Pulsed Eddy-Current (PEC) Nondestructive Evaluation

Q. What is the difference between pulsed and conventional eddy-current nondestructive evaluation?

A. In conventional eddy-current nondestructive evaluation (NDE), eddy currents are excited in a conductor by passing an alternating current through a coil in close proximity to the conductor. The ac current is time-harmonic and sinusoidal in nature and gives rise to eddy currents of a similar nature.

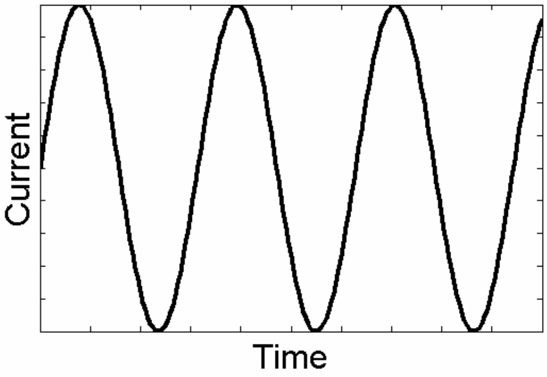

Figure 1: Typical sinusoidal wave.

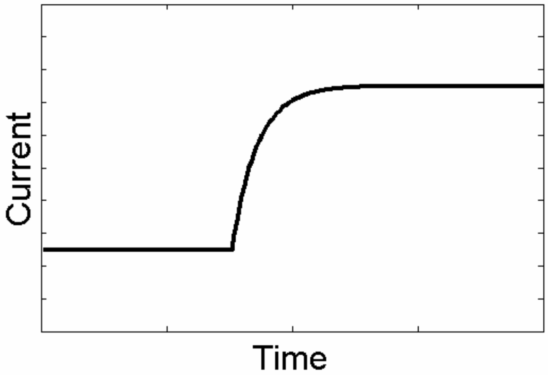

Figure 2: Typical PEC waveform.

In contrast, pulsed (or transient) eddy currents are excited by means of a non-sinusoidal coil current. The exact nature of this current varies between the different PEC systems but a typical form is shown to the left. In most systems a steady-state current is allowed to persist for some time before the waveform repeats. The length of this steady state period is usually made sufficiently long such that any eddy-current signals have completely decayed away.

In both conventional and pulsed eddy-current inspection systems, detection can be carried out using the excitation coil (absolute mode), a separate pick-up coil or a magnetic field sensor such as a Hall device. In conventional systems, the eddy-current response manifests itself as a change in amplitude and phase of the detector signal with respect to some fixed reference. In PEC NDE, rather than observing phase and amplitude changes, a pulse *emf* (in the case of coil detectors) or field (in the case of magnetic field detectors) is observed. The parameters of this pulse, i.e. its shape and amplitude, are used to infer material condition.

As in conventional EC NDE, a null or reference is usually taken prior to making a measurement. This null is subtracted in software with PEC systems to leave the characteristic pulsed eddy-current response. Figure 3 shows the typical corrosion responses obtained from a two-layer plate system. The arrangements contained three levels of corrosion in the bottom surface of the upper plate, at 3.2 mm, 4.4 mm and 5.1 mm. From the figure it can be seen that both the amplitude and rise time of the responses are affected by corrosion depth. Indeed, corrosion closer to the specimen's surface produces a more instantaneous (and larger) response than corrosion that is deeper.

