Boundary element modelling of the impressed current cathodic protection of an offshore platform

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Abstract

For most steel structures in a marine environment, corrosion is a big problem as it relates to long-term safety. Cathodic protection is an effective method to resist corrosion in seawater. In most cases, the design of cathodic protection systems depends on the empirical expertise of the corrosion engineers. To achieve the protection potential of the whole structure, excess protective current is usually applied, which leads to the waste of protection material. In this paper, the boundary element method was used to simulate the impressed current cathodic protection of an offshore oil platform to achieve ideal potential and current distribution. The location and the amount of anodes with different current demand were calculated using the commercial software BEASY, which has many applications in the corrosion field. The boundary condition of the model is defined as the parameter of the anode and the cathode of the system, which can be identified from the polarization curve of the material in seawater. A physical model was also built to verify the numerical modelling results, and the experimental results were consistent with the computation predictions. The research proved the efficiency and accuracy of the boundary element method for the impressed current cathodic protection of offshore structures.

Keywords: boundary element method, corrosion, impressed current cathodic protection, offshore platform.

1 Introduction

As the demand of energy grows rapidly, the offshore oil and gas exploitation has become an important assurance of energy supply. Cathodic protection is an effective technology to prevent a steel structure from suffering severe corrosion in the marine environment. Generally, the operation lifetime of an offshore oil platform is about 20 to 30 years, and the cathodic protection system is also designed for the same lifetime as that of the structure. However, in many marine oil exploiting fields, the offshore platform in operation usually exceeds its design life because of the rich petroleum reservoir and the inaccurate prediction of the mining rate. According to statistical data, 35% of the 20-year old platforms need to continue to serve the production; this demands complete structural health evaluation and the necessary reinforcement to guarantee the structure's safety. The cathodic protection system is one of the important parts of such reinforcement, and repairing or renovating is needed for the original system to accommodate the need of future operation life. On the other hand, for most of the offshore platforms built 10 to 30 years ago, the sacrificial cathodic protection system was the most common method to resist the marine corrosion. The consumption rate of the anodes of the system sometimes exceeds the original design rate because of the effect of marine environment factors, poor anode quality and inadequate anode current.

Though the impressed current cathodic protection (ICCP) and sacrificial anode cathodic protection are both used in offshore structures, they have different features. For those offshore structures which require extending or retrofitting their cathodic protection, the impressed current system is an economic and simple choice which has great advantages over the sacrificial anode system. Firstly, a large amount of galvanic anodes are usually installed on land before launching to the designated area; if all these anodes are retrofitted underwater, it would incur a great expense, while the ICCP can reduce most of the installation work. Secondly, as the structural surface has changed considerably compared with the original steel surface because of calcareous deposits and coating failure or breakage, it is difficult to evaluate the accurate current demand for protection, and once the amount and the location of the anodes has been determined, the current cannot be adjusted, while the ICCP can conveniently adjust the output current according to the monitored potential and current. So for marine structures which need retrofitting, the ICCP is the optimal choice.

However, the selection of cathodic protection parameters is a big problem that causes concern among corrosion engineers. For a long time over the last decades, the design depended on the experience of engineers, especially with regard to the location and the amount of the anodes. With the dramatic advances in numerical simulation and computing technology, computer modelling methodology was applied to the cathodic protection field. Among such modelling, the boundary element method (BEM) has shown great advantages with respect to accuracy for large marine structures. Compared to other numerical analysis methods, such as the finite element method (FEM) [1, 2] and the finite difference method (FDM),

BEM analysis can effectively solve three dimensional problems for structures of large size with less meshing requirements [3–6].

In this contribution, the BEASY software [7], developed on the basis of the boundary element method, was used to aid the design of an ICCP system and a physical jacket platform model was built in a seawater tank. The computed results and experimental data were compared to check the validity of the numerical analysis.

2 Experimental work

2.1 The ICCP principle

Metal corrosion is an electrochemical reaction with oxidation and reduction reaction on different electrodes. For steel in seawater, the following reactions occur:

In these reactions, Fe with solid state converts to Ferrous II ions with aqueous state, which means the loss of the steel. To inhibit the oxidation reaction, some measures have been taken to prevent the corrosion. For the cathodic protection, a type of metal with more negative potential or a power source connect with steel and provide additional electrons. In an ICCP system for a steel structure, a DC power (or rectifier converting AC power to DC power) and a type of non-consumable anode are required. The principle of ICCP for a steel structure in marine environment is depicted in Fig. 1.

Figure 1: Diagram of impressed current cathodic protection.

In practice, the design of ICCP usually refers to some standards or criteria, such as NACE RP0176 and DNV RPB401. The most important point of the design is that overprotection and under protection must be avoided. The commonly accepted protection potential is from -850 mV to -1050 mV vs. silver/silver chloride electrode.

The selection of proper protection potential and current density is very important since this concerns the final distribution of ICCP. The current density for ICCP is dependent upon environmental factors such as pH value, salinity, oxygen content, coating integrity, marine fouling, sea currents, pressure and calcareous deposit among others.

The numerical simulation provides an effective method to help advance understanding of the distribution of the potential and current density for marine structures. As the offshore installation cost is very high, the simulation can model the real-time corrosion protection condition in advance to reduce unreasonable problems caused by the design.

