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(71) Applicant: ABB AMDATA INC. [US/US]; 100 Day Hill Road, Windsor, CT 06095 (US).

(72) Inventors: LAREAU, John, P. ; 274 Salmon Brook Street, Granby, CT 06035 (US). LEONARD, David ; 124 Leitch Street, Springfield, MA 01109 (US).

(74) Agents: MULHOLLAND, John, H. et al.; Intellectual Property Law Dept. 612-1936, ABB Business Services Inc., 1000 Prospect Hill Road, Windsor, CT 06095 (US).

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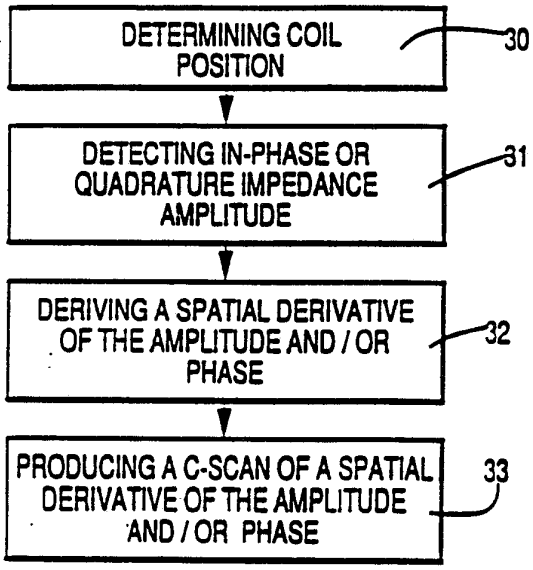

(57) Abstract

An eddy current imaging system (15) includes an eddy current sensing coil (17) positioned proximate a workpiece for scanning the workpiece to produce a signal (21, 22) indicative of the integrity of the workpiece for regions in an x, y array of data. Such a signal (21, 22) may be a complex impedance signal representative of the amplitude and/or the phase of the signal. Two data processing techniques are disclosed for enhancing the display of a flaw in the workpiece. The first includes the step (30) of calculating a spatial derivative of the amplitude and/or phase indicative signal from the coil (17) and providing an image of the spatial derivative to produce a C scan of the spatial derivative. The second includes the steps (35, 36) of determining the regions of maximum ascent and/or descent of the signal for regions in the scan and calculating an impedance plane trajectory from the data array of path points for displaying a reconstructed optimum signal independent of path pattern.

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EDDY CURRENT IMAGING SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to an eddy current imaging system for detecting flaws and for measuring property characteristics of materials. More specifically, this invention relates to a method of eddy current testing wherein a C scan of a spatial derivative of the amplitude and/or phase of a probe signal is provided in either real time, or for post processing analysis. Still more particularly, this invention relates to a method of determining scanned image sections with maximum ascent or descent of detected data and calculating an impedance plane trajectory for displaying an optimum flaw indication signal independent of scan pattern. Still more particularly, this invention relation to a method and apparatus for displaying a first spatial derivative of the instantaneous phase of the impedance of a signal generated by scanning a material with a selected eddy current sensing probe, in combination with a reconstructed optimum scan path calculated as a function of the regions of maximum ascent or descent of the data and an impedance plane trajectory.

A number of non-destructive techniques have been developed for detecting a displaying information regarding the structural integrity of a member. Such techniques have included eddy current testing methods for detecting flaws and measuring property characteristics. Systems utilizing such techniques are commercially available. In the case of flaw detection, the proximity of a material flaw to the test coil causes a change in the complex impedance of the coil which is detected and decoded by electronic circuitry in the system. Once the test parameters of frequency, coil size and orientation have been set,

the response with an axisymmetric coil is nearly a sole function of the spatial relationship between the flaw and the test coil. Thus, for any set of surface coordinates x, y, the test response is calculable.

