EDDY CURRENT TOOLS FOR EDUCATION AND INNOVATION

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1. Introduction

The signal generation in eddy current (EC) technique is hard to understand. Unlike x-rays or ultrasonics no obvious shadow models or echo phenomena can explain it. To overcome this drawback and to make EC technique more popular in education and innovation some tools were developed making the signal generation more transparent.

The first tool is an all-digital EC instrument with USB interface. Transparent probes give an insight into their inner construction. They are easy to handle and produce evident signals of typical defects on reference test objects provided together with the instrument. The instrument allows learning inspection for surface and hidden defects, material sorting and wall or layering thickness assessment. For experienced inspectors it opens the chance to optimize settings and different types of filtering in x-y- and y-t-mode. The system generates EC protocols not wasting time for handwriting and drawing. For teachers the tool offers new opportunities to demonstrate an EC instrument using common data projectors and to switch between the lecture material and the instrument operation “on the flight”.

The second tool is a semi-quantitative simulation code showing the correspondence between probe action and signal behaviour. The student guides a virtual probe over a virtual workpiece and may adjust lift-off effects, conductivity, frequency to get familiar with the signals of surface defects and hidden defects.

2. Theory

The effect of electrical, magnetic and geometric parameters on the eddy current signal is described in the normalized impedance plane (Foerster plot) independently from the probe. But it is not easy to understand the complicated hodographs and trajectories of the point movement mirroring the real and imaginary part of the impedance related to the reactance of the “empty” probe. A real eddy current instrument cannot demonstrate these trajectories exactly. Neither the normalization nor the influence of the test frequency or the conductivity may be displayed directly.

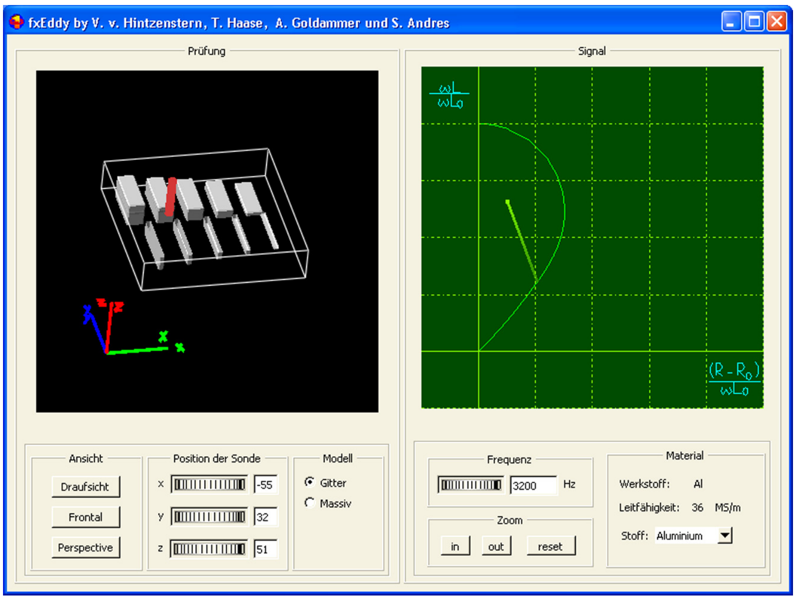


Fig. 1: Simulated inspection, left-hand side: Pick-up probe over non-ferromagnetic material; right-hand side: Lift-off signal in the normalized impedance plane.

To bridge this gap a semi-quantitative tool was developed by the students V. v. Hintzenstern, T. Haase, A. Goldammer und S. Andres of the Otto-von-Guericke-University Magdeburg (Germany). It is able to visualize the most important effects avoiding time consuming and expensive numerical modelling algorithms. It forgoes exact field theory on behalf of speed and handling. The tool wants to be a textbook for playing.

