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Modelling of Corrosion Under Insulation for Piping System

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Abstract: Corrosion under insulation (CUI) is the external corrosion on the surface of pipe, carbon manganese steel, or austenitic stainless steel that occurs beneath insulation as a result of water penetration. CUI is one of the most severe types of corrosion, defined by electrochemical deterioration of an alloy or metal when insulated. CUI existed when there was water and oxygen on the steel surface, and the corrosion rate was determined by the type of insulation, the chemical composition of the water, the availability of oxygen, and the temperature. The goal of this examination is to use a time-based series to detect and monitor the quantity of water intrusion absorbed in the insulating material. This monitoring inspection is carried out by putting in the pipe system in the UTHM region. The AR, ARX, and ARMAX models were built using 150 data points. When compared to the AR and ARX models, the ARMAX model with parameter (12, 11) yields the best results, with an MSE reading of 0.06627 and FPE of 0.1066. As a consequence of this research, we can conclude that the ARMAX model is more practical and accurate than the other models for detecting water ingress in a pipe system.

Keywords: CUI, Water Ingress, AR, ARX, ARMAX, Piping System

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1. Introduction

Corrosion under insulation (CUI) is the external corrosion on the surface of pipes and/or vessels made of low alloys, carbon manganese steel, or austenitic stainless steel that occurs beneath insulation as a result of water penetration. CUI is often localized corrosion that is difficult to detect since it is hidden behind the insulating material until it becomes a significant issue, especially in chemical facilities that have been in operation for a long time. CUI is a big issue in their sectors since it goes unnoticed behind insulation and accounts for up to 40% to 60% of pipeline maintenance costs.

CUI existed when there was water and oxygen on the steel surface, and the corrosion rate was controlled by the type of insulation, the chemical composition of the water, the availability of oxygen, and the temperature. The insulating material contributes to the CUI in three ways: I by forming an annular region that can collect water and other corrosive media, (ii) by removing impurities that exacerbate the corrosion process, and (iii) by wicking and or absorbing water and keeping it against the substrate.

Corrosion under insulation (CUI) is one of the most severe types of corrosion, defined as the electrochemical deterioration of an alloy or metal while it is insulated. Since CUI is hidden under an insulation or cladding layer, surface measurement techniques cannot detect it. CUI is often considered as one of the most difficult industrial issues due to its inability to be tracked and high expense. CUI can also manifest as pitting corrosion, stress corrosion cracking (SCC), and, in rare cases, galvanic corrosion, in which moist insulation containing salts allows current to flow across dissimilar metals (Bai, et al., 2016). In practice, if the protective coating fails, moisture can slowly penetrate through the metal/insulation contact, causing waterlogging or moisture retention at the interface. The combination of moisture and metal under the insulation results in a concentrated CUI, which subsequently spreads over broad regions of metallic equipment. Under the insulation, CUI seems to be concentrated and distributed in areas (Cao, et al., 2019).

2. Methodology

In this study, parameter mathematical model is applied on the corrosion under insulation at piping system. The aim of this study is to provide appropriate out flow model validation for parametric model. The results of model validation is to investigate the total water ingress under insulation. Three conditions of simplified gas furnace identification and time series analysis: AR, ARX and ARMAX model. The model then constructed and solve by using the MATLAB software to analyse the data.

2.1 System Identification

The primary goal of system identification is to find an appropriate model based on the system's input and output data. The model structure presented in the instance of a given system should ideally be the same as the actual structure. In practice, the model structure defined will not necessarily be the same as the real system structure. To avoid bias in parameter estimates due to either over-fitting or under-fitting, the efficacy of the model presented should always be validated. Several techniques of testing the model's efficacy have been proposed, including a cross correlation study based on residuals used in gas furnace identification (Wei, et al., 2001). The first version of the System Identification Toolbox (SITB) was published in 1987. The 2012 upgrade is the most completely redesigned and re-engineered version yet. It adds a slew of new features and model items. There is convergence with other toolboxes that operate with linear dynamic models, such as the Control Structure Toolbox (CSTB) and the Robust Control Toolbox (RCTB), such that they may be implemented easily from the user's perspective. The code has been extensively rebuilt in accordance with the current MATLAB object-oriented programming paradigm (Singh, et al., 2012).