2.2 ICCP experiment

To simulate the cathodic protection condition of a marine structure, a scaled-down physical model of a jacket platform was constructed referring to a real platform of China National Offshore Oil Corporation (CNOOC). The jacket platform had a symmetrical design with four legs and three levels in the vertical direction. The legs and the support tubes of the platform had different diameter. The form and dimensional details of the platform are shown in Fig. 2. The platform was made of steel without any coating on the surface. All the terminals of tubes were sealed to avoid the ingress of seawater.

Figure 2: Detailed dimensions of the platform (mm).

The platform was placed in a marine environment modelling tank, which was as described in an earlier publication [8]. The modelling tank was large enough to place the jacket platform within it. An accurate control system was designed to model the flow of the tide through a paddle wave maker and a siphon tube. The solution in the tank was fresh seawater pumped from the sea.

For the design of an ICCP system for a marine structure, some factors are needed including seawater resistivity, total protective current required, the anode type and the design life.

The total current requirement (I_{req}) for an offshore structure can be calculated as the product of the total exposed area (S) of the structure and the current density (i_j) for protection; this is expressed as:

$$I_{req} = i_j \cdot S \quad (4)$$

After the total current has been decided, the major problem is how to distribute the current to the whole structure, so the arrangement of the anodes is very important.

To investigate the effect of the distance between anode and structure, the anode was placed at a distance of 20 cm and 60 cm from the platform.

The electrochemical polarization experiment was conducted using a traditional three-electrode cell setup. The working electrode was steel with dimensions 1 cm × 1 cm × 1 cm and the exposed area was 1 cm². The reference electrode was saturated calomel electrode (SCE) with Luggin capillary, and the counter electrode was rectangular platinum sheet. The working electrode was abraded gradually using 600, 800 and 1200 grit Sic paper, degreased by acetone, washed with distilled water and dried in air.

Electrochemical experiments were carried out using a Parstat 2273. The polarization curve measurement performed a scan starting from -200 mV to +200 mV vs. open circuit potential at a scan rate of 0.5 mV/s.

3 Results and discussion

3.1 Boundary element method

The boundary element method applied to the corrosion analysis solves the Laplace equation [8]:

$$\nabla^2 \phi = 0 \quad (5)$$

subject to the boundary conditions illustrated in Fig. 3.

Some assumptions are made leading to simplifications of the corrosion conditions. Γ is the entire surface of the electrolyte domain Ω , comprising Γ_1 , Γ_2 , Γ_{3a} and Γ_{3b} ; ϕ and I represent, respectively, the potential and current density at a point; ϕ_0 and I_0 are the initial constant values of potential and current density, respectively; $f_a(\phi_a)$ and $f_c(\phi_c)$ are relationships between the potential and current density of anode and cathode, respectively. For the ICCP system, the boundary condition parameter of anode is specified as a constant potential or constant

current value, and the cathode parameter can be measured using linear polarization method.

The BEASY software, which was designed for solving the Laplace equation and the corresponding computation algorithm, has been used in the corrosion field for several years. The key points in obtaining an ideal computation result are the construction of the model and the application of the third boundary condition as described in Fig. 3.

Figure 3: Boundary conditions for BEM.

3.2 Numerical modelling

The first step in the cathodic protection modelling is the development of the numerical model in a graphical user interface. The model was built using the coordinates of every point in the design drawing sheet. In the numerical model, all the dimension parameters were introduced into the BEASY software, including the cross-support tubes in the vertical and horizontal direction, including the diameters of every tube. On this basis, the anode model was added, with the accurate dimension, shape and location on the model. The computer model of the platform is shown in Fig. 4.

After completing the building of the computer model, the polarization data obtained from an electrochemical experiment were digitized into the software polarization database; this constituted the third boundary condition in the computer modelling. Besides the parameters mentioned above, the environmental conditions of the seawater solution were also very important, since the electrical conductivity and the temperature would affect the potential and current distribution of the cathodic protection system.

In the experimental investigation, three impressed current anodes were placed on each side of the jacket, that is, a total of 12 anodes. To evaluate the influence of the distance between anode and jacket platform on the cathodic protection, the anodes were arranged at different distances from the platform.

Figure 4: Computer model of the platform.

The calculated results for the potential distribution over the jacket are depicted in Fig. 5. With the anodes at a distance of 20 cm from the jacket, the value of the potential was in the range from -979.3 mV to -1068.9 mV, while with the anodes at a distance of 60 cm from the jacket, the value of the potential ranged between -980.9 mV and -1075.4 mV. The potential contours can visually reflect the potential distribution as well as the effect of anode location and number on the jacket. The actual potential distribution on the platform was measured to verify the numerical results. For 20 typical points on the platform, the results showed that the difference between numerical modelling and measured results was less than 12 mV, which was sufficiently small to confirm the effectiveness of the boundary element method for ICCP modelling.

4 Conclusions

In this research, the potential distribution over a jacket platform with impressed current cathodic protection in seawater was modelled using the boundary element method. The effect of different arrangements of the amount and location of the anodes on the cathodic protection was also assessed. BEM modelling was shown to be suitable for analysing the cathodic protection system of an offshore jacket.

Figure 5: Potential distribution of the platform with ICCP: anodes at a distance of (a) 20 cm, (b) 60 cm.

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