(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau

(43) International Publication Date
3 December 2015 (03.12.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/183298 A1

(51) International Patent Classification:
G01R 19/25 (2006.01) *G01B 11/02* (2006.01)

(21) International Application Number:
PCT/US2014/040149

(22) International Filing Date:
30 May 2014 (30.05.2014)

(25) Filing Language: English

(26) Publication Language: English

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(54) Title: SYSTEMS FOR MONITORING POWER TRANSFORMERS AND METHOD OF OPERATING THE SAME

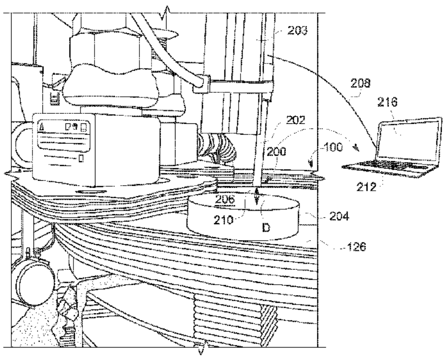

FIG. 3

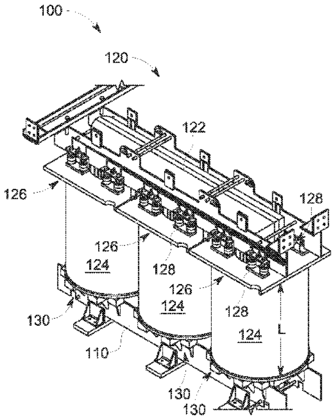

FIG. 2

(57) Abstract: A system for monitoring a transformer includes a fiber optic probe configured to transmit and receive photonic signals and a processor coupled to the fiber optic probe. The transformer includes a winding coil and a top ring assembly coupled to the winding coil. The monitoring system also includes a target reflector positioned proximate the fiber optic probe. The target reflector is configured to receive photonic signals from the fiber optic probe and reflect photonic signals toward the fiber optic probe.

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

SYSTEMS FOR MONITORING POWER TRANSFORMERS AND METHOD OF OPERATING THE SAME

BACKGROUND

[0001] The field of the disclosure relates generally to power transformer monitoring systems and, more particularly, to a fiber optic-based probe to monitor a position of the windings and/or the top ring assembly of a power transformer, thereby determining a clamping force induced on the windings by the top ring assembly..

[0002] Most known alternating current (AC) power systems include power transformers configured to convert electric power at a first voltage to electric power at a second voltage. Many of these known power transformers include internal clamping and positioning devices that clamp the transformer primary and secondary windings. For example, individual windings are separated through key spacers and a frame assembly clamped by a top ring maintains the winding assembly. These devices are installed within the transformer tank prior to sealing at the factory during the manufacturing process.

[0003] The health of the transformer is at least partially related to the clamping pressure of the primary windings. Over time, the clamping and positioning devices for the windings loosen due to, e.g., shocks sustained during transportation, short circuit faults, and aging and depolymerization of insulation materials. For example, many known transformers include an insulating system including cellulose paper immersed in oil. As the cellulose paper ages, effects such as depolymerization cause the paper to become brittle such that the durability against mechanical stresses is substantially reduced. As the insulating paper embrittles and pieces of the paper are transported into the oil, the clamping pressure on the winding coil is reduced.

[0004] Any change in clamping pressure of the windings will result in a change in the distance between the frame and the winding. This change in clamping pressure decreases with time, the associated winding displacement increases with time, and the service life of the power transformer may be reduced if the transformer is not taken out of service and inspected periodically and the windings repositioned and reclamped as necessary. Known monitoring techniques, e.g., frequency response analysis, short circuit impedance measurements, and visual inspections, are limited to offline monitoring. As such, the transformer must be removed from service, at least partially disassembled, and reassembled. These maintenance activities are costly and time-consuming. Also, such techniques as frequency response analysis are subject to inconsistent results as a function of the data being collected under different scan conditions and by different people.

[0005] Online monitoring techniques using installed instrumentation are substantially limited due to the inside of a power transformer being an electromagnetically active environment with monitoring signal interference prevalent therein. Other online monitoring techniques are limited to detection of changes in the audible noise level proximate the power transformer. Such listening is not a reliable indicator of changes in the clamping pressure.