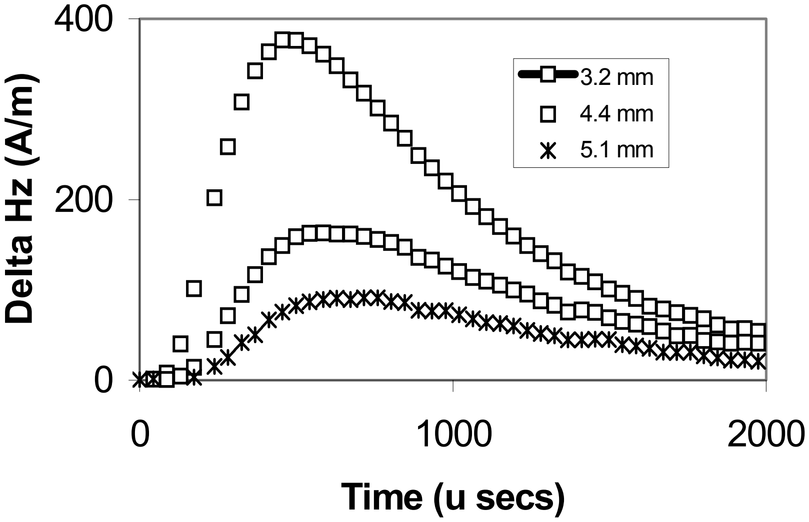

Figure 3: Typical response from a two-layer plate.

Q. What are the advantages of the pulsed eddy-current approach?

A1. If a Fourier transformation were applied to the drive waveforms shown in Figure 2, there would be only a single peak for the conventional excitation method, and a broadband response for the PEC method. This broadband response results in multiple frequencies generated simultaneously into the work piece by the PEC method. Remembering that penetration depth is governed by the skin-depth relationship;

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$

ω = angular frequency
μ = permeability
σ = conductivity

it can be said that the information contained in a PEC response signal pertains to multiple depths. Since it is not normal to Fourier transform the PEC signals, how is the depth information extracted from the signals? In looking at the excitation waveform from Figure 2, it can be seen that the current starts to change very rapidly after an initial steady state value has been established. This rapid change in current corresponds to high-frequency eddy-current components and therefore to a near-surface inspection. As time progresses, the rate-of-change of current slows which reduces the effective eddy-current frequency; inspection depth increases correspondingly. From this type of response, liftoff can be read from the initial part of a pulse response signal, flaw information from the middle and overall specimen thickness using information from the tail-end of the signal.

A2. Iowa State University's PEC system utilizes a Hall sensor rather than an induction coil to measure the eddy-current signals, see opposite. The response of an induction coil drops off with decreasing frequency. The same is not true of Hall sensors where the sensitivity does not change below 100 kHz or so. This is extremely useful when looking for deep penetration where information is contained in the very lowest frequencies. Induction-coil based systems attempt to overcome this problem by pumping more power into the coil but there are diminishing returns and other practical problems to this approach.

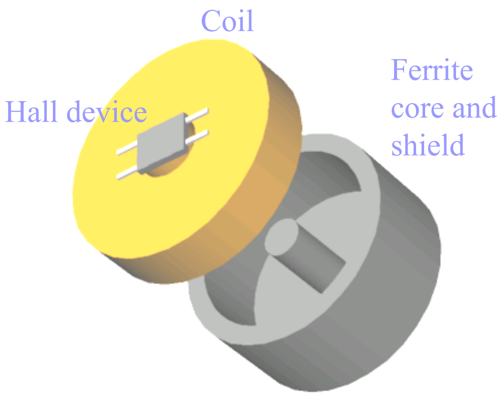

Figure 4: ISU's PEC Probe

Q. What contributions can PEC make to industry?

A. A Hall-device based PEC inspection instrument would be expected to offer a number of advantages over conventional EC inspection systems in the aerospace industry. Through several operational advantages, PEC systems can improve detection capabilities with respect to hidden cracks and corrosion. These operational advantages are;

i. Deeper penetration through the use of solid-state magnetic-field sensing devices.
ii. An approach that is broadband leading to the capability to distinguish between flaws in different layers and to compensate for liftoff.
iii. Readily adapted to work with array sensors.

Q. Where is PEC going at Iowa State University?

A. Final work on the FAA contract is being completed, and the writing of the final report has begun. Two NDT vendors have been approached and have expressed an interest in licensing the PEC system. We will be having more detailed discussions with these companies in the near future.