A noise variance model of a differential eddy current coil used for coating thickness determination

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Real-world measurements are always affected by noise, e.g., thermal noise. For accurate parameter estimation results based on measured data, e.g., for sensitive coating thickness determination, the minimization of noise influences is essential. This paper focuses on modeling the noise behavior of an eddy current measurement system for coated steel sheets, involving the measurement of the excitation current and the induced pick-up voltage, followed by FFT analysis and fundamental wave evaluation. From this, sheet metal parameters can be determined. The presented model describes the propagation of noise from a noisy sinusoidal excitation current to the induced voltage in the pick-up coils. This noise model is successfully verified by means of measurements and thus validated. Such a model is necessary for the development of a maximum likelihood estimator for coating thickness. Furthermore, it can serve as a basis for the optimal design of an eddy current sensor system.

Keywords: Eddy current testing, noise model, analytical model, coating thickness determination

1. Introduction

Eddy current testing (ECT) is widely used in industry for non-destructive testing of electrically conductive specimens. This paper introduces a novel noise variance model for a differential ECT coil setup, shown in Fig. 1. The coil setup is used for coating thickness determination of electrically conductive coatings, e.g., zinc, on ferromagnetic steel sheets. The underlying analytical ECT model of the induced voltage U of this arrangement originates from [1]. Specifically, it involves excitation with sinusoidal currents, followed by measurement of the induced voltages. The amplitude and phase of these currents and voltages are then determined through FFT and fundamental wave analysis. The noise model presented in this paper takes into account the number of samples N acquired and the applied windowing function. It is assumed that the excitation current's noise can be modeled as normally distributed AWGN. Furthermore, thermal noise and quantization noise which occur in the data acquisition system are considered. The developed noise model gives insights into the impact of different noise and system parameters and thus can be used for optimizing the sensor system design, as commonly known in radar signal processing.

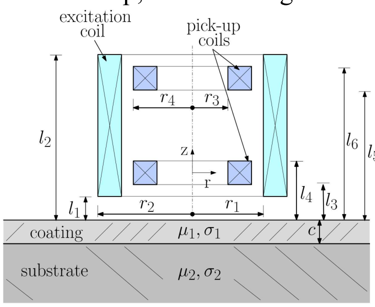

Figure 1: Used ECT coil setup with dimensioning.

2. Results and discussion

Since the used analytical model [1] is available in complex form, while amplitudes and phases are measured, the calculated standard deviations in the measured voltage must be converted into real and imaginary parts using a first-order Taylor series expansion. The relationships for the phase and amplitude estimation variances depending on the FFT's windowing function used are given in [2]. With the derived model an estimate for the variance in the amplitude and phase of the induced voltage as a function of the excitation current noise and the additional noise sources can be given. Measurements on a test bench yield the magnitude spectrum in Fig. 2, which the noise model approximates well. In the final paper, the derivations of the noise model, additional measurements at different excitation frequencies, and Monte Carlo simulations are carried out in detail.

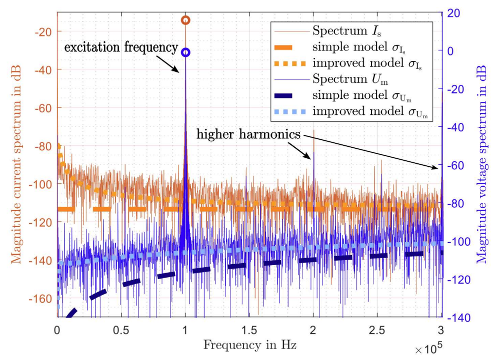

Figure 2: Spectrum of the measured voltage and current in comparison with the developed models.

References

[1] Dodd, D., Luquire; Spoeri. (1969), Some Eddy-Current Problems and Their Integral Solutions, OAK RIDGE NATIONAL LABORATORY.

[2] Schuster, S. et al., (2009), "The Influence of Windowing on Bias and Variance of DFT-Based Frequency and Phase Estimation", doi: 10.1109/TIM.2008.2006131.

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