# Education in eddy currents – from single probes to arrays

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**Abstract**

Eddy current inspection may be learned directly on a notebook, tablet or smartphone. The students work with their beloved devices they know best. This makes the contact to a complicated inspection method not only less painful but even creates a certain enthusiasm.

The paper presents interactive eddy current tools for learning and teaching. It aims to help beginners to understand this non-destructive inspection method. The tools work with up-to-date Windows notebooks, Android smartphones and tablets. All typical tasks like sorting, crack detection, 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 using reference pieces. For teachers and trainers the tools offer best opportunities to demonstrate an eddy current instrument using data projectors.

Not only single probes but also probe arrays may be plugged directly to a Windows notebook allowing simple eddy current imaging. An engraved aluminium test sheet is used as reference piece to be read from both sides.

## 1. Introduction

Eddy current (EC) method uses electromagnetic energy to inspect the near-surface region of conductive material for different kinds of anomalies very efficiently. No couplant is needed and the inspection speed is very high. Unfortunately, the signal generation in EC technique is hard to understand. Contrary to 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 (1-3).

## 2. Android smartphone as eddy current instrument

### 2.1 Hardware

The first tool is an app for Android smartphones using the audio jack as probe interface. The eddy current probe is fed by the audio output ranging up to 20 kHz of inspection frequency. The field strength can be controlled by the phone's volume. The received signal is put to the microphone pin of the audio interface. All signal processing is done digitally and uses the huge capabilities of current devices. Figure 1 shows the kit.

**Figure 1. Smartphone as eddy current instrument. The kit contains a probe and reference pieces for many eddy current inspection tasks.**

*2.2 Software*

The software accomplishes signal generation, demodulation, amplification, phase rotation and filtering. The demodulated signal is shown as a flying dot on the xy-plane. The student can adjust all essential settings directly from the touch screen. The dot movement may be recorded and afterwards modified in gain and phase. Additionally, a yt-indication is possible. For further details see the paper "Smartphone turns into eddy current instrument" in these proceedings.

## 3. Windows notebook as eddy current instrument

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 box to be connected to a PC, notebook or Macbook running Windows. The software is copied from the USB stick. It does not need nor installation, nor annoying 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. Figure 2 a) shows the case with the USB box, the probes and the references, Figure 2 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).
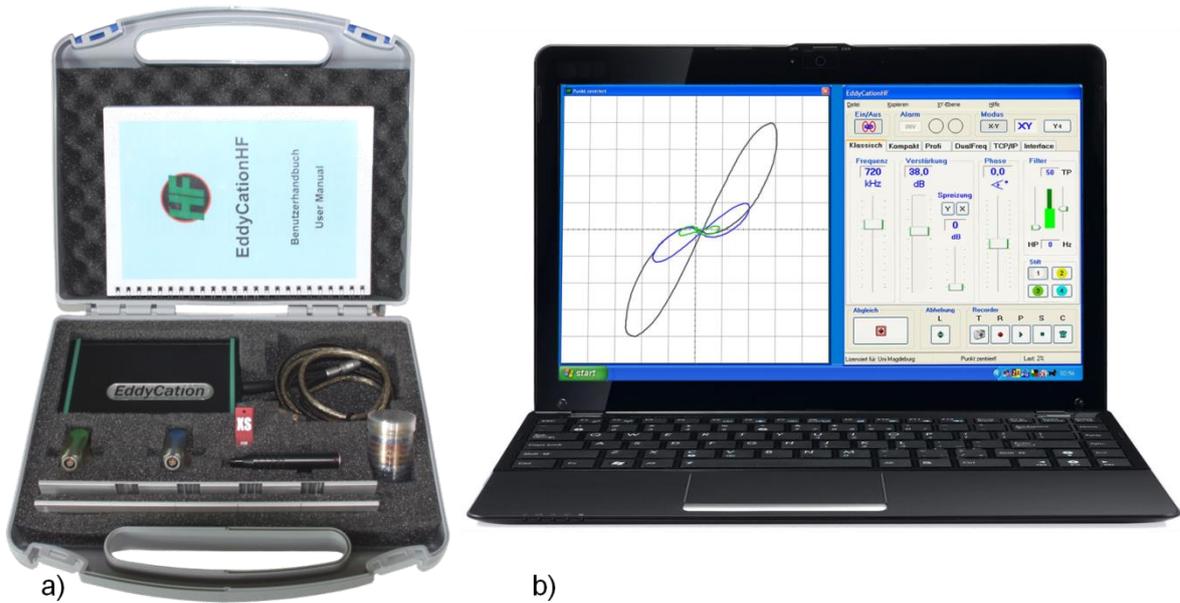
**Figure 2. Instrument, probes and references of an EddyCation kit, b) user interface on a notebook**

