expressed as
\[ Z = \sum \frac{N - 1}{d} A \]  
where \( N \) is the number of turns, \( d \) is the current per turn, and \( A \) is the magnetic potential due to eddy currents.

In order to detect the existence of a crack inside the conductor, we have to evaluate the signal generated as a result of the changes in intensity and the phase of the induced electromotive force.

The computation results of the ECT by the finite element method (FEM) are shown in Fig. 5. Both impedance trajectory changes and the impedance versus probe position dependence during the testing are illustrated.

Although the pancake probe exhibits the largest ECT signal, the determination of the crack size, its position, depth and width is quite difficult to be achieved using this of ECT probe. The reason is the fact that the eddy currents induced by this probe do not easily penetrate inside the external conductors.

According to the signal’s amplitude, position of the peaks in the signal, its symmetrical shape and trace one can easily determine not only the existence of the crack inside the conductor, but also the position, length, depth and even the shape of the crack.

The topics to be discussed in the solution of the ECT problems are the operational frequency range, short or long the test piece without crack, scans over various inner and outer cracks, investigation of the lift-off noise, investigation of the tilting noise.

4. CONCLUSION

The main aim of the paper has been to show electromagnetic phenomena, which determine the operation principles of various material NDT methods. Especially, acoustic and electromagnetic methods have been described. The EMAT method of acoustic nondestructive testing has been explained and experimental arrangement for conducting nonmagnetic material investigation has been introduced.

The defectoscopy using the EMAT makes possible to investigate the material structure without any acoustic coupling, which is advantageous for the scanning method of the sample structure visualization. The coils made on different substrates are usable in the wide temperature range, as well.

The important advantage of conductive materials NDT by EMAT probe is no limitation of defects evaluation with respect to their position under the surface due to the skin-depth effect.

The NDE by EC techniques have been described for defect characterization in conducting objects. The computations by FEM and obtained simulation results have been presented for the pancake probe arrangement. The major advantages of the EC method are its simplicity and its sensitivity to tight defects. The disadvantage of ECT is its insensitivity to defects that are deeply embedded below the surface of a tested object.

REFERENCES


1. INTRODUCTION

Nondestructive testing techniques based on ultrasonic phased array technology are more and more applied in various industrial context, as they provide improved adaptability to different inspection configurations. Among those configurations, two specific items have to be assessed that usually limit the inspection performances – irregular geometrical profile and complex materials. As a conventional probe is moved over an irregular profile (whether the probe is used at contact or immersion), the radiated beam may be drastically modified in terms of sensitivity and orientation, so that the detection and characterisation of actual defects may not be ensured. Ultrasonic inspection of complex – in terms of material and geometry – structures has to overcome major limitations: unknown actual direction and focusing pattern of the transmitted beam, which leads to degraded performances for detection and identification of defects, complex interpretation of results due to spurious echoes or multiple modes, low signal-to-noise ratio due to sensitivity loss, etc. The use of multiple transducers and/or settings allow to perform different techniques which may give the better results. Obviously, phased array techniques provide an efficient alternative way to improve the adaptability and flexibility of the inspection methods, compared to standard probes, as they may be used to master the ultrasonic beam thanks to delay or amplitude laws, for instance for any scanning position of the array probe moved over a varying profile. Phase array probes may also be used to transmit/receive waves through complex layered specimen, thus to select and perform the optimum inspection mode.

2. PRINCIPLES OF OPERATION AND FEATURES OF PHASED ARRAY

A conventional ultrasonic UT probe consist of a piezoelectric element, while that for phase array UT probe has multiple piezoelectric elements, very close together (on the order of a wavelength of sound). Large conventional ultrasonic probes give good flat coverage but have a small beam angle. Small elements have a much larger beam divergence angle. It is this large angle that makes possible the most useful features of the phased array technique - beam steering and dynamic focusing. In its simplest form, an array is a single large transducer (piezoelectric material) cut into very small segments or elements. It takes less energy to excite the smaller mass of these tiny elements. As a result, they transfer and receive energy with much greater efficiency.

A linear array can steer the beam by pulsing the individual elements of the array at different times. The individual "waves" combine to form a straight or oblique beam. By controlling the phase during reception of each element you reverse the process and produce a electronically steerable and focussable beam. The phase of the pulses driving each element can be controlled. This is equivalent to controlling the time delay between each pulse and all the others. The sound waves combine (add) according to these delays or phases and can be focussed and steered electronically. This can be done very fast so real time images can be formed that can be focussed in any area of the image. Because the linear array is phased in one direction the electronic focus is a line focus, very much like a cylindrical transducer with an electronically controlled focus and direction.

Fig. 1. Sound beam steering by phased array probes
The division of a radiating surface in single elements which can be exited with different delay times and separations is the way to get a more detailed surveying. 3 basic possibilities of beam region character, Fig. 1.

