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- (73) Patenthaver: **General Electric Company, 1 River Road, Schenectady, NY 12345, USA**
- (72) Opfinder: **CAMPBELL, Lam Arthur, 4425 Westway Park Boulevard, Houston, TX 77041, USA**
SIPILÄ, Pekka Tapani, Freisinger Landstrasses 50, 85748 Garching N. Munich, Tyskland
- (74) Fuldmægtig i Danmark: **O3C Konsult AB (A Questel Company), PO Box 6088 , 17106 Solna, Sverige**
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DESCRIPTION

BACKGROUND OF THE INVENTION

[0001] The subject matter described herein relates generally to stress sensing in ferromagnetic materials, and more particularly, to non-contact systems and methods for the sensing of stress in ferromagnetic materials.

[0002] Ferromagnetic materials have a magnetostrictive property that causes the materials to change shape in the presence of an applied magnetic field. The inverse is also true. When a force is applied to a ferromagnetic material, the magnetic properties, such as magnetic permeability, of the material change. A magnetostrictive sensor may sense the changes in magnetic permeability and, because the changes are proportional to the amount of stress applied to the ferromagnetic material, the resulting measurement may be used to calculate the amount of stress.

[0003] The changes in the magnetic permeability due to stress applied to the ferromagnetic material, however, may be small, making accurate measurement difficult. At least some known magnetostrictive sensors are used with a ferromagnetic material that has had a magnetic field permanently induced in at least a portion of the material to facilitate measuring the stress in the material. This step may require magnetically encoding the material to be sensed. Such an operation is typically expensive. In addition, such an operation makes it more difficult to retrofit existing systems with a magnetostrictive sensing system because the material to be sensed may have to be removed from the system to undergo permanent magnetic encoding, e.g., a shaft of a gas turbine engine. In at least some other magnetostrictive sensing systems, a temporary magnetic field is induced in a ferromagnetic material, and a magnetic field detector senses transient changes to the magnetic field. In such a system, steady state stress measurements may not be accurately measured or may be necessarily difficult to acquire.

[0004] WO 2012/152720 A1 discloses a magnetic based contactless measuring sensor and a magnetic based contactless measuring method allowing contactless measuring without the need of pre-processing the sensing object. The sensor may measure at least one of a distance, a motion or a speed with respect to an object being sensed, or a torque or a force applied to an object being sensed. A first magnetic field generator unit generates a magnetic field towards the object to be sensed. A first magnetic field detector unit is adapted for detecting a first magnetic field generated by the first field generator unit and being influenced by a respective distance, motion, speed, applied torque and applied force to be measured, and for outputting a first signal representative for the detected magnetic field. A second magnetic field generator unit and a second magnetic field detector unit may also be used. It is then possible to evaluate the difference between the first and second signals and the difference used to eliminate disturbing effects. A field generator coil is driven by either a DC or a specific AC signal and with this produces magnetic flux beneath the surface of the test object.

BRIEF DESCRIPTION OF THE INVENTION

[0005] In one aspect, a system for sensing stress in a ferromagnetic material is provided according to claim 1.

[0006] In another aspect, a method for measuring stress in a ferromagnetic material is provided according to claim 6.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007]

FIG. 1 is a schematic view of a system for sensing stress in a ferromagnetic material;

FIG. 2 is a schematic view of the stress sensing system shown in FIG. 1 showing options for transmitting power to a sensor head and, optionally, a magnetic flux device;

FIG. 3 is a schematic view of an alternative embodiment of the stress sensing system shown in FIG. 1 that is configured for measuring both steady state and transient torque in a ferromagnetic rotatable shaft;

FIG. 4 is a perspective view of a sensor head that may be used with the stress sensing system shown in FIG. 3;

FIG. 5 is a graph that shows the effect in signal linearity and hysteresis of a conditioning magnetic flux applied to a rotatable shaft by the torque sensing system shown in FIG. 3; and

FIG. 6 is a flow chart of an exemplary method for measuring stress in a ferromagnetic material using the stress sensing system shown in FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

[0008] FIG. 1 (not according to the invention) is a schematic view of a stress sensing system 10 for sensing the stress in a ferromagnetic material 12. Stress sensing system 10 includes a magnetic flux device 22 for inducing a first conditioning magnetic flux 23 in ferromagnetic material 12. Conditioning magnetic flux 23 induced in ferromagnetic material 12 facilitates increasing the signal-to-noise ratio (SNR) of the magnetic signal to be detected and signal linearity, and reduces the hysteresis associated with stress sensing system 10. By increasing the SNR, magnetic flux device 22 facilitates measuring stresses in ferromagnetic material 12 with less total current being required to operate stress sensing system 10. The lower current

requirement permits stress sensing system 10 to be operated in hazardous environments where prior magnetostrictive sensors could not be used.

[0009] As used herein, the term "hysteresis" refers to the irreversibility in magnetic permeability of a ferromagnetic material with respect to the applied stress inducing it. In addition, the term "hysteresis loop" refers to a closed curve representing the variation of the magnetic permeability of a ferromagnetic material with respect to the applied stress as the applied stress is changed through a complete cycle.

