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Development of a portable device for measuring the corrosion rates of metals based on electrochemical noise signals

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A B S T R A C T

This work deals with the design of a portable device for measuring and monitoring corrosion variables. The measured variables are the electrochemical potential (*EP*) and electrochemical current (*EC*). Using these signals the localization index (*LI*) and the corrosion rate (*CR*) can be estimated. Since electrochemical potential (*EP*) and electrochemical current (*EC*) are weak signals, an electronic circuit was designed and developed for measuring these two variables. The electronic circuit includes a signal amplifier, a physical filter, and an Analog to Digital Converter (ADC). To estimate the *IL* and *CR* the statistical method and Neural Network method were used and compared. The device advantages are its low-cost of construction, its portability and the possibility to analyze the corrosion variables in different materials. Experimental tests carried out using 6061-T6 aluminum shown the effectiveness of the proposed device and methods and the versatility of the portable device.

1. Introduction

Metals are materials with different characteristics and properties, such as hardness, malleability, ductility, among others. Because of their properties metals are widely used in the industry. The metals most commonly used are steel, zinc, aluminum, and copper, any of this metals can suffer corrosion. The corrosion is characterized by the metal destruction, due to the metal exposure to different environmental aggressive agents. These agents include humidity, temperature, air, vapor, pollutants, etc.

Corrosion is present in most of the metal parts of machinery and industrial equipment, as well as in pipes and containers of industrial processes. The corrosion consequences are diverse, some of them are a reduction of the pipe surfaces thickness, leakage, the presence of pollution substances, or an equipment damage as a result of a leak. Furthermore, the expenditure of additional costs to repair or replace the corroded surface must be considered. Corrosion has been the cause of accidents such as the flight 243 of Aloha Airlines in 1988 ([1]) or the accident caused by a gas pipe explosion in Guadalajara, Mexico in 1992 ([2]).

There are different corrosion types (uniform, general or localized) some of them are more destructive than others. To identify the corrosion type is necessary to estimate the localization index (*LI*). Knowing the *LI* will allow to take preventive actions and prevent any damage caused by an aggressive corrosion. The corrosion rate must be calculated to determine the lifetime of metals. The CR can be calculated using physical or electrochemical methods. In literature, important works have been reported on the corrosion analysis using the EN technique [3–5]. Authors in [3] mention that the EN is one of the most promising in situ electrochemical methods in corrosion and electrochemical science.

Nowadays, exists different devices to estimate the corrosion rate however they are usually expensive for example the PT-6000 corrosometer with a price of $1 572.45 USD, the Gill AC potentiostat with a price of $7 618.72 USD, the Checkmate-1 corrosometer with a price of $4 649.65 USD, Aquamate corrater with a price of $2 925.24 USD. To deal with the devices cost different research works have been developed to propose lower cost devices as an alternative. The authors in [6–8] presented the development of devices for measuring the EN to estimate corrosion variables.

The authors in [6] developed a method and apparatus for the identification of corrosion in metal objects. The method consisted in

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analyzing the statistical distribution of the signals generated between two electrodes, exposed to the same conditions of the metal object. The authors used ANNs for the analysis.

A computerized system for real-time monitoring the electrochemical noise and for estimating the corrosion rate was developed and presented in [7]. The system was configured to use three electrodes and one Analog to Digital Converter (ADC) to obtain the electrochemical noise signals. Once the signals were measured, a computational system analyzes the signals by statistical parameters (mean value, standard deviation, variance) to obtain the corrosion rate and corrosion type.

A device for the remote monitoring of the electrochemical corrosion processes was developed and presented in [8]. The device was configured to use the electrochemical technique for the corrosion levels estimation. The device probe used the three nominally identical electrodes configuration. The system works via remote, sending the voltage and current measures via modem to a computer which realize the signal processing.

In literature, different works have reported two different electrode configurations to measure electrochemical noise [9–12]. One of them is the three identical electrodes configuration, and the other is two identical electrodes and one reference electrode usually of a different material (silver, platinum, titanium, etc.). In the first configuration, one of the electrodes is used as a pseudo-reference electrode, this configuration is used in the industry for developing field tests, while the second configuration is commonly used in laboratory tests.

The ANNs have proven to be a good tool in applications where the system inputs are noisy or incomplete. In different works ANNs have been developed for estimating some corrosion parameters [13–17].

Authors in [13] used an ANN to predict the corrosion rates of transmissions lines in Brasil. The ANN was developed with a multilayer perceptron with ten neurons in the input layer (moisture, rain, wind, etc.), and two intermediate layers of sigmoid neurons and one output neuron with a linear function (purelin) to amplify the received signal to the actual corrosion values. The Levenberg–Marquardt back-propagation algorithm was used for the neural network training.