Most eddy current instruments provide either a strip chart or a complex impedance phasor plot of the detected data from the test coil to the instrument. In either case, the dynamic response of the test coil is a function of its position, as previously indicated, and the dynamics of the motion of scanning. Since both of these types of response are basically presentations of an instantaneous impedance of the coil as a function of time, the dynamic signal is this a function of scan speed and scan direction for the test coil relative to the test specimen, and particularly with respect to a flaw. In general, therefore,the approach used for flaw detection is to scan in such a manner that coil motion is perpendicular to the major axis of a flaw. However, in the general case, this presumes some a priori knowledge of the location and extent of the flaw orientation. An advantage of this scanning motion is that the maximum contrast signal, i.e. one having the highest signal to noise ratio, results from the perpendicular intersect of coil path and flaw outline which thus facilitates flaw detection.

Prior systems have also included a display of the complex impedance of the signal from the test coil as a function of the position of the coil rather than as a function of time. Such a C scan display, as such a display is common referred to, usually depicts the amplitude of a component of the impedance, although some prior art systems have also displayed phase in a C scan mode. In either case, the actual spatial position is usually inferred from the temporal data

using an assumption of constant scan velocity and the plot of either signal amplitude or signal phase versus x-y position is indicated.

In particular, an instrument available from Zetec referred to in the art as a MIZ-18 instrument produces C scan plots of amplitude of the test signal from the coil, or a time derivative of the amplitude of the test signal from the coil.

However, the interpretation of such signals is still based on spatial information, even though the amplitude, phase, and time derivatives of the amplitude are useful. Such systems which use time derivatives are dependent on an assumption of constant velocity, as noted above, to deduce the spatial relationship of a detected flaw, especially in the presence of background noise. By using the assumption of constant velocity to deduce position, it has been determined in another context that the image sections with the maximum ascent or descent of the test signal is a significant method for detecting subsurface flaws.

Thus, it has remained a significant problem in this art to provide a system in which the mechanical scanning system and the data acquisition parameters can be determined somewhat independently so that the scanning can be done in any convenient format such as a meander pattern or by raster scanning without sacrificing the quality of the test results. As a practical example of where such an approach would be beneficial is the inspection of a structure of an airplane wing. Mechanically, the easiest way to scan the wing is in a meander scan along the length of the wing with incremental indexing steps at the end of each stroke. Typically, flaws would emanate from rivet holes at any arbitrary orientation and the above scan would be expected to miss some flaws due to poor

signal to noise ratio conditions at certain flaw orientations. With such a scan pattern system, the locally optimum scan direction could be determined and this scan synthesized from the available date. In this manner, the optimum mechanical and signal criteria can be simultaneously satisfied.

Accordingly, it has also remained a significant problem in this art to provide a reconstructed optimum scan path based on scan data wherein the optimum path traverses a flaw edge in a given pixel at a right angle, or near thereto, for maximizing the signal-to-noise ratio.

BRIEF SUMMARY OF THE INVENTION

Directed to achieving the forgoing objects and addressing the problems noted for this art, the invention relates to a method and program apparatus for contrast imaging a workpiece with an eddy current imaging means including an eddy current sensing coil positioned proximate the workpiece and traversing said workpiece in a pattern. Thus, the workpiece is scanned to produce a signal indicative of the impedance of said workpiece proximate said eddy current sensing coil. The method includes the steps of providing a signal from the impedance indicative signal representative of the amplitude and/or phase of the signal; calculating a spatial derivative of said amplitude and/or phase indicative signal; and providing an image of the spatial derivative.

Preferably, the step of providing an image of said spatial derivative includes the step of producing a C scan of the spatial derivative.

If desired, the step of producing the C scan may be performed in approximately real time relative to said scan of said workpiece.

Another significant feature of the invention relates to determining an optimum calculated scan path independent of the actual scan. This second feature of the invention includes a method and apparatus for receiving scan signals from an eddy current sensing coil; determining the maximum ascent and/or descent of the signal values of the scanned image sections, preferably on a pixel-by-pixel basis, using spatial operators preferably gradients, and detecting true flaw signals therefrom in the presence of background regions of maximum ascent and/or descent are used for calculating an impedance plane trajectory from a data array of path points and the maximum descent region. The amplitude of the gradient is a primary indicator of the presence of a flaw and the direction of the maximum gradient is used to determine the optimum path for signal reconstruction. From these calculations, the optimum signal path is determined independent of scan pattern. In practical terms, the calculated scan pattern is at or near a right angle to the flaw outlined to maximize contrast.

