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Interface circuit for impedance sensors using two specialized single-chip microsystems

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ABSTRACT

The paper presents an interface circuit designed for the measurement of impedance parameters of sensors or measurement cells installed on technical objects. The interface circuit allows measurement of the modulus and argument of impedance in the range of $10\,\Omega \le |Z_x| \le 10\,\mathrm{G}\Omega$ at a measurement frequency in the range of 0.01 Hz to 100 kHz. The new solution based on two specialized SoC AD5933 microsystems has been used. This has allowed to obtain miniaturization, low power consumption and low-cost of the circuit of the impedance interface. During tests of the realized prototype using the reference object, the object impedance measurement errors have been determined and they do not exceed ±1.6% (for relative error of impedance modulus) and ±0.6° (for absolute error of impedance argument). The obtained accuracy is fully acceptable in case of impedance measurement of anticorrosion coating in the field. The comparison measurements performed with the aid of Solartron set of instruments showed that the impedance measurement accuracy of the proposed module is comparable to laboratory set of instruments. The important advantage of the used solution based on AD5933 microsystems is lowering the power consumption down to ca. 0.7 W, which makes possible powering the measurement module from a PC using +5 V from the USB. It is a very profitable feature for a module designed to work directly in the field.

1. Introduction

There are many technical and biological objects, the parameters of which are determined by impedance measurement. An example of such approach is monitoring and diagnostics of anticorrosion protection (anticorrosion coatings) of large technical objects like pipelines, bridges, fuel tanks, etc. on the basis of impedance measurement of the protective coatings [1–3]. When using medical sensors, the impedance measurement can be applied for testing of tissues, physiological liquids, skin, etc. in order to diagnose the state of disease of organs [4–6]. An example of environmental protection and safety is the use of impedance measurement for monitoring of water percolation of dikes [7–9].

The above-mentioned examples show that there is quite a number of applications of impedance measurement for testing of different objects in real-life conditions. The measurements are performed using impedance sensors or measurement cells connected to a measurement circuit located near the tested object (often directly in the field, in difficult-to-reach places). This requires to design the measurement circuit in the form of an interface circuit which estimates impedance parameters and sends them to the controlling computer. This implies the need of miniaturization, low power consumption and ability to work in difficult environment conditions. The interface with such features is the subject of the paper. The use of specialized energy-efficient electronic chips of highest-scale integration, e.g. SoC microsystems (AD5933), microcontrollers (AT32UC3B1256), and also the use of measurement methods based on digital signal processing (DSP) [10] were necessary to realize the interface.

2. Sensors

One of the most important fields of the use of impedance measurement in the industry (economy) is the monitoring of anticorrosion protection of the different objects due to huge losses caused by corrosion. Also due to safety reasons, it is necessary to determine the condition of the anticorrosion coatings in order to estimate the time of renovation. This extorts the need of the impedance measurement of the coating and diagnose their performance, also in the field, directly on the protected object using a sensor–measurement cell.

2.1. Equivalent circuit model

The view of the cell located on a high-voltage pylon and connected to the impedance interface is shown in Fig. 1a, and a cross-section of the coating and the cell in Fig. 1b [11]. When the coating is new and the protection is based on the barrier mechanism, there is no penetration of electrolyte into the coating and the equivalent

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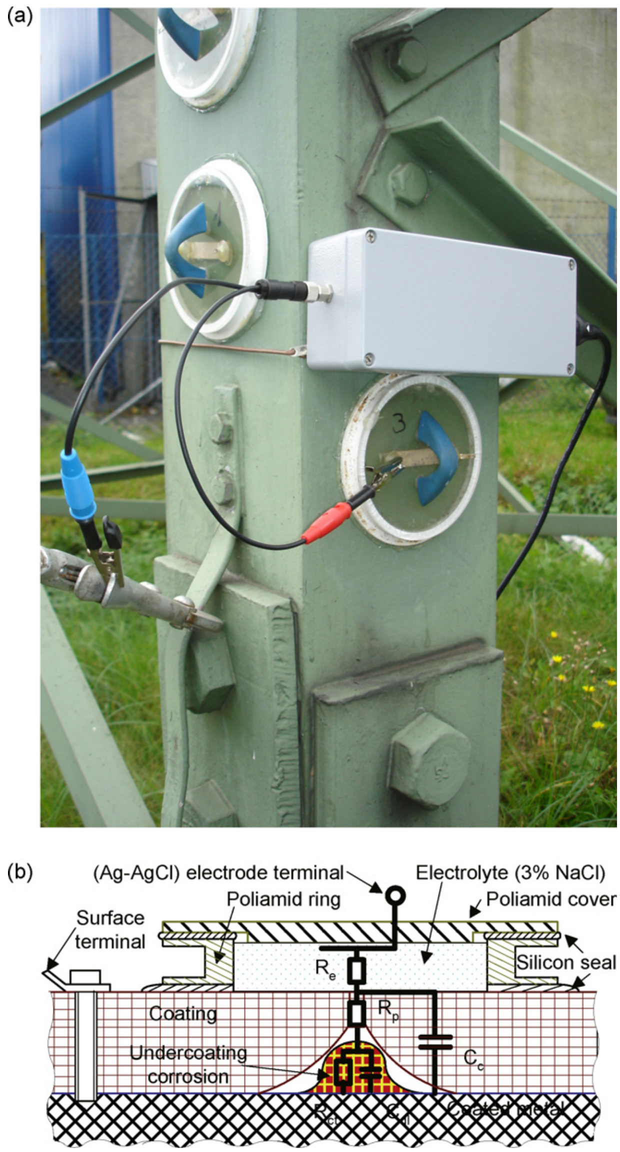

