JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 16, Preprint 52 submitted 24 July 2013

Response Surface Method Application to Cathodic Protection in Steel Piling

Mohammed Hliyil Hafiz ,P.E.

Materials Engineering Department – University of Technology-Iraq.

Email:drmhh1962@gmail.com

Abstract

The most effective method to overcome the corrosion problem is Cathodic Protection (CP) which represents a control method in the steel piling corrosion. In this work the response Surface Method (RSM) is used to model the Cathodic Protection System (CPS), predict the potential protection by finding the optimum factors levels which satisfyi the maximum potential protection. The suggested BBD matrix structure for protection potential is output dependent variable and four input independent variables (resistivity, sacrificial anode alloy, distance between anode and cathode and cathode surface area), this matrix structure is statistically chosen. The optimum design of experiment (DOE) for steel wall was 27 experiment runs. This design can be used to assess the effect of factors on protection potential for SCPS and its reliablility. This design can be used to predict the potential protected with optimum factors levels. The optimum region of protection potential is satisfyied with (25 Ω.cm resistivity, Al-8%Zn (anode alloy), 10 Cm distance, 36 Cm^2 cathode surface area.

Keyword: Cathodic Protection, Sacrificial anode, Box-Behnken Design, Optimization Cathodic Protection, RSM.

1. Introduction

Optimization is an important subject in the statistical design of experiments. Box–Behnken statistical experiment design and the response surface method (RSM) are used to investigate the effects of the four independent variables on the response functions and to determine the optimal minimizing and maximize the potential protected. In order to *maximize* the protection when it is fractionated with sacrificial cathodic protection, we can choose low level settings for resistivity, distance between anode and cathode, surface area for steel wall (cathode), and middle level for sacrificial anode alloy. The optimization procedure involves studying the response of the statistically designed combinations, estimating the coefficients by fitting the experimental data to the response functions, predicting the response of the fitted model and checking the adequacy of the model [1]. In engineering processes two types of variables are studied, first type is called continuous variable and it covers all variables that can be measured like weight, length, concentration and second type is called discontinuous variable and covers all variable that cannot be measured like anode alloy. Here we have a problem in the variables studied in this work because we have two types of the variables. To avoid this problem it is suggested the coded value for the variables and their limits in the optimization function be applied.

2. Aim of this Work

The aim of this research is to study optimum protection potential predicted by sacrificial cathodic protection for steel piling in seawater.

3. Experimental Equipments

3.1 Materials

Low carbon steel wall which is used in Al-Zubair Harper in the south of Iraq was used as a structure to be protected (cathode), three different anode alloys were used as sacrificial anode (Al-12%Si, Al-8%Zn, Pure-Al). The main reason using this alloy type is the characteristics of the Al base alloys are used as sacrificial anode for cathodic protection in seawater environment because of the light weight of the Al-base alloys.

3.2 Response Surface Optimization Method (RSM)

Response surfaces were computed using all (27 designs) to demonstrate that despite the use of a limited number of design variations, the proposed RSM would yield sets of “best” design parameters that would cluster in a region of the design space where the “best” measure of performance may exist [2]. The first goal for Response Surface Method is to find the optimum response. When there is more than one response then it is important to find the compromise optimum that does not optimize one response. [3] [4]. The second goal is to understand how the response changes in a given direction by adjusting the design variables. In general, the response surface can be visualized graphically [3]. Response-surface methodology comprises a body of methods for exploring optimum operating conditions through experimental methods. Typically, this involves doing several experiments, using the results of one experiment to provide direction for what to do next. This next action could be to focus the experiment on a different set of conditions, or to collect more data in the current experimental region in order to fit a higher-order model or confirm what we seem to have found [5]. The approximation of the response function y

= *f (x1, x2,…. xq) + e* is called *Response Surface Methodology* [3]. RSM is built by using MATLAB 7.0 language to run and estimate the response effects and draw this effect and the predict value for optimum factors that are estimated by RSM method. The polynomial equation derived to represent applied as a function of the independent variables tested. Where Y is the predicted applied and χ_1, χ_2, χ_3, and χ_4 are the coded values for resistivity, sacrificial anode alloy, distance between anode and cathode and surface area of structure protected required, respectively. The coefficient estimate for the parameter optimization suggests that all the independent variables studied (χ_1, χ_2, χ_3, χ_4) and four quadratic terms (χ_1^2, χ_2^2, χ_3^2, and χ_4^2) significantly affect the protection potential.