[0010] In the exemplary embodiment (not according to the invention), magnetic flux device 22 is a coil located proximate a sensor head 14 and ferromagnetic material 12. Magnetic flux device 22 is driven by either a direct current (DC) source or an alternating current (AC) source (neither shown in FIG. 1), the choice of which is in part dependent on the geometry of ferromagnetic material 12. Alternatively, magnetic flux device 22 may be any magnetic field inducing device that enables stress sensing system 10 to operate as described herein, for example, without limitation, magnetic flux device 22 may be a permanent magnet.

[0011] Stress sensing system 10 includes a sensor head 14 positioned proximate to ferromagnetic material 12 with a gap 13 defined between sensor head 14 and ferromagnetic material 12. Sensor head 14 is typically coupled to a frame or fixture (not shown) to maintain the sensor head 14 in the proper orientation. In addition, generally, sensor head 14 includes electrical coupling to a power supply device (not shown in FIG. 1) for supplying the current necessary to generate the magnetic flux used for sensing the stress in ferromagnetic material 12.

[0012] In the exemplary embodiment (not according to the invention), sensor head 14 includes an excitation coil 16 that is wrapped around a core 18. Core 18 may be fabricated from any ferromagnetic material. Excitation coil 16 has an AC signal is passed through it to induce a second magnetic flux 17 in ferromagnetic material 12. Driving excitation coil 16 with an AC signal to induce second magnetic flux 17 facilitates measuring both transient and steady state stress in ferromagnetic material 12.

[0013] In addition, in the exemplary embodiment (not according to the invention), second magnetic flux 17 permeates ferromagnetic material 12 and returns to excitation coil 16 such that a detector 20 measures second magnetic flux 17. The permeability for regions of ferromagnetic material 12 change because of stresses applied to the material. Detector 20 is configured to transmit a signal (not shown) indicative of these changes, e.g., detector 20 transmits a signal indicative of the changes in second magnetic flux 17 to a processor 24. Detector 20 may be based on several types of magnetic field sensors (magnetometers) including, without limitation, magnetoresistive, flux gate, coil, Hall Effect, and magnetoinductive sensors. Selection of a specific magnetic field sensor depends upon certain characteristics, such as, without limitation, flux density, resolution, accuracy, and number of magnetic axes.

[0014] Processor 24 processes the signal received from detector 20 by using standard

electronics, e.g., without limitation, an amplifier and a filter. The signal from detector 20 may be communicated by wire or wireless methods. Wireless communication devices such as radio transmitters (not shown) may be integrated within stress sensing system 10 and mounted about sensor head 14 to transmit the signals to a receiver (not shown) of processor 24. Processor 24 is any known processor, such as, without limitation, a microprocessor or other computing device. Processor 24 may be co-located with sensor head 14 or located separate from sensor head 14.

[0015] Alternatively, stress sensing system 10 may be fabricated as a packaged unit with sensor head 14 and magnetic flux device 22 being formed unitarily. In one such embodiment, magnetic flux device 22 includes excitation coil 16. In another such embodiment, where detector 20 is a coil, magnetic flux device 22 includes detector 20. In further alternative embodiments, magnetic flux device 22 may be a permanent magnet coupled directly to sensor head 14.

[0016] In the system according to the invention, the detector 20 is a coil and has two functions: The coil operates simultaneously as an excitation coil, such as excitation coil 20, and a detection coil, such as detector 20. According to the invention the coil is driven simultaneously by both an AC and a DC source. In addition, the AC source may simultaneously transmit signals to the coil at two or more different frequencies.

[0017] In the exemplary embodiment, magnetic flux device 22 induces conditioning magnetic flux 23 in ferromagnetic material 12. The conditioning magnetic flux 23 and second magnetic flux 17 generated by magnetic flux device 22 and excitation coil 20, respectively, may be either parallel or perpendicular to each other. In the exemplary embodiment, where magnetic flux device 22 is a coil located proximate sensor head 14 and ferromagnetic material 12, the conditioning magnetic flux 23 is parallel to the generated second magnetic flux 17. Alternatively, where magnetic flux device 22 is a permanent magnet, the conditioning magnetic flux 23 may be perpendicular to the second magnetic flux 17.

[0018] In some alternative embodiments, additional sensors, for example proximity, magnetic field, or temperature, may be positioned proximate ferromagnetic material 12. Proximity sensors may be used to monitor gap 13 defined between ferromagnetic material 12 and sensor head 14. Additional magnetometers may be used to monitor background magnetic fields, such as, without limitation, the earth's magnetic field and extraneous electromagnetic interference (EMI). In addition, temperature sensors may be used to monitor temperature changes. Gap changes, temperature changes, and background EMI may affect the signal received by detector 20. By monitoring gap 13, temperature changes, and background EMI, the magnitude of the assorted effects may be substantially reduced by processor 24.

[0019] In operation, detector 20 measures a change in magnetic field strength in ferromagnetic material 12 proximate the sensor head 14. The measurements of detector 20 are transmitted to processor 24 and then to a programmable logic unit 34 (not shown in FIG. 1) located away from ferromagnetic material 12. Programmable logic unit 34 is configured to

process signals received from sensor head 14 to obtain a measurement of the stress in ferromagnetic material 12.