2.2 Experiment of CUI

In this experiment, two types of sensors will be installed on the site. To commence, we are applying a petal sensor (Wi Corr CUI sensor) to detect moisture beneath the insulation at a particular distance. The humidity sensor is next, which is to moisture and liquid at that location of interest. This thesis project illustrates the prototype of a pipe system that will be implemented at UTHM. In this experiment, we will apply three types of pipe layout systems: spool, bend, and flange combination. This pipe segment will include three sensor locations, as well as cladding and insulation. The petal sensor will be put on top of the rockwool insulation, while the humidity sensor will be placed within the insulation.

2.3 Data Communication

A transmitter, often known as a radio transmitter, is an electrical device that generates radio waves using an antenna. A gateway is a piece of hardware that serves as a "gateway" between two networks. The role was to receive data from the transmitter. It enables machines on a local network to send and receive data across the internet. The devices that send and receive data are known as the transmitter and receiver. Following that, the sensor observes the process's behavior, which is to detect the water content within the insulation. The data received from the sensor is then sent to the transmitter. The data will be sent through the pipe and received at the receiver. Finally, the receiver will process the data and send it back to the transmitter, who will then broadcast it to the gateway.

3. Result and Discussion

The experiment was carried out outside the C17 building at Universiti Tun Hussein Onn Malaysia (UTHM). Every 6 hours of operation, the result of water ingress will be automatically gathered. The pipe system was outfitted with two kinds of sensors: petal sensors and humidity sensors. The sensor will create moisture and humidity data, which will be recorded automatically by the gateway and transceiver. The collected data of water intrusion will be converted into a chart to compare which decreasing percentage is the best.

3.1 Parameter Estimation

The goal of water ingress data identification is to choose the best sub model from a predefined complete model set. This research will look at the term, selection, and parameter estimate. The symbol "+" indicates that the residual correlation test was successful, whereas the character "x" indicates that the residual correlation test was unsuccessful. The goal of this validation test is to ensure that the identification model meets specific requirements. The criteria in this example are the auto-correlation test of the model residual between output and model residuals. The limit and the auto correlation confidence limit are both within the 95 percent range and parallel to the X-axis. The line shows that the model is impartial and offers an accurate representation of the data.

3.2 Final Prediction Error

When developing expectation models, the primary goal is to create a model that most exactly forecasts the desired target esteem given new information. The prediction error approach is used to identify most polynomial models. Typically, determining the delay and model order for the prediction error technique is a trial and error procedure. Estimate the delay by monitoring the impulse response or testing plausible values in an Auto Regressive (AR), Auto Regressive with External Input (ARX), or Autoregressive Moving Average Exogenous (ARMAX) model. Using prediction errors or another criterion, select the delay that offers the best model fit. Using a delay, test alternative AR model orders and select the ones that offer the greatest match.

