US007557570B2

(12) **United States Patent**
Crouch et al.

(10) **Patent No.: US 7,557,570 B2**
(45) **Date of Patent: Jul. 7, 2009**

(54) **SYSTEM AND METHOD FOR PRODUCING COLOR CONTOUR MAPS OF SURFACE DEFECTS OF HIGH PRESSURE PIPELINES**

(75) Inventors: **Alfred E. Crouch**, San Antonio, TX (US); **Todd Goyen**, San Antonio, TX (US); **Patrick C. Porter**, Houston, TX (US); **Shawn Laughlin**, The Woodlands, TX (US)

(73) Assignee: **The Clock Spring Company L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 268 days.

(21) Appl. No.: **11/556,307**

(22) Filed: **Nov. 3, 2006**

(65) **Prior Publication Data**

US 2007/0126422 A1 Jun. 7, 2007

Related U.S. Application Data

(60) Provisional application No. 60/732,959, filed on Nov. 3, 2005.

(51) **Int. Cl.**
G01N 27/82 (2006.01)
G01B 7/06 (2006.01)

(52) **U.S. Cl.** **324/229**; 324/221; 324/240; 324/202

(58) **Field of Classification Search** 324/220, 324/228–243, 202, 221
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,939,404	A	2/1976	Tait	
4,064,452	A	12/1977	Toth	
4,134,067	A	1/1979	Woodbury	
4,247,819	A	1/1981	Shimada et al.	
4,258,319	A	3/1981	Shimada et al.	
4,312,231	A	1/1982	Kawashima et al.	
4,368,429	A	1/1983	Jamison	
4,423,636	A	1/1984	Plante	
4,425,545	A	1/1984	Scalese	
4,467,281	A *	8/1984	Davis et al.	324/232
4,495,587	A	1/1985	Plante et al.	
4,523,473	A	6/1985	Chamuel	
4,578,643	A	3/1986	Junker et al.	
4,608,534	A	8/1986	Cecco et al.	
4,628,260	A	12/1986	Kimato et al.	
4,631,688	A	12/1986	Boehm et al.	
4,646,013	A	2/1987	Tornbloom	
4,687,992	A	8/1987	von Bernus et al.	
4,706,021	A	11/1987	Chamuel	

(Continued)

FOREIGN PATENT DOCUMENTS

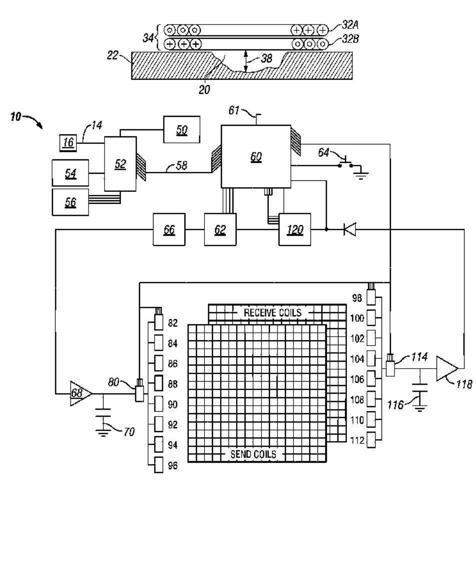
JP 11051905 A * 2/1999

Primary Examiner—Jay M Patidar
(74) *Attorney, Agent, or Firm*—Tim Headley; Headley IP Law

(57) **ABSTRACT**

A system for mapping a surface defect in an electrically-conducting material by measuring a change in the resonance of the material includes a flexible printed circuit board and a two dimensional array of transducers printed on the flexible circuit board, wherein each element of the array includes two transducer coils in a paired arrangement. A receive circuit connected to the coils is tuned to a resonant frequency, and the transducer coils operate in a send/receive mode. In another feature of the invention, there are means for converting a change in measured resonance to a visual display of the depth and width of the surface defect.

8 Claims, 3 Drawing Sheets



U.S. PATENT DOCUMENTS

4,837,510	A	6/1989	Tornblom	
4,851,774	A	7/1989	Tornblom	
4,853,634	A	8/1989	Tornblom	
4,864,235	A	9/1989	Tornblom	
4,954,778	A	9/1990	Champonnois et al.	
4,965,519	A	10/1990	Tornblom	
5,047,719	A *	9/1991	Johnson et al.	324/242
5,182,513	A	1/1993	Young et al.	
5,184,070	A	2/1993	Besendorfer et al.	
5,262,722	A	11/1993	Hedengren et al.	
5,345,514	A	9/1994	Mahdavieh et al.	
5,363,040	A	11/1994	Horn	
5,389,876	A *	2/1995	Hedengren et al.	324/242
5,446,378	A	8/1995	Reich et al.	
5,452,182	A *	9/1995	Eichelberger et al.	361/749
5,537,334	A	7/1996	Attaoui et al.	
5,670,879	A	9/1997	Zombo et al.	
5,793,206	A	8/1998	Goldfine et al.	
6,067,857	A	5/2000	Cooper et al.	
6,344,739	B1 *	2/2002	Hardy et al.	324/220
6,429,646	B1	8/2002	Han	
6,519,535	B1	2/2003	Petri et al.	
6,541,963	B2 *	4/2003	Mednikov et al.	324/225
6,545,467	B1	4/2003	Batzinger et al.	
6,812,697	B2	11/2004	McKnight et al.	
6,914,427	B2 *	7/2005	Gifford et al.	324/242
7,010,987	B2	3/2006	Antonelli et al.	
2002/0027436	A1	3/2002	Taylor	
2003/0071615	A1 *	4/2003	Schlicker et al.	324/242
2003/0164700	A1	9/2003	Goldfine et al.	
2003/0227288	A1	12/2003	Lopez	
2004/0056656	A1	3/2004	McKnight et al.	
2004/0066188	A1	4/2004	Goldfine et al.	
2004/0066189	A1	4/2004	Lopez	
2004/0075432	A1	4/2004	Loud	
2004/0139805	A1	7/2004	Antonelli et al.	
2004/0232911	A1	11/2004	Schlicker et al.	
2004/0257072	A1	12/2004	Samson	
2005/0146324	A1	7/2005	Goldfine et al.	
2005/0206374	A1	9/2005	Roney, Jr. et al.	
2005/0231194	A1	10/2005	Baldi et al.	
2006/0103389	A1	5/2006	Bespalov et al.	
2006/0170420	A1	8/2006	Nishimizu et al.	

