

A New Capacitive Imaging Technique for NDT

Geoff G. DIAMOND, David A. HUTCHINS
School of Engineering, University of Warwick, Coventry, UK

Abstract. A new technique for NDT has been developed which is capable of imaging a wide range of materials and structures, ranging from insulators to metallic conductors. The approach, known as Capacitive Imaging, uses electrode arrays in air to produce an AC electric field distribution within the material. Scanning the electrodes over the material causes a change in the field distribution, and hence changes in output voltage. Capacitive coupling allows the technique to work on a wide variety of material properties, without the disadvantages associated with conventional eddy current and potential drop methods. Images are presented of carbon fibre composite materials, Perspex and metals, illustrating the range of application in NDT.

Introduction

There are many different types of non-destructive inspection techniques that are routinely used in industry. Amongst the most common, however, are ultrasound, X-rays, dye-penetrant and eddy current inspection.

Ultrasound is one of the most widely used techniques in civil, aerospace and medical applications. Normally, tests are carried out using either a water-bath or a contact approach. However, the use of water or gel as a couplant may not always be suitable for certain inspection situations, e.g. where the material absorbs water, or where surface contamination or damage would result. There has thus been increased interest in using air as the coupling medium [1]. The use of X-rays has always been a popular technique for difficult materials [2], but X-rays systems use ionizing radiation and so require proper screening to protect the users. In addition, they are also comparatively expensive.

The current range of electromagnetic techniques that are most commonly used for the characterisation of structures include eddy current inspection [3], ac and dc potential drop methods [4] and magnetic flux leakage techniques [5]. Eddy currents in their most common form use a coil containing an ac current, placed close to the surface of the sample being tested. This generates an eddy current at the surface of a conducting material, and variations in this process can be sensed by monitoring the impedance of the coil. Potential drop methods also require the material to be conducting, and often use electrodes or arrays which contact the surface, and many electromagnetic and magnetic techniques can only be used on certain materials [6,7]. Here a new approach is proposed, where a pair of capacitive electrodes is used to generate an electric field distribution within the material. The process is akin to placing the unknown material between the plates of a parallel-plate capacitor, but with the two electrodes co-planar and not in parallel. This process, described more fully below, thus effectively measures the dielectric properties of the material. The new technique uses a set of simple electrodes, which are placed above the surface of the object to be imaged. An ac voltage is applied to one or more electrode, and a signal detected on others. The technique has the potential for imaging the internal structure of many materials,

without requiring contact to the surface. It could also readily be extended to arrays for rapid *in-situ* imaging, without the requirement for mechanical scanning.

2. The electrostatic approach for material inspection

Conceptually, the technique is very straightforward. Figure 1 illustrates the principle of the approach when two planar metallic electrodes are used. These are oriented at a fixed distance away from, and parallel to, the surface of the sample to be inspected. A voltage drive waveform is then applied to the source electrode. This waveform can take many different forms but in the simple case presented here, it is a sinusoidal signal of a fixed frequency. An alternating electrostatic field is established, with field lines passing through the object, whereby charge is then induced on the surface of the second electrode. These coupled charges can be detected via standard techniques such as charge amplifiers, processed and outputted as a dc voltage level.