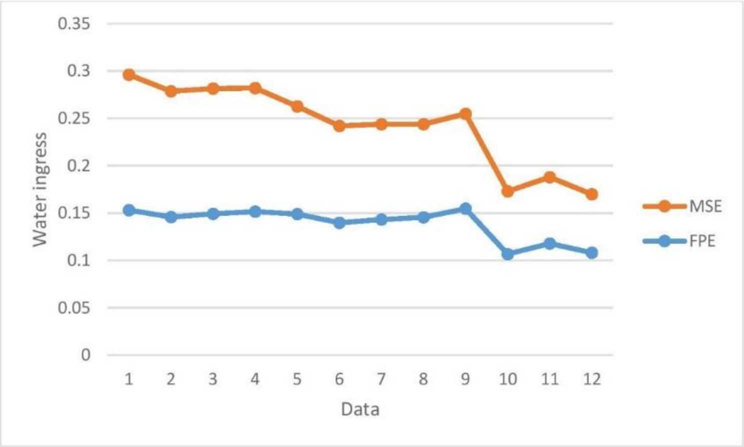

Figure 3.1: Graf of MSE and FPE data for ARMAX model

Term	$\hat{a}_1$	$\hat{a}_2$	$\hat{a}_3$	$\hat{a}_4$	$\hat{a}_5$	$\hat{a}_6$
Estimated Parameter	- 0.6713	+ 0.002592	- 0.1583	- 0.3997	+ 0.3421	+ 0.1371
Term	$\hat{a}_7$	$\hat{a}_8$	$\hat{a}_9$	$\hat{a}_{10}$	$\hat{a}_{11}$	$\hat{a}_{12}$
Estimated Parameter	- 0.149	+ 0.1529	- 0.3907	- 0.1563	+ 0.2884	+ 0.06496
Term	$\hat{c}_1$	$\hat{c}_2$	$\hat{c}_3$	$\hat{c}_4$	$\hat{c}_5$	$\hat{c}_6$
Estimated Parameter	- 0.7147	- 0.135	- 0.213	- 0.1491	+ 0.2118	+ 0.2858
Term	$\hat{c}_7$	$\hat{c}_8$	$\hat{c}_9$	$\hat{c}_{10}$	$\hat{c}_{11}$	
Estimated Parameter	- 0.1068	+ 0.06399	- 0.6077	- 0.08714	+ 0.5398	
FPE(Final Prediction Error): 0.1066, MSE(Mean Squared Error): 0.06627						