[0020] FIG. 2 is a schematic view of stress sensing system 10 showing options for transmitting power to sensor head 14 and, optionally, magnetic flux device 22. Such options include Option A, Option B, and Option C, each further described below. As shown in Option A, stress sensing system 10 includes a battery 26. Battery 26 transmits power to sensor head 14 and, if required, to magnetic flux device 22 through processor 24. In an alternative embodiment, Option A also includes a data logger 28. Data logger 28 collects data from sensor head 14 through processor 24. Such data may be retrieved and analyzed to provide non-real time information on the stresses being applied to ferromagnetic material 12. The data also may be used to provide real-time input for controls, as in Option B, and therefore may not be logged. Alternatively, the data may be both logged by data logger 28 and used to provide real-time input for controls.

[0021] As used herein, the term "real-time" refers to at least one of the time of occurrence of the associated events, the time of measurement and collection of predetermined data, the time to process the data, and the time of a system response to the events and the environment. In the embodiments described herein, these activities and events occur substantially instantaneously.

[0022] As shown in Option B, stress sensing system 10 includes a wireless power supply device 30, a wireless communication system 32, and programmable logic unit 34. Wireless power supply device 30 is any power source that enables operation of stress sensing system 10 as described herein, including, without limitation, an inductive power supply. In the exemplary embodiment, wireless power supply device 30, wireless communication system 32, and programmable logic unit 34 are located apart from sensor head 14. Alternatively, wireless power supply device 30, wireless communication system 32, and programmable logic unit 34 may be positioned in any location that enables stress sensing system 10 to operate as described herein.

[0023] As shown in Option C, the power to sensor head 14 and, optionally, magnetic flux device 22, and data transfer from sensor head 14 occurs through processor 24. A wired power supply device 36 transmits power to sensor head 14. Additionally, a wired communication system 38 transfers the data between sensor head 14 and processor 24. Alternatively, data transferred from sensor head 14 to wired communication system 38 may be stored in a storage medium (not shown) of programmable logic unit 34.

[0024] In alternative embodiments, Options B and C of stress sensing system 10 may include a battery, such as, without limitation, battery 26 (shown with Option A). Battery 26 may be used to transmit power to stress sensing system 10 during a power failure. In such alternative embodiments, during normal operation, battery 26 may be in a stand-by mode.

[0025] FIG. 3 is a schematic view of an alternative embodiment of stress sensing system 10

that is configured for measuring both steady state and transient torque in a ferromagnetic rotatable shaft 112. A torque sensing system 100 includes a magnetic flux device 122 for inducing conditioning magnetic flux 23 in rotatable shaft 112. In the exemplary embodiment, rotatable shaft 112 is a shaft fabricated from a ferromagnetic material. Magnetic flux device 122 is a permanent magnet that is adjacent to, but does not contact, rotatable shaft 112. Alternatively, magnetic flux device 122 may include any magnetic field inducing device that enables torque sensing system 100 to operate as described herein. For example, without limitation, magnetic flux device 122 may be a coil located proximate a sensor head 114 and rotatable shaft 112.

[0026] In the exemplary embodiment, sensor head 114 includes a core 118. Core 118 may be fabricated from any magnetic material, e.g., without limitation, iron. Core 118 includes a cross axis yoke 124. In addition, in the exemplary embodiment, core 118 includes four members 130, 132, 134, 136 that extend planarly outward from a yoke portion 128. The four members 130, 132, 134, 136 are substantially orthogonal to each other around yoke portion 128. Furthermore, each of the four members 130, 132, 134, 136 terminates in an end distal from yoke portion 128. In alternative embodiments, yoke 124 can have any number of members and any configuration that permits yoke 124 to operate as described herein. Furthermore, each member may extend from yoke portion 128 in any configuration and for any length that permits each member to operate as described herein.

[0027] FIG. 4 is a perspective view of sensor head 114. In the exemplary embodiment, an excitation pole element 138 extends outward from yoke portion 128 perpendicular to a planar surface defined by yoke 124. In addition, four member pole elements 140, 142, 144, 146 extend outward from yoke 124 substantially perpendicular to the planar surface defined by yoke 124 and substantially parallel to excitation pole element 138. In the exemplary embodiment, member pole element 140 extends from the distal end of member 130, member pole element 142 extends from the distal end of member 132, member pole element 144 extends from the distal end of member 134, and member pole element 146 extends from the distal end of member 136. In alternative embodiments, core 118 may have any number of pole elements extending from yoke 124 in any configuration that allows core 118 to operate as described herein.

[0028] In the exemplary embodiment (not according to the invention), sensor head 114 includes an excitation coil 116 wound around excitation pole element 138. In addition, a detection coil 120 is wound respectively around member pole elements 140, 142, 144, 146. More particularly, one detection coil 120 is wound around member pole element 140, one detection coil 120 is wound around member pole element 142, one detection coil 120 is wound around member pole element 144, and one detection coil 120 is wound around member pole element 146. In the exemplary embodiment (not according to the invention), during operation, an AC signal is passed through excitation coil 116 to induce second magnetic flux 17 in rotatable shaft 112. Second magnetic flux 17 flows from the excitation pole element 138 of the core 118, through rotatable shaft 112, and returns back to member pole elements 140, 142, 144, 146 of the core 118 where detection coils 120 sense the amount of returning second

magnetic flux 17.