The foregoing features may also be used in combination.

BRIEF DESCRIPTION OF THE DRAWINGS:

In the Drawings:

Fig. 1 shows a representative array of areas on an aircraft that are tested for corrosion, to which the subject invention is applicable;

Fig. 2 is a block diagram of a representative apparatus for practicing the invention;

Fig. 3 shows an absolute probe used for corrosion mapping using a probe coil adjacent a test sample to produce a signal for the system of the invention;

Fig. 4 shows a differential probe used for crack detection using a pair of probe coils adjacent a test sample to produce a signal for the system of the invention;

Fig. 5 shows a driver/pickup probe used for crack detection where the sensitivity of a differential probe is inadequate;

Fig. 6 is an illustration of a flow routine illustrating one feature of the invention;

Fig. 7 is another illustration of a flow routine illustrating the steps of determining the maximum ascent/descent of received data for synthesizing a calculated flaw path independent of the actual traversal path; and

Fig. 8 illustrates the step of using the calculated flaw path with a step of calculating an impedance plane trajectory for handling data for displaying optimum signal strength independent of path position or scan pattern.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 shows a portion of a fuselage of an aircraft 12 having typical and representative areas 13 that are inspected for corrosion or cracks to detect potential for component failures. Usually, a structural failure in an aircraft 12 is caused by fatigue cracking, corrosion, or a combination of both. To non-destructively evaluate such aircraft, it is considered desirable to provide a reliable technique to detect surface and subsurface cracking on the order of 0.06 (1.5mm) long and corrosion wall loss of about

10% to satisfy safety concerns. The invention can thus be applied, by way of example, for non-destructive evaluation (NDE) of the surfaces of an aircraft; however, it is not limited to this field of use. It may also be used for vessel evaluations, by way of example.

Fig. 2 is a representative block diagram of a system 15 providing hardware for incorporating the principles of the invention in a laboratory environment The system 15 includes a manual scanner 16 for securing an eddy current probe 17 for traversing an area of scan. A suitable manual scanner is available from the assignee of this invention under Model No. 4020. In a commercial environment, a number of scanning devices can be used, including those which scan a test sample manually, automatically according to a predetermined x-y scan, such as a raster scan, or by meander scanning. The choice of scanner is somewhat determined by the nature of the test sample.

Suitable eddy current test probes 17A, 17B and 17C are representatively shown in Figs. 3 to 5 to provide an analog output signal representative of the phase and amplitude of the test signal detected by the probe 17 from the test sample. The analog output from the eddy current probe 17 is provided to an eddy current instrument 19, such as a Zetec Model No. MIZ-20A, suitable for receiving the output from the eddy current probe. The eddy current probe 17 is a two axis encoding device proving the spatial information necessary to plot the analog data 21 as well as generate the synchronizing pulses 22 for acquiring data on a preset grid. Typically, the data 21, 22 is obtained in increments of one quarter of the coil diameter.

The eddy current instrument 19 used in the system 15 is a single frequency instrument with an operating range from about 100 Hz to about 2MHz. Alternatively, as four frequency instrument can be used when multiparameter mixing is beneficial.

The system 15 includes a computer, such as an IBM AT compatible computer 24, connected to an Amdata encoder board 25 which in turn is connected to the manual scanner 16. Data collection in an x,y mode continues for each scan of the scanner 16 for coordination with the digitized data representative of the analog scan signals 21, 22 through the analog to digital converter board 26. To display the data upon command in real time, or upon processing, a color monitor 28 and a color printer 29 are provided.

The system 15 is configured to measure a number of quantities as a function of the coil position 17. Among those quantities are the in-phase impedance amplitude, and the quadrature impedance amplitude of the test sample according to the analog signal generated by the probe. In addition, the system 15 is programmed to determine through near real time calculations, the following quantities: (1) impedance vector magnitude; (2) impedance vector phase; and (3) various orders of spatial derivatives of the impedance vector magnitude and the impedance vector phase. The displays may be on strip charts or on complex impedance phasor plots.