Fig. 1 displays the set-up. On the left-hand side a virtual probe is moved over a virtual reference piece by three position wheels. The reference piece contains slots (to simulate cracks) and local wall reductions from the back side. On the right-hand side a virtual eddy current instrument visualizes all signals in the normalized impedance plane. The user may zoom in to recognise details of the point movement. Additionally the frequency and the material under inspection may be selected. The impedance variation caused by wall reduction and surface cracks is shown in Fig. 2.

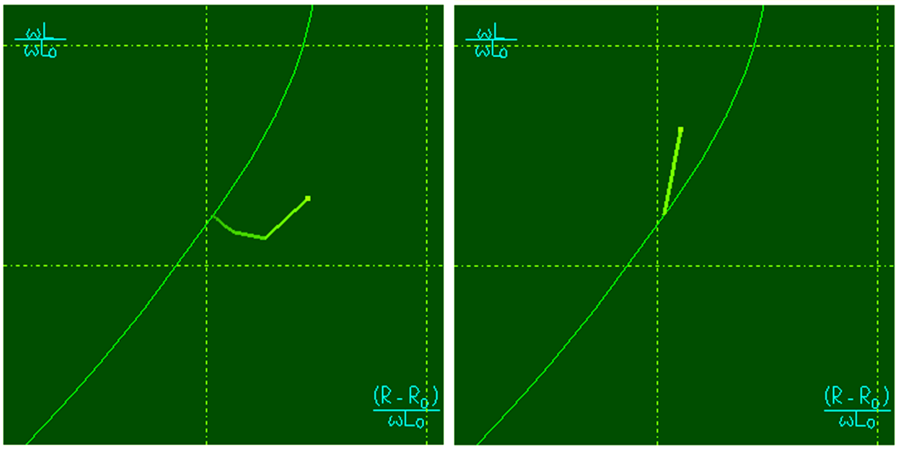


Fig. 2: Signals of reduced wall (left) and surface crack (right).

3. Experience

3.1 Hard- and Software

For practising eddy current inspection stand-alone instruments are too expensive to give every student a single instrument. Moreover, a student first time facing a real pick-up probe and a real eddy current instrument is completely concentrated on the probe handling and will not be able to generate a regular signal on the screen.
For this reason a kit was developed containing all necessary components for teaching and learning the basics of eddy current inspection. This kit is called EddyCation® (derived from eddy current and education). Its main component is a small USB-adapter to be connected to a common PC or notebook owned and used by most teachers and students. The software is copied from a USB-stick. It does not need nor installation, nor boring passwords nor permissions. EddyCation converts the notebook into an easy to use eddy current instrument with a huge xy-plane display. The student stays in his well known environment and may focus on signal recording and interpreting.
To overcome the handling problem of probes for beginners, EddyCation comes with sliding probes. These probes are transparently housed giving an insight onto the coil arrangement. Fig. 3 shows an absolute probe sliding over an aluminium strip with hidden defects.