* cited by examiner

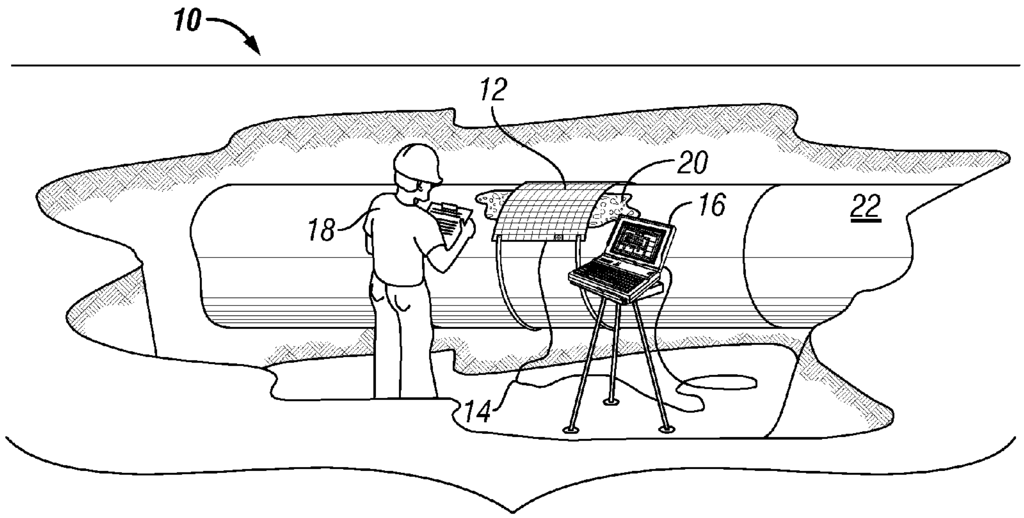


FIG. 1

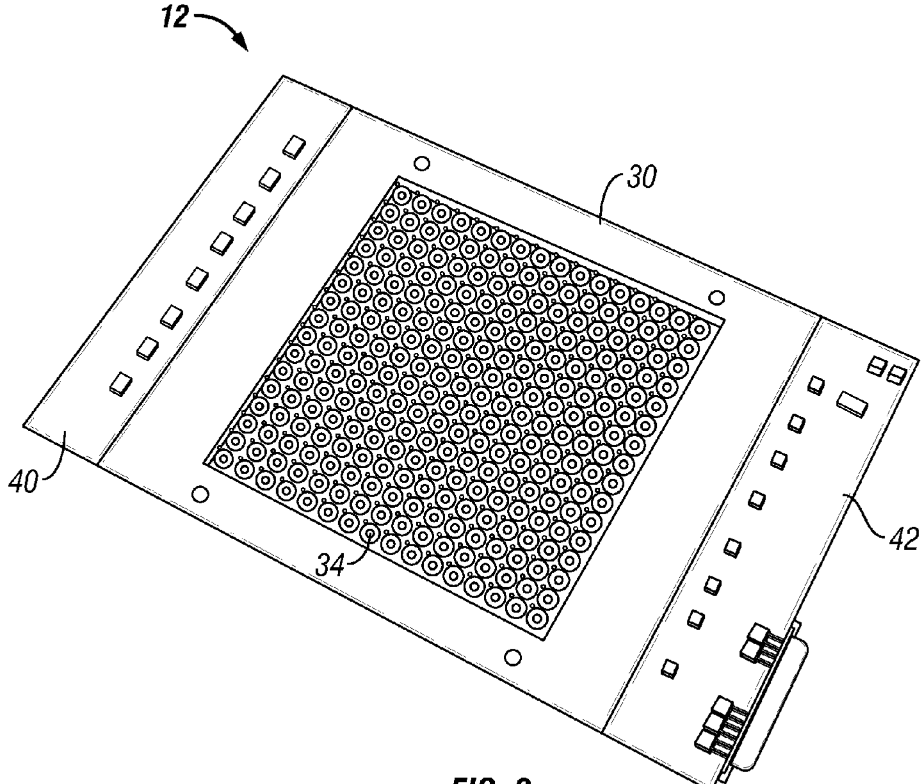


FIG. 2

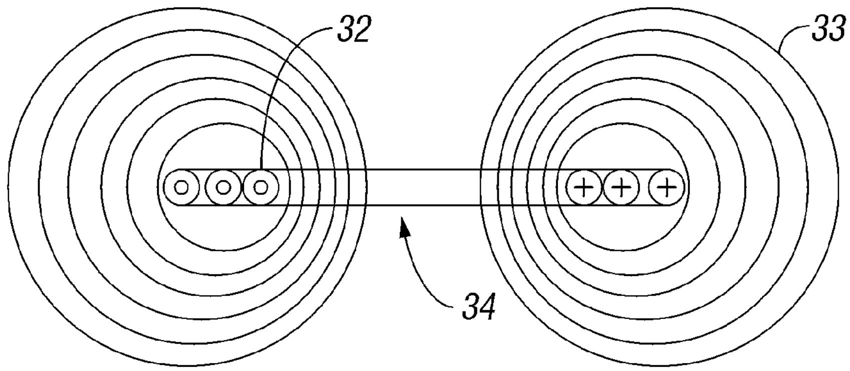


FIG. 3A

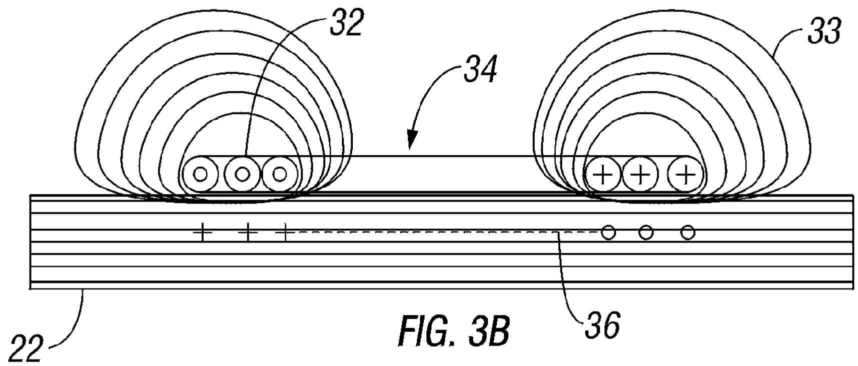


FIG. 3B

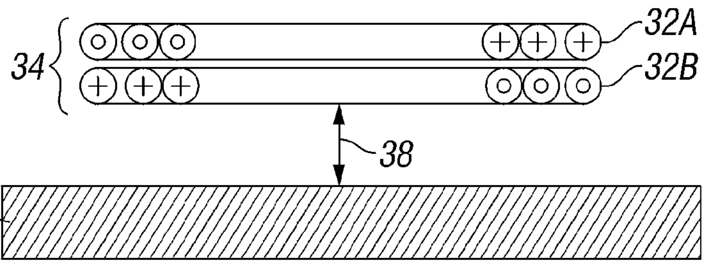


FIG. 4A

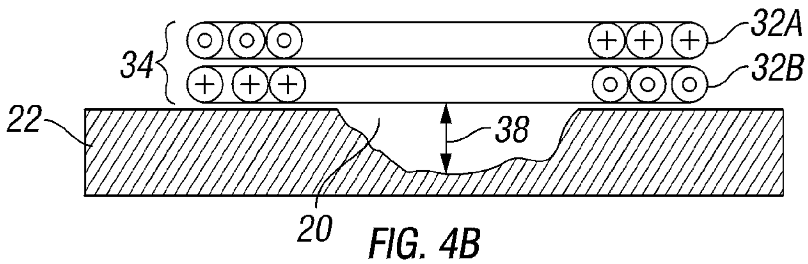


FIG. 4B

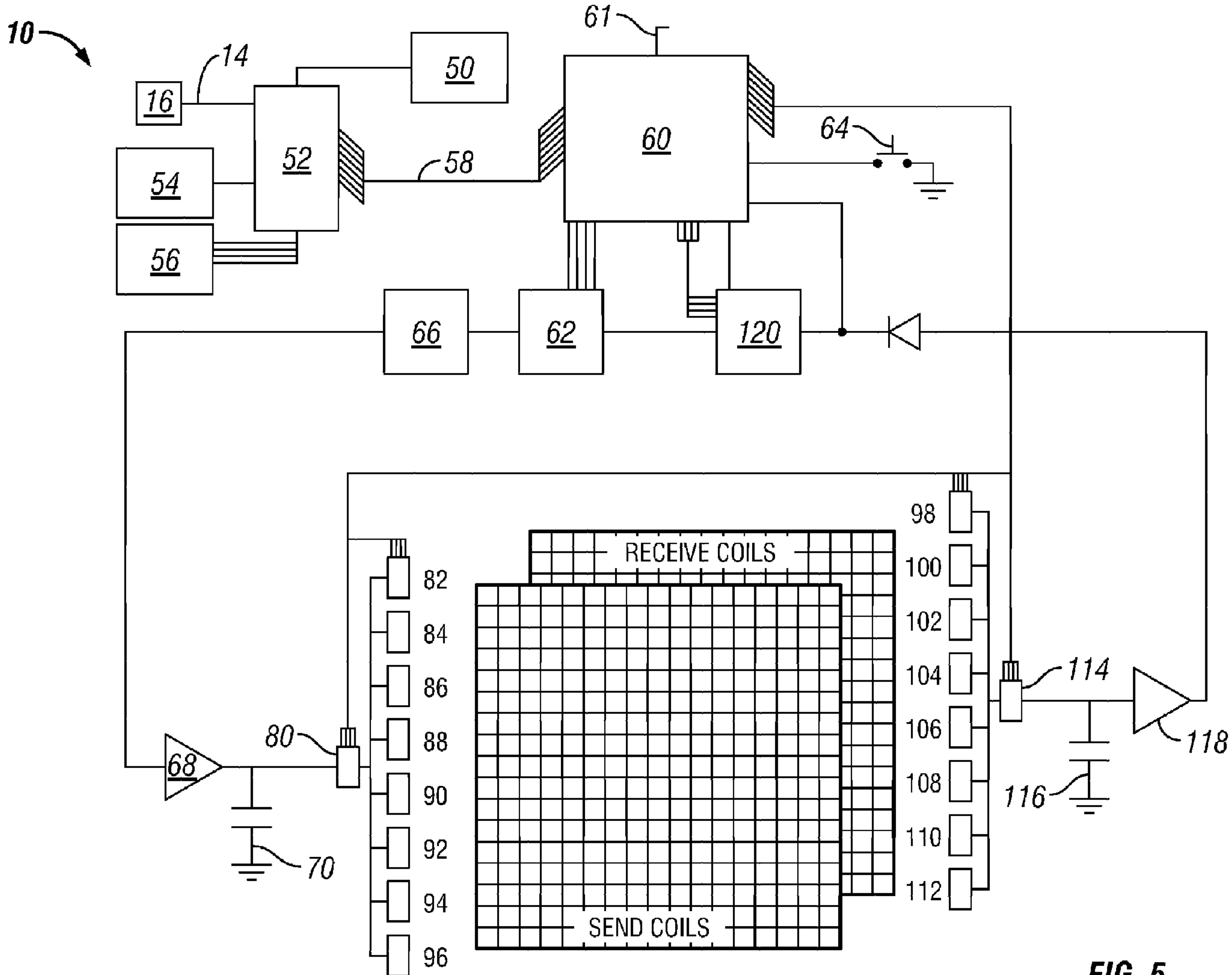

10
14
16
50
52
54
56
58
60
61
62
64
66
68
70
80
82
84
86
88
90
92
94
96
98
100
102
104
106
108
110
112
114
116
118
120
RECEIVE COILS
SEND COILS

FIG. 5

SYSTEM AND METHOD FOR PRODUCING COLOR CONTOUR MAPS OF SURFACE DEFECTS OF HIGH PRESSURE PIPELINES

CROSS-REFERENCES TO RELATED APPLICATIONS

This patent application claims the benefit of provisional patent application Ser. No. 60/732,959, filed Nov. 3, 2005.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

None.

REFERENCE TO A "SEQUENCE LISTING," A TABLE, OR A COMPUTER PROGRAM LISTING APPENDIX SUBMITTED ON A COMPACT DISC AND AN INCORPORATION BY REFERENCE OF THE MATERIAL ON THE COMPACT DISC

None.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The invention relates to devices for measuring the geometry of defects that have altered the surface of an electrically conducting pipe.

(2) Description of the Related Art

Pipelines and other structures used in the petrochemical industry are generally made of steel, and are pressurized. Defects such as corrosion, gouges, cracks, or other imperfections or features that remove or alter a portion of the steel can affect the ability of the pipe or structure to operate