A first and significant feature of the invention is that the instantaneous phase of the impedance, i.e. a first spatial derivative of the impedance is displayed. Thus, Fig. 6 shows a subroutine programmed into the apparatus 15 of Fig. 2 to produce a C scan of a spatial derivative of the amplitude and/or phase of the coil signal coordinated with the coil position of the eddy current coil 17.

Thus, in step 30, the position of the coil 17 is determined by the encoder board 25 cooperating with the scanner 16. The in-phase or quadrature impedance amplitude is detected from the analog signal output by the coil probe selected, as in step 31. From the data of step 31, a spatial derivative of the amplitude and/or phase of the signal is derived, as in step 32, thus enabling the production of a C scan of the derived spatial derivative.

Display of the spatial derivative as described reduces a major component of the signal noise and improves flaw detection. Indeed, prior systems display total signal phase signals including noise which reduces erroneous readings. Thus, flaw detection is improved.

A second significant feature of the invention is shown by the subroutines of Figs. 7 and 8. Since the eddy current test signal at any given point in the scan is independent of the scan path, the storage of data with precise location information in the system 15 of Fig. 2 allows for the post processing calculation of dynamic signals for an arbitrary scan path. Although the instantaneous signal from the test coil 17 is path independent, the dynamic signal is path dependent and is the usual form of signal which is most readily used for interpretation of results for crack or flaw detection. Indeed, the signal to noise ratio, or the image contrast, can be enhanced by proper selection of the scan path, whether real or reconstructed.

Accordingly, a routine is provided for automatically determining the optimum path which is calculated based on the direction of maximum ascent/descent by algorithms used to determine maximum gradients in signal amplitudes of the signals from the test coil 17 of the eddy current instrument 19. Both

the gradient magnitude and direction are determined. With this method, the most efficient scan path for mechanical considerations, typically, a rectilinear scan, can be used to acquire data while any scan path can be synthesized from the recorded data to optimize flaw detection, even without a prior knowledge of the flaw orientation. This provides a significant second advantage for the system.

Fig. 7 thus shows an initial subroutine for determining the optimum calculated path by first determining the direction of the maximum ascent/descent of the scan image section using spatial operators, usually gradient operators. This technique permits location of a flaw or crack which then can be used to determine the optimum path for scanning that flaw or crack in a direction at or nearly perpendicular to the flaw or crack. The optimum path is a reconstructed one from the data of the original scan. Thus, in Fig. 7, a step 34 of receiving the scanned signals is followed by the mathematical step 35 of determining the maximum ascent/descent of the scanned image sections, preferably in a pixel-by-pixel basis, using spatial operators, and in particular gradient operators, as shown in step 36. The step 37 is the step of determining true flaw signals in processing the data according to the subroutine of Fig. 8.

The subroutine of Fig. 8 permits a reconstruction of a signal trace by synthesizing an arbitrary scan path along the direction of maximum ascent/descent. The initial step 40 in the subroutine is a step of receiving signals representative of regions of maximum ascent/descent, as in Fig. 7 as discussed above. Those signals are used to calculate an impedance plane trajectory from the data array, as in step 41. In the data array from which the gradient

was calculated in accordance with Fig. 7, the signal is only a function of position relative to a flaw and is path independent for symmetric coil designs of the type shown in Figs. 3 to 5. However, the optimum signal that an analyst would use for a determination of flaw/no flaw is highly path dependent. Thus, the signal generated in the direction of the maximum gradient provides the optimum signal to noise ratio and is the best estimate of the true flaw characteristics. Accordingly, by the steps of Fig. 8, a display of the optimum signal independent of the scan pattern used to acquire the data is possible, as shown in step 42. There are significant practical advantages of analyzing data as described herein. First,, the mechanical scanning system and the data acquisition parameters can be determined somewhat independently. Second, since an eddy current scanning system works best when the sensing coils 17 traverse a flaw at right angles, a optimum path can be developed through calculations, whether or not the original scanning was done in a raster scanning or a meander scanning mode, without sacrificing the quality of the test results.

When applied to an aircraft structure, such as in Fig. 1, for example, a scan produces data which are analyzed for the maximum regions of ascent/descent. When applied to a situation involving cracks radially emanating from a rivet, for example, the analysis produces an optimum calculated path which is circular to intersect the crack at about a right angle.