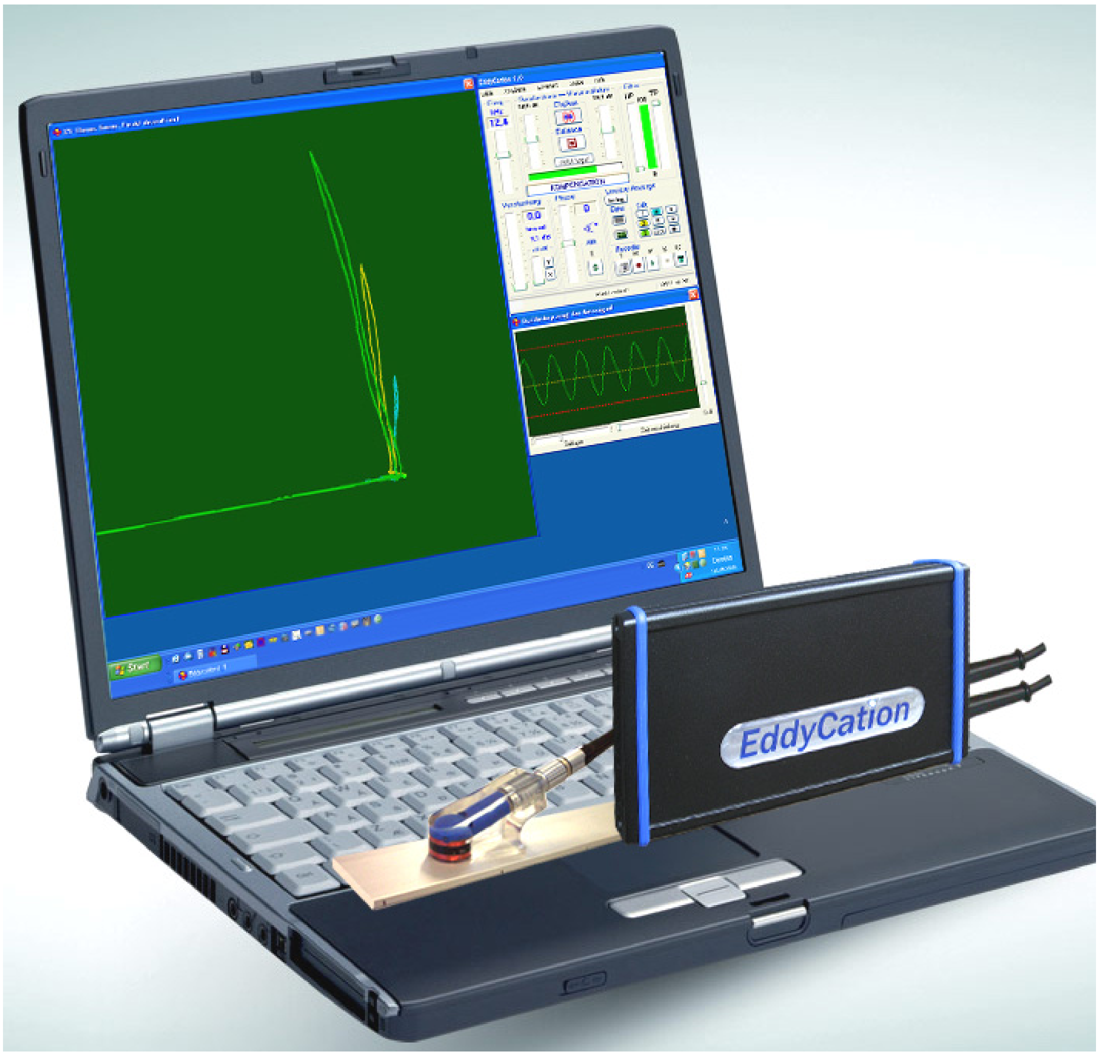


Fig. 3: Transparent sliding probes to ease the understanding and handling of eddy current probes

How does an eddy current instrument work? In a stand-alone instrument the hardware generates the test signal (mostly of sinusoidal shape), picks up the measurement and demodulates, filters, rotates, amplifies and displays it. These instruments may perform very well but they are expensive.

