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(54) Title: ARTIFICIAL DEFECT FOR EDDY CURRENT INSPECTION

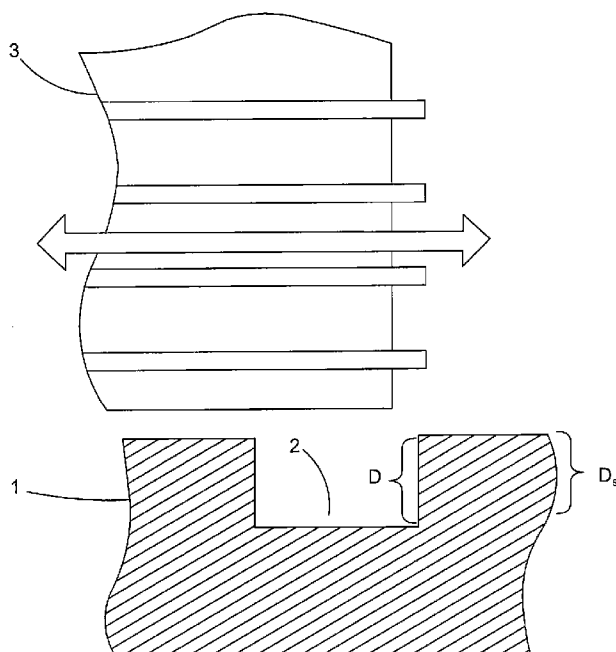


FIG. 1

(57) Abstract: A flex circuit for creating artificial defects uses a thin conductive layer with rectangular slots therein representing defects. A thin insulating over-layer is used to protect the conductive layer as well as the EC probe. The flexible circuit is then temporarily attached to the surface of the part to be inspected. A feature of the described system is that it is directly scalable to an EDM notch. Eddy currents are limited by the skin depth phenomenon. The subject approach uses a thin conductive layer which is scalable to a thicker lower conductive layer like a conventional EDM notch. In this way, a thin conductive artificial defect can electromagnetically represent a thicker albeit less conductive EDM notch. The flexible circuit makes it easier to place multiple notches in complex part geometries than with EDM, and allows for more accurate relative positioning between slots, as required for array and wide coverage probes.



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ARTIFICIAL DEFECT FOR EDDY CURRENT INSPECTION

Technical Field

[0001] The present disclosure relates to techniques and equipment for identifying defects and, more particularly, to a method and a device for creating an artificial defect for eddy current detection calibration.

Background

[0002] It is important in some fields to inspect for a detect surface defects in parts before placing those parts into use or providing such parts for sale. One manner of detecting surface defects is to induce and analyze eddy currents in the surface of interest. In this way, cracks and other defects will show an altered eddy current response relative to an undamaged part.

[0003] However, in order for eddy current detection of defects to work properly, the eddy current detection sensitivity should be calibrated prior to or during analysis. It is known to machine small notches into parts, e.g., via EDM, to simulate defects and allow for calibration. However, this technique sacrifices a specimen of the part in question. Thus, for expensive parts, the technique may prove prohibitively expensive. In addition, EDM notches can be difficult to form in complex geometries as to size and position.

[0004] A technique to calibrate eddy detection equipment for surface defect analysis without damaging a specimen is disclosed in U.S. Pat. 6,734,664 to Bryson et al. This technique involves placing a conductive strip of material within a sheet of nonconductive nonmagnetic material. The effect of the strip of conductive material during eddy current analysis is calibrated initially by comparison to a known defect, and then thereafter can be used to independently calibrate the eddy current detection response. However, the device may be difficult to reuse after detachment from a given sample, and depending upon the conductive material used, the device may be expensive enough to discourage disposal.

[0005] It will be appreciated that this background section discusses problems and solutions noted by the inventors; the inclusion of any problem or solution in this section

is not an indication that the problem or solution represents known prior art except as otherwise expressly noted. With respect to prior art that is expressly noted as such, the inventors' summary thereof above is not intended to alter or supplement the prior art document itself; any discrepancy or difference should be resolved by reference to the prior art document itself. It will be further appreciated that solving the noted problems, while desirable to the inventors, is not a limitation of the appended claims except where expressly noted, since the claimed invention is susceptible to a wide variation in implementation techniques.

Summary

[0006] In an embodiment a test strip having one or more artificial defects formed therein is used as a current calibration standard for eddy current testing, a part coverage specimen, and a POD specimen. This allows the test strip to replace artificial defects formed in the part under test itself.

