Using Eddy Current for Corrosion Inspection

Today's pulsed eddy current instruments speed up the process of corrosion inspection in the aerospace industry and offer better images of the displayed results

BY JOHN P. HANSEN

The eddy current technique is a tried and tested inspection method that can offer significant, practical advantages over other techniques in certain situations. For example, paint coatings and insulation need not be removed, as eddy current inspection is a noncontact method. There is also no need for any couplant — unlike ultrasonic inspection, it can be used on wet surfaces — and there is no need for consumables as with dye penetrant and magnetic particle inspection techniques. Eddy current testing is suitable for a wide range of applications. It is universally applied in crack detection. By measuring material conductivity, it is used in quality control in nonferrous metal sorting and in sorting ferrous metals according to required material properties. It is used to assess coating thickness and tube wall thickness, and it is also used to detect subsurface corrosion.

Corrosion Detection

Corrosion is an undesirable feature, in varying degrees, of all metal structures and components. The detection of corrosion is a vital part of any in-service maintenance corrosion management program in all industrial sectors, from pipeline corrosion in the oil and gas sector to fuselage corrosion in the aerospace industry — Fig. 1.

The complete spectrum of NDE techniques is used in the fight against corrosion. Magnetic particle and dye penetrant look at near-surface corrosion and surface cracking. Remote visual inspection using the latest endoscopy equipment is used to detect and capture images of corrosion within machinery and pipework systems. Radiography is widely employed in the process sector. The process sector, too, provides extensive potential for the application of ultrasonic techniques, from automated pipeline corrosion mapping to the latest in situ ultrasonic sensing systems that can be remotely interrogated on demand. A major area of application for eddy current has long been in the inspection of aircraft fuselages and wings for both cracking and corrosion. Although this has proved to be a successful technique for this job, it is often a long and laborious process. However, the latest developments in eddy current technology have sped up the inspection process, as well as improved the imaging of displayed results and extended the functionality of the technique.

Fig. 1 — Eddy current inspection in the aerospace industry.

The Evolution of Eddy Current Technology

In its most basic form, eddy current technology relies on the creation of circulating, electrical eddy currents in the conducting surface of a magnetic material when an AC current flows in a coil in close proximity to the conducting surface. When this coil is then scanned across the material surface, changes in the material's physical properties, geometry, and conductivity, and the presence of any flaws will interrupt or reduce the eddy current flow, causing a reduction in the loading on the coil and increasing its effective impedance. Consequently, by monitoring the voltage across the coil, changes in amplitude and phase shift can be used to show changes in material properties. Conventionally, this information has been displayed on an impedance or phase plane diagram. Today's portable eddy current instruments offer extremely high levels of performance and fast inspection. They feature built-in storage capacity and data displays use the latest video graphics array, thin-film transistor, or light-emitting diode technology. They can be used in a variety of situations and some instruments can drive individual probes at separate frequencies and in different modes, so that they can be used to carry out simultaneous thickness measurement and crack detection. However, conventional eddy current instruments suffer from limited corrosion monitoring functionality, both in terms of speed of inspection and in terms of inspecting for corrosion at different depths within a structure. This is especially important in the aerospace sector, where structures are often assembled by means of riveted lap jointing of various layers or skins.

Depths of Inspection

The depth of penetration of eddy currents into conductive

JOHN P. HANSEN (john.p.hansen@ge.com) *is senior engineer at GE Inspection Technologies, St. Albans, England.*

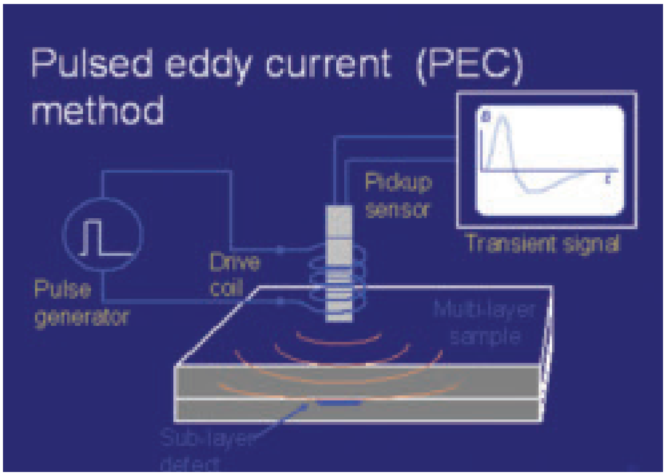

Fig. 2 — The pulsed eddy current method.

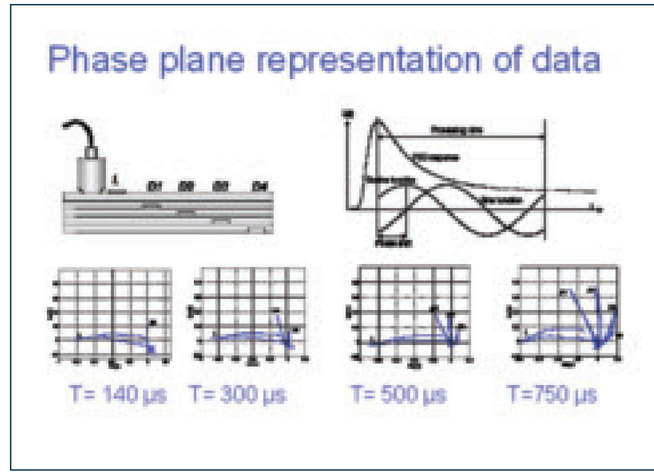

Fig. 3 — Representation on the standard impedance plane.