While a preferred embodiment of the invention has been illustrated, it will be apparent to those skilled in the art that various modifications and changes may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A method for contrast imaging a workpiece with eddy current imaging means including an eddy current sensing coil positioned proximate said workpiece and traversing said workpiece in a pattern, thus to scan said workpiece and produce a signal indicative of the impedance of said workpiece proximate said eddy current sensing coil, said method including:

providing a signal from said impedance indicative signal representative of the amplitude and/or phase of said signal for selected scan positions;

calculating a spatial derivative of said amplitude and/or phase indicative signal; and

providing an image of said spatial derivative for said selected scan positions.

2. The method as set forth in claim 1 wherein the step of providing an image of said spatial derivative includes the step of producing a C scan of said spatial derivative.

3. The method as set forth in claim 2 wherein the step of producing said C scan is performed in approximately real time relative to said scan of said workpiece.

4. The method as set forth in claim 1, including a step of storing said signal, wherein said calculating step is performed at a time later than said scan of said workpiece.

5. A method of displaying a contrast image of a flaw in a workpiece which is scanned by an eddy current coil to produce an in-phase or quadrature impedance amplitude, comprising the steps of:

deriving a spatial derivative of said amplitude and/or phase; and

producing said contrast image by displaying said spatial derivative.

6. The method as set forth in claim 5 wherein said spatial derivative is displayed as a C scan of said flaw.

7. The method for contrast imaging a workpiece with eddy current imaging means including an eddy current sensing coil positioned proximate said workpiece and traversing said workpiece in a pattern, thus to scan said workpiece and produce a signal indicative of the impedance of said workpiece proximate said eddy current sensing coil for each scanned position of interest, said method including:

determining for said signal indicative of the impedance of said workpiece the maximum ascent and/or descent of the scanned image sections by spatial operators; and

detecting true flaw signals in the presence of background noise from said regions of maximum ascent and/or descent.

8. The method as set forth in claim 7 further including the steps of:

calculating an impedance plane trajectory from a data array of path points and the direction of maximum ascent and/or descent regions; and

displaying an optimum signal independent of scan pattern of said workpiece.

9. The method as set forth in claim 7 wherein the step of using spatial operators includes the step of using gradient operators.

10. A method for contrast imaging a workpiece, comprising the steps of:

scanning said workpiece with an eddy current imaging means including an eddy current sensing coil positioned proximate said workpiece to produce data representative of the integrity of said workpiece in an x, y group;

determining from said x, y group of data the regions of maximum ascent and/or descent of the scanned image sections;

calculating from said x, y group of data and the maximum ascent and/or descent of the scanned image sections an impedance plane trajectory; and

determining an optimum signal independent of an original scan pattern.

11. The method as set forth in claim 11 wherein the step of determining the maximum ascent and/or descent includes the step of using spatial operators.

12. The method as set forth in claim 12 where the step of using spatial operators includes the step of using gradient operators including both magnitude and direction of the gradient vector.

13. The method as set forth in claim 10 further including a step of detecting true flaw signals in the presence of background noise after determining the regions of maximum ascent and/or descent.