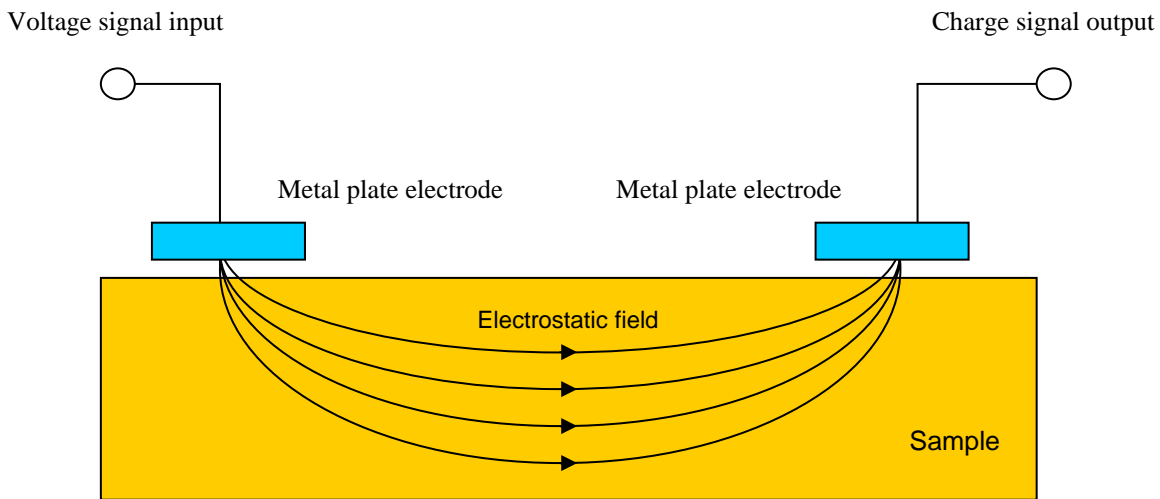


Figure 1: Schematic diagram of the electrostatic imaging system

The presence of a sample affects the electrostatic field pattern established between the two electrodes, and hence also affects the detected signal. In essence, the presence of sample in the region of space between the plates perturbs the field lines between these two electrodes and this manifests itself as a change in capacitance. Hence, the presence of defects or gross changes in the material properties within the sample under test will modulate the effective dielectric constant of the inter-electrode volume as the probe is scanned over the surface.

At first sight, the above may seem similar to eddy current methods, with the coils simply replaced by flat electrodes. However, the mode of operation is completely different. In the case of eddy currents, the coil is used to maximise the creation of an induced current within the material, caused principally by maximizing the oscillating magnetic field generated by the coil at the sample surface. Eddy currents are then generated which circulate within the material (which should have a reasonably high conductivity) in closed loops, and these are detected by the same or a separate coil. The depth of penetration of these eddy currents is controlled, as in the present case, by the electrical properties, which

in turn determine the skin depth at a certain frequency. However, the system described here differs in that it maximises the electric field component and hence induces an electrostatic field within the material. The absence of a coil minimizes the magnetic field component, and the air gap stops a direct ohmic current that would be generated by intimate contact between the electrodes of the device and any metallic/conducting specimen. Hence eddy current generation is discouraged, whereas an electrostatic field is established between the two electrodes, which can be used for imaging. As in eddy currents, the frequency range of operation is chosen to suit the sample properties.

3. Experimental Arrangement

Figure 2 shows the experimental arrangement used for the electrostatic imaging experiments. The experiments used a capacitance setup that employed a single pair of electrodes. These were made from copper plates, etched onto a printed circuit board (PCB) substrate. The PCB was also coated in copper on its obverse side to ensure that the radiated electric field emanated predominantly in the direction towards the sample. This electrode

