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Digital Signal Processing for Eddy Current Parameter Identification in Measurement Applications

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Summary:
This paper presents a simplified eddy-current testing system design that minimizes hardware complexity by leveraging digital signal processing (DSP). An architecture for the digital-to-analog and analog-to-digital converters is shown that ensures precise temporal correlation between transmitted and received signals. By converting these signals to in-phase and quadrature (IQ) format, additional filtering, spectral analysis and parameter tuning is possible. This design has been applied in both educational and spectroscopic measurement contexts, demonstrating the efficiency of its implementation.

Keywords: eddy current, digital signal processing, soft sensors, system modeling, material characterization

Introduction

When eddy-current methods are used in non-destructive testing (NDT) or evaluation (NDE), there are fundamentally two different kinds of measurements commonly carried out. Probably the more common one in NDE is the measurement of the impedance of the sensor system followed by some modeling of the obtained response. One of the first descriptions is that of Dodd and Deeds [1], resulting in analytical solutions for plates. An early lumped element model was developed by Libby [2] by treating the measurement chain as a transmission line, for which the total impedance can be calculated. The element parameters can be used to obtain the inductance of the coil, which allows inferring the properties of the material under investigation [3]. If the transmission line model is segmented, defects in the material or layered properties of a composite can be included explicitly [4]. The preceding models are preferred for a single-coil measurement setup. For sensors with separate transmission and receiver coils, the natural model is that of a transformer with losses [5].

Alternatively, the voltage transfer function can be used to achieve similar results, but with considerable simpler measurement devices. For transformer-style eddy current sensors, a model for a lossy transformer including different material elements has previously been described by the authors [6,7]. Besides the much simpler hardware requirements, voltage transfer based measurements lend themselves especially well to implementation in software defined logic. In this article, the system architecture underlying the previous work is described and its applicability to both non-destructive testing and evaluation are shown.

System Design

The fundamental principle underlying the present design is keeping the physical hardware as simple as possible and carrying out most of the data processing in digital signal processing (DSP). The eddy current sensor itself is a transformer-type, consisting of a transmitter and receiver coil on a common cylindrical core.

The only system components realized as electronic devices are the excitation coil driver which is a digital analog converter and an analog digital converter on the receiver coil. Both operate on time-domain low frequency signals using commercial-grade chip sets. To achieve accurate temporal correlation between the transmitted and received signal that is required for later processing of the material response, the transmitted analog signal is also fed into a secondary channel of the analog digital converter. This way, any time delay between generation of the digital transmitted signal and acquisition of the digital received signal can be neglected. This layout is illustrated in Fig. 1.

Once the digital signal has been acquired, both loop-back and received signal can be converted to in-phase and quadrature (IQ) format by applying a two all-pass filters designed to have a relative difference in phase response of 90° over a large frequency range [8]. In this form, further

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processing such as filtering or spectral analysis is straightforward.

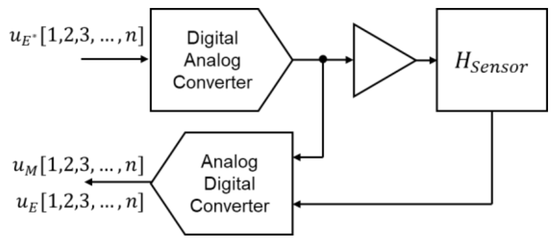

Fig. 1. Architecture of the digital-analog interface. u_E and u_M refer to the excitation and measured signal used in processing, u_{E^*} is the original generated signal.

One significant advantage of this design is that it does not require impedance measurement while still obtaining the full response characteristic. The digital nature of further processing also enables rapid development cycles for new analytic methods not easily possible in conventional circuits.

Application

This design has been applied first to eddy-current testing application in the form of an application for educational use. Here, the low hardware requirements are used to enable many students to participate in exercises while having the capability of modifying many parameters of test equipment [9]. The DSP here consists of a sinusoidal signal generator on the sending side and complex division of the measured and transmitted signal, offset/zero correction O, phase correction φ and amplification A which result in a value in the complex plane V that can be directly displayed, as shown in eq. (1):

$$V = \left(\frac{u_M}{u_E} - O\right) \cdot exp(-i\varphi) \cdot A \qquad (1)$$

A more complex application is found in the spectroscopic application previously mentioned. In this case, the excitation is a broadband noise signal. The response is therefore also an uncorrelated noise-like signal which is affected by the material under test. Since only the sensor itself is in the analog loop, its transfer function can be found by Fourier transform of the time domain signal and complex division. As the only system part interacting with the material, this transfer function must include all effects of the material's electromagnetic properties (as well as those of the coils). The details have been described in [7], but most importantly this transfer function can be modeled as that of a lossy transformer with two major contributions: the direct transfer of energy between the sender and receiver coil with a phase delay depending on the material as well as a part relating to the eddy currents themselves which involves the induced currents and the leakage coefficient. In this case, the main advantage of the digital system is in its ability to identify the model parameters using the entirety of the available information.

Summary

Using DSP techniques, rapid development of new analysis techniques for the application of eddy currents in the field of non-destructive evaluation and material characterization is possible. This advantage has been used to develop a new modeling approach for the voltage transfer function of eddy current sensors in transformatoric circuit.

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