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Short history of cathodic protection for fixed offshore structures

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Abstract

In this paper, the design of cathodic protection systems for offshore structures has been reviewed. Application of aluminum and aluminum-zinc alloys anodes is more desirable than the other sacrificial anodes. According to a lot of experiments about the materials, size and the environment conditions, the considerable and interesting developments in these anodes has been observed. Also there are some investigation in the field of simulation and computerizing of the design and performance of these anodes. It has been found that a titanium anode, coated by a layer of precious metals, is a suitable anode in the impressed current method.

The effect of some factors such as the distance between anodes, temperature and current density has been studied.

Introduction:

The various offshore structures can be classified as (1) platforms, (2) semi-submersibles and (3) wells, pipelines and sub sea installations. The presence of corrosive ions and powerful motion of seawater and the existence of some microorganisms are caused to accelerate the rate of corrosion.

Cathodic protection is now an accepted and necessary technique for protection of offshore structures [1]. Cathodic protection systems are also designed to provide continuous protection. The design is usually is the result of an economic tradeoff among initial installation cost, protection from physical damage and accessibility for repair and maintenance [2].

Cathodic protection can be defined as a technique of reducing or eliminating the corrosion rate of a metal by make it the cathode of an elechochemical cell and passing sufficient current through it to reduce its corrosion rate [3].

Two types of cathodic protection systems are commonly used:

1) Impressed current (active) systems

2) Sacrificial anodes (passive) systems

In recent year, hybrid systems – combinations of impressed current and sacrificial anodes – have been used for very large marine structures [3].

There are a lot of studies to introduce the new and modern cathodic protection systems. Generally it can be found that the protection of specifically steel structures would be possible by utilizing suitable sacrificial anodes with a coated layer.

Offshore platforms:

These structures will have to stand up to the rigors of the weather found in many of the offshore locations. It will be subject to massive tidal longitudinal forces and these will be increased by fouling on the structure and further increased if bulking cathodic protection is applied. The steels that are used in the construction of the platform and in particular in the high stress area will be of a type that will be susceptible to hydrogen embitterment if excessive cathodic protection is applied. Also the welding will not normally be possible.

To determine the optimized conditions of protection of systems, three items should be evaluated: (1) existing unprotected structure, (2) existing cathodically protected structures and (3) proposed effective system [4]. The most popular and common system is found to be the sacrificial anodes systems [3].

Until 1972, corrosion engineer had to assume that cathodic protection systems would perform in deep water as they do in shallow. Then, McKinley reported that anode performance was affected by depth [5].

The design of cathodic protection systems:

Cathodic protection criteria:

Potential measurements: according to references a negative (cathodic) voltage of at least 0.80 (V) between the platform and a silver- silver chloride reference electrode contacting the water, is necessary [3].

Visual inspection: visual inspection should indicate no progression of corrosion beyond limits acceptable for platform life [3].

Corrosion test coupons: In this criterion, corrosion type and rate that is within acceptable limits for the intended platform life must be indicated [3].

It should be noticed that, the silver- silver chloride (Ag / AgCl) electrode has been widely used as a practical reference electrode in seawater for the past 20 years. It can be used in the wide range of different sea waters [6].

Comparison of impressed- current and sacrificial anode systems:

Sacrificial anode cathodic protection systems are simpler and the capital cost of small systems are normally used for the protection of large structures or where the low conductivity of the electrolyte makes sacrificial anodes impractical [3] & [7].

Sacrificial anode systems:

Aluminum and aluminum-zinc alloys, have become the preferred sacrificial anodes for cathodic protection of offshore platform.

This is because aluminum anodes have reliable long – term performance when compared to magnesium. Aluminum also has better current/weight characteristics than zinc. But the major disadvantage of aluminum is that aluminum alloys will not corrode reliably onshore or in freshwaters. Unfortunately, it is necessary to add mercury, antimony, indium or tin to the aluminum alloy to and heavy – metal pollution concerns have led to bans on the use of mercury alloys in some locations [3].

Jensen et al. in 1978 have investigated the zinc anodes for offshore buried pipeline at elevated temperature. The results from this laboratory study indicate that pure zinc, Zn – 0.02 Mg and Zn – 0.05 Cd will not be useful as buried bracelet anode materials for elevated temperature service [8].