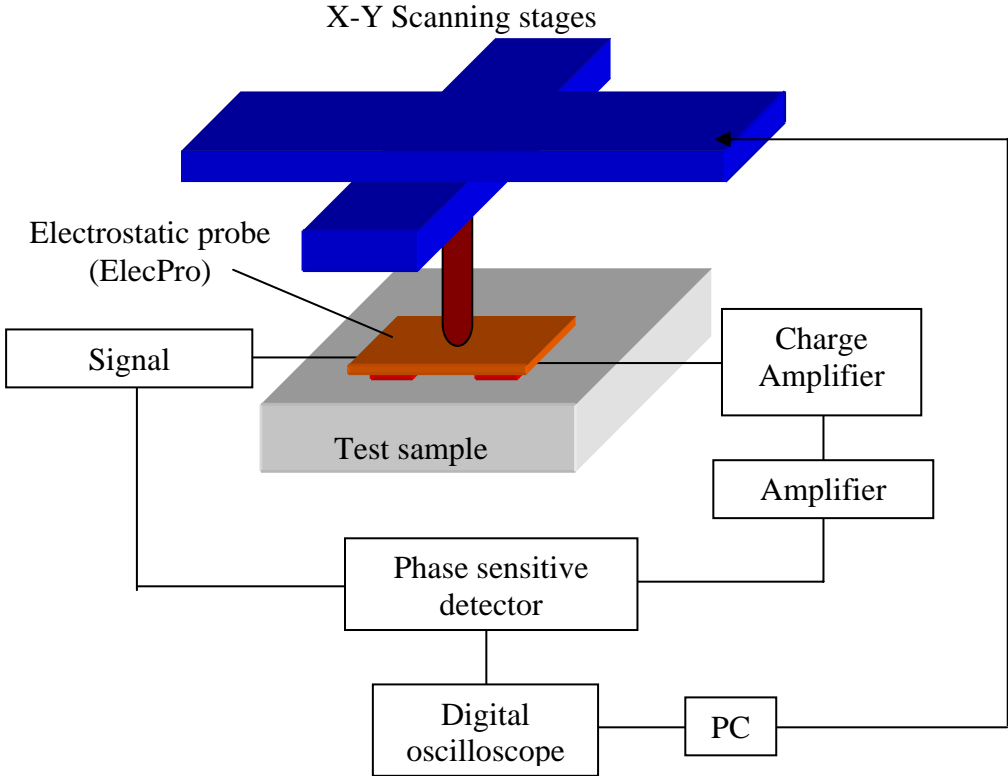


Figure 2: Experiment arrangement for the collection of data using the electrostatic imaging system.

assembly was then mounted within a grounded metal enclosure to provide shielding from stray fields and also to serve as a convenient housing with which to hold and manipulate the probe. A range of probes were used – each one having varying differences in the shape and and spacing of the matching electrode pairs. The sensing face of the probe assembly was then placed (usually about 5mm) above the surface of the specimen, with an air gap separating the electrodes from the surface.

Each copper electrode can be used as either a source or receiver. To generate an electrostatic field, one of the plates was used as a transmitter and connected to a Levell function generator Model TG301. A 10 kHz voltage signal was used in many experiments, although this could be adjusted up to 1MHz. The received signal was then processed successively by a charge amplifier, a pre-amplifier and a lock-in detector (Brookdeal Electronics Ltd: model PSD 411). The latter unit added phase-sensitive detection to the system, and this was found to greatly improve the signal-to-noise ratio of the received signal. The output signal from the lock-in amplifier was a simple dc voltage level that was proportional to the instantaneous value of the dielectric property of the material averaged over the field distribution within the material. This value was finally captured by a digital oscilloscope and transferred to a PC for data storage. Electrostatic imaging was performed using a two-axis scanning system, where the electrodes were scanned at a constant separation over the surface of the sample, keeping the air gap as constant as possible. The resolution of the image was determined by the step size of the scan, which in this case it was set to 2mm.

4. Results and discussion

Consider first the two samples representing the two extremes in electrical conductivity, namely thin metal and Perspex. The sample geometries and the resulting images are shown for these two cases in Figures 3 and 4 respectively. Consider first the metallic sample, an image of which is shown in Figure 3(a). This is an image taken by scanning a pair of 10 mm square electrodes, such as those shown schematically in Figure 1, over the surface of a thin (0.075 mm thick) aluminium plate, placed horizontally on two aluminium blocks on either side (see figure 3(b)). These blocks, separated by 100 mm, show up as the dark areas, with the region of air gap behind the thin metal plate being displayed as the lighter (lower amplitude) areas. The approach seems to have distinguished between air and metal on the far side of a thin metal wall. Note that the high frequency of 1 MHz was chosen for this thin shim material to illustrate the technique; for thicker metal samples, a lower frequency would be required.