The final function used to draw response surface plot is:

$$Y=806 -72*\chi_1+ 0.33*\chi_2 -2*\chi_3 -8.75*\chi_4 + 36*\chi_1^2 -14.25*\chi_1\chi_2 - 5.75*\chi_1\chi_3 -11.25*\chi_1\chi_4 - 92.8*\chi_2^2 - 1.5*\chi_2\chi_3 -1.25*\chi_2\chi_4 + 8.8*\chi_3^2 + 1.25*\chi_3\chi_4 + 15.75*\chi_4^{\ 2} \quad \text{--- (1)}$$

$$Y=806 - 72*(\rho) + 0.3*(a_n) - 2*(d) - 8.75*(a) + 36*(\rho)^2 - 14.25*(\rho * a_n) - 5.75*(\rho* d) - 11.25*(\rho * a) - 92.875*(a_n)^2 - 1.5*(a_n * d) - 1.25*(a_n * a) + 8.875*(d)^2 + 1.25*(d * a) + 15.75*(a)^2 \quad – (2)$$

where: ρ is the resistivity (Ω.Cm), a_n is the sacrificial anode alloy, d is the distance (Cm), a is the cathode surface area (Cm^2); A…..o represents the estimated coefficient.

Equation (2) represents the prediction equation with acceptable error; the maximum error value of the prediction results from programming explained in Table (1).

4. Results and Discussion

Fig.1 shows RSM plot of resistivity and sacrificial anode alloy it shows the optimum region for protectionl potential satisfy which is lower (-1) level for resistivity and with middle (0) level for sacrificial anode alloy (Al-8%Zn alloy). Fig.2 shows RSM plot of resistivity and distance showing the optimum region for protection potential satisfying the lower (-1) level for resistivity and lower (-1) level for distance.

Fig.3 shows RSM plot of resistivity and surface area for the structure to be protected it shows the optimum region for protection potential is satisfying lower (-1) level for resistivity and lower (-1) level for surface area for the structure to be protected.

Fig.4 shows RSM plot of sacrificial anode alloy and distance showing the optimum region for protection potential is satisfying a lower (-1) level for distance and with middle (0) level for sacrificial anode alloy.

Fig.5 shows RSM plot of sacrificial anode alloy and surface area for the structure to be protected showing the optimum region for potential potential is satisfying middle (0) level for sacrificial anode alloy (Al-8%Zn) and lower (-1) level for surface area for the structure to be protected.

Fig.6 shows RSM plot of distance and surface area for the structure to be protected showing the optimum region for potential protection satisfying lower (-1) level for distance alloy and lower (-1) level for surface area for the structure to be protected. Table (1) lists the predicted values of protection potential. And we can neglect other insignificant estimated coefficients and reduce the prediction equation with unacceptable error to:

$$Y=806 - 72*(\rho) - 8.75*(a) + 36*(\rho)^2 - 14.25*(\rho * a_n) - 11.25*(\rho * a) - 92.875*(a_n)^2 + 8.875*(d)^2 + 15.75*(a)^2 \quad -(3)$$

Response surface optimization method gives the predicted potential when two factors change and the other two factors are at constant with zero level (middle level). Because of this reason it is seen the RSM cannot satisfy the optimum prediction result in this work then we go to the other methods.

5. Conclusion

1- Obtain the predict equation by RSM

Potential (predicted) = 806 –72(resistivity) + 0.333(anode alloy) – 2(distance) – 8.7(cathode area) + 36(resistivity)2 – 92.8 (anode alloy)2 + 15.75(cathode area)2 – 14.5(resistivity/anode alloy) – 11.25(resistivity/cathode area).

2- The optimum predicted potential which is obtained by RSM is (-752.36 mV) while the maximum potential which is obtained experimentally is (-969 mV). Accordingly, the RSM is unsuitable for our case. For this reason it is preferred to use another optimization methods .

References

[1] Miao Li A, Chuanping Feng, ''Optimization of process parameters for electrochemical nitrate removal using Box–Behnken design'', China University of Geosciences (Beijing), China, 2010.

[2] Claudio D. Fassardi, Karsten Hochkirch, ''SAILBOAT DESIGN BY RESPONSE SURFACE OPTIMIZATION'', Auckland, 2nd High Performance Yacht Design Conference, 2006

[3] Nuran Bradley, ''The Response Surface Methodology, MSc. In Applied Mathmatics & Coputer Scince'', Indiana University of South Bend, 2007, *Email::* nbradley@iusb.edu.

[4] Oehlert, Gary W. ''*Design and analysis of experiments: Response surface design''*,

ISSN 1466-8858 Volume 16, Preprint 52 submitted 24 July 2013

W.H. Freeman and Company, New York. 2000.

[5] Russell V. Lenth, ''Response-Surface Methods in R, Using rsm, Updated to version 1.40'', The University of Iowa, 2010.