In the study on the of sacrificial anodes for ocean bottom applications, it is shown that the performance of aluminum anodes is dependent on whether the environment is sea water, anaerobic mud covered with sea water, or sand covered with sea water. Most aluminum alloys show a substantial decrease in current capacity when operating in saline mud as compared to sea water or saline sand. However, an aluminum alloy containing 0.04% Hg plus 4.0% Zn largely overcomes the degrading effect of saline mud [9].

From the obtained results, aluminum anode replacement on offshore platforms by bracelet attachment, have a suitable performance compared with other types of anode attachment systems [10].

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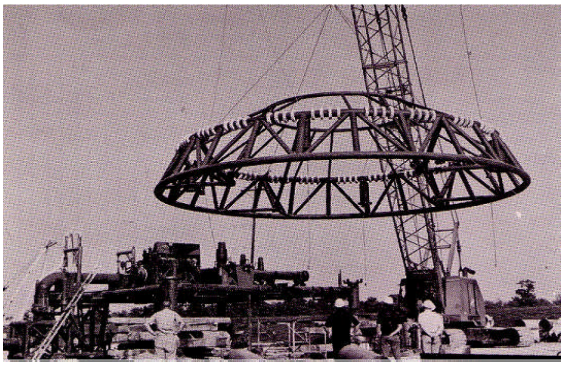

Fig 1) Galvanic anodes on submarine valve platform

It is also shown that no signs of corrosion in the structure under the anode supporting bracelet were found [11].

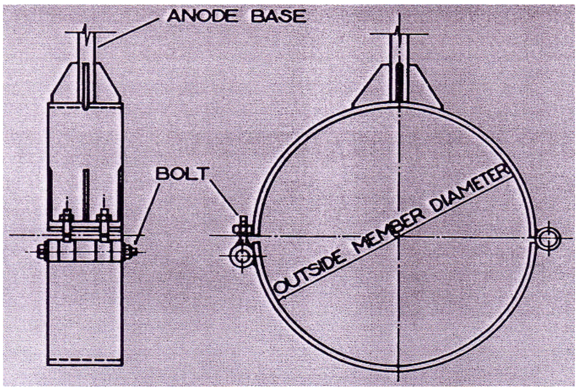

Fig 2) Bracelet for anode attachment

In 1974, Reding and Boyce have studied the cathodic protection performance of offshore anodes at a simulated depth of 650 feet. They showed that Pb–Ag–Sb anode consumption rates are two times more than the normal rate when operating at 1.6 A/dm^2 in 650 feet deep water as compared to operation in shallow water [5].

In 1996, it has been observed that for Auger tension leg platform cathodic protection system in deep and cold water applications, Al–Zn–Si–In anodes which contain nominally 5% Zinc, have a better performance that which of them contain 3% Zinc [12].

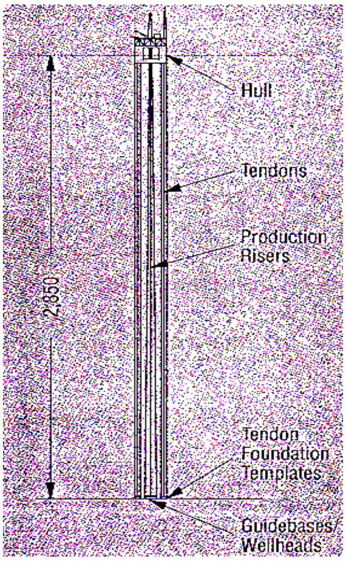

Fig 3) Auger Tension leg platform components

It has been reported that, in the Persian Gulf, in deeper water (52 m), the structure galvanic anodes deliver 8 Amperes per well and protect the bare casing to 915 m [13].

In a research in 1999, Kiefer et al. analyzed the cathodic protection systems of fixed offshore platforms. The analysis showed that significant variations may occur in the number of retrofit anodes required from one section of structure to another. The selective distribution of retrofit anodes by section should promote uniform jacket potential and anode consumption [14].