One can move a beam along the line of a linear array which is the parallel scan of the medical diagnostic. More important for NDT is the sector scanning using short pulses of an electronic amplifier system offering 3 basic possibilities of beam region character, Fig. 1.

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3. EMAT AND PHASED ARRAY

Electromagnetic-Acoustic Transducer (EMAT) technology is a Non Destructive Ultrasonic Testing method that differs from piezoelectric ultrasonics in the way the sound is generated. In traditional ultrasonics a piezolectric crystal is used to transduce electrical energy into mechanical energy. The vibration makes its way into the test piece via the couplant.

\[ \frac{\partial^2 \varepsilon}{\partial t^2} - \frac{\partial^2 \varepsilon}{\partial z^2} = \frac{1}{d} \left( \frac{\partial \mathbf{B}_z}{\partial t} \times \mathbf{E} \right) \]

(2)

where \( d \) is the density of the metal and \( z \) is the speed of ultrasonic wave. In non-magnetic materials the Lorentz force is the one contribution to the generation of sound. In a ferromagnetic material, additional forces are produced by magnetostriuctive stresses. Ultrasonic wave is no more a linear function of the applied magnetic field. According to these principles EMAT then consists of a means for producing a static bias field, i.e., a permanent magnet or electromagnet, plus a coil of wires carrying a direct current drive.

EMAT provides all of the capabilities of ultrasonic testing with some distinct advantages. These unique advantages make it especially well suited for automated applications in industrial environments. An EMAT probe becomes a simple end-of-arm tool that combined with the proper electronics and software can be integrated into a production line to provide reliable inspection without human intervention.

EMAT technology, combined with phased array techniques (principles are shown in chapter 2) uses horizontally polarized shear waves to improve the inspectability of unstressed steel welds, dissimilar metal welds, butt-welded, cladding, etc. These, and other components can now be completely inspected regardless of access considerations due to the use of the transparent nature of the material. The probe generates shear waves. The inspection for hard to access flaws such as intergranular corrosion cracks in stainless steel piping welds or cast stainless steel welds is made possible with unmatched accuracy and ease.

Although EMAT can generate SH wave, which is suitable for detection of flaws in the austenitic welds, conventional EMAT has such disadvantages as shorter pulse length and poor time resolution. The phased array method allows pulse length to shorten and makes the scanning condition (incident angle) optimized by using the variable angular function. The operation of phased array is always constrained by the size of the array and the spacing of the elements to a limited range of wavelength.
The division of a radiating surface in single elements which can be exited with different delay times and sequence positions to an electronic controlling unit offering 3 basic possibilities of beam region character, Fig.1.

One can move a beam along the line of a linear array which is the parallel scan of the medical diagnostic. More important for NDT is the sector scanning that can be done by employing a small array offering 2 basic possibilities of beam region character. Fig.2.

A more or less curved distribution of the delay times produces a focusing which can also be used to compensate the influence of curved coupling surfaces.

Annular array probes Fig.3-2

Annular array probes are made up of a set of concentric rings. They allow the beam to be focused to different depths along the axis of the transducer. The surface of the rings is in most cases constant, which implies a different width for each ring.

Matrix array probes Fig.3-3a, b

These probes have an active area divided in two dimensions in different elements. This division can, for example, be in the form of a checkerboard, or sectorized rings. These probes allow to be driven by combining electronic focusing and deflection in space.

These probes are made up of a set of elements arranged in a circle. These elements can be directed either towards the interior, or towards the exterior, or along the axis of symmetry of the circle. In the latter case, a mirror is generally used to give the beam the required angle of incidence.

The basic possibilities of beam webulation, Fig.2, of wedge equipped probes with linear phased array are shown: variation of the incidence (A), the skewing (B) and angle (C). The angle can be changed only within the plane of incidence. One may produce mainly skewing angle variations within the plane perpendicular to the plane of incidence. By a combing probe type with a rotated linear phased array system one produces skewing- and angle incidence variations.

Typically, element sizes of phased array range from 0.5 - 2.5 mm although arrays can have custom element sizes and can be arranged in custom configurations with the particular geometry developed to meet an ultrasonic application need. Linear, annular (circular elements divided into doughnut-shaped elements) and matrix arrays are in basic configurations.

Linear array probes, Fig.3-1

These probes are made up of a set of elements juxtaposed and aligned along an axis. They enable a beam to be moved, focused, and deflected along a plane.

Annular array probes Fig.3-2

Annular array probes are made up of a set of concentric rings. They allow the beam to be focused to different depths along the axis of the transducer. The surface of the rings is in most cases constant, which implies a different width for each ring.