safely. When a defect or imperfection is discovered it must be assessed using engineering techniques defined in the operating code covering the installation, or by using methods developed and approved by the operator. This assessment requires a calculation using the material properties and design standards of the original construction, and measurements of the defect or imperfection.

Defect assessment in high pressure pipes is typically performed for corrosion, gouges or metal loss defects, and typically follows one of three industry-accepted methods. The most common is B31G (ASME B31G, Manual for Determining the Remaining Strength of Corroded Pipelines). This assessment technique requires the length and maximum depth of a metal loss or corrosion defect, which, with pipe material information and original design standards, can be used to calculate a safe operating pressure for the defect.

More complex assessment methods can be used to minimize unnecessary repairs. Using modified material properties and a different shape factor, a modified assessment can be made that is less conservative than the original B31G. This is known as the 0.85 dt method. This technique also requires that the length of the defect or imperfection and the maximum depth of the defect or imperfection be known. These measurements are used to calculate a safe operating pressure for the defect or imperfection.

The assessment technique with the least variability is the exact or effective area technique. This technique uses the exact cross-sectional area of the defect. The area is determined from an axial depth profile which uses the maximum corrosion depth at each axial measurement spacing. This axial depth profile is projected to a linear representation of the defect, and then the area of metal loss is calculated.

Each of these methods is defined in detail in the appropriate code. Each method specifies the defect measurements required to make the calculation to determine the effect of the defect or imperfection on the safety of the pipeline or installation.

Regardless of which assessment method is used, the input data are usually provided by local measurements on the outside of the pipe or structure.

The simplest case is that of a single isolated corrosion pit or area of metal loss. A scale measures the length of the defect area. A dial extension gage (pit gage) is placed over the pit (assuming the base will span the pit) and the maximum depth read and recorded. Slightly more complicated is the case of several overlapping pits or metal loss areas or a small patch of corrosion. In such cases, the length can still be measured with a scale. An attachment, such as a bridging bar, often spans the entire defect or imperfection, providing a reference surface from which to measure depth. It is not always possible to readily locate the deepest pit or metal loss within the grouping from a visual examination, so several independent depth measurements must be taken. It is also difficult to determine if defects in close proximity interact as defined by the rules outlined in the appropriate codes.

