NDT&E International 62 (2014) 167–171

Contents lists available at ScienceDirect

NDT&E International

journal homepage: www.elsevier.com/locate/ndteint

Correction of eddy current measurements to obtain accordance with simulation results

Dieter Joneit [a], Michael Nadler [b], Henning Heuer [a]

[a] Fraunhofer Institute for Nondestructive Testing Dresden, Germany
[b] HTS GmbH Coswig, Coswig, Germany

ARTICLE INFO

Article history:
Received 22 August 2013
Received in revised form
4 November 2013
Accepted 26 December 2013
Available online 4 January 2014

Keywords:
Eddy current testing
Impedance measurement
Simulation

ABSTRACTS

Forecasting an eddy current inspection task using simulation software is relevant for a better understanding of new problems. Simulation results have to be validated to prove how good the simulation is in compliance with the reality. A comparison of the simulated results and the direct output of an ET device very often lead to significant discrepancies. It can be shown that the reason for these discrepancies lies in the testing equipment itself and how these measurement errors can be corrected. Examples illustrate the strong correlation between simulation results and corrected measured values.

1. Introduction

Forecasting of an inspection task by simulation software is needed for better understanding of new problems and for choosing most suitable probes. VIC3D by Victor Technologies and CIVA by CEDRAT are well known software, which are optimized exactly for these purposes.

Simulation results have to be validated to prove how good the simulation is in compliance with reality. Using impedance analyzers or network analyzers the measured values show this good compliance [1–5]. Nevertheless the accuracy of simulation can be improved [9] and it will be done further.

Using a typical eddy current testing system, the measurement results may be completely different and without any accordance to the simulation results. However, we have to use ET systems for practical purposes. Why do they not display similar values? What are the reasons for these large discrepancies?

As it will be shown below, the reason for these discrepancies lies in the testing equipment itself. The displayed measurement results contain phase errors that occur in the ET instruments and are not related to the effects of the eddy current in the material to be analyzed.

2. Structure of an eddy current testing instrument

In order to understand the reasons for the problems and to find solutions we have to look briefly at the structure and principles of an eddy current instrument as shown in the simplified circuit diagram (Fig. 1).

The measurement frequency is generated by an oscillator powered by a coil driver to the excitation voltage U_E and placed on the excitation coil.

The coil current I_L flows through the w windings of the excitation coil and results in a magnetic flux φ:

$$\varphi = I_L \times w \tag{1}$$

In the w windings of the receiving coil, the changes of the magnetic flux induce the receiving voltage U_R:

$$U_R = -w \times \frac{d\varphi}{dt} \tag{2}$$

It will be gained using a certain gain factor G and transferred to the demodulator to generate the real and imaginary part of the measurement result.

The demodulation is made by the reference signal. This technique is also defined in the standard DIN EN ISO 15548-1 for ET systems. It will be shown that even this detail is the reason for the measurement errors.

Eddy current systems usually present the measured values in units of voltage, or even simpler as percentage of screen height or ADC values. In this case, these voltages U have to be calculated from the displayed values M by gain G. (U_{max} is the maximal voltage, M_{max} the maximal value to be displayed.)

$$U = M \frac{U_{\max}}{M_{\max}} e^{G/20} \tag{3}$$

0963-8695/$ - see front matter Crown Copyright © 2014 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ndteint.2013.12.010

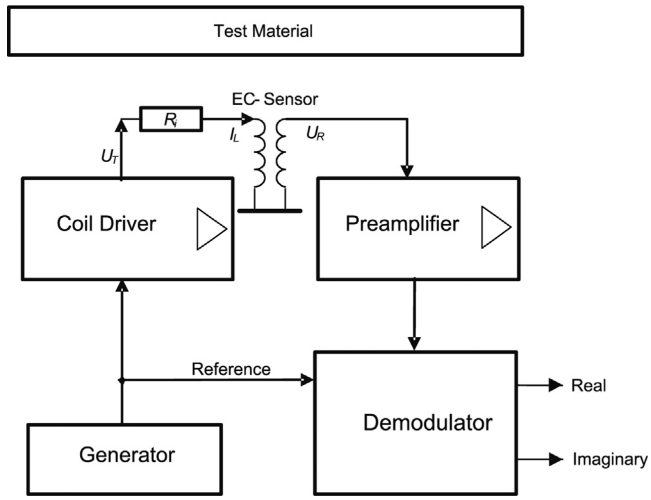

Fig. 1. Simplified circuit diagram of a test instrument.

