Chapter 14

Impedance-Based Wireless Sensor Network for Metal–Protective Coating Evaluation

Ronghua Yu  
North Dakota State University, USA

Qixin Zhou  
North Dakota State University, USA

Yechun Wang  
North Dakota State University, USA

Chao You  
North Dakota State University, USA

ABSTRACT

Researchers have been focused on the influences of flowing fluid on the corrosion of bare metals, but there is little emphasis on the degradation of metal-protective coating. Evaluating the metal-protective coating usually uses the Electrochemical Impedance Spectroscopy (EIS) method. EIS is a technique used for evaluating coating permeability or barrier performance based on the electrical impedance of coating. This paper presents a new impedance-based wireless sensor network for metal-protective coating evaluation. This wireless sensor network consists of two parts: impedance-based wireless sensor nodes and a wireless data base that are equipped with a network analyzer (AD5933) and a RF transceiver (CC1111/CC1110). In the experiment, there are three coating panels immersed in flowing deionized water (DI water) and one coating panel immersed in stationary DI water. Experimental results demonstrate that the proposed wireless sensor network is capable to evaluate the coating degrading.

1. INTRODUCTION

Metal-protective coating is widely used in the protection of structures, such as pipelines, bridges and other metal materials (Allahar, Wang, Battocchi, Bierwagen, & Balbyshev, 2009). Traditionally, corrosion happens when metal-protective coating is penetrated by water. Water is an important factor for metal protective coating degradation, mostly resulting in cathodic delamination and blistering near a coating defect. This degradation not only can be of physical origin, such as leading to swelling, a plasticization, and a secondary reticulation or a migration of additives, but also of chemical origin, with hydrolysis phenomena, leaching, and modification of macromolecular

DOI: 10.4018/978-1-4666-4166-5.ch014
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skeleton (Fredj, Cohendoz, Feaugas, & Touzain, 2010). Various factors, for example, polarity, cross linking density, crystalline and glass transition temperature of polymeric binder, can affect water permeation into polymeric coatings (Park, Cudney, & Inman, 2000).

EIS (Gray & Appleman, 2003) is an adequate tool for evaluating protective performance of coating. Equivalent circuit models can be generated based on EIS data. Figure 1 shows a typical model of water percolated coating. The model (Akbarinezhad, Rezaei, & Neshati, 2008) contains the elements of coating capacitance ($C_c$), double layer capacitance ($C_{dl}$), solution resistance ($R_s$), coating resistance ($R_{ct}$), and pore resistance ($R_{po}$). This model is called a Randles Cell, which is one of the simplest and most common cell models. The evaluation of coating is to measure the impedance and phase angle under a frequency range. The corrosion of coating can be reflected through the variation of impedance. Higher frequency will generate lower impedance. In addition, capacitance component will also result in the phase shift between input voltage and output current.

Researches in coating evaluation have been implemented since a long time ago and have yielded some achievements. However, most traditional coating evaluations based on EIS have to use impedance analyzers, such as the Reference 600 Potentiostat provided by Gamry Instruments. This kind of analyzer is expensive (around $40,000) and not convenient to carry in the field tests. Therefore, it is necessary to develop a portable and convenient coating evaluation instrument for metal-protective coatings for field tests based on EIS. Angelini et al. (2006) developed a handheld impedance measurement system that can be used for electrochemical measurement. It can only realize the one point measurement. In addition, they used digital signal processor (DSP) as the main controller and designed the peripheral circuits, such as low pass filter, digital-to-analog converter (DAC) and calibration circuit. Nevertheless, if peripheral circuits are integrated into a single chip, the circuit will be more stable and consumes less power. Analog Devices has made an impedance analyzer chip called AD5933 that can realize a portable, miniaturized and multi-positions monitoring impedance analyzer network. For example, in Park, Yun, and Inman (2007) a new radio-frequency (RF) sensing node is proposed to replace the traditional impedance-based structural health monitoring method in loose bolt inspection application. The sensing node consists of a AD5933, a microcontroller and a RF transmitter. The authors used the AD5933 development board as the sensor node and the size is around 10cm × 8cm. Besides the AD5933 development board, the authors also used another microcontroller development board to control the AD5933 development board. This is still too bulky to carry, especially in field applications. In addition, there is only one sensor node used in the application that is not sufficient for multi-position monitoring.

This paper presents a new Impedance-based Wireless Sensor Network (IWSN) for metal-protective coating evaluation, which is mainly realized by an impedance analyzer (AD5933) and a RF transceiver (CC1111/CC1110). It is a miniaturized impedance analyzer network that can be controlled at a PC terminal by serial communications. The advantages of AD5933 are its low power consumption and the integration of most blocks for impedance spectroscopy. The impedance measurement range of AD5933 is from 1 KΩ to 10 MΩ and the excitation frequency is ranged from 1 KHz to 100 KHz. In order to measure

![Figure 1. Equivalent circuit model of water percolated coating](image)
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