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\[
\frac{1}{2} \alpha^2 \frac{\partial^2 \xi}{\partial t^2} - r_\text{e} \frac{\partial^2 \xi}{\partial z^2} = \frac{1}{d} \mathbf{J} \times \mathbf{B}_\text{r}.
\]

where \(d\) is the density of the metal and \(r\) the speed of ultrasonic wave. In non-ferromagnetic materials the Lorentz force is the one contribution to the generation of sound. In a ferromagnetic material, additional forces are produced by magnetostriuctive stresses. Ultrasonic wave is no more a linear function of the applied magnetic field. According to these principles an EMAT then consists of a means for producing a static bias field, i.e., a permanent magnet or electromagnet, plus a coil of wires carrying a dynamic drive current.

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4. EXAMPLES OF ULTRASONIC PHASED ARRAY APPLICATIONS

A certain number of industries requiring advanced means of Non-Destructive Testing, such as the nuclear, aeronautical or in-line testing industries, constantly seek improvements in the performance of their monitoring systems.

Inspection of blade roots and rotor steelpiles

This inspection, carried out using various miniaturized phased array probes, uses the principle of beam-deflecting wedges to avoid any side lobes. The phased array technology enables the use of a transducer with the capability of detecting the acoustic performance of the defect. So far, this technique has been applied to the detection of defects in the blade root and in the rotor steelpiles. The phased array method is also used for the evaluation of the defect's size and location.

5. CONCLUSION

The growing needs of NDT ultrasonic to reduce inspection time, improve the speed of inspection and increase detection and sizing performance, have resulted in recent years in the development of advanced sensor technologies, such as phased array sensors. These sensors, by using a phased array technique, create a focused acoustic beam that can be moved to different positions to inspect various locations.

REFERENCES


INSTANTANEOUS SWITCHING PROCESSES IN QUASI-LINEAR CIRCUITS

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Summary: The paper considers instantaneous processes in electrical circuits produced by the stepwise change of the capacitance of the capacitor and the inductance of the inductor and by the switching on and switching off of the circuit. In order to determine the set of electrical circuits, for which it is possible to explicitly obtain the values of the currents and the voltages at the end of the instantaneous process, a classification of the networks with nonlinear elements is introduced in the paper. The instantaneous switching process in the moment $t_0$ is approximated when $T > t_0$ with a sequence of processes in the interval $[0, T]$. For quasi-linear inductive and capacitive circuits, we present the type of the system satisfied by the currents and the voltages, the charges, as well as the fluxes in the interval $[0, T]$. From this system, after passage to the limit $T \rightarrow t_0$, we obtain the formulas for the values of the circuits at the end of the instantaneous process. The obtained results are applied for the analysis of particular processes.

1. INTRODUCTION

The instantaneous switching processes in electric circuits are caused by the stepwise change of the parameters of some components, which are from now on called s-elements. One approach for analysis of such processes in circuits with nonlinear components is offered in [1]. This work studies an instantaneous process in the moment $t_0$ in a class of circuits with nonlinear components with the help of approximating sequences of processes in the interval $[0, T]$ when $T > t_0$. For these processes it is possible to obtain explicit formulae for the values of the initial conditions of the process immediately following the instantaneous process. In [2] and [3] the above-mentioned approach is applicable for analysis of instantaneous switching processes respectively in linear circuits with concentrated and distributed parameters.

2. CLASSIFICATION OF THE CIRCUITS WITH ONE S-ELEMENT AND OF THE INSTANTANEOUS SWITCHING PROCESSES IN THEM

Further, the paper studies instantaneous switching processes in electric circuits caused by the instantaneous change of the state of a switch, a capacitor with stepwise changing capacitance, or an inductor with stepwise changing inductance. For this purpose we use the notation of the types of components in a circuit introduced in [1]: 1. a voltage source; 2. a capacitor; 3. a resistor; 4. an inductor; and 5. a current source. With the help of this notation, the closed contours through the s-element with one s-element are separated in the following groups:

- The closed contour through the s-element is called of type m, $1 \leq m \leq 5$, if besides an s-element it contains an element of number $m$ and does not contain elements with numbers greater than $m$ (if such numbers exist).

The circuit with one s-element is of type $1 \leq m \leq 5$ if among its closed contours through the s-element there is at least on of type $m$ and none of types less than $m$. See Fig. 1.

Let in the moment $t_0$ the capacitance of the capacitor $C$ (the s-element) from the circuit in Fig. 1 change from $C_1$ to $C_2$. With $L_0$ and $i_0$ we denote respectively a linear and a nonlinear inductor, $R$ is a nonlinear resistor, and $u(t)$ is the voltage of a source of continuously changing voltage. This circuit is inductive, the s-element in which is a capacitor.

![Fig. 1](image1)

![Fig. 2](image2)

An example of a capacitive circuit is given in Fig. 2. In this circuit, in the moment $t_0$ the switch $S$ is changed from a closed to an open state. With $C_0$ a $C$ and $i_0$ we denote, respectively, a linear and a nonlinear capacitor; $R$ is a resistor with a linearly changing resistance; $u(t)$ and $i_d(t)$ are voltage sources.

If the instantaneous process happens in the moment $t_0$, then for $T > t_0$ it is approximated with a...