BRIEF DESCRIPTION

[0006] In one aspect, a system for monitoring a transformer is provided. The transformer includes a winding coil and a top ring assembly coupled to the winding coil. The monitoring system includes a fiber optic probe configured to transmit and receive photonic signals. The monitoring system also includes a target reflector positioned proximate the fiber optic probe. The target reflector is configured to receive photonic signals from the fiber optic probe and reflect photonic signals toward the fiber optic probe. The monitoring system further includes a processor coupled to the fiber optic probe.

[0007] In a further aspect, a method of monitoring a transformer is provided. The transformer includes a winding coil and a top ring assembly coupled to the winding coil. The transformer further includes a fiber optic probe and a target reflector positioned proximate the fiber optic probe. The target reflector is configured to receive photonic signals from the fiber optic probe and reflect the photonic signals toward the fiber optic probe. The method includes placing the transformer in service and generating signals representative of a position of the top ring assembly. The method also includes generating signals representative of a clamping force induced on the winding coil by the top ring assembly. The clamping force signals are related to the top ring assembly position signals.

[0008] In another aspect, a transformer is provided. The transformer includes a winding coil and an insulation system coupled to the winding coil. The transformer also includes a top ring assembly coupled to the winding coil. The top ring assembly is configured to induce a clamping force on the winding coil. The transformer further includes a monitoring system configured to monitor the clamping force. The monitoring system includes a fiber optic probe configured to transmit and receive photonic signals. The monitoring system also includes a target reflector positioned proximate the fiber optic probe. The target reflector is configured to receive photonic signals from the fiber optic probe and reflect photonic signals toward the fiber optic probe. The monitoring system further includes a processor coupled to the fiber optic probe.

DRAWINGS

[0009] These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0010] FIG. 1 is a block diagram of an exemplary power transformer;

[0011] FIG. 2 is a schematic perspective diagram of an exemplary transformer winding assembly that may be used with the power transformer shown in FIG. 1;

[0012] FIG. 3 is a schematic diagram of an exemplary system for monitoring a transformer that may be used with the power transformer shown in FIG. 1;

[0013] FIG. 4 is a graphical view of an exemplary relationship between winding clamping pressure and values of an optical sensor signal for the system shown in FIG. 3;

[0014] FIG. 5 is a schematic diagram of an alternative system for monitoring a transformer that may be used with the power transformer shown in FIG. 1; and

[0015] FIG. 6 is a graphical view of an exemplary relationship between winding clamping pressure and values of an optical sensor signal for the system shown in FIG. 5.

[0016] Unless otherwise indicated, the drawings provided herein are meant to illustrate features of embodiments of this disclosure. These features are believed to be applicable in a wide variety of systems comprising one or more embodiments of this disclosure. As such, the drawings are not meant to include all conventional features known by those of ordinary skill in the art to be required for the practice of the embodiments disclosed herein.

DETAILED DESCRIPTION

[0017] In the following specification and the claims, reference will be made to a number of terms, which shall be defined to have the following meanings.

[0018] The singular forms “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise.

[0019] “Optional” or “optionally” means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where the event occurs and instances where it does not.

[0020] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about”, “approximately”, and “substantially”, are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value. Here and throughout the specification and claims, range limitations may be combined and/or interchanged, such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise.

[0021] As used herein, the terms “processor” and “computer” and related terms, e.g., “processing device” and “computing device”, are not limited to just those integrated circuits referred to in the art as a computer, but broadly refers to a microcontroller, a microcomputer, a programmable logic controller (PLC), an application specific integrated circuit, and other programmable circuits, and these terms are used interchangeably herein. In the embodiments described herein, memory may include, but is not limited to, a computer-readable medium, such as a random access memory (RAM), and a computer-readable non-volatile medium, such as flash memory. Alternatively, a floppy disk, a compact disc – read only memory (CD-ROM), a magneto-optical disk (MOD), and/or a digital versatile disc (DVD) may also be used. Also, in the embodiments described herein, additional input channels may be, but are not limited to, computer peripherals associated with an operator interface such as a mouse and a keyboard. Alternatively, other computer peripherals may also be used that may include, for example, but not be limited to, a scanner. Furthermore, in the exemplary embodiment, additional output channels may include, but not be limited to, an operator interface monitor.