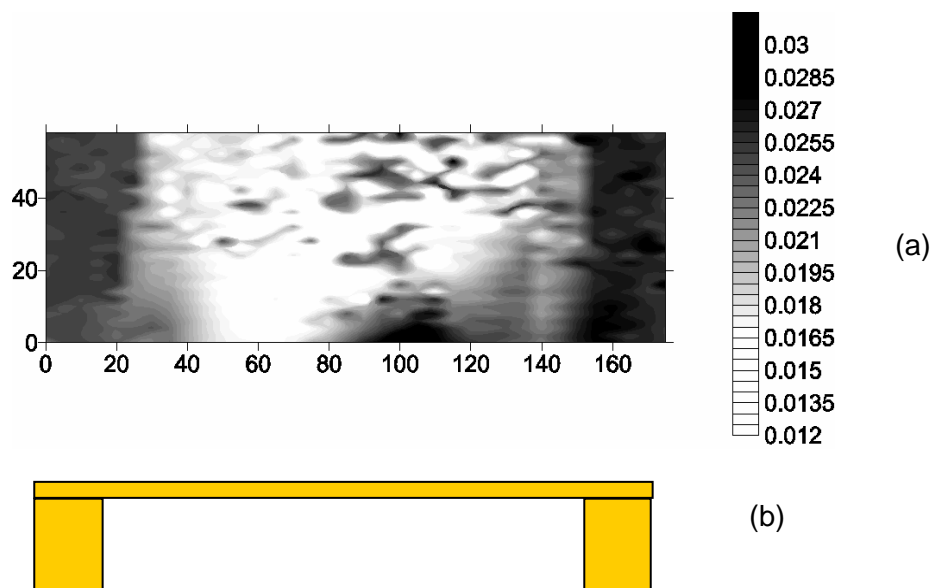


Figure 3: (a) Electrostatic image of a 0.075 mm thick aluminium metal plate, suspended above an air gap; (b) side view of sample.

The technique also has the advantage that it does not need a high conductivity material with which to operate, as the electric field distribution is capable of penetrating large distances into insulating materials. As an example, Figure 4(a) is an image obtained by scanning the same pair of electrodes over the surface of a Plexiglas sample containing a side-drilled hole of 10 mm diameter (Figure 4(b)). The technique has easily detected this hole, and this arises due the different dielectric properties of the Plexiglas and air. Note that this unprocessed image results in a display of the hole that is over an extended area, larger than the nominal 10 mm diameter of the cylindrical hole. This is because of the width (10 mm) of the electrodes, which caused lateral “smearing” of the image.