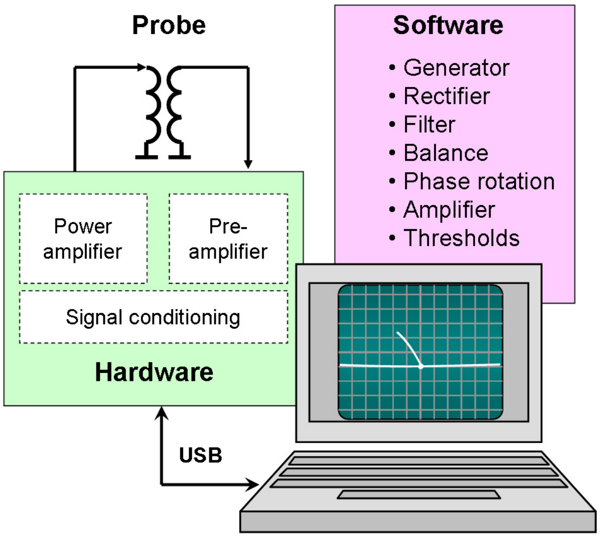


Fig. 4: Structure of the EddyCation system

How does EddyCation work? Over the last years the PCs have developed so rapidly that most work now can be done by the software. The core of the EddyCation system is a Personal Computer or Notebook with Windows® XP, Windows® Vista or Windows® 7 connected to the USB-adapter containing all necessary electronics. The computer processes the measured signal. There a two versions of EddyCation, one working up to 20 kHz and the other up to 5 MHz.
The instrument is controlled by two selectable skins shown in Fig. 5. The classic skin provides separate track bars for frequency, gain, phase and filters. The compact skin has only one single track bar with selectable functions.

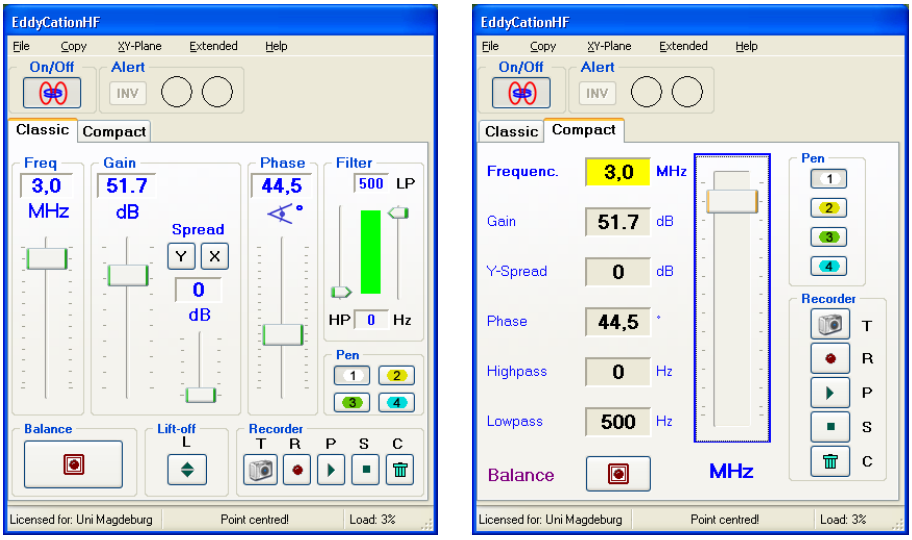


Fig. 5: Classic and compact user interface

3.2 Practice makes perfect

Material sorting is a good introduction to get into the correlation between the normalized impedance plane and the xy-plane indication of an eddy current instrument. For that, EddyCation comes with seven round blanks from materials of different conductivity and permeability. Fig. 6a depicts lift-off signals up to the air point. The hodograph of conductivity may be imagined by joining the end points of the lift-off trajectories. The large influence of the magnetic permeability also becomes obvious. The material point at this gain is far beyond the limits of the xy-plane.
The special sorting problem of coin rejection is investigated by the students most carefully. It can be shown that the Euro-coins are well selected combinations of materials of determined conductivity and permeability. With low effort these coins may be sorted contactless as shown in Fig. 6b.

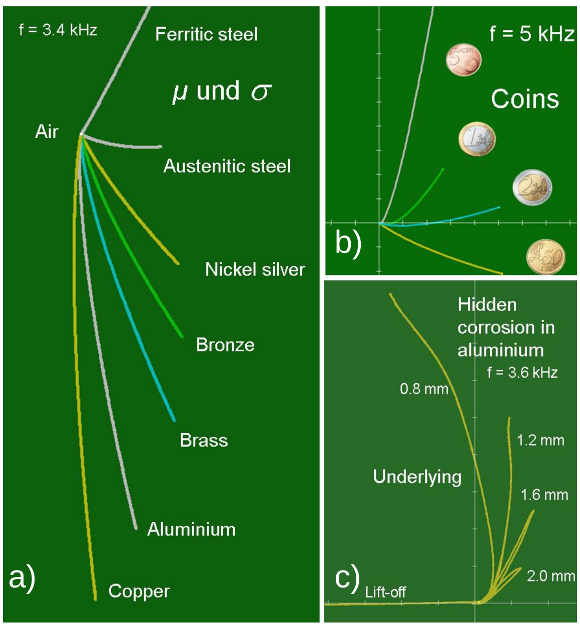


Fig. 6: Different inspection tasks for EddyCation:
a) sorting,
b) coin rejection,
c) detection of hidden corrosion.