Deep water testing sacrificial anodes was carried out by Mackay et al. in 1974. From the results, during 6 months of experiment, the effectiveness of sacrificial anodes at increased water depth is predicted [15].

An experimental sacrificial cathodic protection systems comprised of Zn sheet anodes with an ion conductive gel adhesive was installed to protect an electrically isolated reinforcing steel sub–system in a bridge substructure. The result showed acceptable performance [16].

Four aluminum sacrificial anodes, protecting bare steel specimens were exposed for 6 months in sea water and two types of marine soil to determine their relative electrochemical efficiencies. In a protection system with aluminum and zinc, the zinc anodes became passivated [17].

Doremus and Pass in the study on cathodic protection of 516 offshore structures–engineering design and anode performance, showed that by using of three types of sacrificial anodes, 244 1b, 137 1b and 76 1b, made of Al – 0.045% Zn – 0.45% Hg, the suitable result were obtained economically and practically [18].

In 1987, cathodic protection of aluminum–coated steel in seawater was investigated by Gartland. It has been reported that, the measured corrosion rates of a 200 µm coating, causes lifetime of 1 to 2 years for zinc and 20 to 30 years for the aluminum–based coating [19].

An updated version of sacrificial anodes for cathodic protection of structures immersed in seawater was recently patented. The anode, constructed in two anodic materials (aluminum alloy on the inside and magnesium alloy on the surface), offers significant reduction in the weight and cost due to highly protective calcareous deposit that forms on the immersed structure when these anodes are used [20].

Mechanism of cathodic protection in seawater was studied by Evans. Ionic charge

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transport through pores in the scale is thus best regarded as a diffusion process and ionic migration under the influence of applied field. The potential difference between the mouth and base of the pores is thus diffusion potential across a porous membrane [21].

Keim and Stormmen was investigated the computer modeling in offshore platform cathodic protection systems. They studied on the computerizing of a hybrid system. The purpose of this investigation was to modify and improve the parameters of a cathodic protection system by computer modeling [22].

The composite anode discussed here is made by casting an anode in aluminum alloy on to a steel support in the usual way. Then an external 1.5 – cm layer of magnesium alloy is cast in controlled atmosphere and temperature. Figure 4 is a schematic of the anode.

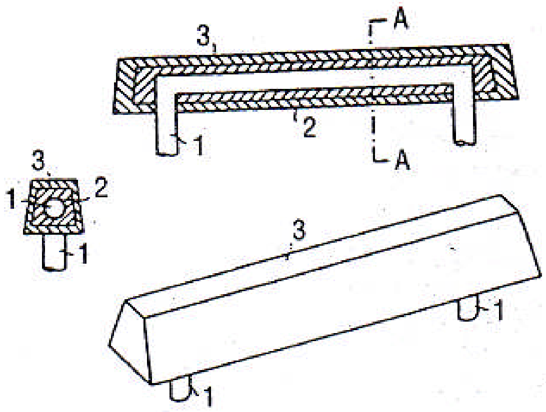

Fig 4) Construction drawing of a composite anode: (1) steel support, (2) aluminum core, (3) magnesium skin

The field tests show that these sacrificial anodes supply a current density considerably higher than that provided by traditional aluminum anodes. When the surface magnesium layer is consumed, the current supplied is between 30% and 60% of that guaranteed, during same period, by aluminum anodes. This drop is due to covering of structure by calcareous deposits and hence requires a reduced protection current. The current reduction leads to a considerable reduction in the mass of aluminum needed, resulting in substantial economic saving [20].

Saetre and Jensen in 1982 studied the developments in cathodic protection of offshore concrete structures. They utilized zinc anodes due to solve some problems which would occur by using the other materials [23].

Syderberger et al. in 1997 reported that offshore installations such as steel jackets, sub sea templates, and pipelines, the cost of a cathodic protection system with a design life of 25 years is typically 0.5 to 1% of their total fabrication and installation costs [7].

Impressed–Current systems:

Impressed–current anodes do not need being anodic to steel and normally they are not. Most materials used as impressed–current anodes are insoluble and corrosion resistant. Same of these materials are: high silicon cast iron, precious metals such as platinum, ceramic anodes consisting of metal anodes on conductive metal substrates and polymer anodes containing embedded graphite conductors [3].