When corrosion or metal loss is extensive and an exact area assessment is needed, it is essential that the defect be accurately mapped to form a contour plot. In these cases, a rectangular grid is drawn or painted on the pipe or structure surface, including the corroded or metal loss area. Depth measurements are taken at each grid intersection. From this array of measurements, either manual or computer-aided processing is used to construct a contour map. The contour map is then used to assess the defect, and calculate a safe operating pressure. All these manual measurement methods are laborious, time-consuming, and error prone.

There have been some devices that automate some aspects of inspections, using eddy current arrays, as, for example, in the following patents, which are incorporated herein by this reference: U.S. Pat. Nos. 5,793,206, 5,182,513, and 5,262,722. However, these all have various limitations, as set forth in U.S. Patent Application No. 20040232911.

U.S. Pat. No. 6,545,467, which is incorporated herein by this reference, states in the abstract, "A flexible eddy current array probe is attached to the contoured exterior surface of the backing piece such that the probe faces the contoured surface of the workpiece to be inspected when the backing piece is disposed adjacent to the workpiece. The backing piece is then expanded volumetrically by inserting at least one shim into a slot in the backing piece to provide sufficient contact pressure between the probe and the workpiece contoured surface to enable the inspection of the workpiece contoured surface to be performed." However, the method disclosed in this patent is primarily concerned with ensuring coupling between a flexible eddy current array probe and a workpiece to be inspected. This patent does not disclose a two-dimensional eddy current array, does not disclose how to use such an array, does not provide the means to map defects, and does not use the flexible substrate to reestablish the contour of the workpiece.

Another device that uses eddy current arrays has been disclosed in the following patent applications, which are incorporated herein by this reference: U.S. Patent Application Nos. 20030164700 and 20040232911. These patent applications disclose a device that has essentially identical sensor arrays with sensing elements aligned in proximity to the drive elements, and conductive pathways that promote cancellation of undesired magnetic flux. These references do not disclose how to reestablish the original surface contour of a pipe, nor do they disclose any way to expand the dynamic range of the testing device.

Another device that uses eddy current arrays has been disclosed in the following patent application, which is incorporated herein by this reference: U.S. Patent Application No. 20060170420, which states in the abstract, "An eddy current testing probe has a flexible substrate adapted to face to a surface of a test article, a plurality of coils which are fixed to the flexible substrate and energized one of which is capable of being changed sequentially, a pressing member for pressing the substrate toward the test article, an elastic member arranged between the substrate and the pressing member, and a movement limiting member for limiting a movement of the pressing member toward the test article." The device disclosed in this patent is again concerned about pressing an eddy current probe against a workpiece, or "test article", and the attendant problems with exerting such pressure. The patent does not disclose how to map the dimensions of surface defects.

In light of the foregoing, a need remains for a flexible two-dimensional eddy current array that 1) provides a means to map defects on a pipe, 2) uses the flexible substrate to reestablish the original surface contour of a pipe, and 3) provides means to expand the dynamic range of the eddy current array.

BRIEF SUMMARY OF THE INVENTION

A system for mapping a surface defect in an electrically-conducting material by measuring a change in the resonance of the material comprises: a flexible printed circuit board; and a two dimensional array of transducers printed on the flexible circuit board, wherein each element of the array comprises two transducer coils in a paired arrangement. A receive circuit connected to the coils is tuned to a resonant frequency, and the transducer coils operate in a send/receive mode. In another feature of the invention, there are means for converting a change in measured resonance to a visual display of the depth and width of the surface defect.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** is an overview showing the conformable eddy current array of the present invention being used to measure a defective surface area of a pipe.

FIG. **2** is a schematic diagram of the conformable array of the present invention.

FIG. **3** is a schematic diagram of the individual coils that comprise the array shown in FIG. **2**.

FIG. **4** is a schematic diagram showing the individual coils and the depth of the surface defect of a pipe.

FIG. **5** is a schematic diagram of the electronics that control the eddy current array.

DETAILED DESCRIPTION OF THE INVENTION

In FIG. **1**, the system **10** of the present invention includes a flexible eddy-current sensor array **12**, and a USB cable **14** that connects the array **12** to a laptop computer **16**. The array **12** receives power from the laptop computer **16** through a USB port. As shown, the system **10** is used by an operator **18** to detect the extent of surface corrosion or defect **20** on an underground pipe **22**.

Referring now to FIG. **2**, the array **12** includes a flexible section **30**. Although the flexible section **30** can be of any size and number of transducers, in the preferred embodiment the flexible section **30** contains **512** coils **32** arranged in **256** coil pairs **34**, with connections allowing each coil to sense pit depth over the area beneath it. The coil pairs **34** are arranged in a square grid with 16 rows and 16 columns. The grid measures 6-inches on each side. The number and size of the coil pairs can be altered to make larger or smaller versions of the flexible section **30** or to alter the resolution of the entire system **10**. Each coil pair **34** consists of a send coil **32***a* and a receive coil **32***b*, one on top of the other, exactly aligned.