[0029] Alternatively, torque sensing system 100 may be fabricated as a packaged device with sensor head 114 and magnetic flux device 122 being formed unitarily. In one such embodiment, magnetic flux device 122 may be a permanent magnet coupled directly to sensor head 114. Alternatively, magnetic flux device 122 may include at least one of excitation coil 116 and detection coil 120.

[0030] The conditioning magnetic flux 23 and second magnetic flux 17 generated by magnetic flux device 122 and excitation coil 116, respectively, may be either parallel or perpendicular to each other. In the exemplary embodiment, where magnetic flux device 122 is a permanent magnet, the conditioning magnetic flux 23 is perpendicular to the second magnetic flux 17. Alternatively, where magnetic flux device 122 may be one of excitation coil 116 and detection coil 120, the conditioning magnetic flux 23 may be parallel to the second magnetic flux 17.

[0031] In the exemplary embodiment, a torque T is applied to rotatable shaft 112. Torque T applies stress along a direction offset $\pm 45^\circ$ from the axis of rotation of rotatable shaft 112. This stress includes both a compressive stress $-\sigma$ and a tensile stress $+\sigma$. The magnetic permeability of rotatable shaft 112 is different in the direction of compressive stress compared with the direction of tensile stress. Detection coil 120 is configured to sense the difference in magnetic permeability. In the exemplary embodiment, torque τ is a force applied to rotatable shaft 112. Other external forces, however, may be applied to rotatable shaft 112 and sensed by torque sensing system 100.

[0032] As used herein, the term "magnetic permeability" refers to the relative increase or decrease in the magnetic flux inside a material compared with the magnetic field in which the material is located.

[0033] FIG. 5 is a graph that shows the effect in signal linearity and hysteresis of conditioning magnetic flux 23 applied to rotatable shaft 112 by torque sensing system 100. Curve 505 is the torque signal received from sensor head 114 with conditioning magnetic flux 23 induced in rotatable shaft 112. Curve 510 represents the torque signal without conditioning magnetic flux 23 induced in rotatable shaft 112. In the exemplary embodiment, curve 505 exhibits more linearity than curve 510 exhibits. In addition, the hysteresis loop of curve 505 is narrower than the hysteresis loop of curve 510, indicating an improvement in the hysteresis associated with torque sensing system 100.

[0034] FIG. 6 is a flow chart of an exemplary method 600 for measuring stress in a ferromagnetic material using exemplary stress sensing system 10. In the exemplary embodiment, a first, i.e., conditioning magnetic flux 23 is induced 602 in ferromagnetic material 12. In the exemplary embodiment, an auxiliary coil driven by either a DC or an AC signal is used to induce conditioning magnetic flux 23. Alternatively, conditioning magnetic flux 23 may be induced with a permanent magnet. Further, second magnetic flux 17 is induced 604 in ferromagnetic material 12. In the embodiment according to the invention, second magnetic flux

17 is induced with excitation coil 20, which is part of sensor head 14. Sensor head 14 is positioned proximate ferromagnetic material 12 with a gap 13 defined between excitation coil 20 and sensor head 14. In addition, changes in second magnetic flux 17 induced in ferromagnetic material 12 are detected 606 by detector 20. In the embodiment according to the invention, detector 20 is a coil wrapped around at least a portion of core 18 of sensor head 14. Alternatively, detector 20 may be one of several types of magnetic field sensors including, without limitation, flux gate, coil and magnetoinductive sensors. Detector 20 is configured to transmit a signal indicative of the changes in second magnetic flux 17, wherein the changes in second magnetic flux 17 are a result of stress in ferromagnetic material 12.

[0035] In contrast to known magnetostrictive sensors, the stress sensing systems as described herein facilitate inducing a conditioning magnetic flux in a ferromagnetic material to increase the signal-to-noise ratio and linearity of the measurement of second magnetic flux, inducing the second magnetic flux, and detecting the changes in the second magnetic flux due in part to stresses applied to the ferromagnetic material. Specifically, the stress sensing systems as described herein facilitate inducing a conditioning magnetic flux in a ferromagnetic material using magnetic field inducing devices such as coils driven by either a DC source or an AC source, and permanent magnets. The second magnetic flux is induced into the ferromagnetic material by a coil adapted to be driven simultaneously by both a direct current DC and alternating current AC to facilitate measuring both transient and steady state stress in the ferromagnetic material. Detecting the changes in the second magnetic flux includes using magnetic field sensors (magnetometers) such as magnetoresistive, flux gate, coil, Hall Effect, and magnetoinductive sensors. Therefore, in contrast to known magnetostrictive sensors, the stress sensing systems as described herein facilitate increasing SNR and signal linearity in the stress sensing system in a manner that reduces costs and simplifies installation. Also, in contrast to known magnetostrictive sensors, the stress sensing systems as described herein facilitates measuring both transient and steady-state stresses in the ferromagnetic material.