## 3.2 Absolute Probes

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. Figure 3a 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.
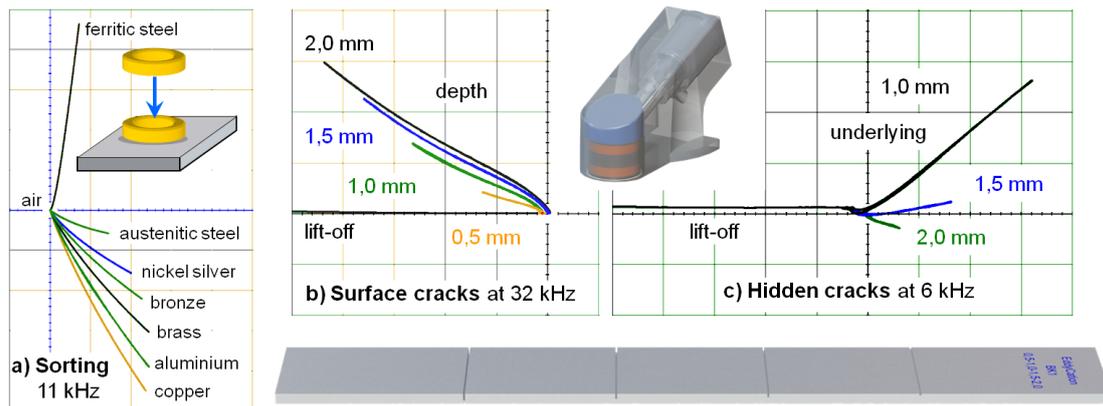


**Figure 3. a) Sorting of 7 materials, b) crack detection using the absolute probe on the aluminium reference**

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 colours. Figure 3b) 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.

Figure 4a) and b) displays wall reduction signals of a 3 mm aluminium strip at different frequencies. Absolute phase angle and phase spread strongly depend on the wall thickness and can be used for remaining wall assessment.
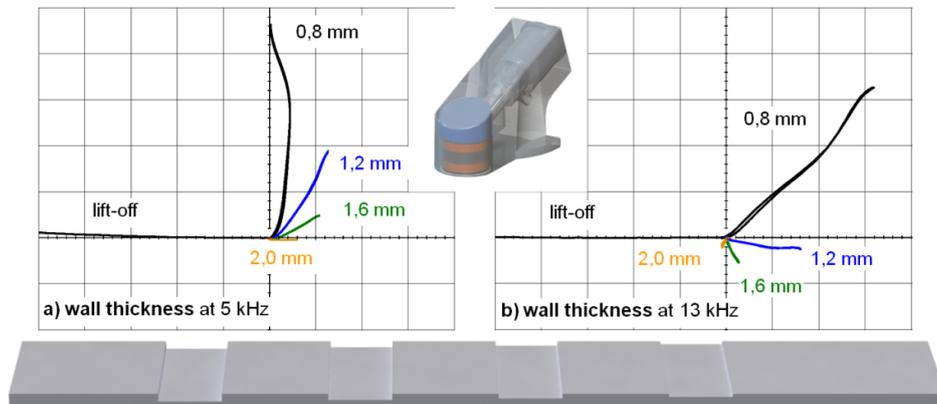


**Figure 4. Signals of hidden wall reductions at different frequencies. The specimen is tested from the smooth side (backside). The signal turns clockwise with increasing frequency but the amplitude reduces.**

## 3.3 Differential Probes

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.
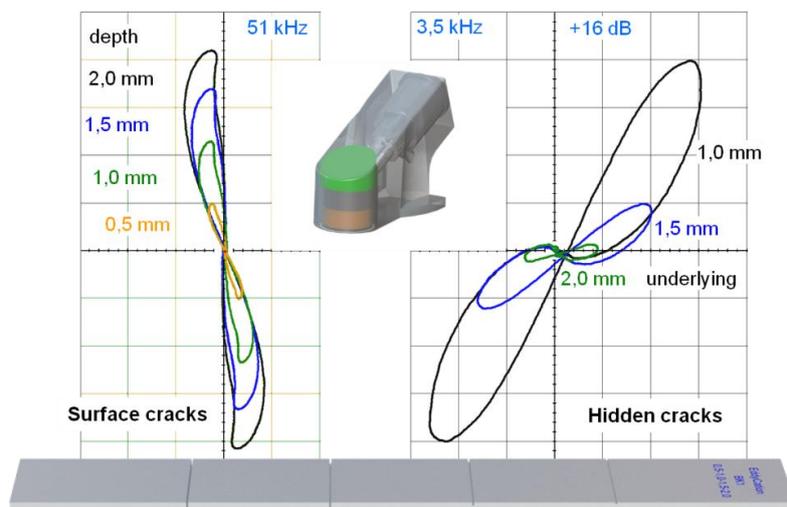


**Figure 5. Differential probe signals from surface and hidden cracks in aluminium**

The differential probe provides the signal pattern in Figure 5. 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 behaviour is a suitable measure for the underlying of the slot. The students learn to guide the probe with correct orientation.