[0022] Further, as used herein, the terms “software” and “firmware” are interchangeable, and include any computer program stored in memory for execution by personal computers, workstations, clients and servers.

[0023] As used herein, the term “non-transitory computer-readable media” is intended to be representative of any tangible computer-based device implemented in any method or technology for short-term and long-term storage of information, such as, computer-readable instructions, data structures, program modules and sub-modules, or other data in any device. Therefore, the methods described herein may be encoded as executable instructions embodied in a tangible, non-transitory, 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. Moreover, as used herein, the term “non-transitory computer-readable media” includes all tangible, computer-readable media, including, without limitation, non-transitory computer storage devices, including, without limitation, volatile and nonvolatile media, and removable and non-removable media such as a firmware, physical and virtual storage, CD-ROMs, DVDs, and any other digital source such as a network or the Internet, as well as yet to be developed digital means, with the sole exception being a transitory, propagating signal.

[0024] Furthermore, 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.

[0025] The power transformer monitoring systems described herein provide a cost-effective method for monitoring power transformers while they are in service. The embodiments described herein use an on-line monitoring system to provide real-time information of the clamping pressure associated with transformer windings. Specifically, the embodiments described herein use a fiber optic probe and a target reflector to measure a gap distance defined between the probe and the target reflector. The probe is coupled to a portion of the transformer that is substantially stationary and the target reflector is coupled to a portion of the transformer that typically experiences position shifting over time while the transformer is in service. Therefore, the measured gap distance between the probe and the target reflector shifts with time, and the gap generally increases. This gap is related to movement of a top ring assembly that is coupled to the transformer windings. The movement measurements are translated into a calculated clamping force induced by the top ring assembly on the transformer windings. Such fiber optic probes are not subject to electromagnetic interference induced within the transformer while it is in service. Therefore, the embodiments described herein substantially reduce the requirement to remove the power transformer from service for disassembly, inspections, and reassembly, thereby reducing the costs of maintenance. In addition, the clamping pressure measurements are consistent over time. .

[0026] FIG. 1 is a block diagram of an exemplary power transformer 100. In the exemplary embodiment, transformer 100 is an oil-cooled transformer. Alternatively, transformer 100 uses any cooling mechanism. Power transformer 100 includes a casing 102, a transformer oil storage tank 104, and a plurality of cooling fans 106. Casing 102 is typically filled with transformer oil to a predetermined height therein. Power transformer 100 also includes three bushings 108, i.e., one for each phase of alternating current (AC) power transmitted through a three-phase electric power system (not shown). Power transformer 100 further includes a platform 110 that supports transformer 100.

[0027] FIG. 2 is a schematic perspective diagram of an exemplary transformer winding assembly 120, sometimes referred to as a transformer core that is used with power transformer 100. Winding assembly 120 is positioned on platform 110. Winding assembly 120 includes a frame 122 and three winding coils 124, i.e., one for each phase. Winding assembly 120 also includes three top ring assemblies 126 (described further below) coupled to frame 122 and each of winding coils 124. Frame 122 includes a plurality of pressure bolts 128 that are coupled to top ring assemblies 126. In the exemplary embodiment, four pressure bolts 128 are coupled to each top ring assembly 126 on each side of frame 122, i.e., eight pressure bolts 128 per each top ring assembly 126. Alternatively, any number of pressure bolts 128 is used for each top ring assembly that enables operation of transformer 100 as described herein. As such, pressure bolts 128 are used to induce a predetermined clamping pressure on winding coils 124 through top ring assemblies 126 during manufacture prior to installation of casing 102 (shown in FIG. 1).

[0028] Winding assembly 120 further includes three end block assemblies 130 coupled to platform 110 and each of winding coils 124. Each end block assembly 130 is formed from an electrically-insulating material, e.g., and without limitation, wood, that insulate winding coils 124 from ground potential through platform 110. End block assemblies 130 also facilitate inducing the predetermined clamping pressure on winding coils 124. Winding assembly 120 also includes an insulating system (not shown in FIG. 2) that includes cellulose paper immersed in oil. Winding coil 124 extends a longitudinal distance L from top ring assembly 126.

