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CATHODIC PROTECTION SYSTEM : A STUDY OF IMPRESSED CURRENT SYSTEM

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RINGKASAN: *Sistem Perlindungan Katod (SPK) digunakan untuk mengurangkan pengaratan dengan cara meminimakan perbezaan keupayaan voltan di antara terminal anod dan katod. Ini boleh dicapai melalui sistem arus bekasan dengan mengenakan arus dari sumber elektrik pada struktur yang hendak dilindungi. Apabila arus yang dikenakan mencukupi, seluruh struktur akan berada pada satu keupayaan, maka tapak anod dan katod tidak wujud. SPK selalunya digunakan pada pelbagai jenis struktur seperti talian paip, tangki simpanan bawah tanah, kunci dan badan kapal. Dalam kerja ini, dua kaedah penggunaan perlindungan katod menggunakan sistem arus bekasan dan anod kordan telah dikaji. Walaubagaimanapun, hanya sistem arus bekasan diukur secara ujikaji. Nilai arus kiraan dan ukuran diambil untuk sistem arus bekasan. Ukuran arus keluaran yang diambil setiap minggu menunjukkan ada pengurangan dalam arus yang diperlukan dengan masa, yang disebabkan oleh pengurangan permukaan anod semasa hayat sistem tersebut.*

ABSTRACT: Cathodic Protection System (CPS) is used to reduce corrosion by minimising the difference in voltage potential between the terminal of anode and cathode. This can be achieved via impressed current system by applying a current from an electrical source to the structure to be protected. When enough current is applied, the whole structure will be at one potential, thus anode and cathode sites will not exist. CPS is commonly used on many types of structures such as pipelines, underground storage tanks, locks and ship hulls. In this work, the two methods of applying cathodic protection by using an impressed current system and sacrificial anode had been reviewed. However, only impressed current system was measured experimentally. The calculated and measured current values were obtained for impressed current system. The measurement of the output current taken each week showed that there is a decrease in the required current with time due to the reduction of anode surface during the lifespan of the system.

KEYWORDS: Cathodic protection system, corrosion, impressed current

INTRODUCTION

Corrosion is a major problem for any metal structure, particularly in environment where they are exposed to conditions that accelerate corrosion. It occurs as a result of a difference in voltage potential on the surface of a metallic object attributed to the non-uniformity in the surrounding electrolyte, changes in the crystal structure due to aging or weathering, or irregularities caused during manufacturing (Sarfi *et. al.*, 1993).

In general, corrosion can be defined as the deterioration of a substance or its properties whether chemically, electrochemically or physically due to the reaction with its environment, either atmospheric or soil environment. Some of the most common corrosion prevention measures are coating, cathodic protection, and electrical insulation.

Metals do not corrode to a great amount of electrolytes in the atmosphere as the whole metallic surface acts as anode and cathode simultaneously, thus, the corrosion process proceeds slowly. However, in the soil environment, due to the presence of ions at a certain depth that initiates the formation of an ionic gradient along the foundations, the richest areas in salts becomes anodic and after a certain period of time, it can corrode the underground metal structures (da Silva and Hoffman, 2001).

In principle, cathodic protection can be used in various applications particularly in a condition where a metal is immersed in an aqueous solution of an electrolyte, ranging from relatively pure water to soils and to solution of acids. The suitability of this method will depend on many factors. As the method is electrochemical, both of the structures to be protected and the anode used for protection must be in both metallic and electrolytic contact.

Cathodic protection cannot be applied for controlling atmospheric corrosion as it is not feasible to immerse an anode in a thin condensed film of moisture of rainwater's droplets. The complexity of the systems to be protected and the variety of techniques available for cathodic protection are in direct contrast to the simplicity of the principles involved. At present, the application of this method of corrosion remains more of an experience of the practitioner rather than a science. An ideal solution would afford a proper defense against corrosion at minimal cost. Otherwise, it will be insufficient, uneconomical and under certain circumstances it may accelerate corrosion instead of preventing it.

Many different studies have been carried out to improve this protection mainly in the chemical aspect and in the types of anodes. Others investigate the electrical variables and their calculation.

