EDDY CURRENT NOTEBOOK AND SMARTPHONE APPS

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ABSTRACT

The paper presents interactive eddy current tools for learning and teaching. It aims to help beginners to understand this non-destructive inspection method. They work with up-to-date Android Smartphones and Windows notebooks. All typical tasks like sorting, crack inspection, hidden defect and corrosion inspection and even dynamic inspection using low and high pass filtering and signal indication in xy- and yt-mode may be learned. For teachers and trainers the tool offers best opportunities to demonstrate an eddy current instrument using data projectors. Not only single probes but also probe arrays may be plugged to a Windows notebook. They allow for easy eddy current imaging. An engraved aluminium sheet is used as reference piece to be read from both sides.

Key words: All-digital eddy current instrument, pitch-catch probe arrays, linear and circular arrays, imaging, dynamic inspection

1. Introduction

Eddy current method uses electromagnetic energy to inspect the near-surface region of conductive material. No couplant is needed and the inspection speed is very high. Unfortunately, the signal generation in eddy current technique is hard to understand. In contrary to x-rays or ultrasonics no obvious shadow models or echo phenomena can explain it. To overcome this drawback and to make eddy current technique more popular in education and innovation some apps were developed for practicing this inspection method. The apps are combined with a set of probes and references necessary for teaching and learning. The resulting kits are called EddyCation (derived from eddy current and education).

2. EddyCation for Android

The audio system and processor performance of up-to-date smartphones is sufficient for eddy current inspection from 1 kHz up to 20 kHz [1]. The probe is attached to the audio jack simulating a head set. Of course, the pinout of the audio jack has to meet the smartphone’s requirements. The quality of the jack also plays an important role because of contact resistance. Gold-plated contacts are best suited. For efficient learning well designed references are needed. Fig. 1 displays a complete kit.
Fig. 1: Left: EddyCationSmart kit consisting of the Smartphone (Galaxy Note 4), the reference set and an absolute probe. Right: Eddy current signals of different materials in the xy plane on the smartphone screen.

Round blanks and the aluminium body represent a broad conductivity and permeability spectrum. When the probe approaches the blanks so-called lift-off-lines of different length and orientation are drawn. The right part of Fig. 1 shows these lines. Basing on these two parameters the material can be identified. One learns about the influence of probe inclination and edge distance.

Narrow slots represent surface cracks. Two references from different materials provide the opportunity to compare crack signals. One of them is made from well conducting aluminium and the other from weak conducting but slightly ferromagnetic stainless steel. For both materials optimal inspection parameters have to be found. Fig. 2 gives an idea of the signal pattern. The reference pieces may be removed from the aluminium body and be flipped to simulate hidden cracks.

Fig. 2: Surface crack inspection: Left: Slots of different depth in aluminium simulate surface cracks in highly conductive material. Right: Slots in austenitic steel represent cracks in poorly conductive but slightly ferromagnetic material.

Wall reduction may be caused by corrosion or erosion at the inner side of a component but should be detected from the outer side. Eddy currents at low frequency are used to obtain high penetration depth. The according reference piece has milled grooves on the back side. The practitioner learns to select a suited frequency according to the penetration depth and phase spreading. This is the basis for remaining wall thickness assessment. Fig. 3 shows this situation.
Fig. 3: Wall reduction in aluminium: Left: At 4 kHz all reductions are well detectable. The phase spreading is mediocre. Right: At 12 kHz the phase spreading is significantly better but due to lower penetration not all reductions can be detected.

3 EddyCation for Windows

A small USB box is connected to a PC, notebook or macbook running Windows. The according software may even run from the USB stick not needing installation, logins nor passwords. 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 [2]. Fig. 4 a) shows the case with the USB box, the probes and the references, Fig. 4 b) displays the user interface on a notebook screen.

How does EddyCation work? The core of the EddyCation system is the computer generating and processing the signals. The USB box includes DA and AD converters with frequency ranges up to 20 kHz (for low frequency kits) and up to 5 MHz (for high frequency kits).

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 an absolute probe and seven round blanks from materials of different conductivity and permeability. Fig. 5a) 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 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.

![Fig. 5: a) Sorting of 7 materials, b) crack detection using the absolute probe on the aluminium reference](image)

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 absolute probe is designed for easy handling with big foot avoiding tilting. The software offers the opportunity to record the signal in different colors. Fig. 5b) and c) show that open and hidden cracks produce very different signal orientations. These signals easily can be distinguished using the method of phase discrimination.

![Fig. 6: Surface crack inspection using the high frequency absolute probe](image)

The latest version of EddyCation works in a frequency range up to 5 MHz and comes with an appropriate high frequency probe. Fig. 6 displays surface crack signals obtained from a 4 layer Rohmann crack reference from ferritic and austenitic steel, aluminium and titanium. Even on the low conducting titanium reference the surface crack signals are easily distinguishable. The crack signal provides a significant angle to the lift-off signal enough for separating both signals. 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. 7 brings up that this circumstance permits to estimate the remaining wall. Valuable information about eddy current behavior may be gathered with different inspection frequencies.
Fig. 7: Signals of hidden wall reductions at different frequencies. The specimen is tested from the smooth side. The signal turns clockwise with increasing frequency but the amplitude reduces.

Differential probes are able to detect local differences in the material properties. If correctly guided they bring up very small defects like cracks or pores even below the surface. But the operation of these probes is not intuitive. The students should take care of the orientation of this probe type. Like with the absolute probe, the contact area is big. The probe easy slides over the anodized aluminium sheet.

Fig. 8: Differential probe signals from surface and hidden cracks in aluminium

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 (by 16 dB) but the phase behavior is a suitable measure for the underlying of the slot. The students learn to guide the probe with correct orientation.