[0029] FIG. 3 is a schematic diagram of an exemplary system 200 for monitoring power transformer 100. Monitoring system 200 includes a fiber optic probe 202 coupled to a structural member 203 positioned a predetermined distance above top ring assembly 126 (only one shown in FIG. 3). Structural member 203 is coupled to, or a portion of, frame 122 (shown in FIG. 2). Fiber optic probe 202 is configured to transmit photonic signals, i.e., photons within a predetermined frequency/wavelength range with a predetermined photonic flux density. Monitoring system 200 also includes a target reflector 204 positioned proximate and below fiber optic probe 202. Target reflector 204 includes a polished, mirrored surface 206 and configured to receive the photonic signals from fiber optic probe 202 and reflect a portion of the photonic signals back toward fiber optic probe 202. Fiber optic probe 202 is also configured to receive the reflected photonic signals from target reflector 204 with a diminished photonic flux density.

[0030] In the exemplary embodiment, fiber optic probe 202 is any fiber optic position/gap sensor that transmits and receives photonic signals to enable monitoring system 200 to operate as described herein. Fiber optic probe 202 is coupled to a fiber optic cable 208. Fiber optic probe 202 and fiber optic cable 208 are configured with sufficient optic fibers for transmission of emitted outgoing photons and reflected incoming photons. In some embodiments, fiber optic probe 202 and fiber optic cable 208 include dedicated fibers for the emitted signals and the reflected signals. In other embodiments, fiber optic probe 202 and fiber optic cable 208 include same fibers for both emitted signals and reflected signals. Fiber optic probe 202 is any fiber optic device that emits photonic signals and collects return photonic signals to enable monitoring system 200 to operate as described herein.

[0031] Also, in the exemplary target reflector 204 is any mirrored device that reflects the photonic signals to enable monitoring system 200 to operate as described herein. In some embodiments, a reflective surface of top ring assembly 126 may be used rather than target reflector 204. As described above, the photonic flux of the reflected photons is diminished as compared to the photonic flux of the photons transmitted from fiber optic probe 202.

[0032] A ratio of the number of photons received from target reflector 204 to the number of photons transmitted from fiber optic probe 202 represents a value, i.e., measurement of a gap distance D between a tip 210 of fiber optic probe 202 and mirrored surface 206 of target reflector 204. As measured gap distance D increases, the ratio decreases, and such a decrease is indicative of the value of measured gap distance D. As such, the ratio is inversely proportional to gap distance measurements D with a known relationship.

[0033] Monitoring system 200 further includes a processing device 212 coupled to fiber optic probe 202 through fiber optic cable 208. In some embodiments, accessory equipment to convert the photonic flux signals to electronic signals compatible with processing device 212 are placed between fiber optic probe 202 and processing device 212. In the exemplary embodiment, processing device 212 is a laptop computer. Alternatively, processing device 212 is any device that enables operation of monitoring system 200 as described herein, including, without limitation, a desktop computer, a distributed control system (DCS), a PLC, a Supervisory Control and Data Acquisition (SCADA) system, and a hand-held device. Processing device 212 includes a display device 216 coupled thereto, i.e., in the exemplary embodiment, an integrated laptop screen. Alternatively, display device 216 is any device that enables operation of monitoring system 200 as described herein. Also, casing 102 (shown in FIGs. 1 and 2) includes at least one cable penetration (not shown) defined such that fiber optic cable 208 extends therethrough.

[0034] Processing device 212 is configured to receive the photonic flux values of the transmitted and received photon signals and generate the photonic flux ratio. In some embodiments, fiber optic probe 202 is configured to generate the photonic flux ratio values and transmit such values as signals to processing device 212. Processing device 212 is also configured to convert the photonic flux ratio values to a gap distance measurement D and then convert gap distance measurement D to a position measurement of top ring assembly 126. Processing device 212 is further configured to convert the position measurements of top ring assembly 126 to signals representative of measurement values of the clamping force induced on winding coil 124 by top ring assembly 126. Further, display device 216 is configured to display real-time force measurements induced on winding coil 124 by top ring assembly 126 while power transformer 100 is in service.