[0036] Some embodiments involve the use of one or more electronic or computing devices. Such devices typically include a processor or controller, such as a general purpose central processing unit (CPU), a graphics processing unit (GPU), a microcontroller, a reduced instruction set computer (RISC) processor, an application specific integrated circuit (ASIC), a programmable logic circuit (PLC), and/or any other circuit or processor capable of executing the functions described herein. The methods described herein may be encoded as executable instructions embodied in a computer readable medium, including, without limitation, a storage device and/or a memory device. Such instructions, when executed by a processor, cause the processor to perform at least a portion of the methods described herein. The above examples are exemplary only, and thus are not intended to limit in any way the definition and/or meaning of the term processor.

REFERENCES CITED IN THE DESCRIPTION

Cited references

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Patent documents cited in the description

- WO2012152720A1 [0004]

PATENTKRAV

1. System (10) til registrering af spænding i et ferromagnetisk materiale (12), hvilket system omfatter:

mindst én magnetisk flux-indretning (22), der er konfigureret til at inducere en
5 første konditionerende magnetisk flux (23) i det ferromagnetiske materiale (12); og

en sensor (14), som er positioneret nærmest ved det ferromagnetiske materiale (12), idet sensoren omfatter:

en kerne (18);

mindst én excitationsspole (20), der er konfigureret til at inducere en anden
10 magnetisk flux (17) i det ferromagnetiske materiale (12), hvor den mindst ene excitationsspole (20) er viklet omkring kernen (18) og er konfigureret til at blive drevet samtidigt af både en jævnstrøms-(DC)-kilde og en vekselstrøms-(AC)-kilde; og

hvor den mindst ene excitationsspole (20) er konfigureret til at blive drevet samtidigt som en excitationsspole (20) og som en detektor (20), der er
15 konfigureret til at detektere ændringer i den anden magnetiske flux (17) forårsaget af spænding, som er påført det ferromagnetiske materiale (12).

2. System ifølge krav 1, hvor kernen (18) omfatter:

et åg (124), der omfatter:

en del (128); og

20 mindst ét led (130, 132, 134, 136), der strækker sig fra delen (128), idet det mindst ene led (130, 132, 134, 136) terminerer i en tilhørende ende distalt fra delen (128);

et excitationselement (138), der strækker sig fra delen (128); og

et ledpolelement (140, 142, 144, 146), der strækker sig fra det mindst ene
25 led (130), hvor hvert ledpolelement (140, 142, 144, 146) i det væsentlige er parallelt med excitationselementet (138).

3. System ifølge krav 1 eller krav 2, hvor den mindst ene magnetisk flux-indretning (22) omfatter mindst én af en permanent magnet og en spole.

4. System ifølge et hvilket som helst foregående krav, hvor sensoren (14) er konfigureret til at måle spænding i det ferromagnetiske materiale (12) uden at
5 komme i kontakt med det ferromagnetiske materiale (12).

5. System ifølge et hvilket som helst foregående krav, hvor systemet (10) er fabrikeret som en pakkeenhed, idet sensoren (14) og den mindst ene magnetiske flux-indretning (22) er dannet som én enhed.

6. Fremgangsmåde (600) til måling af spænding i et ferromagnetisk
10 materiale (12), hvilken fremgangsmåde omfatter:

inducering (602) af en første konditionerende magnetisk flux (23) i det ferromagnetiske materiale (12);

inducering (604) af en anden magnetisk flux (17) i det ferromagnetiske materiale (12) ved anvendelse af mindst én excitationsspole (20), hvor
15 inducering af en anden magnetisk flux i det ferromagnetiske materiale omfatter, at den mindst ene excitationsspole (20) drives samtidigt af både en jævnstrøms-(DC)-kilde og en vekselstrøms-(AC)-kilde; og

detektering (606), ved anvendelse af mindst én detektor (20), af ændringer i den anden magnetiske flux (17), som er induceret i det ferromagnetiske materiale
20 (12), hvor ændringerne i den anden magnetiske flux (17) mindst delvist er korreleret til spænding i det ferromagnetiske materiale (12), og

drift samtidigt af den mindst ene excitationsspole (20) som en excitationsspole (20) og som detektoren (20).

7. Fremgangsmåde ifølge krav 6, hvor inducering af en første
25 konditionerende magnetisk flux (23) i det ferromagnetiske materiale (12) omfatter positionering af mindst én magnetisk flux-indretning (22) i en forudbestemt afstand fra det ferromagnetiske materiale (12).

8. Fremgangsmåde ifølge krav 6, hvor inducering af en første konditionerende magnetisk flux (23) i det ferromagnetiske materiale (12) omfatter inducering af den første konditionerende magnetiske flux (23) med mindst én permanent magnet.
9. Fremgangsmåde ifølge krav 6, hvor inducering af en første
5 konditionerende magnetisk flux (23) i det ferromagnetiske materiale (12) omfatter inducering af den første magnetiske flux (23) med mindst én spole (16).
10. Fremgangsmåde ifølge krav 6, hvor inducering af en anden magnetisk flux (17) i det ferromagnetiske materiale (12) omfatter positionering af den mindst ene excitationsspole (20) i en forudbestemt afstand fra det ferromagnetiske materiale (12).