A further important topic is the detection of wall reductions caused by hidden corrosion for instance. Within EddyCation a special aluminium strip simulates this defect by milled grooves. The students learn to interpret eddy current signals according to their phase shift. With increasing underlying the phase shift increases. Fig. 6c brings up that this circumstance permits to estimate the remaining wall. Valuable information about eddy current behaviour may be gathered with different inspection frequencies.

EddyCation offers the opportunity to record the signal in different colours or to record the track tip only. The so called tip marker helps to keep the report clear. If a signal tracks follows the previous track and only differs in magnitude, the tip marker picks up only one single measurement instead of the whole track. Fig. 7 gives an example of coating assessment on aluminium. That way, instructive reports are generated being much helpful to prepare for the exam.

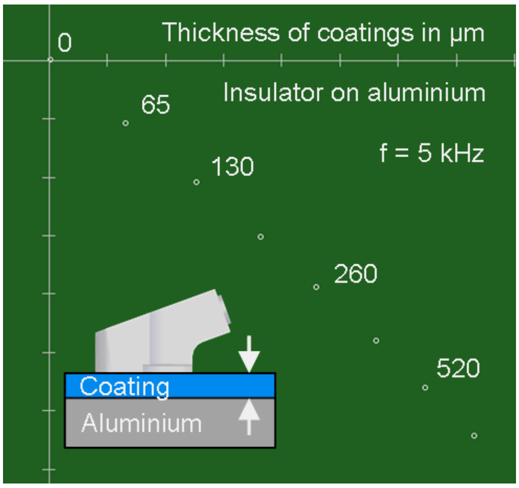


Fig. 7: Eddy current assessment of coating thickness using the tip marker

EddyCation covers the wide topic of crack inspection by a single reference piece. Slots of different depth have been eroded into an anodized aluminium strip. This strip may be inspected from both sides to simulate open and hidden cracks.
The differential probe provides the signal pattern in Fig. 8. The signal magnitude of the open slots increases significantly with increasing depth but only slightly turns clockwise. The magnitude of the hidden slot signals is much weaker (here -12 dB) but the phase behaviour is a suitable measure for the underlying of the slot.

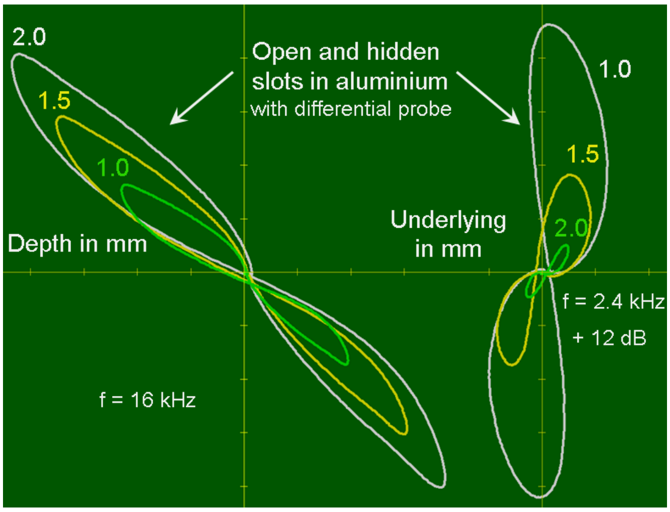


Fig. 8: Differential probe signals in the linear xy-plane. Combined picture from open and hidden slots signals.