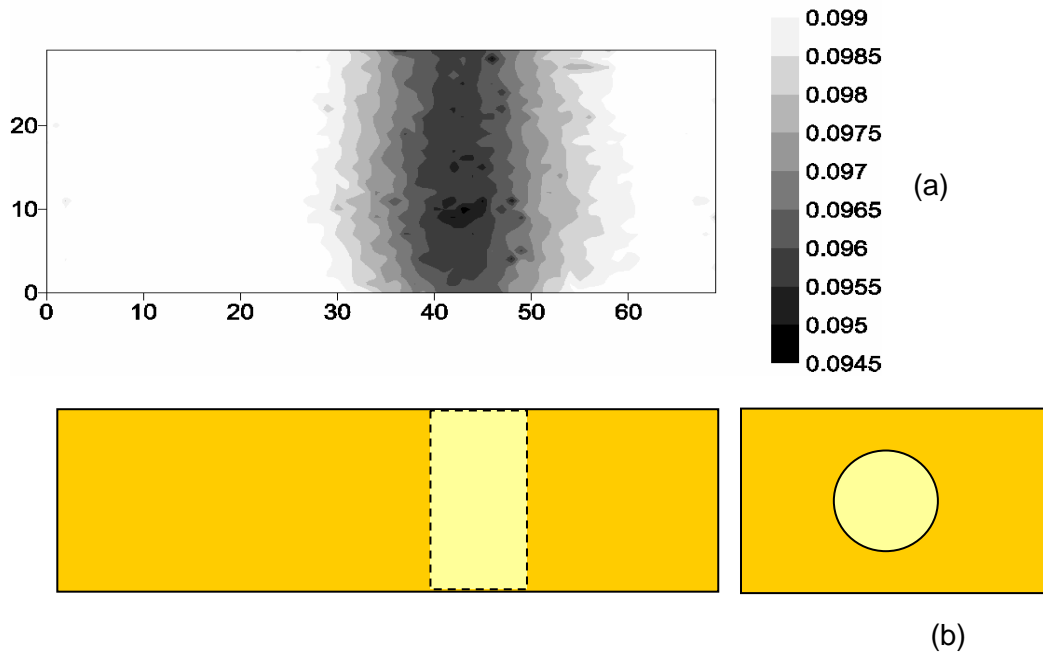


Figure 4: (a) Electrostatic image of a Perspex plate containing a side-drilled hole of 10 mm diameter. (b) Diagram of the Plexiglas sample as viewed from the top surface (left) and the side (right).

A series of tests were also carried out to image the inner core of carbon fibre composite samples, of the type used for aerospace applications. Here, delaminations between sub-surface layers can cause a significant loss in strength. Such samples represent a severe test of the system, in that such composites are usually constructed with outer carbon fibre composite plates with a fairly high electrical conductivity. These might thus be expected to screen the inner structure to some extent.

Figure 5(a) is a photograph of a cross-section through such a composite. This sample was a composite panel with Nomex honeycomb reinforcement, and the frequency was selected so as to optimise sensitivity to the inner core. As can be seen from the resulting image of this sample, shown in Figure 5(b), the regular inner structure of the Nomex honeycomb can be seen. This demonstrates that the field lines from the electrodes have penetrated into the Nomex after passing through the outer conducting layers of the composite.

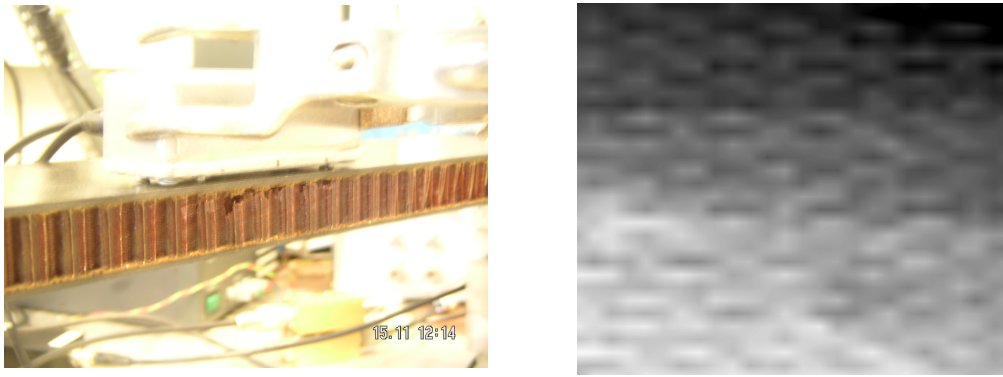


Figure 5: (a) Photograph of a carbon-fibre composite panel of 25 mm thickness, showing the outer carbon fibre skins and inner Nomex core. (b) Electrostatic image of the composite sample from the top surface, showing the internal Nomex reinforcement structure.

Further images were also obtained for a sample containing impact damage. Photographs of both sides of the sample are shown in Figure 6, where it can be seen that the area of delamination extended beyond that of the original impact.