DRAWINGS

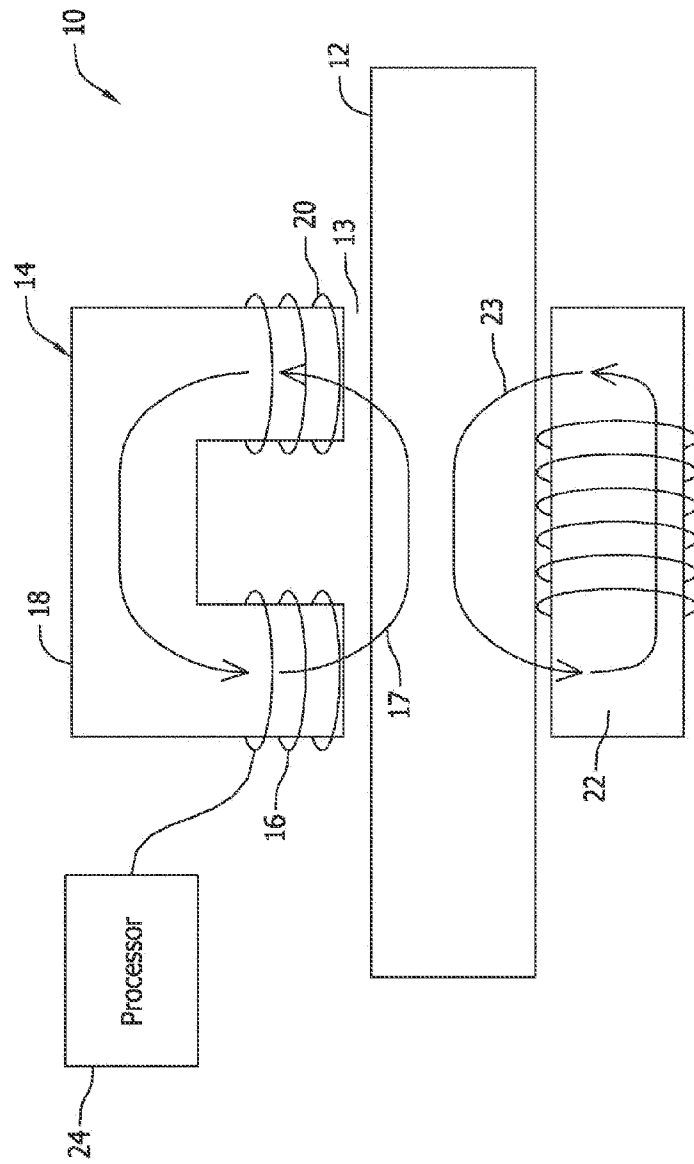


FIG. 1

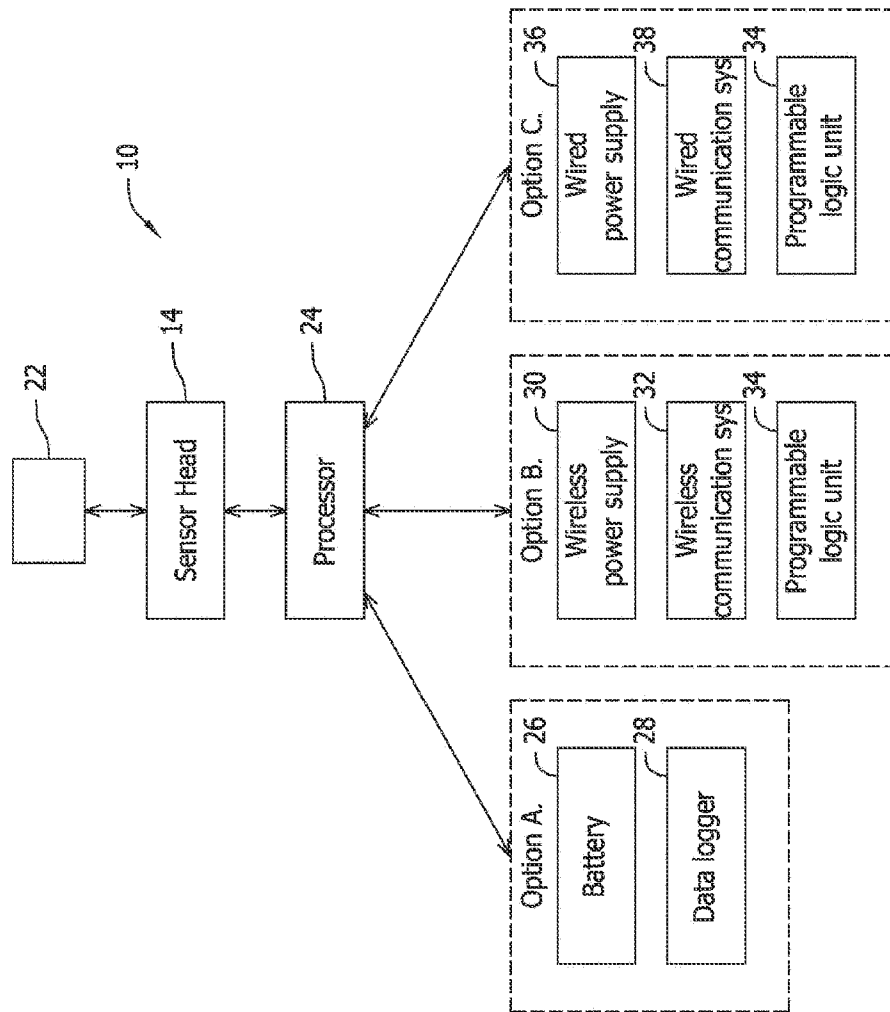