FIG. 1

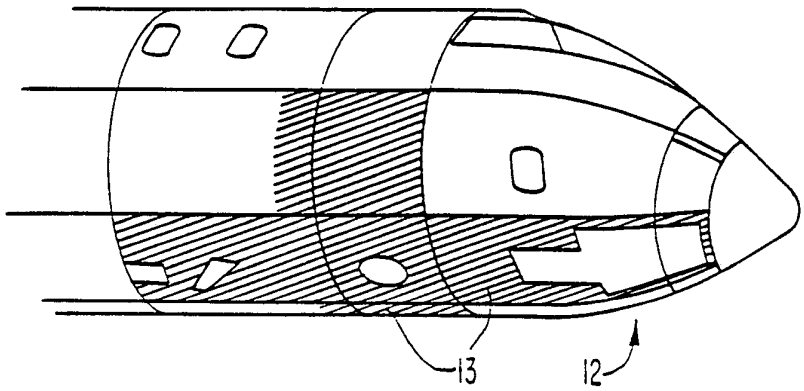
13
12

FIG. 2

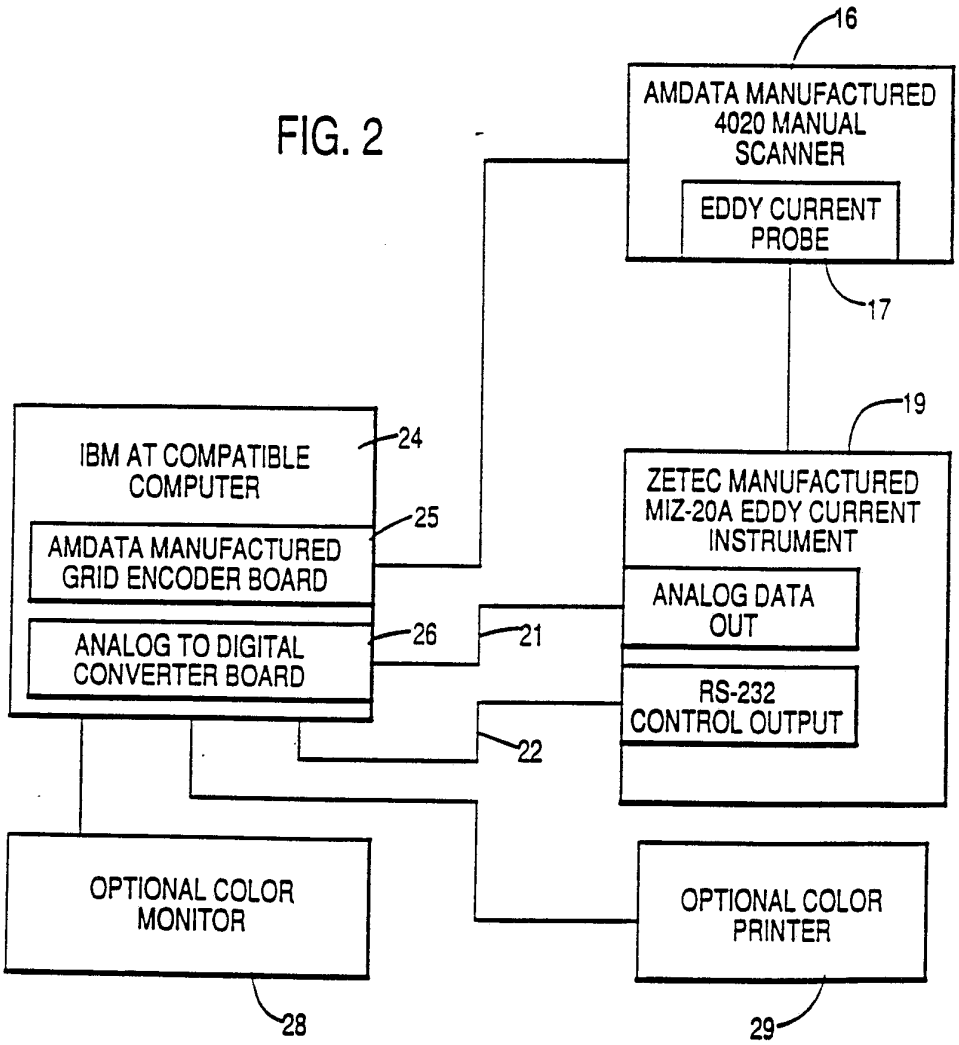
16
AMDATA MANUFACTURED 4020 MANUAL SCANNER
EDDY CURRENT PROBE
17
19
IBM AT COMPATIBLE COMPUTER
24
25
AMDATA MANUFACTURED GRID ENCODER BOARD
ANALOG TO DIGITAL CONVERTER BOARD
26
21
ZETEC MANUFACTURED MIZ-20A EDDY CURRENT INSTRUMENT
ANALOG DATA OUT
RS-232 CONTROL OUTPUT
22
OPTIONAL COLOR MONITOR
28
OPTIONAL COLOR PRINTER
29