Favetto and Osella (1999) used numerical simulation to calculate the current induced in a buried pipeline due to magnetic storm. Sarfi *et. al.* (1993) suggested new techniques for optimal design of cathodic protection system in which they tried to minimise the cost of sacrificed anodes and for simplicity, they only considered linear system in their study. Sen (1991) had formulated a new formula based on the national institute of standards and technology data to estimate the corrosion rate due to environmental factors and soil type. The paper also discussed on how to design a proper cathodic protection system to minimise the corrosion of steel used for underground structure.

El Ghitani and Shousha (1995) had implemented the microprocessor-based cathodic protection system that was able to adjust the protection current automatically, according to the state of

Table 1. pH range and corrosion rate

Type of soil	pH value range	Corrosion rate
Extremely acidic	< 4.5	highest
Very strongly acidic	4.5 to 5.0	
Strongly acidic	5.1 to 5.5	
Mediumly acidic	5.6 to 6.0	
Slightly acidic	6.1 to 6.5	
Neutral	6.6 to 7.3	least
Mildly alkaline	7.4 to 7.8	
Moderately alkaline	7.9 to 8.4	
Strongly alkaline	8.5 to 9.0	
Very strongly alkaline	9.1 >	higher

Table 2. Soil resistivity and corrosion rate

Soil Resistivity (Ohm- meter)	Type of corrosion rate (Mils/ year)
< 25	Severely corrosive (>13)
26-50	Moderately corrosive (9-12)
51-100	Mildly corrosive (4 - 9)
>100	Least corrosive (<4)

Moisture Content

This depends on the season, location, soil type, ground water level and particle size. Corrosion increases with higher moisture content due to higher salt solubility.

Aeration

Aeration is a measure of the availability of oxygen to the metal and is dependent on particle size and distribution. Corrosion would increase with the increase of aeration.

Other Factors

These factors are difficult to classify because they are due to the combination of many factors which include the effect of temperature, bacterial or interference current effects. They contribute no more than 10% of the total corrosion rate and in many cases are neglected.

COATINGS

Atmospheric conditions can be expected to occur on exposed metal surfaces. Condensation, rainfall, acid rain, acid fog and other atmospheric pollutants could cause most surface type corrosion. Condensation produced moisture that provides an electrolyte on the surface to support the corrosion reaction (Kale *et.al*, 1999).

Coatings are often used for corrosion control where it insulates the anode and cathode of the corrosion cell from the environment. Selection of a coating for a particular application requires detailed knowledge on the environment and the type of service. After a coating is selected, great care must be exercised to ensure that the coating is properly applied. Coating failure usually occurs due to improper application and not due to a breakdown of the coating material. Surface preparation is also critical to coating performances.

The proper selection and application of coating system will reduce the total metal loss but it will not prevent corrosion. Unfortunately, coatings would concentrate the corrosion activity at the imperfections. This would intensify the corrosion rate and results in more rapid penetrations as compared to when the structure was uncoated.

From a practical standpoint, the coating can never be perfect. Over time, the coating can develop areas of reduced resistance, pinholes or damage due to the installation of new underground facilities. In the case of excessive coating, cathodic protection system might not be able to maintain the required potential along the length of the system. However, as the cathodic protection system maintains the pipe at an electrical potential more negative than surroundings, it will be protected from galvanic corrosion, even if the coating damage exits (Hoppe *et. al.*, 1996).

ELECTRICAL INSULATION

Electrical insulation is another method of corrosion control that can be used to break the conductor which connects the anode and cathode in the corrosion protective system. Insulation fittings come in many forms which include unions, couplings, flanges and spools. They are most often used to electrically separate dissimilar metals. Insulation only serves to break apart obvious corrosion cells. It will not prevent local corrosion activity resulting from each metal due to different oxygen concentrations.

CATHODIC PROTECTION

Cathodic protection is the most effective way of protecting underground metal structures. It operates by stopping the current flow from the metal to the electrolyte by neutralising it with a stronger current of opposite polarity from an external source (da Silva and Hoffmann, 2001). Two methods basically used in cathodic protection systems are sacrificial anode (passive method) and impressed current (active method). Both methods provide satisfactory results, each with its own advantages and disadvantages.

Sacrificial Anode

Sacrificial anode is based on the principle of dissimilar metal corrosion and the relative position of specific metals in the galvanic series. It uses the natural potential difference that exists between the structure and a second metal (sacrificial anode) in the same environment to provide the driving voltage. Figure 1 shows the schematic diagram of cathodic protection using sacrificial anode.