[0035] FIG. 4 is a graphical view of an exemplary relationship 300 between the clamping pressure/force induced on winding coil 124 by top ring assembly 126 (both shown in FIG. 2) and values of a sensor signal transmitted from fiber optic probe 202 (shown in FIG. 3). Graphical relationship 300 includes a y-axis 302 representative of the magnitude of the output of optic probe 202 that is representative of the ratio of the number of photons received from target reflector 204 (shown in FIG. 3) to the number of photons transmitted from fiber optic probe 202, that in turn represents a value, i.e., measurement of gap distance D between tip 210 (shown in FIG. 3) of fiber optic probe 202 and mirrored surface 206 (shown in FIG. 3) of target reflector 204. Y-axis 302 includes units of direct current volts (V) extending from 0V through 3.5V in incremental units of 0.5V. Graphical relationship 300 also includes an x-axis 304 representative of clamping pressure exerted by top ring assembly 126 on winding coil 124 in units of pounds per square inch (psi) extending from 0 psi to 2500 psi in incremental units of 500 psi. Graphical relationship 300 further includes a curve 306 that shows clamping pressure generally increasing as the magnitude of measured gap values increase. In the exemplary embodiment, the output of fiber optic probe 202 is inversely proportional to the photonic flux ratio. Therefore, the measured gap distance D (shown in FIG. 3) indicative of movement of top ring assembly 126 over time is representative of the clamping force induced on winding coil 124 by top ring assembly 126. As described above, processing device 212 (shown in FIG. 3) generates the clamping force values as a function of the measured real-time values of the output of fiber optic probe 202.

[0036] FIG. 5 is a schematic diagram of an alternative system 400 for monitoring power transformer 100. System 400 includes fiber optic probe 202 with tip 210 and target reflector 204 with mirrored surface 206. In this alternative embodiment, power transformer 100 includes a structural member, i.e., a tie-bar 402 that is positioned a predetermined radial distance R from the winding coil 124. Also, fiber optic probe 202 is coupled to tie-bar 402. Power transformer 100 includes an insulation system 404 coupled to winding coil 124 including cellulose paper 405 immersed in oil (not shown).

[0037] Power transformer 100 also includes a substantially non-conductive coupling mechanism 406 coupled to insulation system 404. In the exemplary embodiment, non-conductive coupling mechanism 406 is formed from one of cellulose paper and wood to secure target reflector 204 proximate and below fiber optic probe 202. Alternatively, non-conductive coupling mechanism 406 is any insulating material in any configuration that enables operation of monitoring system 400 as described herein, including, without limitation, straps and fasteners. In this alternative embodiment, system 400 measures movement of a portion of windings 124 that is representative of the movement of top ring assembly 126 and the clamping force induced on winding coil 124 by top ring assembly 126.

[0038] In the exemplary embodiments described herein, configurations that include system 200 (shown in FIG. 3) positioned proximate the top of winding assembly 120 and system 400 positioned at some point along longitudinal distance L radially outboard of winding assembly 120, both systems including fiber optic probe 202 and target reflector 204 are shown. Alternative embodiments include, without limitation, any configuration that includes a portion of the optical path between probe 202 and reflector 204 parallel to a winding axis extending through winding coil 124 and top ring assembly 126, for example, and without limitation, a path that bends 90 degrees with a mirror. Also, alternatively, and in contrast to systems 200 and 400 that include one stationary portion and one moveable portion, some embodiments include two moveable portions, e.g., and without limitation a probe 202 on one winding coil 124 and a reflector 204 on a second, and adjacent, winding coil 124.