FIG. 2

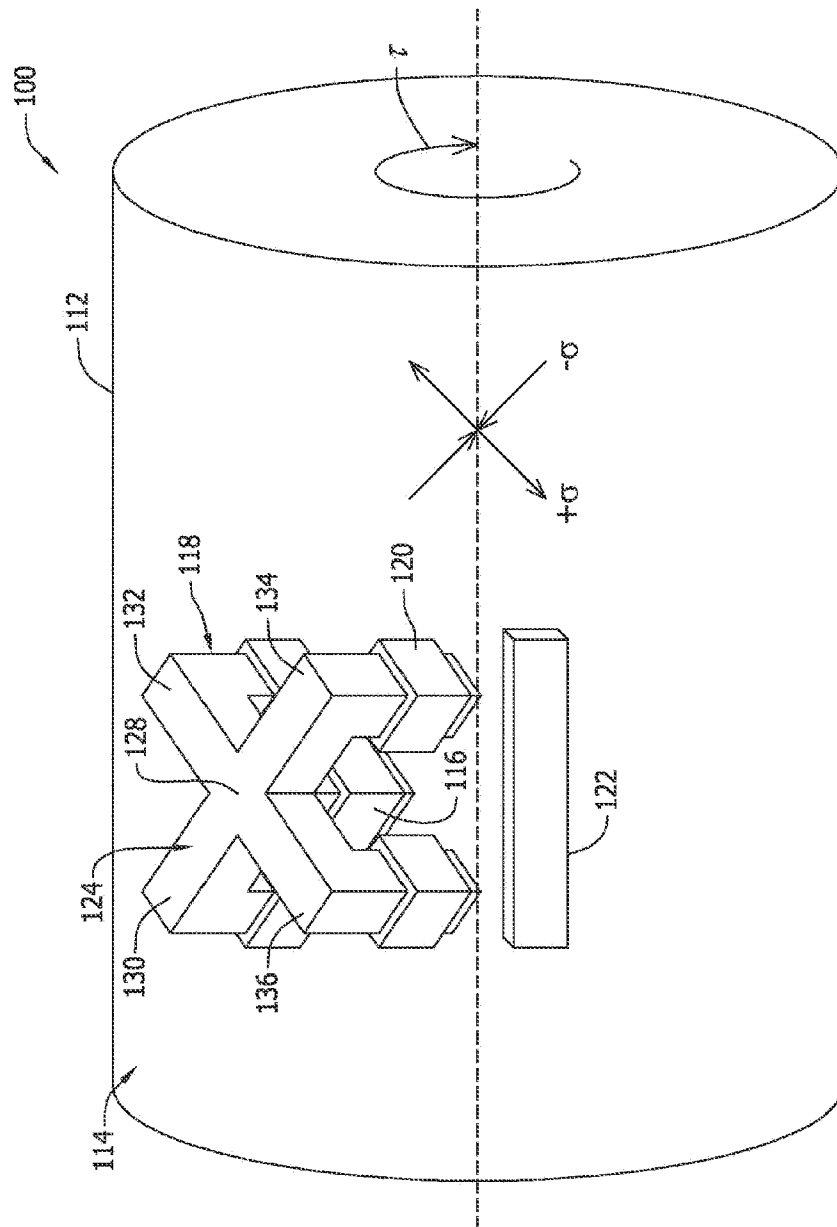


FIG. 3

114

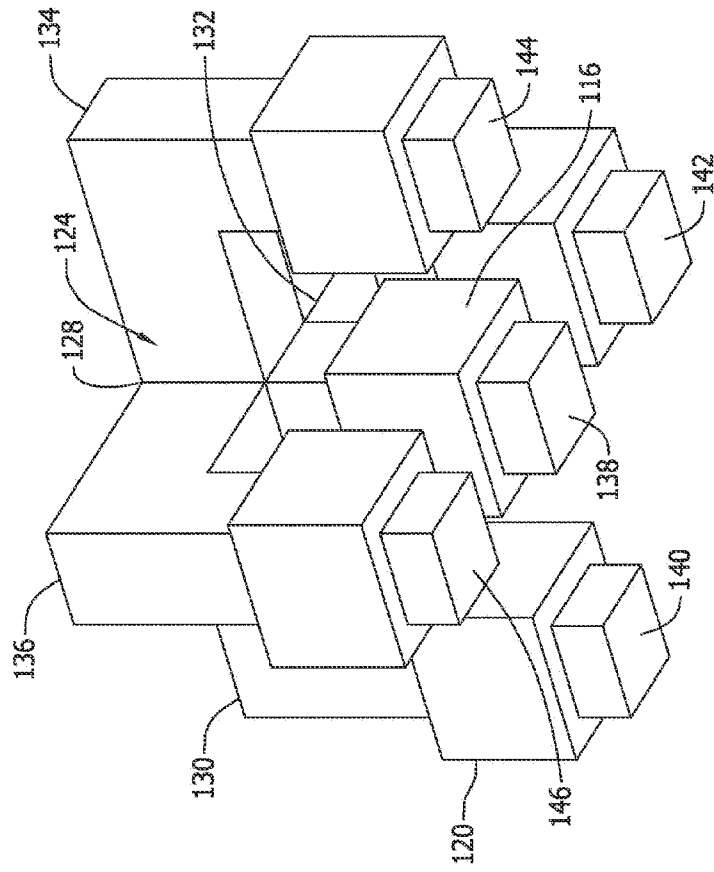