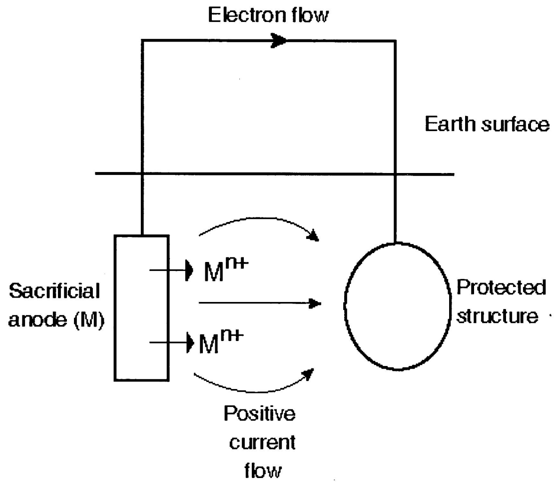

Figure 1. *Cross-sectional diagram of cathodic protection using sacrificial anode*

This method is applicable and effective in a system with a low current requirement of less than 100 mA and well-coated structure in a low resistivity soil. The anode must be a more electro-negative metal than the protected structure and placed along or around it. The consumption rate of sacrificial anode is dependable on the magnitude of current generated as well as the material of which the anode is made of.

The advantages of sacrificial anode method are it requires no external power supply, minimum maintenance and installation cost, and seldom cause interference problems to other systems. The disadvantages are limited driving potentials and current outputs, limitation of soil resistivity, mutual interference in multiple or parallel installation and must be periodically replaced.

Impressed Current

Impressed current uses a power supply or a rectifier with an anode to protect the metal structure. Current is injected from the anode through electrolyte to the surface of the buried metallic structure.

This system has the advantage of controlling the amount of current received by the buried metal structure through the adjustment of the power supply.

Figure 2 illustrates the use of an external power supply to provide the cathodic polarisation of the structure.

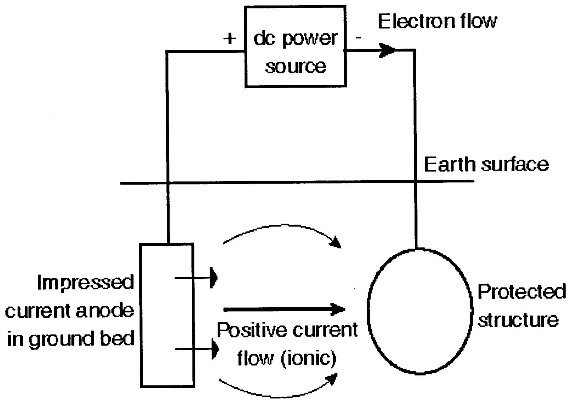

Figure 2. *Cross-sectional diagram of cathodic protection using the impressed current technique*

From Figure 2, it can be seen that the structure is cathodically polarised (its potential is lowered) and the positive current returns through the circuit to the power supply. Thus, to achieve cathodic protection, the impressed current-electrode and the structure must be in both electrolytic and electronic contact.

The calculated value of anode to cathode resistance, the number of anodes required and total current required could be found (Sheir *et. al.*, 1994) as:

$$R_a = \frac{\rho}{2\pi L}\left[\ln\frac{4L}{r} - 1\right] \quad (1)$$

$$N = \frac{0.0052\rho}{R_a L}\left[\ln\frac{8L}{d} - 1\right] \quad (2)$$

$$r = \sqrt{\frac{a}{\pi}} \quad (3)$$

Total current required, I = current density x protected area (4)

Where:

R_a is the anode-to-electrolyte resistance (ohm)
N is the number of anodes required
ρ is the resistivity of the water (ohm cm)
L is the length of anode (cm)
r is the equivalent radius of anode (cm)
a is the cross section of anode (cm^2)
d is the diameter of the column (cm)

The resistances of the anode and conductors are very small with respect to electrolyte resistance and can be neglected.

The main advantages of the impressed current system are the large current output allows it to protect large structures, applicable in high resistivity soil environments, and for bare and poorly coated structures, flexibility in controlling the current output. The disadvantages are higher installation and maintenance costs, monthly power costs and interference problem with neighbouring structures.