3. Correction of the runtime error

We do not connect a probe to the ET instrument, but make a short connection between the output and the input at the points where the probe is usually connected. It is expected that we measure the excitation voltage with a phase angle of zero. But this does not happen. Depending on the measurement frequency a different phase angle is displayed.

Fig. 2 shows a setup with the coil driver and preamplifier located next to the coil. Input and output signals to the test system are sent through 2 × 0.3 m long coaxial cables.

The measured phase angle of this setup is shown in Fig. 3. If necessary, the angles were enlarged by multiples of 180° to obtain a smooth shape of the curve. According to the frequency f, an associated runtime t can be calculated.

$$t[\mu s] = \frac{\varphi[^\circ]}{f[\mathrm{MHz}] \times 360^\circ} \tag{4}$$

As it can be seen, large phase angles appear using high frequencies. The reason for that is simple.

The measuring signal takes a specific runtime on the path oscillator → coil driver → sensor → preamplifier → demodulator, before it can be evaluated by the reference signal. The path of the reference signal is significantly shorter and the runtime is smaller. The difference of the runtime between measurement and reference signal results in the phase shift, which causes a phase angle error depending on the frequency.

In the measurement setup in Fig. 2, a runtime difference of approximately 12 ns is calculated from the measured phase angles.

A frequency of 800 kHz has a period of 1.250 ns. At this frequency, the runtime difference is approximately 1/100 and the corresponding phase angle is 3.5°. At a frequency of 8 MHz it is nearly 35°.

At a frequency of 20 MHz with a period = 50 ns, the runtime is almost 1/4 of this value and the phase angle is nearly 90°. Now it is practically impossible to tell, what the real and what the imaginary part of the displayed values are.

This phase shift is a specific behavior of the test setup and the ET instrument, and has to be excluded from the acquired results.

By measuring the phase angle while directly connecting output to input (as shown in Fig. 2), we achieve the necessary correction angle φ_K.

For the correction, we have to determine the phase angle and the absolute value using the displayed real part R and the imaginary part X.

$$\varphi = \arctan\frac{X}{R} \tag{5}$$

$$Z = \sqrt{R^2 + X^2} \tag{6}$$

The correct phase angle φ_m can be calculated by means of the correction angle φ_K.

$$\varphi_m = \varphi - \varphi_K \tag{7}$$

Finally, we get the corrected complex values R_m and X_m

$$R_m = Z \cos \varphi_m \tag{8}$$

$$X_m = Z \sin \varphi_m \tag{9}$$

For this calculation it does not matter whether the values R and X are available as voltage, percentage of screen height, ADC values or impedances. For the following correction, the voltages have to be calculated by (3), if necessary.

This runtime error appears on all ET systems using a reference signal for demodulation (see Fig. 1).

The correction angle φ_K is not constant, but it depends on the frequency and has to be measured after each frequency change. It is also influenced by temperature and has to be measured intermittently. Therefore, this short connection should be done by a switch element [6].

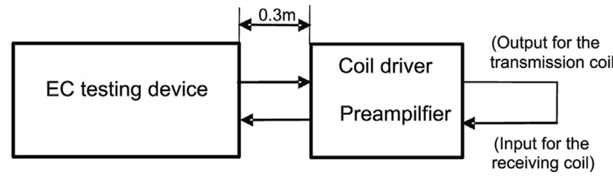

Fig. 2. Direct connection of output and input of the test setup. The output and input for the probe are directly connected.

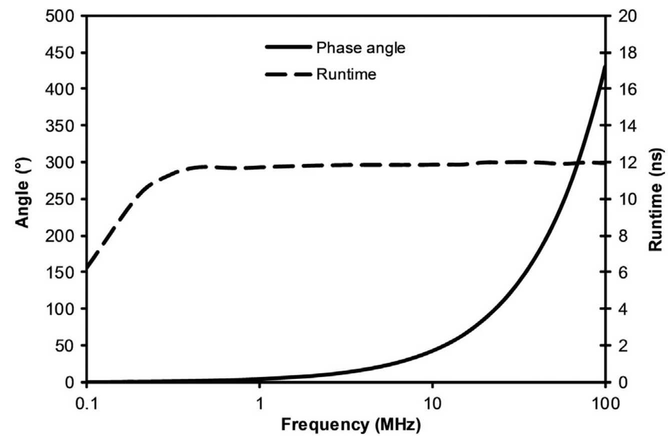

Fig. 3. Phase angle respective runtime of the test setup.

4. Correction of the phase shift error

In addition to the error caused by the runtime, there is another basic phase error that is caused by the typical way the demodulation is being performed in ET instruments.

The reference signal used for the demodulation of the receiving voltage is synchronous with the excitation voltage.