In 1991, Hedborg studied the cathodic protection in Cook Inlet arctic water. It was concluded that, high oxygen solubility and high tidal velocities in Alaska's Cook Inlet presents unusually severe corrosion conditions. Also, lead–silver anodes deployed on the seafloor have had reasonable success. Maximum current densities of 10 to 12 A/ft^2 of lead have a service life of approximately seven years [24].

Mesh anode cathodic protection system was studied in 1991. The construction, activation, and initial performance of a mesh anode cathodic protection system on a bridge deck have been described [25].

Gjorv and Vennesland investigated a new probe for monitoring steel corrosion in offshore concrete platforms. They found that the rate of corrosion in such cases depends on the ration of the surface of cathode to anode. This ratio, also have relation with the design of structure [26].

According to the investigation of Jensen and Abrahamsen, the anode weight should be estimated from Fig 5. This figure gives the average current requirement for at least four years and reflects both painted and unpainted structures. [27]

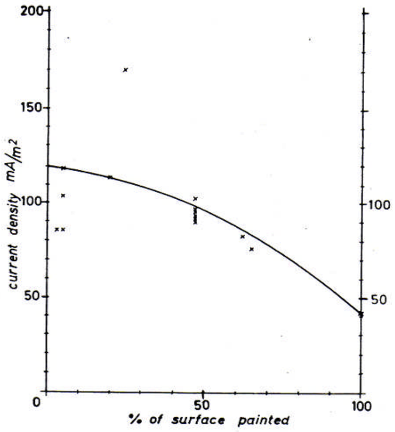

Fig 5) Calculated current density versus percentage painted, submerged steel surface on 15 semi–submersible rigs

Vennett et al. studied the design of the cathodic protection system for Conoco's North Sea Murchison platform. The value of current densities is listed in Table 1. The size of impressed–current anode was 1 m in length, 20 mm in diameter and a coating platinum layer with the thickness of 20 μm.

Tab 1) Cathodic protection design criteria for platform

Item	Current Density (mA/m^2)	(mA/ft^2)
Submerged structural steel	130	12
Gas riser and flow line bundle sheaths	200	18.6
Oil riser	300	27.9
Monel	250	23.3
Steel in mud (piles)	30	2.8
Diesel fuel storage	30	2.8
Each well casing (A)		10

In a study on the cathodic protection of Mississippi riser dock in 1973, to protect cathodically the pilings supporting of the tanker loading dock, 84 high silicon cast iron anodes were utilized, which these anodes in four groups distributed 600(A) through the structure [28].

Anthony in 1974 investigated the cathodic protection system of a platform in Alaska. Current densities in the range of 2.34 to 3.72 mA/m^2 are required and some times to entire proper current distribution, 4.645 mA/m^2 may be needed for protection [29].

From the results obtained by Jelinek et al. in 1996, it can be concluded that for several reasons, including high maintenance cost of the impressed current system, the number of impressed current has been reduced and retrofitting of sacrificial anodes has been required [30].

An equation was introduced by Cochran, which defined the anodes to sea water resistance at any selected percentage amount. By these equations various practical structure geometry resistances can be early calculated [31].

Britton and Holt purposed a computerized cathodic protection survey system for offshore platforms. This system has been employed on a number of structures in the Gulf of Mexico. This technique demonstrates how computer technology has facilitated rapid collection of comprehensive cathodic protection system performance data in 92 m water depth [32].

Strommen et al. in 1987 studied the cathodic protection system modeling using the boundary element method. This suggested program had capabilities for analysis of dynamic and temporal effects on cathodic protection simultaneously and predicted the time dependent current density and potential behavior resulting from the formation of a calcareous deposit [33].

The effect of various parameters on the design of a cathodic protection system, also have been studied by Saleh Rad et al. They found that type and value of transformer–rectifier voltage depends on the distance between anodes. By increasing the distance between anodes, the value of anode resistance decreased. Also the value of current density increased at elevated temperatures. The relation between required current density for polarization and protection of steel structure in seawater is linear [34].

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