### 3.4 Dynamic inspection

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.
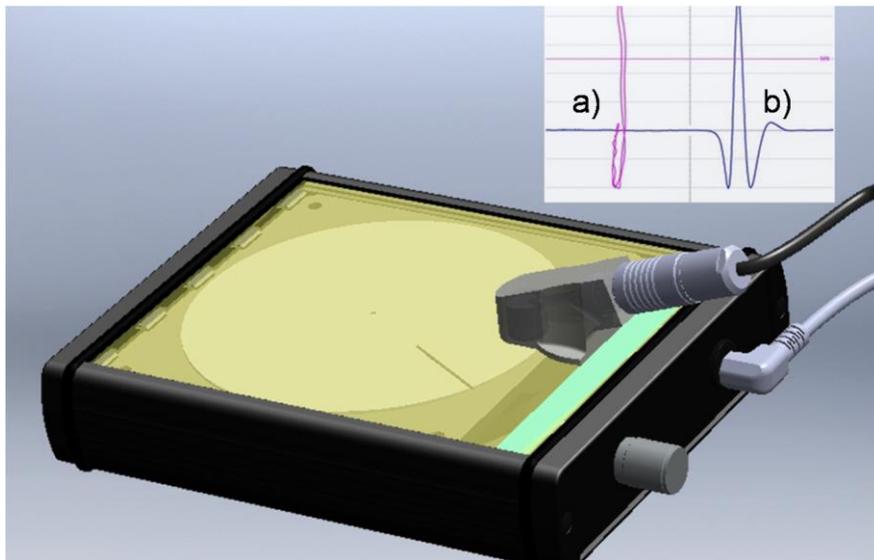


**Figure 6. Rotating aluminium disc below glass fiber cover**

Figure 6 shows this specimen. An aluminium disc with a slot rotates with an adjustable speed below a glass fibre 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 6a) but also in the yt-mode in time domain 6b). 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 as a smell riffle. Now the student closes the low pass filter until the riffle has vanished and the slot signal remains as big as it was before. Now the high pass filter is closed as far as the slot signal does not get its symmetric shape.

## 4. Eddy current array for Windows notebook

The linear array in figure 7 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.
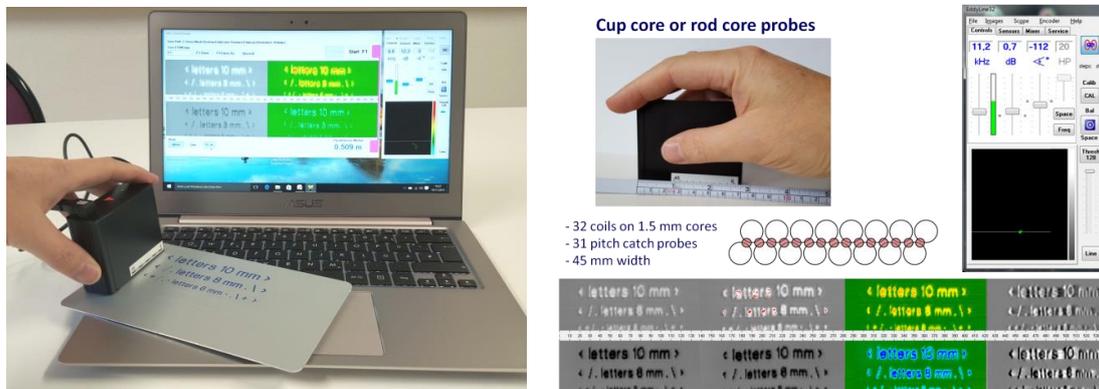


**Figure 7. Sensor array, left: control window, right: array over the reference sheet. Eddy current images of the sensor array, from left to right: raw data, data with y-threshold, false colour image, high pass filtered image**

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 colour 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.

## 5.   Conclusion

EddySmart and EddyCation (www.eddycation.de) make eddy current teaching and learning much easier. 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 playfully easy to learn.

**References and footnotes**

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