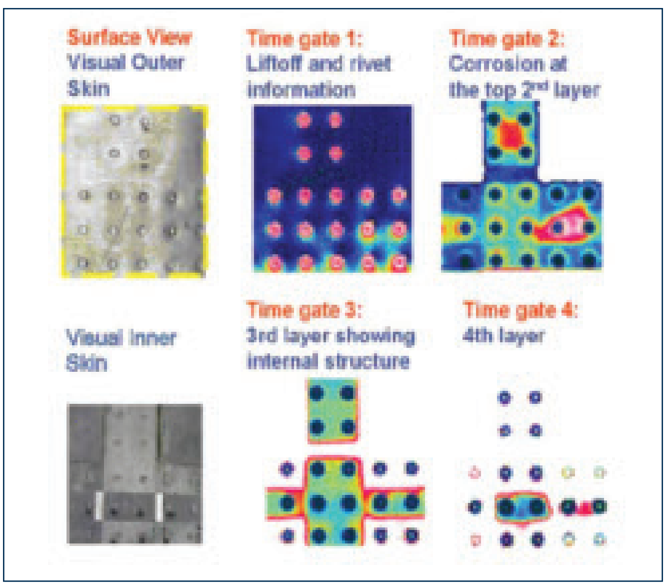

Fig. 4 — Time evolution of a PEC signal.

materials is dependent on the frequency of the excitation current: the lower the frequency, the greater the depth of penetration. Consequently, when eddy current is used to carry out simultaneous thickness measurement and crack detection, one high-frequency probe and one low-frequency probe are employed. This is fine if the approximate thickness of the material is known, as the thickness-measuring probe can be selected accordingly. However, when corrosion takes place at various layers within a material, then what is required is a means of injecting a range of frequencies, especially low frequencies, into the material.

In the past, this has been attempted by either using time multiplexing systems, to switch between frequencies, or by simultaneous injection with all frequencies together. This can be quite a lengthy and laborious process, particularly for time multiplexing, where it is necessary to wait for several cycles when the frequencies are switched before the data can be sampled. In addition, because of this time delay, the two samples are taken at two different times, and hence two different locations, as the probe is manually scanned. However, even with the faster simultaneous injection process, the highest speed of response is usually many times slower than the lowest frequency used. Moreover, the amount of energy injected into the probe is reduced in proportion to the number of frequencies employed. Multifrequency equipment is still used, but it has been found that significant improvements in speed, accuracy, and presentation of results can be achieved by using pulsed eddy current.

Pulsed Eddy Current

Pulsed eddy current (PEC) differs from conventional eddy current in that the drive coil is excited by a broadband pulse rich in low frequencies, the range of frequencies of the pulse being dependent on its length — Fig. 2. This generates a large amount of data and this must be handled by sophisticated sensors and processing capability. The sensors that have proved most suitable for the task are solid-state magnetic sensors such as Hall effect, giant magnetoresistive (GMR), and giant magnetoimpedance (GMI) sensors, all of which produce an output voltage that is directly proportional to the measured magnetic flux. They also offer a better signal-to-noise ratio at low frequencies compared with pickup coils. (With GMR sensors, the resistance drops dramatically as magnetic field is applied. In contrast, GMI sensors demonstrate a drop in impedance.)

Once the high-quality, "scrambled" transient pulse return signal is received, it is subjected to Fourier analysis using sophisticated algorithms and electronics. It can be displayed in the form of a variation of amplitude (or phase) with frequency. By sampling different delay times, or time gates, within a pulse, different parts of the frequency spectrum, and hence different depths, can be evaluated and these can be displayed on a standard impedance plane — Fig. 3.

Pulsed Eddy Current Instrumentation for the Aerospace Sector

Both military and civilian aircraft make extensive use of single aluminum sheets and lap splices, which are riveted connections between several thin (0.7–3 mm) aluminum layers. These have conventionally been inspected by multiplexing EC excitation frequencies in time or by mixing different frequencies to look at different layers depths. Pulsed excitation is the equivalent of superimposing a range of frequencies simultaneously at one point. A new transient response is also collected at every point and the processing time interval is chosen to have indications from all defects in the inspected material — Fig. 4.