FIG. 3

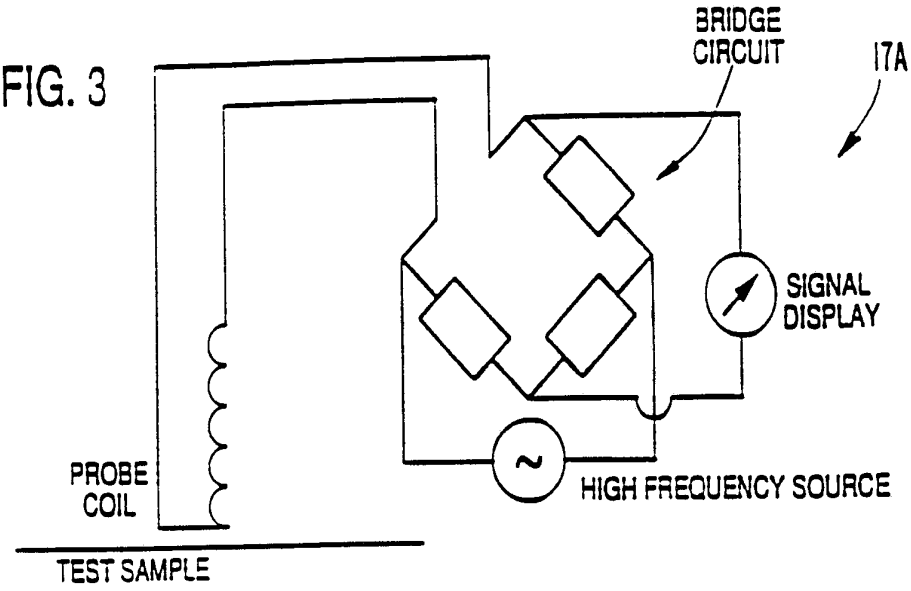

FIG. 4

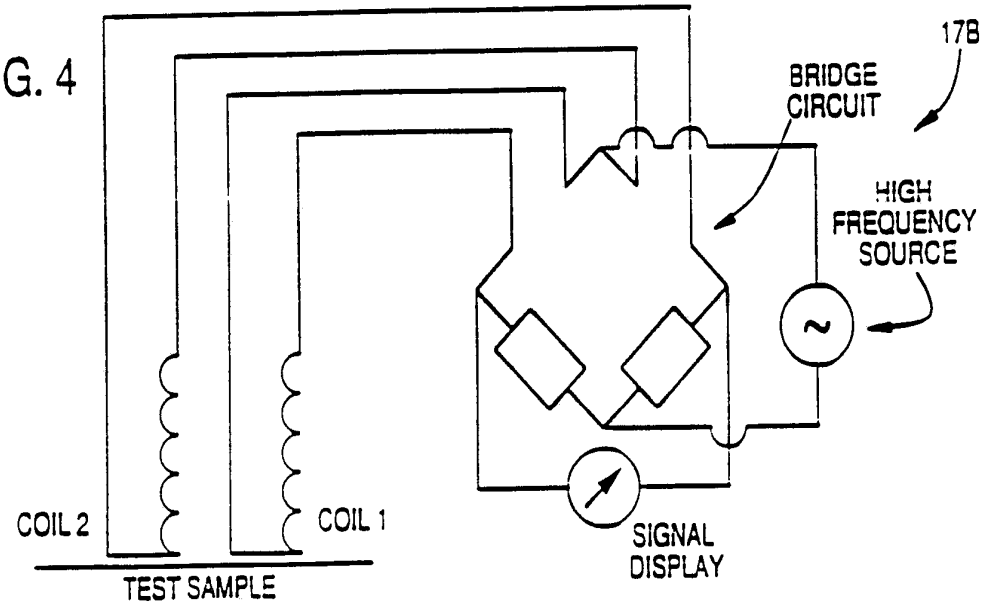

FIG. 5

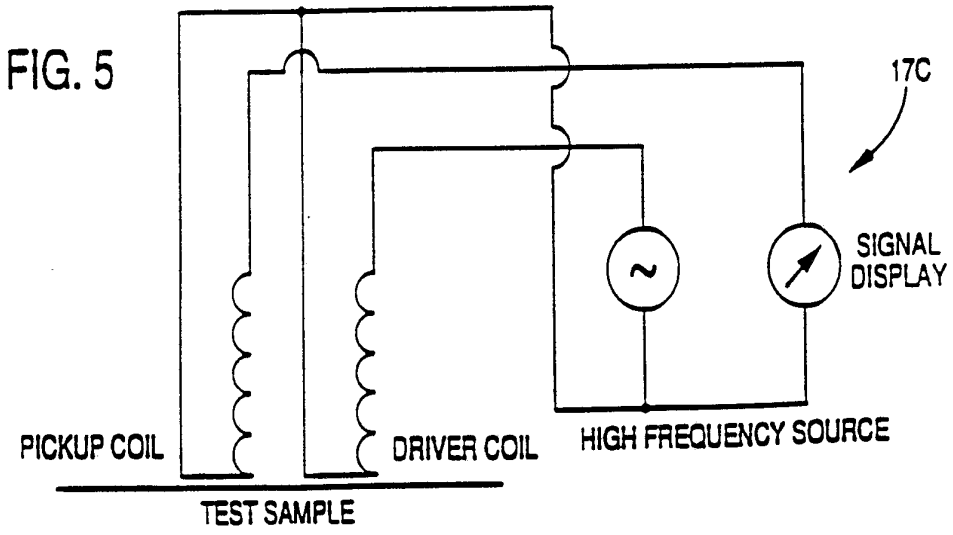

