Electrostatic-capacitive imaging - a new NDE technique

Warwick NDT

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G. Diamond, D.A. Hutchins, T.H. Gan and K.K. Leong School of Engineering, University of Warwick, Coventry CV4 7AL, UK
M.D.C. MolesOlympus NDT Canada, 73 Superior Avenue, Toronto, Ontario, Canada M8V 2M7

Abstract:

A new technique for NDE 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 Electrostatic Capacitive Imaging (ECI), 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 conductivities and permittivies, without the disadvantages associated with conventional eddy current and potential drop methods. Images are presented of carbon fibre composite materials, concrete, Plexiglas and metals, illustrating the range of application in NDE. The effect of electrode shape and excitation frequency will be discussed in terms of image resolution and depth of penetration

Introduction

Non-destructive inspection techniques for bulk solids are based on many different principles. Ultrasonic acoustics and various (usually multi-frequency) electromagnetic techniques are currently the most popular.

Acoustics suffer mostly from the inherent problems of acoustic impedance mismatching between air and solid material that can adversely affect both material selectivity and spatial resolution.

Electromagnetic NDT techniques can often produce ambiguous results unless one has extensive prior knowledge of the electrical properties of each of the materials within structure under evaluation. Also, the presence of metallic components within a non-conducting solid can sometimes "screen" the deep interior of a specimen from conventional EM inspection techniques such as induced eddy currents and radar.

A new technique being investigated at Warwick uses capacitance-based electrostatic imaging that permits non-destructive evaluation of many variegated structures to be performed *in-situ* via front-sided/ single-sided inspection.

The separation distance between paired electrodes controls the penetration depth of the electric field into the bulk of the specimen. Using a single frequency circumvents problems where frequency dependent capacitative and polarisation effects can impede both material selectivity and spatial resolution.

In principle, *any* multi-phasic medium can be imaged with this technique. Examples of such media are such things as subsurface voids within walls or under floors and the estimation of the thicknesses of layers of building materials

As this process relies upon the detection of localised changes of the dielectric constant of the structure (and perturbations of the applied electric field within the material too), these variations can be then plotted as *contrasts* in order to produce images. Hence, no prior calibration of the instrument or extensive prior knowledge of the actual material(s) under test is required in order to fully resolve its structural characteristics.

Instrumentation

In their simplest form the sensor probes are a the two plates of parallel plate capacitor that has been opened out to become a coplanar plate capacitor as illustrated in Figure 1 below. The signal is then amplified via a charge amplifier and so any change in amplitude effectively due to a change in capacitance of the device due localised dielectric variations / field perturbations within the locus between the plates.

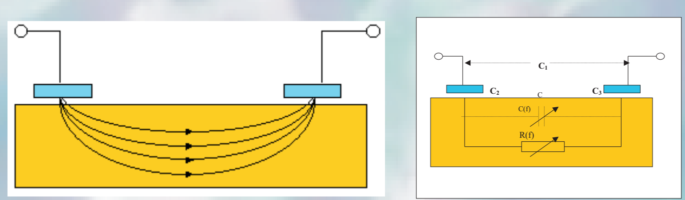


Figure 1: Schematic of the process and equivalent ircuits

After impinging upon the surface of the specimen, the degree of penetration into its bulk, is an exponential function of the distance from the surface and is described by the standard relation for skin depth given in Equation (1)

$$\delta = \sqrt{\frac{2}{\mu_0 \sigma \omega}} \qquad (1)$$

Where δ is the distance beneath the surface where the field strength is 1/e that of its initial value.

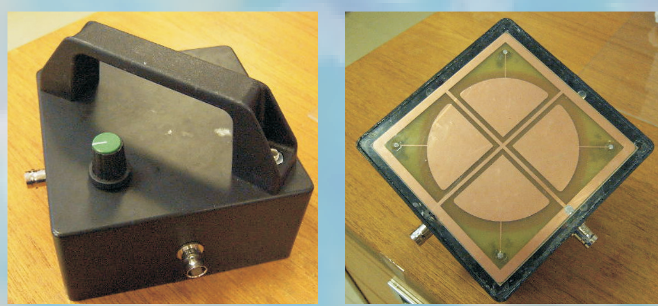


Fig. 2 Examples of basic type of of sensor probe. Shown here are the four-quadrant integrated response devices (Containing all the necessary support electronics too)

Depth Resolution

As mentioned previously, scans are performed at a *single fixed frequency.* The depth resolution of structural characteristics of the specimen is mainly accomplished by altering the distance between pairs of electrodes.