Fig. 1. (a) The photography of cells for impedance measurement of anticorrosion coatings on a high-voltage pylon and (b) cross-section of the anticorrosion coating and the measurement cell.

circuit contains only two elements: capacitance C_c (of the order of a few tens to a few hundreds pF) and resistance R_p (a few, up to several hundreds GΩ) modelling properties of the material of the coating (the electrolyte resistance R_e is much smaller and practically negligible). After some time, the coating loses the barrier protection and the electrolyte starts to penetrate the coating, but the coating still has adhesion properties and there is no undercoating corrosion. At this stage, the electrolyte in the pores influences the R_p, the value of which is decreasing more and more when the electrolyte penetrates the coating. Additionally, the electrolyte penetration of the coating causes the increase of the dielectric constant, which leads to an increase of the capacitance C_c. At the next stage, the coating is broken and the undercoating corrosion appears. The equivalent circuit is extended by new elements: double layer capacitance C_{dl} and charge transfer resistance R_{ct}. Following the corrosion's expansion, the value of R_p is continuously decreasing and finally the coating is destroyed and the equivalent circuit contains only R_{ct} and C_{dl}.

Resuming, the knowledge of the above-mentioned parameters allows to estimate the quality of the anticorrosion coating and to avoid corrosion-caused losses. The difficulty of coating equivalent circuit identification lies in the fact that the RC elements are differing considerably in their values and elements with small and large values are shunting each other. Thus, for the identification of the components, the impedance measurement is required in a wide frequency range, starting from very low, of the order of mHz up to MHz, which is called impedance spectroscopy.

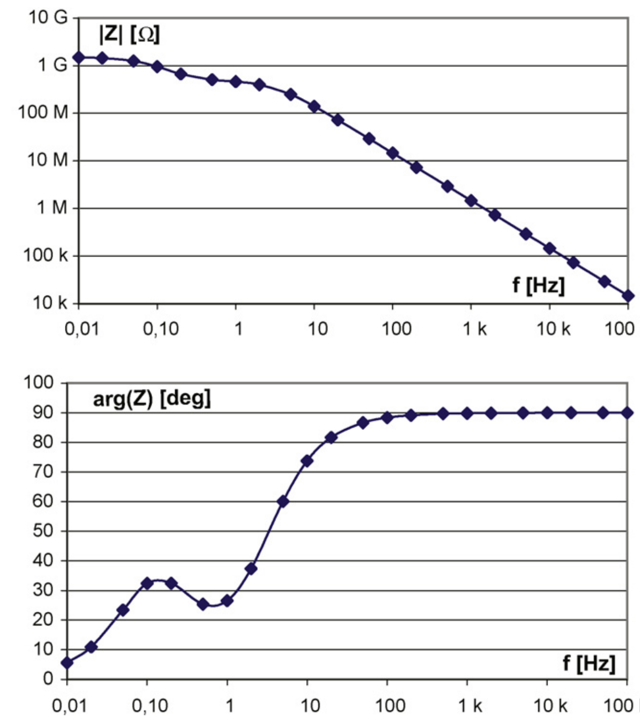

Fig. 2. Exemplary modulus and argument graphs of the impedance of the anticorrosion coating.

2.2. Impedance spectroscopy

An example of the modulus ($|Z|$) and argument ($\arg(Z)$) characteristic of the impedance of a high-thickness anticorrosion coating in the early stage of the undercoating rusting, is presented in Fig. 2. It is a very important moment, because the immediate renovation of the coating can stop the corrosion.

The characteristic inflection of curves in the frequency range of 10–0.1 Hz points out that the equivalent circuit contains elements C_{dl} and R_{ct}, showing the undercoating corrosion is at the early stage. For the identification of the parameters of the equivalent circuit of the coating, the most effective is the method using an impedance spectroscopy.

In the impedance spectroscopy technique, two steps can be distinguished: the measurement and an analysis. In the first one, the vector measurement of impedance Z is performed in a wide frequency range to determine real $\mathrm{Re}(Z)$ and imaginary $\mathrm{Im}(Z)$ parts or modulus $|Z|$ and argument $\arg(Z)$ of impedance, using contact electrodes or a measurement cell placed on the tested object. In the second step – an analytical one, on the basis of the impedance spectrum, the parametric identification of the model (in most cases in the form of a multi-element RC two-terminal network) is made using Complex Nonlinear Least Square (CNLS) method for fitting the model to the experimental spectrum [12–14].

In this paper we deal with the main difficulties and problems lying in the measurement stage. They arise from the necessity of the measurements in a wide frequency range and also from the need to adapt to test objects in real-life conditions directly in the field. This implies the need of miniaturization, low power consumption and ability to work in difficult environment conditions while assuring metrological parameters comparable to labora-