A new portable pulsed eddy current instrument, Pulsec, has

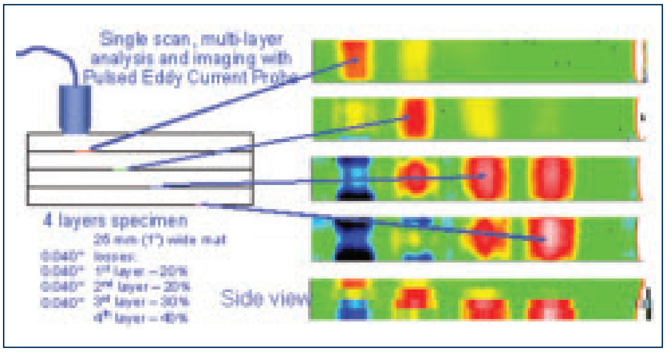

Fig. 5 — Subsurface penetration.

been developed by GE Inspection Technologies with this aerospace application specifically in mind. It uses GMR sensors that offer excellent magnetic sensing capabilities, high sensitivity to applied magnetic fields, good temperature stability, low power consumption, a wide working frequency band, and small size. It also employs an array system with 32 elements in a single probe, covering a width of 1 in. (25.4 mm). This significantly improves scanning efficiency and speed, as the uniformly spaced elements, which are electronically multiplexed, generate a scan over the width of the probe rather than just at the element itself. As a result, for thin (2-mm) materials, normal scanning speeds of 40 mm/s are achievable and this falls to 18 mm/s for fine scanning. For 10-mm-thick materials, normal scanning speed is still around 20 mm/s and fine scanning around 4 mm/s, although speed scanning can be of the order of 50 mm/s.

Another significant feature of the new instrument is its ability to produce multilayer C-scan images in addition to the conventional impedance plane display — Fig. 5. This is achieved by joining together the consecutive snapshot scans and providing display imagery that the nonexpert user can interpret with greater ease, greatly facilitating defect recognition. Ease of interpretation is also helped by allowing the vertical component of the processed data to correspond to a given color palette so that corrosion is immediately recognizable and the percentage of material lost at a particular layer is clearly indicated. Onboard processing provides a percentage readout of this material loss and the physical size of corroded area can be established by a cursor. Operation is simple and involves first calibrating the inspection and then performing the scan. The information is then processed and a report produced that gives the name of the job, incorporates the images, and includes any required notes. This is then produced as a rich text file document and can be exported to a USB memory stick for storage or postinspection analysis.

The Future

As with any technology, portable pulsed eddy current undergoes continuous development. Current work includes investigations into 2D sensors, where x-y coded probes will allow faster, easier coverage and provide instantaneous imaging of areas of interest without mechanical scanning. Work is also being done on extending the size and width of probes for special applications, and ways to increase scanning speeds are being developed. Improvements in crack detection are progressing as, currently, cracks are detected only at given orientations. Three-dimensional reconstruction is another exciting development area, involving image combination from different time slots. Faster data recall and reduced storage requirements are promised by developments in preprocessing and data compression, while automatic flaw recognition will further increase ease of data interpretation.

Conclusions

Pulsed eddy current incorporating array probes has all the advantages of conventional eddy current but offers additional, significant benefits. As the full range of frequencies is generated and received, the operator no longer has to select a specific frequency before an inspection. Because of the wide frequency spectrum, data richness is also considerably enhanced to allow the creation of NDE images that are easier to interpret than conventional impedance plane representations and the combination of pulsed eddy current and array probes allows faster data acquisition. Furthermore, initial inspection using pulsed eddy current facilitates any subsequent inspection as it defines the optimum frequency for examination at particular depths.❖

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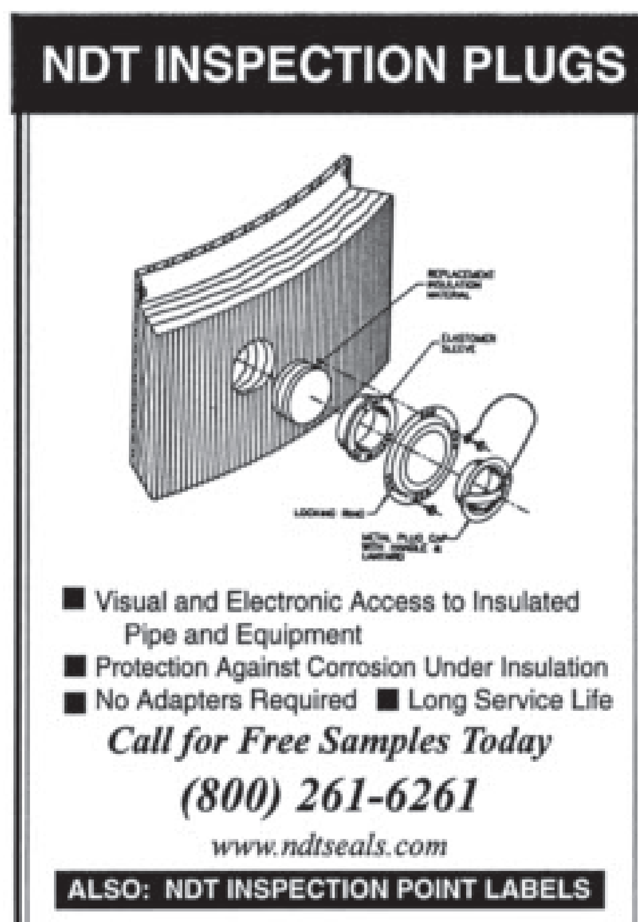

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