Filtering is a big problem for beginners because there is no understanding for the effect of filters on the shape of the signals. In commercial eddy current training courses beginners start to learn filtering with a hand-held rotating probe. It is hard to manage the probes handling and at the same time to adjust the low and the high pass filters. For this goal a rotating specimen has been developed.

Fig. 9 shows this specimen. An aluminium disc with a slot rotates with an adjustable speed below a glass fiber plate. Any eddy current probe may be placed on this plate not touching the rotation disc.
The eddy current signal can be displayed in the common xy plane but also in the yt-mode in time domain. For yt-mode it is necessary to synchronize the indication with the revolutions of the disc. The eddy current signal is processed by the software that catches the slot signal and automatically synchronized the indication. When the probe is lifted the image freezes for reporting. No other connection to the notebook is necessary. The student may now concentrate on filter adjustment. Often the question arises how to adjust the low pass filter? Is it better to open it widely or better to close it as much as possible? For that question a switching power supply with a light band was installed in the housing. The power supply sends disturbances to the probe clearly visible in the signal. Fig. 10 a) shows the complete signal.

The slot signal is the biggest followed by the four controller signals of every disc revolution. The small riffle is produced by the switching power supply. Now the student clearly can understand to what extend to open or close the low pass filter. He closes this filter until the riffle has vanished and the slot signal remains as big as it was before. The motor controller signals are reduced but did not vanish. If the low pass is closed further the controller signals reduce but also the slot signal decreases. This situation has to be avoided. Instead, the high pass filter is closed as far as the slot signal does not get its symmetric shape. Now it is easy to define a threshold distinguishing the slot signal from the motor controller signals.
4 Eddy current arrays for Windows notebooks

Instead of a single sensor many sensors may be combined into a sensor array. The principle of such sensor arrays has been presented by the authors in [3-12]. The speed of electronic field movement ranges from 0.4 to 3 m/s according to the inspection requirements. The arrays may be fitted for flat and curved surfaces. Fig. 11 gives some ideas for convex objects like pipes, rods or rails.

![Fig. 11: Potential applications of probe arrays for curved surfaces](image)

The fixed shape arrays provide a constant geometry and low wear. It is easy to guide them manually. A position encoder wheel is the basis for imaging. The linear array in Fig. 11 is guided over the area of inspection and provides eddy current images in real time. A rotary encoder picks up the displacement of the array and cares for correct imaging. All necessary electronics is located in the array’s housing, so that a single USB-cable to the notebook is sufficient for energy supply and data transfer. The photograph on the left shows an array over an engraved aluminium sheet as reference piece. The image on the right shows the probe arrangement and gives some result images. The graphic user interface may be used like single probe interfaces.

![Fig. 12: Sensor array, left: control window, right: array over the reference sheet. Eddy current images of the sensor array, from left to right: raw data, data with y-threshold, false color image, high pass filtered image](image)

The engraving is clearly readable from the front side and the back side also. The first image on the left represents the original data, the second includes a threshold and the third is a false color representation. For edge enhancement may be used filters, e.g. band or high pass filters. A common band pass has to be adopted to the velocity of array over the object. Spatial filtering avoids this disadvantage. Not the time but the displacement is the filter base. The spatial frequency is given by the number of repetition per length. This way, this filter does not depend on the velocity of the movement. On the right side of the result image the effect of high pass filtering is demonstrated. At the same time, this filter eliminates the need of balancing each sensor of the array.
Fig. 13 displays a real aluminium cast with hidden anomalies. The photograph in 13a) does not give any evidence of material anomalies. The eddy current image in 13b) shows a bright loop of conductivity disturbance. After rework of one millimeter of the material surface even the photograph brings up inclusions of aluminium oxide.

The arrays are also suited for concave objects like tube inspection from the inner surface. Fig. 14 displays a probe for 21 mm inner diameter tubes.

Four spring-loaded heads cover the complete circumference. Additional sensors record the wall thickness. The inspection speed reaches up to 120 mm/s. The probe contains all analogue and digital hardware for the arrays and is connected to a notebook by an extended USB cable of up to 30 m length. No additional power supply is required making the handling most comfortable.

Fig. 15 shows one of the heads and its measurement in the complex plane. All sensor signals may be watched simultaneously either in the complex plane or in the C-Scan display. If necessary each sensor may be adjusted individually. The head carrier is made from titanium for minimal wear out. Flexible strips connect each head to its electronics.

The C-Scans are recorded from the x- and the y-components of all sensors. The travel distance is recorded by a cable driven wheel encoder. The encoder itself is also plugged in a USB-port of the notebook.
Fig. 16: Circumferential C-Scan image of an austenitic steel tube of 21 mm inner diameter with standard calibration defects of different distance. The scan consists of 36 sensor tracks.

Fig. 16 displays a 600 mm section of an austenitic steel tube of 21 mm inner diameter. Groups of standard calibration defects with different distance become visible.

5 Conclusion

EddyCationSmart for Android is a powerful and inexpensive eddy current training tool set. It is based on sound systems of up-to-date smartphones. The students work with their device they know best. Apart from the smartphone, a sensor and the app are needed. If necessary, a set of reference pieces may be provided.

EddyCation for Windows may be used with a low frequency or a high frequency box, depending on the goal of the education course. For training of filter adjustment a rotary specimens is available.

Eddy current arrays offer new opportunities in surface and subsurface characterization. The arrays may be guided mechanically or manually. Their shape may be adopted to the objects surface and it is possible to provide images very easy. All advantages of eddy current method like non-contact, single sided and easy to handle are united in the array technique.

References