Obviously open and hidden cracks produce very different signal magnitudes so that they cannot be displayed in one single xy-plane plot. Whether the gain is adjusted to surface cracks leaving the hidden crack signals too small or the gain is opened for hidden cracks overdriving the surface crack signals beyond the xy-plane limits. EddyCation solves this problem by a logarithmic xy-plane option (blue background) able to display signals of widely varying magnitudes. The absolute probe signals shown in Fig. 9 illustrates this option.

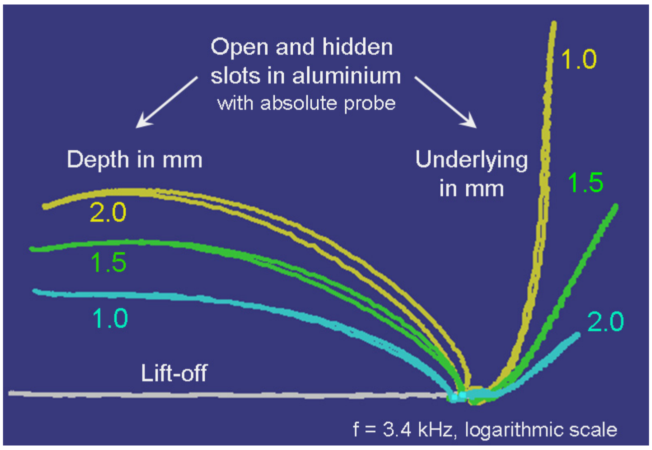


Fig. 9: Absolute probe signals of open and hidden slots in the logarithmic xy-plane

The latest version of EddyCation is able to work in a frequency range up to 5 MHz and comes with an appropriate probe. On a titanium reference with narrow slots simulating surface cracks the signals of Fig. 10 are recorded. The crack signal provides a significant angle to the lift-off signal enough for separating both signals.

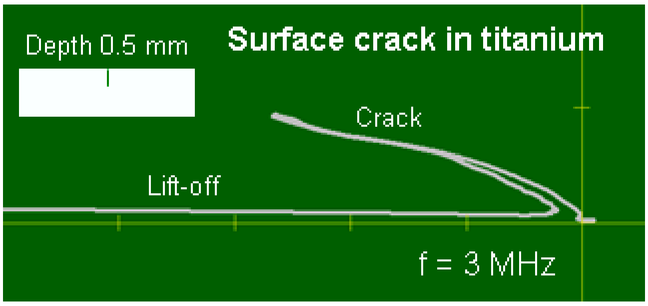


Fig. 10: Signals of a 0.5 mm slot in titanium at 3 MHz

Even carbon fibre-reinforced plastics can be inspected. Fig. 11 displays the signal of a pitch-catch probe turned on the surface. Eddy currents may spread along the fibres better than across. The anisotropy of conductivity is a suitable basis for fibre orientation assessment with good signal-to-noise ratio [1-13].

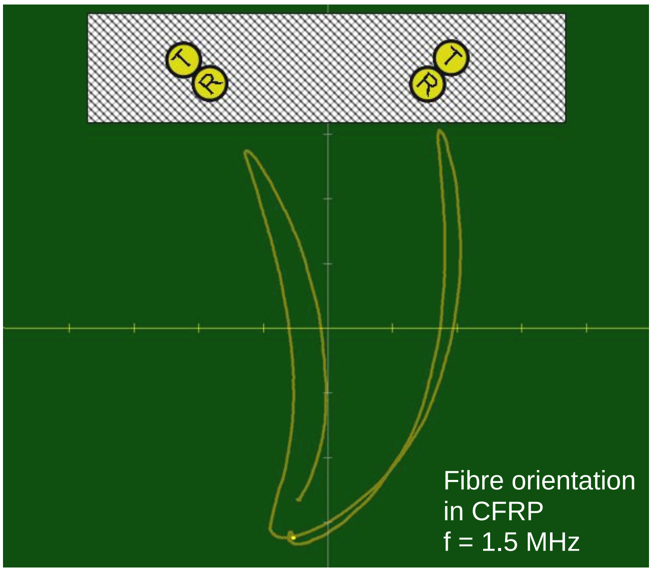


Fig. 11: Pitch-catch probe over bi-directional carbon-reinforced plastics (CFRP), T-transmitter, R - receiver.