METHODOLOGY

In this work, the two methods of cathodic protection are reviewed.

Sacrificial Anode's Model Design

Figure 3 shows sacrificial anode arrangement to protect the carbon steel pipe by using zinc as an anode. The zinc anode is welded to the carbon steel pipe by steel rod to provide continuity for the current flows. The structure is immersed in a saltwater solution to imitate the seawater environment.

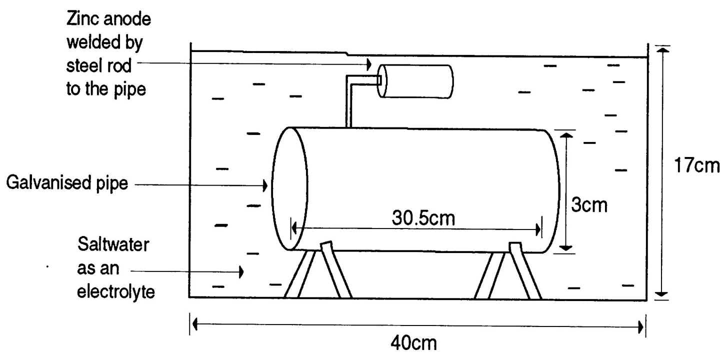

Figure 3. *Sacrificial anode plan to protect carbon steel pipe*

Impressed Current's Model Design

Figure 4 shows the impressed current design to protect the carbon steel pipe. The model comprises the dc power source, an impressed current zinc anode, the saltwater solution and the structure to be protected. The power source drives positive current from the zinc anode through the saltwater solution and to the structure. The structure is thereby cathodically polarised and the positive current returns through the circuit to the power supply. To achieve cathodic protection, the zinc anode and the carbon steel pipe both are electrolytic and electrically contact. Figure 5 shows the photo of impressed current model.

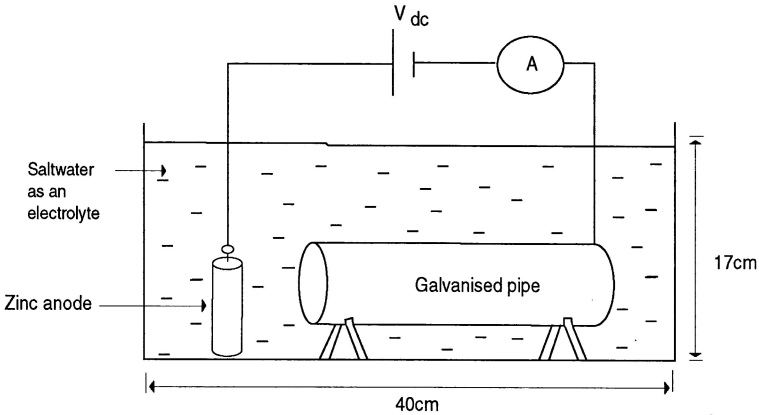

Figure 4. *Impressed current plan to protect carbon steel pipe*

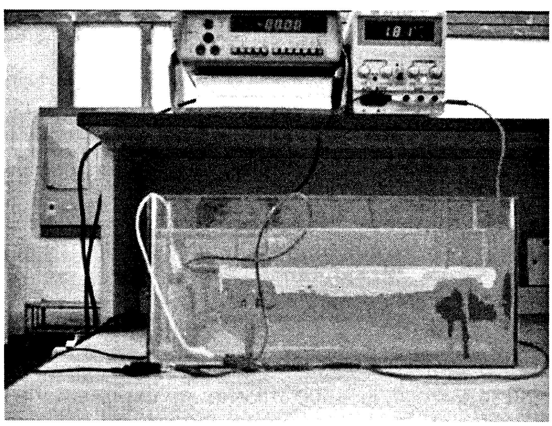

Figure 5. *Impressed current model to protect carbon steel pipe*

RESULTS AND DISCUSSION

The model for sacrificial anode had been constructed and observed. Due to its construction, it was difficult to measure the current. Furthermore, the amount of current flowing would be small and the variation would be even smaller. The anode's surface only undergoes significantly small changes. Spots of corrosion can be seen visually on the anode's surface. Reduction in mass is almost undetectable.

Current for impressed current system was calculated using the above mentioned equations [equation (1), (2), (3) and (4)] and it was found to be 3.32 mA, while the measured value obtained from the model was 3.54 A.