The flexible section **30** is a printed circuit that contains the coil pairs **34**. The flexible section **30** will conform to the shape of the pipe or structure being assessed, and is stiff enough to reestablish the original contour of the pipe or structure. The flexible section **30** is a printed circuit board, manufactured by the Speedy Circuits Division of PJC Technologies, Inc., 5331 McFadden Avenue, Huntington Beach, Calif. 92649. The section **30** provides the reference surface from which lift-off measurements can be referenced, representing the depth of the defect **20** or feature immediately under a coil pair **34**. The axial and circumferential position of each measurement is acquired from the position of the coil pair **34** within the section **30**.

Referring now to FIG. **3**, eddy current lift-off is the method of pit depth or metal loss measurement in the pipe **22** used by the conformable array **12**. If an alternating electrical current flows in a coil **32**, a magnetic field **33** is created about the coil **32** (FIG. 3A). If the coil **32** is placed near an electrically conducting material, such as the pipe **22**, the magnetic field **33** penetrates the pipe **22** and causes reaction currents **36** (eddy currents) to flow in the pipe **22** (FIG. 3B). The effect of this eddy current **36** is to oppose the force or current that created it, which is manifest as a change in the impedance of the driving coil **32***a*. The amount of change depends, among other things, on the distance between the coil and the electrically conducting material **22**. For crack-like defects the crack itself will impede the eddy current, resulting in a change of coupling, and a sensor change that can be measured.

Referring now to FIG. **4**A, if a single coil **32** of a coil pair **34** is subject to an alternating current, and is placed over an electrically conducting material **22**, the coupling between the active coil **32***a* and the second coil **32***b* of the pair **34** will be altered leading to changes that are manifest as a change in the impedance of the coil **32**. This change in impedance may be detected as a measure of the distance **38** from the coil pair **34** to the conducting surface **22**. Referring now to FIG. **4**B, if the coil pair **34** is placed near the surface of the conducting material **22** with a defect **20** present, the coupling change will be a function of the depth **38** and size of the defect **20**.

Referring again to FIG. **2**, in addition to the flexible section **30**, the array **12** includes two rigid sections **40**, **42** that contain the electronics to address each of the coils **32** individually. This requires thirty-four 16-channel multiplexers. Sixteen 16-channel multiplexers are needed to address the 256 send coils **32***a* with one additional 16 channel multiplexer being required to ensure that only one of the multiplexers is active at any given time. The same holds true for the receive coils **32***b*. Other systems on the rigid sections **40**, **42** generate a sine wave signal, filter the analog portion of the circuits to minimize interference, provide a USB interface, regulate and filter power supplies for both the digital circuits and the analog circuits, and provide oscillators to provide clock and timing for the digital systems.

Referring now to FIG. **5**, these systems of the rigid sections **40**, **42** are shown. The laptop computer **16** connects via the wire **14** to the rigid sections **40**, **42**. Power distribution chip **50** protects the sections **40**, **42** and the laptop computer **16** from power spikes that can be caused by capacitive loads.

USB interface chip **52** is model no. FT245BM, manufactured by FTDI. Chip **52** sends and receives data from and to the laptop **16**. Oscillator **54** is a 6 MHz oscillator to operate the chip **52**. EEPROM **56** is a 1K serial EEPROM that can be programmed from the USB chip **52**. The EEPROM **56** tells the USB chip **52** that it is dealing with a Conformable Array. Data lines **58** are outputs from a microcontroller **60**. This is where the coil data is sent from the microcontroller **60** for transfer to the laptop computer **16**. Connector **61** is used to program the microcontroller **60**.

The microcontroller **60** is model no. MSP430X14X, manufactured by Texas Instruments. The microcontroller **60** controls all the functions of the array **12**. The microcontroller **60** is used to address multiplexers that select a single coil pair **34** for activation. The microcontroller **60** sends a digital stream to a direct digital synthesizer **62**, telling it to output a 4.2 MHz sine wave. The synthesizer **62** is model no. AD9834, manufactured by Analog Devices. The microcontroller **60** sends an output voltage via a 4-channel multiplexer, model no. ADG704, manufactured by Analog Devices. The multiplexer simply outputs 2.5 volts, which is connected to a lamp in a switch **64** through various resistors that simply increase the current to the lamp causing it to flicker or flash. The switch **64** is a data acquire button. When it is depressed it takes 3.3 volts on one of the resistors to ground, which then takes a pin of the microcontroller **60** to ground, initiating data capture.

The sine wave from the digital synthesizer **62** is output into a 6 pole Butterworth low pass filter **66**. The filter **66** is made from model no. AD8039, manufactured by Analog Devices. The filter **66** removes signals at a frequency greater than 7 MHz. The output of the filter **66** is directed to a high pass filter that removes signals below 106 kHz, and is then input to a high-speed, high-current buffer amplifier **68** to provide the necessary drive current to the send coil **32***a*. The amplifier **68** is model no. BUF634, manufactured by Texas Instruments. A capacitor **70**, 1000 pF, creates a resonant circuit with the drive coil at 4.2 MHz.

The output of the drive amplifier **68** is routed to the input of a 16-channel multiplexer **80**, model no. ADG706, manufactured by Analog Devices.

The multiplexer **80** connects to sixteen 16-channel multiplexers, **82-112**, which are each model no. ADG726, manufactured by Analog Devices. These multiplexers **82** to **112** are in a dual 16-channel packages.