3.3 *Time and thresholds*

In addition to the x-y-data representation EddyCation may use the y-t-mode. At two selectable velocities the point can be moved along the x-axis, representing in this mode the time.
The Y-component can be recorded and evaluated according to the signal magnitude using different thresholds. Among them are both simple x-y-thresholds as shown in Fig. 12 and more complex types like symmetric and circle thresholds.

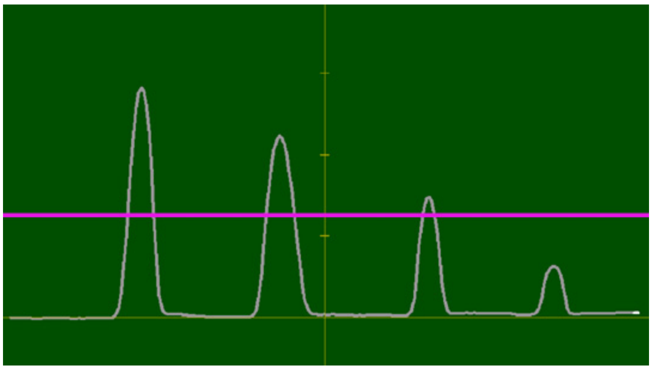
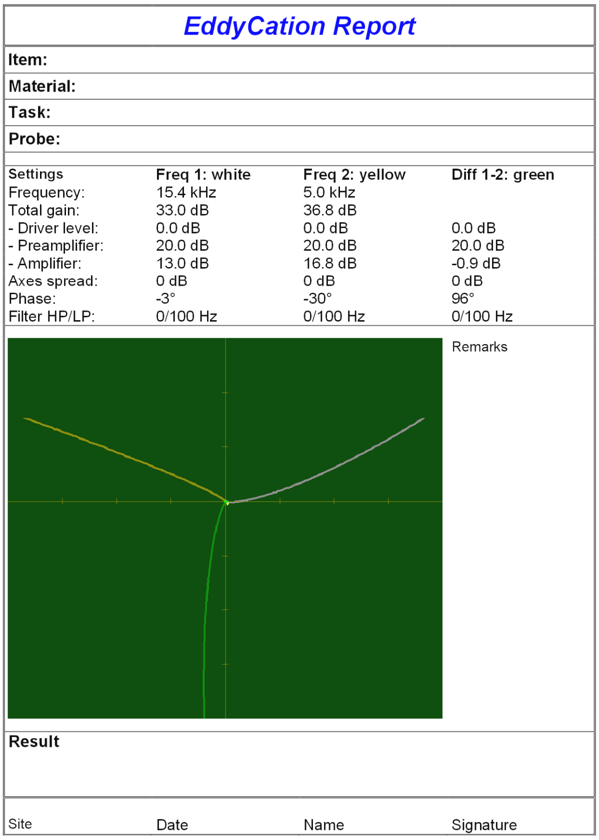


Fig. 12: y-t-mode with threshold for signal evaluation

3.4 *Automatic reporting*

Many stand-alone instruments may be connected to a printer for reporting. Difficulties occur when the reports should be archived or transmitted to other sites. Here, EddyCation lets you generate a MS-Word® report automatically. Fig. 13 shows an example. All settings and the xy-plane image are included. The student can concentrate on the essentials e.g. the interpretation of the eddy current signals. Directly in MS-Word® he can add comments and conclusions. The report can be printed like any other document. If the PC is connected to a network, the reports can be gathered, compared, transmitted or archived. Anyhow, the report remains on the hard disc of the student's notebook and he can repeat what he has learned.