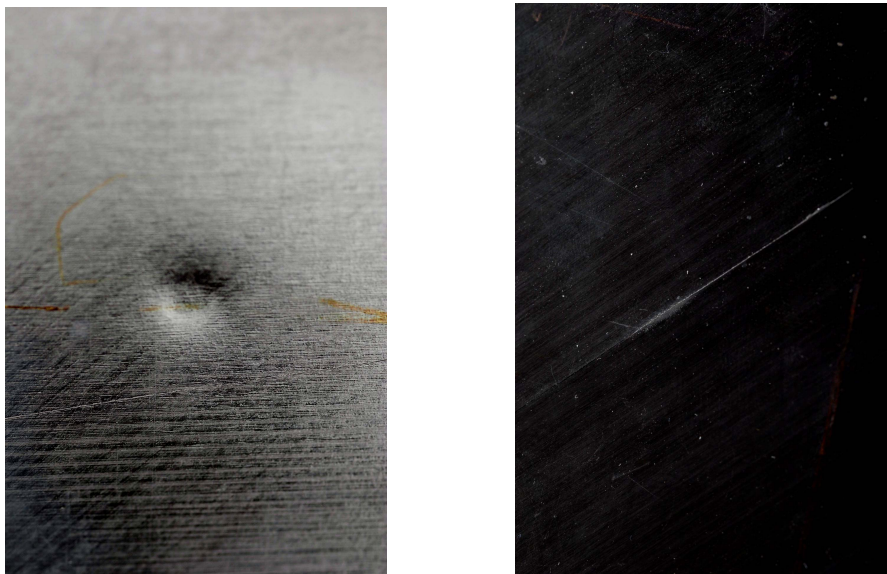
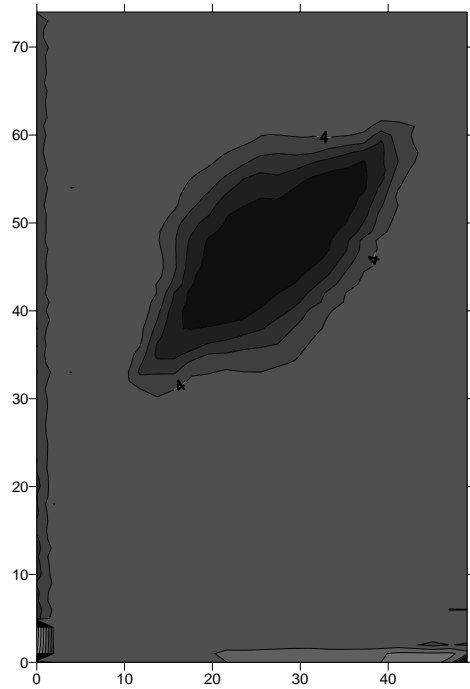


Figure 6: (a) Photographs of a carbon-fibre plate containing impact damage, due to impact on the side shown to the left. The back surface of the sample is shown to the right.

Figure 7 shows a comparison of scans produced by both (a) air-coupled ultrasound and (b) the capacitive imaging technique. It can be seen that both techniques indicate that an extensive area of damage was produced within the sample, and that this extended beyond the area visible from the front surface of impact. Note also that the two techniques agree in the general size and shape of the area of damage, indicating that both approaches are detecting similar effects.



Air-coupled ultrasound in through-transmission



Single-sided capacitive imaging

Figure7: Images of the carbon-fibre plate containing impact damage, obtained from air-coupled ultrasound (left) and capacitive imaging (right).

5. Conclusions

The single sided electrostatic inspection technique reported here has certain unique advantages for NDT applications. The images in this paper appear to be the first such examples to be obtained by such an imaging technique, which has the potential to be used on a wide range of material types, and in many NDE application areas where traditional methods may be difficult. For instance, the detection of metallic components in many materials should also be possible. Indeed, there may be many opportunities in offshore testing, as in principle the technique is readily adaptable to underwater use. Another point to note is that the bulk electrostatic fields within a specimen are not expected to be affected unduly by any changes in magnetic properties of the material - unlike eddy current methods and the specific problems that they encounter currently when inspecting certain types of weld.

In conclusion, this technique has great promise in many NDT applications where conventional methods have difficulty.

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7. References

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