Each of the multiplexers **82-112** is connected to a row of coils **32**. The lowest 4 bits of the binary address counter cause each of the 16 multiplexers **82-112** to address one coil **32** of each row at a time. All sixteen multiplexers **82-112** are doing this coil sweep continuously and at the same time. The multiplexer **80** ensures that only one coil **32** is being activated at any given time. The multiplexer **80** couples the output of the driver amp **68** to a single multiplexer **82-112** at a time. For example, on initial startup the binary address count is 0000 0000. The lowest 4 bits, 0000 to 1111 address the A1 to A16 outputs of the multiplexers **82-112** and the top 4 bits, 0000 address the multiplexer **80** to output drive signal to only the first of the multiplexers **82-112**. As the count progresses the driver signal remains connected to the same multiplexer until the bottom 4 bits have reached 1111, which will be the sixteenth coil in row **1**. At this time the bottom 4 bits return to 0000 but the top 4 bits change to 1000. This then routes the drive signal to the second multiplexer of the group **82-112**, and the process begins again. In this manner all coils are independently activated.

The output of the drive amplifier **68** is also routed to the input of a 16-channel multiplexer **114**, model no. ADG706, manufactured by Analog Devices.

The output of the multiplexer **114** is the input to a 1000 pF capacitor **116**, which is used to create a resonant circuit with the inductance of the receive coil at 4.2 MHz. The output of the multiplexer **114** is also the input to a non-inverting amplifier **118**, model no. AD8038, manufactured by Analog Devices. A half-wave rectifier at the output of the amplifier **118** converts the AC 4.2 MHz output signal to a DC level, which is the input to a dual operational amplifier **120**, model no. AD8572, manufactured by Analog Devices. The first stage is simply a non-inverting amplifier with a digitally controlled gain. The gain is set by a digital potentiometer, which takes its gain setting from the microcontroller. The output of stage **1** is also the input to the microcontroller. The output of stage **1** is the input to the second stage of this amplifier. This second stage is a low pass filter with a cutoff frequency of 1.2 kHz. This filter ensures a cleaner signal than may be available at the stage **1** output. This output is input to the microcontroller. In video mode the output of stage **1** input of the microcontroller is the active port. When the acquire data button **64** is depressed it makes the output of stage **2** of the final stage of the receive amplifier the active port. At this time the microcontroller **60** samples each received signal multiple times and averages the response. This average value is then sent to the USB interface chip **52** to be sent to the laptop computer **16**.

In operation, the laptop computer **16** is used to acquire the data from each coil pair **34**. When these measurements are acquired, they are input to the conformable array analysis software where the signal is compensated according to the response curve previously established by a calibration procedure to produce an accurate map of the defect **20** or imperfection being assessed. This defect map can then be used to assess the defect **20** or imperfection and determine the affect that the defect or imperfection will have on the integrity of the structure being assessed. The software produces a contour map of the defect **20**. The map identifies the location and depth of all features within the scan area, and calculates the maximum safe operating pressure if the structure is a high pressure pipeline **22**. The software allows an operator to calibrate measurements and record other pertinent information for record keeping purposes.

Prior to device operation each of the 256 transducer coil pairs **34** must be calibrated to develop the individual response curve for that transducer pair **34**. This is done by providing a series of known distances from mild steel (or material similar to the material of the structure being assessed if the structure is made from electrically conducting material other than steel) to the coil pairs (called "lift-off") and measuring the receiver response. As calibration points are acquired for various lift-off distances they are fit to a polynomial curve. When sufficient calibration points are acquired, the coefficients of the polynomial curve are calculate and stored. Each transducer pair **34** will have a set of four polynomial coefficients which define its response to distance between the coil pair and the conducting surface. When calibration is complete, the calibration coefficients are written to, and stored in, the microprocessor on the array printed circuit card. This calibration data will reside with the array **12** during its life or until such time as a new calibration procedure is executed

Although this description applies to an array consisting of 256 transducers arranged in 16 rows and 16 columns, designed for a resonant frequency of 4.2 MHz, the size of the array can be changed, and the resonant frequency can be changed.

When the array **12** is first activated by the laptop computer **16**, the display and analysis software requests calibration information from the microprocessor **60**. The microprocessor **60** sends the stored calibration coefficient data back to the array software through the USB cable **14** where it will be stored and used to process that scan. (The calibration data is stored in the microprocessor **60** using a calibration procedure applied to each assembly prior to use.)

The laptop computer **16** sends a "New Scan" command to the Conformable Array circuit board through a USB cable. The laptop computer **16** provides power to the electronics on the array printed circuit board through the USB cable **14**. The "New Scan" command initiates the microprocessor **60** on the array **12** which in turn enables thirty-four 16-channel multiplexers. Sixteen 16-channel multiplexers are needed to address the 256 send coils with one additional 16 channel multiplexer being required to ensure that only one of the multiplexers is active at any given time. This ensures that only one coil is active. The array cycles through all 256 coils sequentially. The same holds true for the receive coils.