EddyCation Report

Item:
Material:
Task:
Probe:

Settings	Freq 1: white	Freq 2: yellow	Diff 1-2: green
Frequency:	15.4 kHz	5.0 kHz	
Total gain:	33.0 dB	36.8 dB	
- Driver level:	0.0 dB	0.0 dB	0.0 dB
- Preamplifier:	20.0 dB	20.0 dB	20.0 dB
- Amplifier:	13.0 dB	16.8 dB	-0.9 dB
Axes spread:	0 dB	0 dB	0 dB
Phase:	-3°	-30°	96°
Filter HP/LP:	0/100 Hz	0/100 Hz	0/100 Hz

Remarks

Result

Site	Date	Name	Signature

Fig. 13: Automatically generated report including settings and signal pattern.

4. Conclusions

EddyCation (www.eddycation.de) makes eddy current teaching and learning more easy. The teacher clearly may demonstrate facts and methods via notebook and data projector. The student keeps motivation and concentration over long terms due to the interactivity and diversity of the work. Eddy current inspection becomes playing easy to learn.

5. References

[1] Prakash, R.; Owston, C.N.: Eddy-current method for the determination of lay-up order in cross-plied CFRP laminates, Composites, 7, (1976), S. 88-92

[2] Vernon, S.N.: A Single-Sided Eddy Current Method to Measure Electrical Resistivity, Mat. Eval., 46, (1988) S. 1581-1587

[3] Valleau, A.R.: Eddy Current Nondestructive Testing of Graphite Composite Materials, Mat. Eval., 48, (1990), S. 230-239

[4] de Goeje, M.P.; Wapenaar, K.E.D.: Non-Destructive Inspection of Carbon Fibre-Reinforced Plastics Using Eddy Current Methods, Composites, 23, (1992) S. 147-157

[5] Khandetskii, V.: Eddy Current Evaluation of Lamination Parameters in Carbon Fibres Composites, World Conf. on NDT, Sao Paulo, 1992, pp. 295-299

[6] Köser, O.; Mook, G.: Simulation und Rekonstruktion von Wirbelstrombildern auf der Basis eines Stromschleifenmodells. Wissenschaftliches Kolloquium Grundlagen der Zerstörungsfreien Prüfung, Dortmund, 13.11.1996, Berichtsband S. 39-50

[7] Vernon, S.N.; John, M.L.: Eddy Current Probe Design for Anisotropic Composites, Mat. Eval. 50, (1992), S. 36-41

[8] Mook, G.; Pohl, J.: Non-Destructive Inspection of CFRP Based Composites, 4th Int. Conf. on Comp. Eng. (ICCE), Hawaii, 1997, S. 681-682

[9] Lange, R. and Mook, G.: Structural Analysis of CFRP using Eddy-current Methods, NDT&E Int., 27 (1994), S. 241-248

[10] Mook, G.; Lange, R.; Koeser O.: Non-destructive characterisation of carbon-fibre-reinforced plastics by means of eddy-currents, Composites Science and Technology 61 (6) (2001) S. 865-873

[11] Mook, G.; Pohl, J.; Michel, F.; Benziger, Th.: Damage Evaluation of Smart CFRP-Piezoceramic-Materials using Non-Destructive Methods, ICCM 12 Conference Paris July 99th, paper 199, ISBN 2-9514526-2-4

[12] Mook, G.; Pohl, J.; Michel, F.; Benziger, Th.: Non-Destructive Inspection of Smart Materials, 15th World Conference on Non-Destructive Testing, Rome, October 15-21, 2000; The e-Journal of Nondestructive Testing & Ultrasonics, ISSN: 1435-4934

[13] Mook, G.; Zerstörungsfreie Charakterisierung von carbonfaserverstärkten Kompositen mit Hilfe des Wirbelstromverfahrens. Jahrestagung DGZfP, Berlin, 21.-23. Mai 2001, BB 75-CD, Vortrag V37