FIG. 4

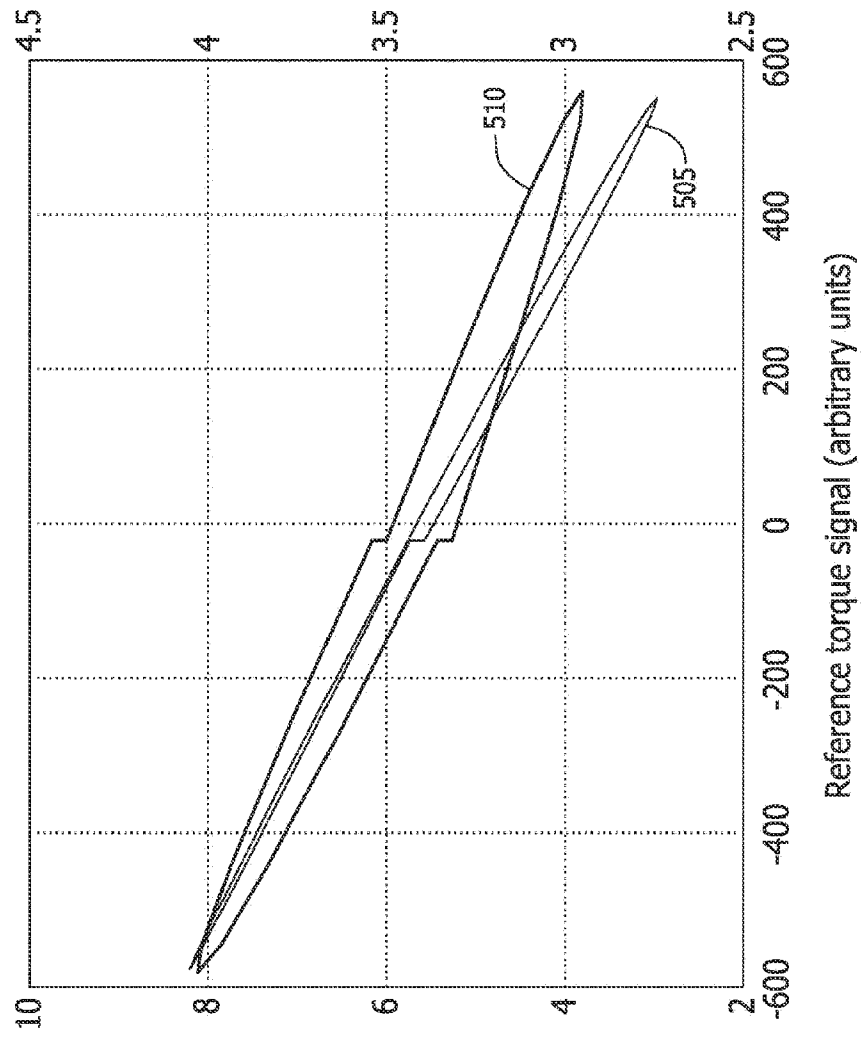


FIG. 5

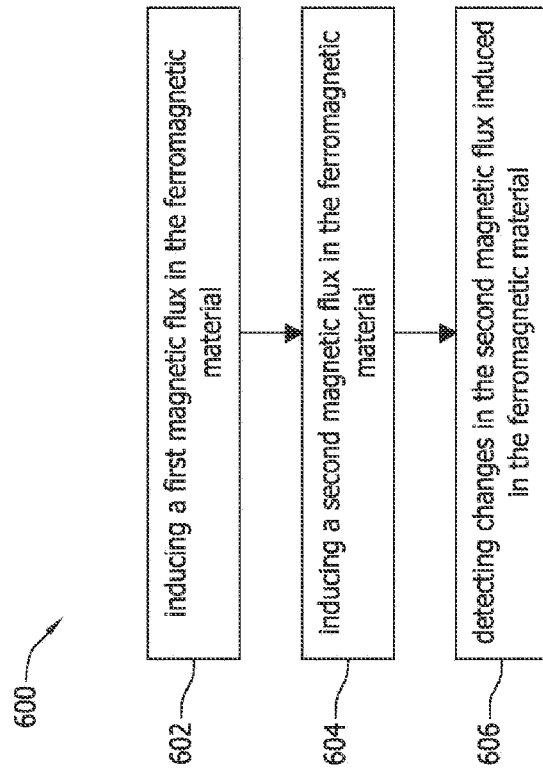


FIG. 6