Figure 3.2: ARMAX parameter Estimation of Output Data water ingress

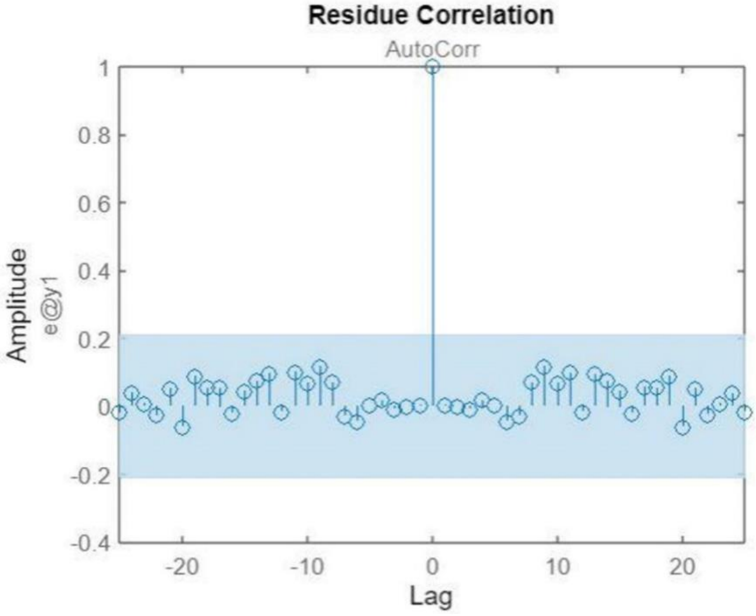

Figure 3.3: Residual correlation test on ARMAX (12, 11) model

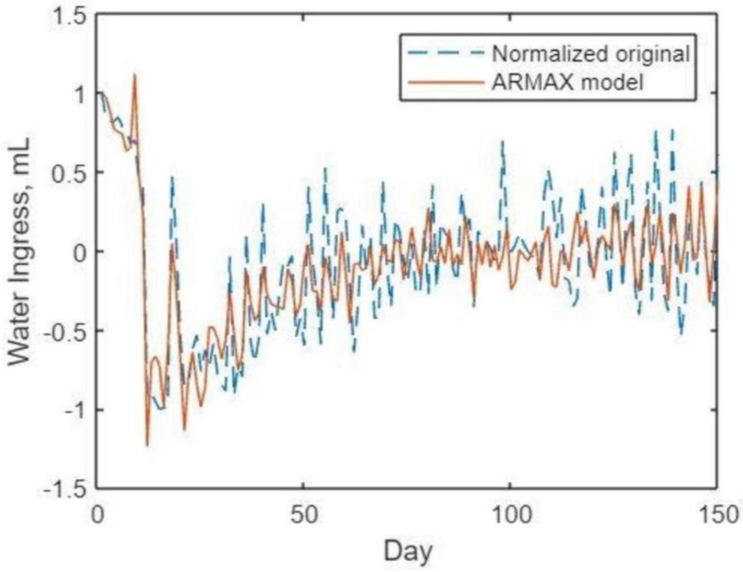

Figure3.4: 1-Step Ahead Prediction Based on the ARMAX (12, 11) model

Table 3.1: Result

Model	MSE	FPE
AR	0.1073	0.1260
ARX	0.1066	0.1472
ARMAX	0.06627	0.1066

Table 3.1 shows the summary of FPE and MSE result of each condition of water ingress data. Based on the observation form the MSE and FPE values of each model, ARMAX model shows the higher dropped number with the MSE reading of 0.06627 and FPE 0.1066 compared to AR model and ARX model. This can be explained by the corresponding dropping value from 0.1545 to 0.1066 for FPE, meanwhile for the MSE it shows the dropping value from 0.1002 to 0.06627. The algorithms of the three estimation methods demonstrate clearly that the computational value of ARMAX model is lesser than the other model. However, all model can be complete the computation of the final prediction error and mean squared error in 12, which is the sampling of the number unknown matrix (na). An increase in the sampling number cannot lead to any further enhancement in system performance because of the increasing number of (na) still show a dropping value. The ARMAX model is found to be feasible and more accurate for use in this research.

Conclusion

As a final observation, the linear stochastic exogenous autoregressive (AR), autoregressive with exogenous input (ARX), and autoregressive moving average with exogenous input (ARMAX) models have been successfully to model the water ingress data of the pipe system. In general, the data from water ingress obtained by ARMAX model show closer agreement with the actual one when compared to those obtained by the AR and ARX model method. The ARMAX model with the number of unknown matrix (12, 11) na and nc gives the lowest FPE of 0.1066 for final prediction error and MSE of 0.06627 for mean squared error, while the ARX model with the number of unknown matrix (12) na gives the highest FPE of 0.1472 for final prediction error and MSE of 0.1066 for mean squared error. By using the linear ARMAX representation and the water ingress identification method, the water content can be accurately forecasted.

The objective of this study has been successfully achieved to detect the water content inside the insulation by using time based series. Based on the forecasted that had been done, the finding can be described as the ARMAX model shows the higher dropped number with the MSE reading of 0.06627 and FPE 0.1066 compare to AR model and ARX model. It can be concluded that the ARMAX model for detected the water ingress at piping system are more feasible and accurate compare with the other model.

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References

[1] Burhani, N. R., Muhammad, M., Rosli, N., Acchar, Wilson, & Burhani. (2019). Combined Experimental and Field Data Sources in a Prediction Model for Corrosion Rate under Insulation. *Sustainability*, 1-13.

[2] Bai, X., Tang, J., Gong, J., Xiaoliang, L., Acchar, & Wilson. (2016). Corrosion Performance of Al- Al2O3 Cold Sprayed Coatings on Mild Carbon Steel Pipe under Thermal Insulation. *Chemical Engineering*, 1-29.

[3] Wei, H., Zhu, Q., Billings, S., Akbari-Fakhrabadi, A., Mangalaraja, R., & Jamshid. (2001). System Identification Using MATLAB. *Automatic control and system engineering*, 1-38.

[4] Singh, Ljung, L., Rajiv, Akbari-Fakhrabadi, A., Mangalaraja, R. V., & Jamshidijam, M. (2012). Version 8 of the System Identification Toolbox. *Symposium on System Identification*, 1-6.

[5] Cao, Q., Brameld, M., Birbilis, N., Thomas, S., Acchar, & Wilson. (2019). On the Mitigation of Corrosion Under Insulation (CUI) of Mild Steel Using Local Cathodic Protection. *Corrosionjournal.Org*, 1541-1551.