Varying the amplitude of the driving signal as well as frequency can also augment depth resolution information. Subsequent software-assisited image reconstruction enables the synthesis of a fully fledged 3-D representation of the bulk specimen

Electric Field "Finger"

One of the key elements of the patent that also enhances the (frequency-independent) spatial resolution of the instrument, is that the probe electrodes are designed in such a way that the creation of enormous electrical stresses effectively directs and focuses the field into a highly-localised region.

This "finger" extends through, and past, the front-surface (either insulating or conducting) barrier of the specimen and probes the hidden underlying material(s) at considerable depths in very precisely defined locations

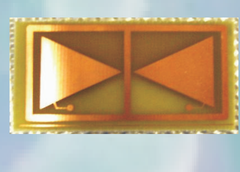
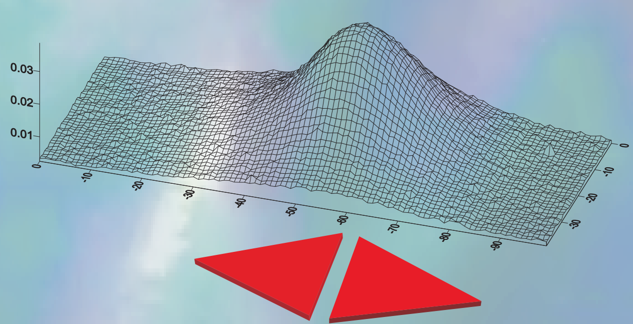


Fig 3 - (a) Opposite, example of focusing probe electrode pair

(b) Below an actual in situ *measurement (via electrometer) of electric field pattern of probe*



Results

Insulators

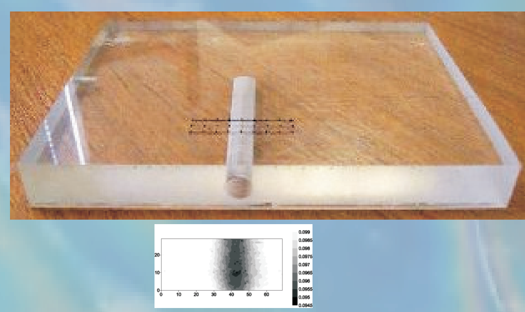


Figure 4: image of a side-drilled hole of 10 mm diameter in a Perspex plate.

Conductors

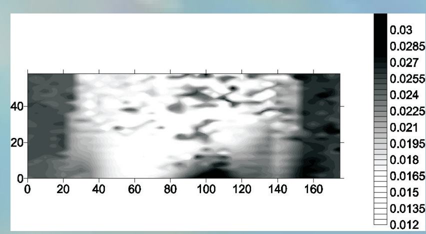


Figure 5: Image of an air gap occluded by a metal plate

Composites

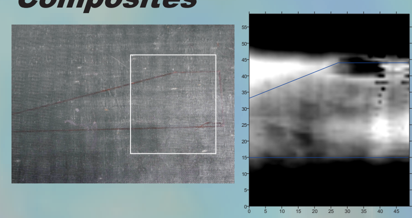


Figure 6 (a) : Image of PTFE "defect" totally encapsulated by conducting CFC matrix

(Samples Kindly Supplied by Daryl Almond of the University of Bath)

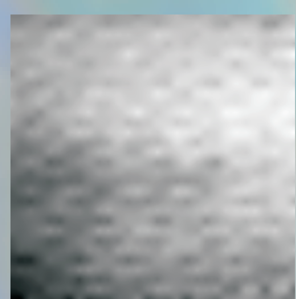


Fig 7 - Single-sided non contact inspection of the sub-surface of the Nomex honeycomb core in typical aerospace composite.

Images acquired through the outer layers of (conducting) CFC

The regular arrangement of the, highly porous, honeycomb structure is clearly visible.

(Sample kindly provided by Michael Moles of Olympus NDT)

Under Water

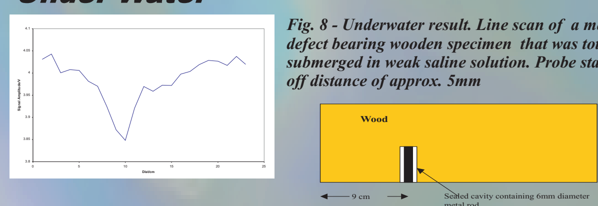


Fig. 8 - Underwater result. Line scan of a metal-defect bearing wooden specimen that was totally submerged in weak saline solution. Probe stand-off distance of approx. 5mm

Conclusions

This appears to be the first time that such a single technique has been used for wide-ranging approach to NDE: one single instrument to accommodate insulators, composites and metals. Even highly porous mixtures of these materials. Surprisingly, an electrostatic technique can be used to scan a metallic sample. However, such materials have a finite conductivity; this means in that electrostatic fields can penetrate to significant depths. The electrode geometry and unique method of focused electric field the field allows highly deffined frequency independent, spatial resolution.

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