[0007] Others features and advantages of various embodiments of the disclosed principles will become apparent from the following detailed description read in conjunction with the appended figures.

Brief Description of the Drawings

[0008] Embodiments of the invention will be described in greater detail below with reference to the enclosed drawings, wherein:

[0009] FIG. 1 is a cross-sectional schematic view of a specimen including an artificial defect formed in the specimen;

[0010] FIG. 2 is a cross-section schematic view of a specimen including an artificial defect created by overlaying a flexible circuit on the specimen;

[0011] FIG. 3 is a schematic view of a flex circuit in accordance with an embodiment of the disclosure;

[0012] FIG. 4 is a pair of images showing the scanning of a part having thereon a flex circuit in accordance with an embodiment of the disclosure; and

[0013] FIG. 5 is a pair of response plots showing the EC response to an artificial defect created in accordance with an embodiment of the disclosure.

Description of Embodiments

[0014] The present invention will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, like numbers refer to like elements.

[0015] The electromagnetic skin depth is the physical characteristic that makes eddy current inspection useful. The electromagnetic skin depth results in the induced current being confined near the surface of a part being tested. The skin depth depends on the frequency, conductivity and magnetic permeability. With the frequency and magnetic permeability known relative to one another, the depth of the flex circuit is determined by the notch depth and the ratio of the square root of conductivities.

[0016] Regarding the skin depth, known as δ (skin depth or standard depth of penetration), $\delta = (\pi f \sigma \mu)^{-1/2}$ where f is the operating frequency (1/s), σ is the material electrical conductivity (1/ohm m) and μ is the material magnetic permeability (H/m).

[0017] Figure 1 shows the cross-section of a conventional EDM notch used as an artificial defect. In particular, the figure shows the low conductivity material 1 as well as a notch 2 machined in the material. In addition, the EC probe 3 is shown. The magnetic permeabilities and electrical conductivities are also shown.

[0018] Figure 2 shows a flex circuit in accordance with an embodiment of the disclosed principles forming the electromagnetic equivalent of the EDM notch. The flex circuit thickness is selected based on the notch depth and material conductivities. The figure shows the low conductivity material 4, with an applied layer of flex circuit 5. A slot 6 in the flex circuit 5 mimics the EDM notch 2 of FIG. 1, but does so nondestructively. The figure also shows the EC probe 3. The flex circuit artificial defect can be made to respond to the EC probe 3 like an EDM notch in the material itself would have. The thickness of the flex circuit conductor is fabricated to be

electromagnetically equivalent to the depth of the EDM notch. With the flex circuit being simple and cheap, this is an efficient replacement for using EDM notches.

[0019] FIG. 3 is a schematic view of a flex circuit according to an embodiment of the disclosed principles. The flex circuit contains an array of slots 10. The figure also shows the structure of the flex circuit, comprising a conductive layer, e.g., copper, topped by a nonconductive layer to protect the circuit as well as to protect the EC probe.

[0020] FIG. 4 shows two different images of an eddy current probe 3 adjacent a strip of the flex circuit material 5 described herein.

[0021] FIG. 5 includes a pair of plots showing the EC probe response to the flex circuit. A first plot 11 shows the amplitude response in a standard coordinate system, while a second plot 12 shows the amplitude response via gray scale.

[0022] The flex circuit uses a thin conductive layer with rectangular slots (etched, laser cut, etc.) therein representing defects. A thin insulating over-layer is used to protect the conductive layer as well as the EC probe. The flexible circuit (conductive layer, insulator) is then temporarily attached (by adhesive or tape) to the surface of the part to be inspected. It may alternatively be more permanently attached via adhesive, tape, epoxy, etc., e.g., to create a dedicated calibration standard, coverage, or POD specimen.

[0023] A feature of the described system is that it is directly scalable to an EDM notch. Eddy currents are limited by the skin depth phenomenon. The subject approach uses a thin conductive layer which is scalable to a thicker lower conductive layer like a conventional EDM notch. In this way, a thin conductive artificial defect can electromagnetically represent a thicker albeit less conductive EDM notch.

[0024] This type of artificial defect is inexpensive to manufacture and can be easily modified in its parameters. The implementation is also more representative of the conventional defect response since it entails a large conductive volume and a small defect. It also makes it easier to place multiple notches in complex part geometries than with EDM, and allows for more accurate relative positioning between slots, as required for array and wide coverage probes.