The send coils **32***a* and receive coils **32***b* are printed on the printed circuit card, one on top of the other, exactly aligned. The microprocessor enables a Direct Digital Synthesis (DDS) system located on the array. The DDS is programmed to output a sine wave drive signal at a frequency of 4.2 MHz and of known fixed amplitude. The frequency (4.2 MHz) is chosen such that the "send coil" **32***a* resonates with a 1000 pF capacitor in air. The receiver coil **32***b* also resonates with a 1000 pF capacitor in air. This 4.2 MHz signal is amplified and buffered and used to drive each of the 256 sender transducers sequentially in turn. The individual transducers are addressed by the microprocessor **60**. The send and receive transducers of a sensor pair **34** are activated in unison. When the array is in close proximity to electrically conducting material the electromagnetic coupling between the coils **32** will be altered and the impedance of the transducer coils changed. The coils will no longer be resonant with the 1000 pF capacitors, and the amplitude of the coupled signal from the receive coil will change. Operating in the resonance range increases the dynamic range of the system **10**. The magnitude of the change will be proportional to the change in inductance of the coil which is proportional to the distance **38** between the coil **32** and the conducting material **22**. The receiver signal is rectified and filtered to provide a DC voltage proportional to lift-off. In the video scan mode the microprocessor will digitize the DC level and send it to the Conformable Array software for viewing. The software will read the amplitude of the signal and apply the appropriate compensation coefficients previously received from the microprocessor prior to displaying the signal as a color contour map. After compensation, the displayed signal will be proportional to the depth **38** of the defect **20**. In this viewing mode each transducer **34** is scanned once by the microprocessor. When the acquire data command is sent to the microprocessor an additional filter is activated to remove minor ripple from the DC level and each receive transducer **34** is scanned multiple times, and an average value stored in the microprocessor. When all 256 transducers **34** are scanned the full data set is sent to the display software for visual inspection and analysis.

In operation the pipe **22** or other structure to be investigated is exposed or otherwise made available to the technician using the conformable eddy current array **12**. The pipe **22** or structure is cleaned to remove lose debris and electrically conducting deposits that may exist in the defect **20** or imperfection being assessed. The conformable eddy current array **12** is attached to a laptop computer **16**, and operated from the conformable array software residing on the laptop computer. The conformable array **12** is positioned over the defect **20** to be assessed. A contour map representing the length, width, and depth of the defect **20** is visible to the operator on the laptop computer. The operator presses the acquire data button **64** on the array **12**. The conformable array **12** takes and averages multiple readings from each transducer **34**, and sends the final data to the software. If the structure being evaluated is a pipe **22**, the software will immediately calculate the affect of the defect **20** on the operating properties of the pipe using commonly applied methods. The system **10** will alert the operator to input certain calibration measurements to ensure accuracy of the readings. If the area to be assessed is larger than the size of the active portion of the array **12**, it can be assessed using multiple scans with the array **12** being carefully repositioned between each scan. The software is capable of stitching the multiple scans into a singe contour map of the defect **20**.

The invention claimed is:

1. A method of producing a color contour map showing the locations, length, width, and depth of all surface defects within a chosen area of the surface of a high pressure pipeline, comprising the steps of:

a. Calibrating each coil pair, each coil pair consisting of a send transducer coil aligned on top of a receive transducer coil, in a flexible array of transducer coil pairs to produce calibration coefficients for each pair;

b. Storing the calibration coefficients in a microprocessor connected to the flexible array;

c. Placing the flexible array of transducer coil pairs on the chosen area of the surface of the pipeline;

d. Tuning a receive circuit connected to the coils to a resonant frequency;

e. Sequentially and independently activating each coil, and activating in unison the send transducer coil and the receive transducer coil of each coil pair, operating the transducer coil pairs in a send/receive mode;

f. Measuring the changes in magnitude of a signal from the receive transducer coil, and applying the calibration coefficients to those changes to produce calibrated changes; and

g. From those calibrated changes, producing a color contour map showing the locations, length, width, and depth of the surface defects in the chosen area.

2. The method according to claim **1**, wherein the resonant frequency is 4.2 MHz.

3. The method according to claim **1**, wherein the array comprises a square grid with sixteen rows and sixteen columns of transducer coil pairs.

4. The method according to claim **1**, further comprising the step of calculating the maximum safe operating pressure of the pipeline.

5. A system for producing a color contour map showing the locations, length, width, and depth of all surface defects within a chosen area of the surface of a high pressure pipeline, comprising:

a. a flexible printed circuit board;

b. a two dimensional array of transducers printed on the flexible circuit board, wherein each element of the array comprises a pair of two transducer coils, and wherein each transducer coil pair comprises a send coil aligned on top of a receive coil;

c. a microprocessor on the flexible printed circuit board, and connected to the array, the microprocessor adapted for storing calibration coefficients for each pair of transducer coils;

d. multiplexers on the flexible printed circuit board, and connected to the array, the multiplexers adapted for addressing each of the coil pairs individually;

e. a microcontroller on the flexible printed circuit board, and connected to the array, the microcontroller adapted for controlling all the functions of the array; and

f. a USB interface on the flexible printed circuit board, and adapted for connecting the flexible printed circuit board to a computer,

wherein a receive circuit connected to the coils is tuned to a resonant frequency, and the transducer coils operate in a send/receive mode.

6. The system according to claim **5**, further comprising means for converting a change in measured resonance to a visual display of the length, depth, and width of the surface defect.

7. The system according to claim **5**, further comprising a square grid with sixteen rows and sixteen columns of transducer coil pairs.

8. The system according to claim **5**, wherein the resonant frequency is 4.2 MHz.

* * * * *