Table 3. Comparison between calculated and measured value for impressed current system

	Calculated	Measured
Current, I_1(mA)	3.32	3.54

Measurement of protective current flows from electrolyte into the structure was taken every week to check the variation of the current value with time. Figure 4 shows the variation of the protective current with respect to time.

Anode performance in impressed current system depends on the electrolyte resistivity as well as the anode material and size. For this model, the seawater resistivity value of 30 Ω has a better conductivity than in soils. The zinc anode is suitable for seawater application as it has a high driving voltage due to it being more active than the structure itself, and low consumption rate as the potential difference between the zinc and the structure is small.

Both models used zinc anode that acts as an auxiliary anode that is composed of a metal more active in the Galvanic Series than the structure to be protected. It serves essentially as a source of portable electrical energy. The potential difference of zinc with respect to steel is about -1.03 V and hence current output per anode is also less. This low voltage is sometimes considered as an advantage over higher impressed voltages in that danger of overprotection to some portion of the system is less.

The current output per anode for the sacrificial anode scheme is only 4.98 mA [calculated from equations (1), (2), (3) and (4)], which is sufficient enough to protect the carbon steel pipe. The estimated resistivity value of 30 Ω is selected because of the use of saltwater as an electrolyte for this model. Total resistance value of 0.572 Ω was calculated according to the formula for a single horizontal rod anode (slender type).

The impressed current system requires a source of direct current and an auxiliary electrode (anode) located some distance away from the protected structure. The dc source is connected with its positive terminal to the anode and its negative terminal to the structure to be protected. In this way, current flows from the electrode through the electrolyte to the structure.

The applied voltage of 2 V is not critical, it only needs to be sufficient to supply an adequate current density to all parts of the protected structure. Observing the calculated and measurement value of current output showed that there is some difference in the value. This is because the calculated values used here were just an estimated value taken from the appropriate table. Therefore there could be an inaccurate estimation of the values.

Figure 6 shows that there is a decrease of current output relative to time. This is due to the reduced anode surface during the lifespan of the system. The dissolving anode must also obey Faraday's Law which is the corrosion of the anode will be proportional to the total current delivered. Therefore, as the anode dissolves, the resistance it presents to the circuit increased and the current measured decreased.

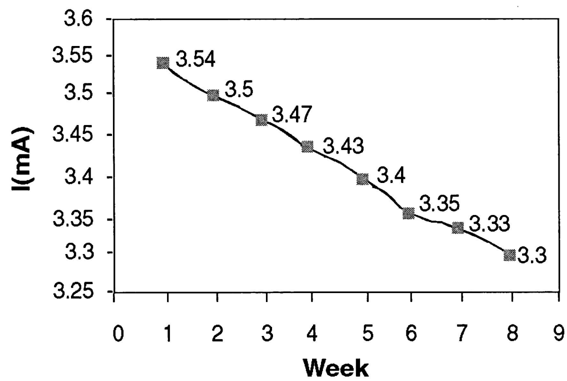

Figure 6. *Current output relative to time*

CONCLUSION

Some industries have accepted corrosion as an inevitable problem and choose to do nothing about prolonging the life of many metals exposed to corrosive environments. However, some take steps in preventing corrosion as the damage due to the gradual destruction of materials costs money to replace. Corrosion should be considered when designing a grounding system as the ground conductors and connectors could be affected by it when they are buried or submerged in a corrosive environment.

Two main methods of cathode protection system, sacrificial anode and impressed current were reviewed in this paper. The design for sacrificial anode makes use of the corrosive potential for different metals. The current required for carbon steel pipe is supplied by the corrosion of the zinc anode that has a higher positive charge than the protected structure. This electric potential (voltage) difference causes a greater attraction of negative free electrons than the ions in the carbon steel pipe. The zinc anode gets sacrificed (corrode) and the corrosion process in the carbon steel pipe is interrupted and hence protected.

The current measurement for impressed current system indicates a decrease of output current due to anode dissolved in the immersed saltwater. The same principle was also applied to impressed current system with the exception of dc voltage source in the system.

The calculation principles and measurement of cathodic protection are quite straightforward and based on assumptions. However, their application in real systems is often sufficiently complex to preclude quantitative determinations.

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