[0025] Moreover, relative to using EDM notches, which requires creating scrap parts for test, coverage, POD and calibration specimens, the cost of scrapping parts is

relatively high. In contrast, there is no need to discard parts setted via the flow circuit described herein because the defect is placed on rather than into the part.

[0026] In the drawings and specification, there have been disclosed preferred embodiments and examples of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for the purpose of limitation, the scope of the invention being set forth in the following claims.

CLAIMS

1. A method of calibrating an eddy current defect detection system for a particular part comprising:
 - creating a flex circuit having a conductive layer and an insulating layer, and one or more slots through the flex circuit;
 - adhering the flex circuit to a specimen of the particular part; and
 - calibrating the eddy current defect detection system by scanning the adhered flex circuit.
2. A test specimen for calibrating an eddy current defect detection system, the test specimen comprising:
 - a specimen of a part; and
 - a flex circuit adhered to a surface of the part, the flex circuit comprising a conductive layer covered by an insulating layer, the flex circuit having one or more slots there through.
3. The test specimen according to claim 2, wherein the dimensions of the one or more slots are selected such that the EC response of a slot is similar to the EC response of an EDM notch.

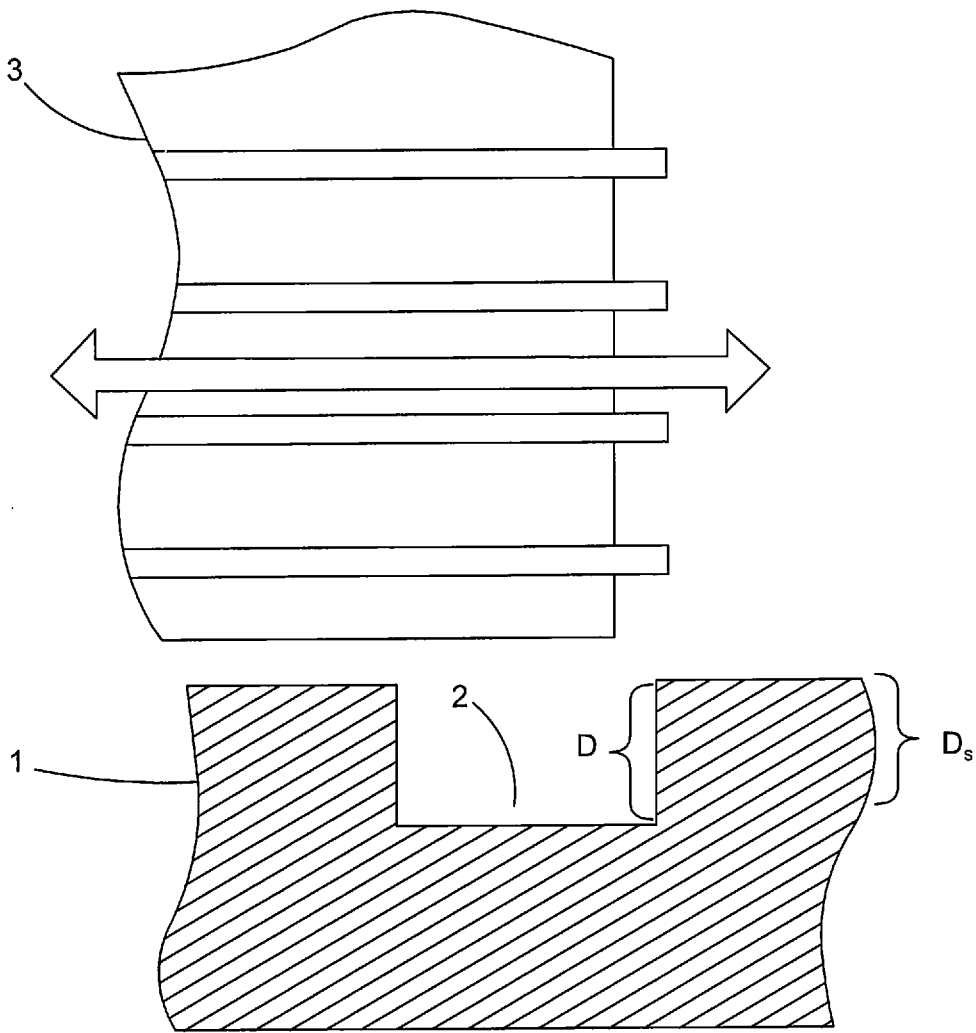


FIG. 1

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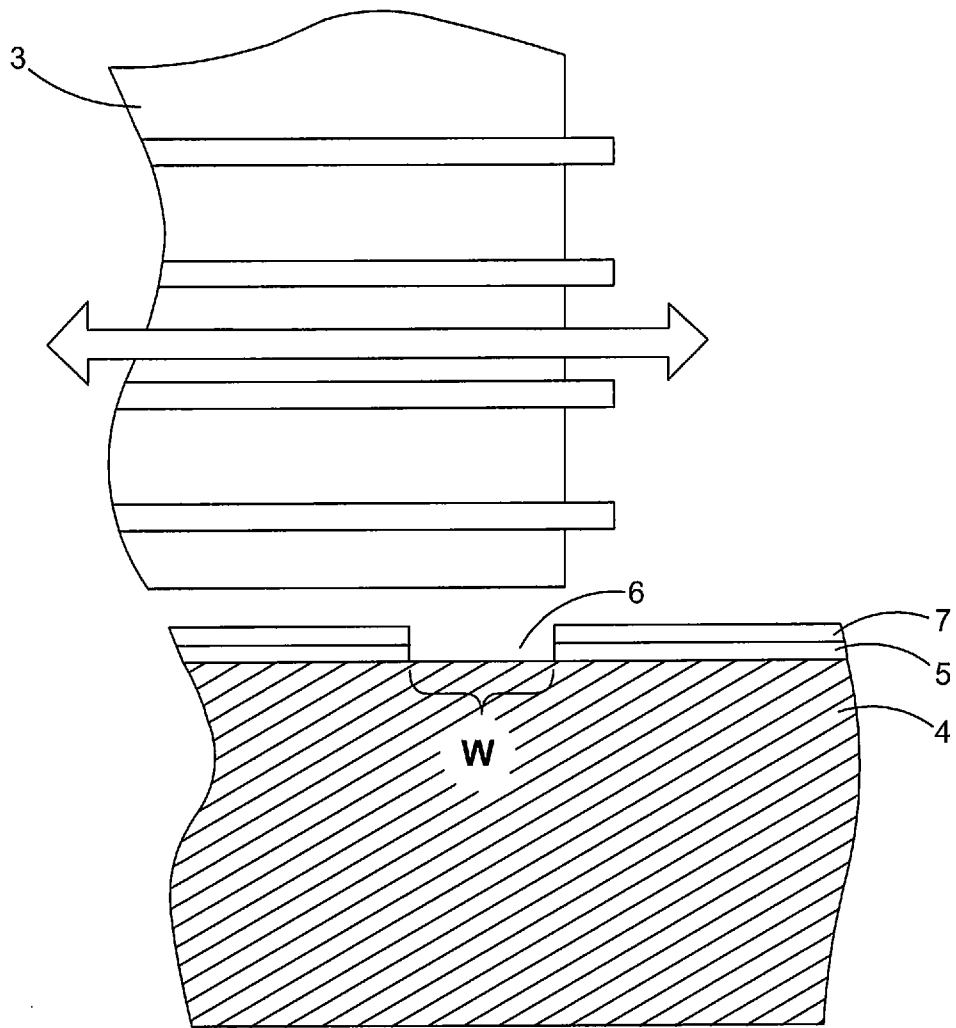