FIG. 6

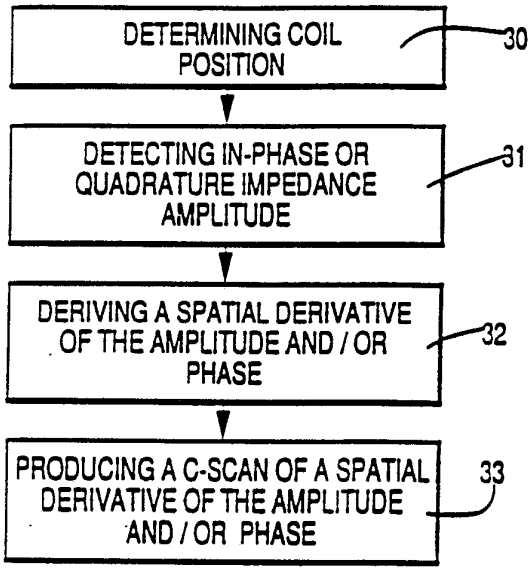

FIG. 7

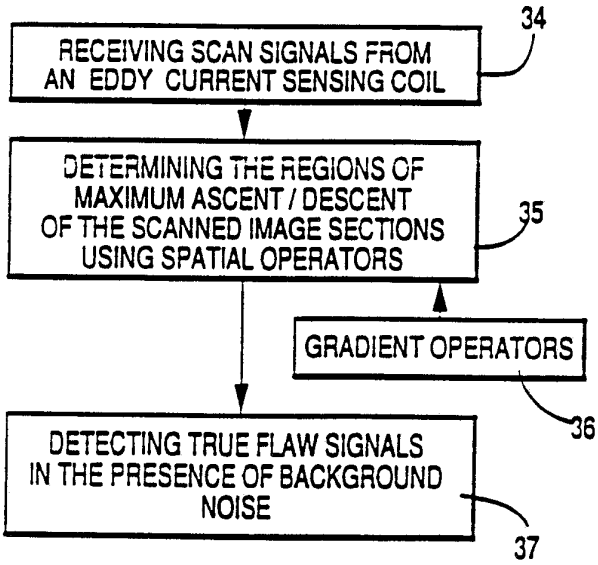
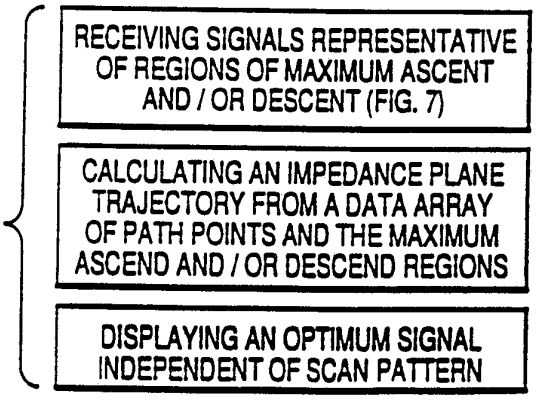
FIG. 8