The corrosion behavior of metals and alloys was predicted using a supervised neural network in the data mining presented in [14]. The collected data were: metal glass current measurements, corrosion rate data on carbon and steel alloys, and grade two titanium current data. The first two groups of data belonged to generalized corrosion and the last to localized corrosion.

The authors in [15] applied an ANN to predict the behavior of metal corrosion. The ANN was feedforward multilayer topology 6-7-1. The clime and pollution variables were used as the ANN inputs. Applying ANNs, the atmospheric corrosion prediction of metals and alloys (carbon steel, galvanized steel, copper, and aluminum) was carried out in [16].

The authors in [17] developed a research on the corrosion rate evaluation of the zirconium-based nano-ceramic layer on galvanized steel in a 3.5% NaCl solution. The authors used a neural network and adaptive neuro-fuzzy inference system to develop the study.

The problem of using electrochemical noise technique to estimate the corrosion variables is to measure the potential and current since they are weak signals. So, these two signals have to be amplified and filtered. In this work, an electronic circuit was designed and developed for measuring these two variables. The electronic circuit includes a signal amplifier, a physical filter, and an Analog to Digital Converter (ADC).

As previously mentioned, the corrosion measurement commercial devices are expensive, while the corrosion measurement low-cost devices presented in the bibliography needs a computer or additional equipment for measuring and processing the *EP* and *EC*.

In the present work, the combination of the electrochemical noise technique with the signals conditioning and the signals processing by means artificial neural networks have resulted in a practical and economical device for estimating the *LI* and the *CR*.

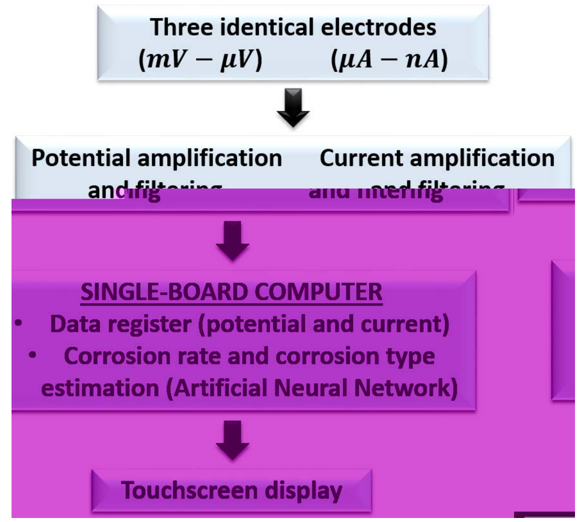

Fig. 1. Block diagram of the device.

2. Corrosion device development

The device components are three identical working electrodes (WE), an electronic circuit board for the signals amplification, a single-board computer for data analysis, and a touchscreen display. Fig. 1 shows the flow diagram of the device operation.

2.1. Electrodes

A probe formed by three identical electrodes of 6061-T6 aluminum was developed to estimate the corrosion type and the corrosion rate of this metal [18].

An epoxy resin was used to encapsulate the three electrodes. For each electrode, one electrode surface was drilled to weld a copper wire or use a connector, (Fig. 2 (a))) while the other surface (the surface area exposed to the solution) was polished with grit paper (Fig. 2 (b))), washed with distillate water and degreased with acetone according to the ASTM G1-90 [19]. The surface area exposed to the solution was 0.3156 cm^2. Fig. 2 (c)) shows the probe immersed in a 3.5% *NaCl* solution.

2.2. System measurement and acquisition

To measure the *EP* and *EC* the three identical electrodes were used. To measure the current signal a zero resistance ammeter (ZRA) array was used and connected to the electrodes WE1 and WE2 (See Fig. 3. To measure the potential, the signal was connected to the electrodes WE1 and WE2, and WE3 was the reference electrode. To eliminate the parasite signals (aliasing) low-pass filters were designed, the cutoff frequency used was 4 Hz.

2.3. Single-board computer and touch screen display

A single-board computer was used to develop the portable device for measuring and monitoring corrosion variables, and a touchscreen display was used to establish a communication interface and a graphical interface between the user and the device.

Fig. 4 shows the final version of the portable device called CRE-1 (at the top right side), versus commercial devices. At the bottom left side of Fig. 4, the on–off switch and connectors of the portable device are shown. At the bottom center of Fig. 4, the fan and the supplied source of the CRE-1 are shown. At the bottom right side of Fig. 4 the electronic circuit board of the CRE-1 is shown.