FIG. 2

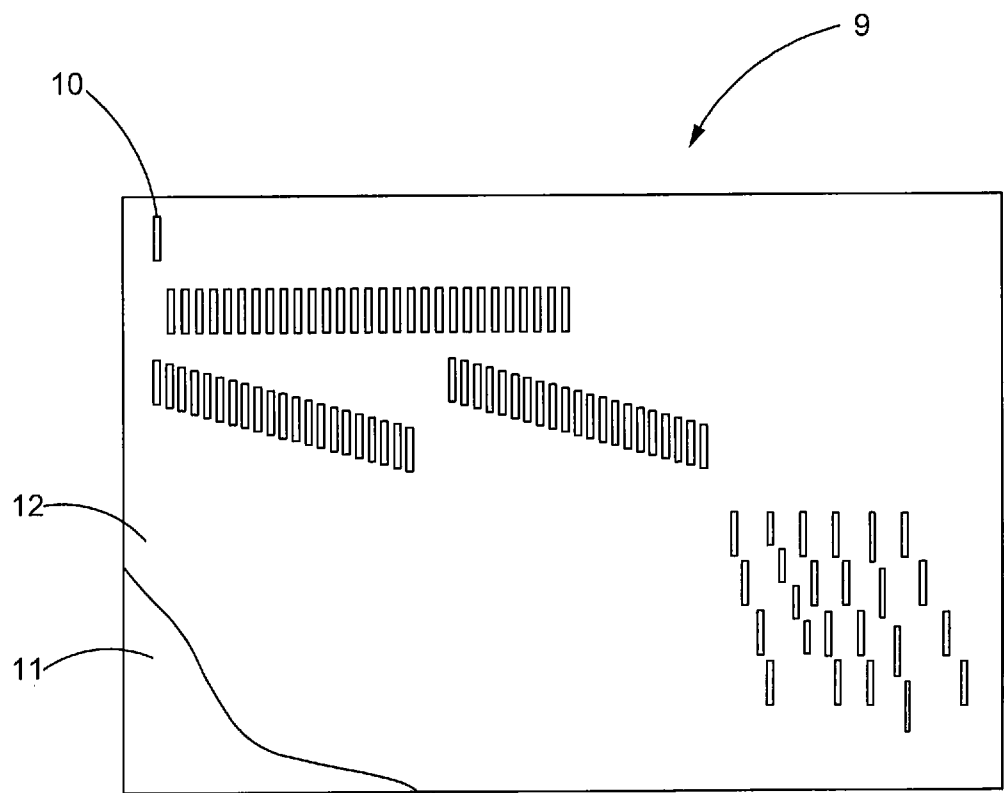
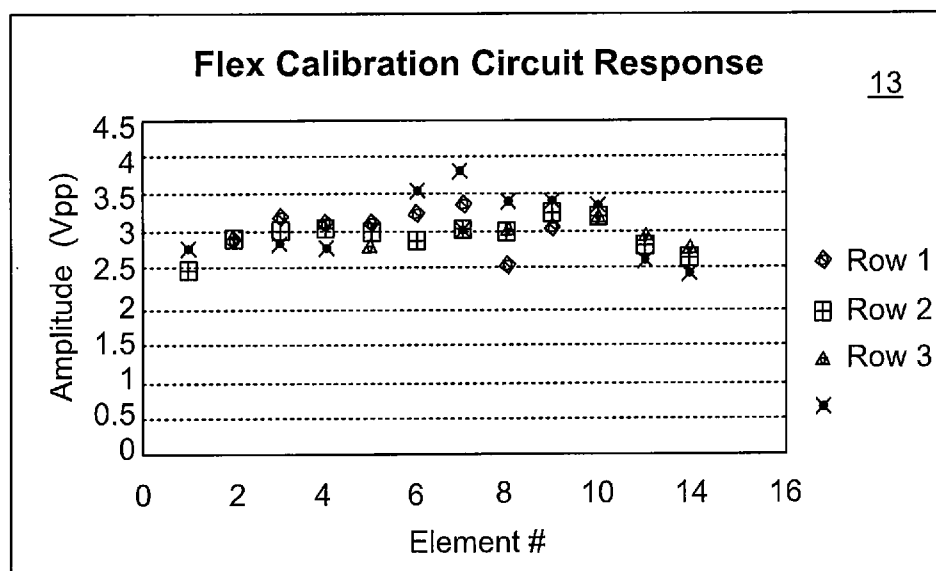


FIG. 3

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**FIG. 4**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2013/057355

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01N 27/90 (2013.01)

USPC - 324/240

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - G01N 27/72, 27/82, 27/90 (2013.01)

USPC - 324/239, 240, 241, 242, 243

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - G01N 27/72, 27/82, 27/90, 27/9086 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase, Orbit, Google Patent, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/0248339 A1 (GOLDFINE et al.) 10 November 2005 (10.11.2005) entire document	1-3
A	US 2007/0126422 A1 (CROUCH et al.) 07 June 2007 (07.06.2007) entire document	1-3
A	US 7,560,920 B1 (OUYANG et al.) 14 July 2009 (14.07.2009) entire document	1-3
A	US 7,626,383 B1 (SUN et al.) 01 December 2009 (01.12.2009) entire document	1-3

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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