rate.

Magnetite (Fe 3O4): have great current density and low consumption however experienced being very fragile and hard to interface with electrically. Platinized Titanium: Platinized anodes offered high current densities combined with very low wear rates.

Mixed Metal Oxide: These anodes are a combination of metal oxides deposited onto a titanium substrate. The material offered advantages over both types of platinized anodes.[4]

With all the methodologies about corrosion protection, one may be tempted to think there are many ways of carrying them out. Be that as it may, actually, protective coatings accomplish corrosion protection in one of only three ways.

Barrier coatings intent to forbid water, oxygen and other chemicals from making contact with the substrate. Since a breach is created between a layer of insulation and the substrate, any dampness or chemical that spreads onto the surface would initiate the corrosion development.

Inhibitive coatings are comprised of pigments that effectively delay chemical reactions. These coatings were intended to keep corrosion from ever developing. Red lead is a well-known example of inhibitive coating. But it was generally utilized before the harmful impacts of exposure to lead were completely perceived. Since lead pigments begin to closely regulated in late 1970s, this strategy of corrosion has been heavily regulated to the point of no longer being widely used.

Sacrificial coatings are self-sacrificing type of coating comprised of a metal which corrodes preferentially to steel. Basically, this technique assumes control over the corrosion process and steers it toward to a path that will not be destructive to the metal, the coating is intended to safeguard.

VII. CONSTRAINT EFFECT

The cathodic reactions will result in an increase in pH with time either by the removal of hydrogen ions or by the generation of hydroxyl ions. A temperature increase usually increases the reaction rate which is the corrosion rate. Increasing seawater temperature leads to decreasing seawater viscosity with a consequent increase in oxygen diffusivity. [5] The rate of dissolution of anode increases with decreasing of pH, at the range of pH 5 to 2. Within the range of about 5 to 12, the dissolution rate of anode is slightly dependent of the pH, where it depends almost on how oxygen rapidly reaches the metal surface.

VIII. DESIGN METHODOLOGIES

The design method for cathodic protection incorporates various essential input constraints. The initial step is to determine the current density requirement, which is based largely upon environmental parameters i.e., water velocity, temperature, dissolved oxygen etc. From this and physical features of the structure, the net cathodic current is then calculated. It can be summarized as following:

Select the current density to be applied: The cathodic protection current demand is the measure of electric power needed to polarize the structure. For planning and configuration purposes, it is generally expected conceivable to depend on conventional assessments given by suggested practice.[1]

Compute total current requirement: By knowing the actual dimensions of the structure to be protected, the surface area can be calculated. The product of the surface area multiplied by current density obtained previously gives the total current required.

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.

Carbon steel pipeline of 0.5m diameter and 100000m length was to be laid in onshore location in Niger Delta region spanning from Delta to Bayelsa State in Nigeria. Impressed current cathodic protection system was designed for installation. The basis of design parameters for pipeline, anode and environment studied are provided in Table 1, 2 and 3 respectively. [7]

Table 1: Anode data

Anode material	Platinum clad
Design life	30mA/m^2
Anode Dimension	0.75m x 0.75m x 3.00m
Utilization of platinum clad	65% kg/amp-yr
Weight of anode	30kg
Backfill length surrounding anode	0.5m
Backfill diameter surrounding anode	0.15m
Cable wire specification	0.0212 ohms per 100ft

Table 2: Pipeline data

Pipeline Grade	X65
Diameter	0.5m
Length	100000m
Coating resistance	18 Ω.m^2
Assumed coating efficiency	55% (0.55)
Design life	35 years
Pipe joint length	4m

Table 3: Soil resistivity

Distance (m)	Resistivity (Ω.m)
0	50
10000	45
20000	50
30000	52
40000	60
50000	65
60000	70
70000	75
80000	74
90000	80
100000	62

Cathodic protection design of the impressed current showed current requirement of 2592150mA, 3024 platinum clad anodes required to attain years' design life and 1127585mV voltage yield needed to satisfactorily protect X65 steel pipeline to be laid in offshore location.

IX. ICCP ECONOMICS

Life cycle cost versus risk of failure is the controlling variable with respect to if impressed current bodes well. Cathodic current frameworks start to look very appealing when current requirements surpass 400 – 500 Amperes and/or when water depth surpasses 200 feet.[4]

ICCP systems are generally good investments. The most basic and important investment in ICCP system is rectifier and it can shield wide range of surface area with reducing marginal costs as the surface area increases. The risk is that ICCP will be operated incorrectly or not maintained properly, however this should not discourage the use of ICCP system.

X. CONCLUSIONS

Based on literature review and work done in area of ICCP, it is evident that a good concrete cover in terms of quality of ingredients, water-cement ratio, mix proportion, etc., has no alternate for avoidance of reinforcement corrosion. Corrosion develops only when a pathway is available for the seepage of chloride, Sulphur dioxide, oxygen, and so on, in the concrete cover. ICCP projects can be completed under 50% cost of replacement cost of the structure. Before deciding to implement an impressed current cathodic protection system, a thorough condition survey of the concrete structure as well as a comprehensive study of existing systems and their potential effectiveness should be conducted.

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