[0039] FIG. 6 is a graphical view of an exemplary relationship 500 between the clamping pressure/force induced on winding coil 124 by top ring assembly 126 (both shown in FIG. 5) and values of a sensor signal transmitted from fiber optic probe 202 (shown in FIG. 5). Graphical relationship 500 includes a y-axis 502 representative of the magnitude of the output of optic probe 202 that is representative of the ratio of the number of photons received from target reflector 204 (shown in FIG. 5) to the number of photons transmitted from fiber optic probe 202, that in turn represents a value, i.e., measurement of gap distance D between tip 210 (shown in FIG. 5) of fiber optic probe 202 and mirrored surface 206 (shown in FIG. 5) of target reflector 204. Y-axis 502 includes units of direct current volts (V) extending from 0V through 3.5V in incremental units of 0.5V. Graphical relationship 500 also includes an x-axis 504 representative of clamping pressure exerted by top ring assembly 126 on winding coil 124 in units of pounds per square inch (psi) extending from 0 psi to 2500 psi in incremental units of 500 psi. Graphical relationship 500 further includes a curve 506 that shows clamping pressure generally increasing as the magnitude of measured gap values increase. In the exemplary embodiment, the output of fiber optic probe 202 is inversely proportional to the photonic flux ratio. Therefore, the measured gap distance D (shown in FIG. 5) indicative of movement of windings 124 and top ring assembly 126 over time is representative of the clamping force induced on winding coil 124 by top ring assembly 126. As described above, processing device 212 (shown in FIG. 3) generates the clamping force values as a function of the measured real-time values of the output of fiber optic probe 202.

[0040] The above described power transformer monitoring systems provide a cost-effective method for monitoring power transformers while they are in service. The embodiments described herein use an on-line monitoring system to provide real-time information of the clamping pressure associated with transformer windings. Specifically, the embodiments described herein use a fiber optic probe and a target reflector to measure a gap distance defined between the probe and the target reflector. The probe is coupled to a portion of the transformer that is substantially stationary and the target reflector is coupled to a portion of the transformer that typically experiences position shifting over time while the transformer is in service. Therefore, the measured gap distance between the probe and the target reflector shifts with time, and the gap generally increases. This gap is related to movement of a top ring assembly that is coupled to the transformer windings. The movement measurements are translated into a calculated clamping force induced by the top ring assembly on the transformer windings. Such fiber optic probes are not subject to electromagnetic interference induced within the transformer while it is in service. Therefore, the embodiments described herein substantially reduce the requirement to remove the power transformer from service for disassembly, inspections, and reassembly, thereby reducing the costs of maintenance. In addition, the clamping pressure measurements are consistent over time.

[0041] An exemplary technical effect of the methods, systems, and apparatus described herein includes at least one of: (a) using fiber optic probes to measure movement of a top ring assembly and/or transformer windings; (b) using known relationships between measured shifts in position of a top ring assembly and/or transformer windings to determine a clamping pressure of the top ring assembly on a winding coil of an in-service transformer; and (c) decreasing a frequency and duration of power transformer outages for visual and instrument inspections.

[0042] Exemplary embodiments of methods, systems, and apparatus for monitoring power transformers while they are in service are not limited to the specific embodiments described herein, but rather, components of systems and/or steps of the methods may be utilized independently and separately from other components and/or steps described herein. For example, the methods may also be used in combination with other systems requiring on-line vibration/movement monitoring and the associated methods, and are not limited to practice with only the power transformers and methods as described herein. Rather, the exemplary embodiment can be implemented and utilized in connection with many other applications, equipment, and systems that may benefit from on-line monitoring in an electromagnetic environment.

[0043] Although specific features of various embodiments of the disclosure may be shown in some drawings and not in others, this is for convenience only. In accordance with the principles of the disclosure, any feature of a drawing may be referenced and/or claimed in combination with any feature of any other drawing.

[0044] 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.

[0045] This written description uses examples to disclose the embodiments, including the best mode, and also to enable any person skilled in the art to practice the embodiments, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

WHAT IS CLAIMED IS:

1. A system for monitoring a transformer, the transformer including a winding coil and a top ring assembly coupled to the winding coil, said monitoring system comprising:

a fiber optic probe configured to transmit and receive photonic signals;

a target reflector positioned proximate said fiber optic probe and configured to receive photonic signals from said fiber optic probe and reflect photonic signals toward said fiber optic probe; and

a processor coupled to said fiber optic probe.

2. The system in accordance with Claim 1, wherein the winding coil extends a longitudinal distance from the top ring assembly, the transformer further includes a structural member positioned a predetermined radial distance from the winding coil and extending along at least a portion of the longitudinal distance, and the transformer further includes an insulation system coupled to the winding coil and a substantially non-conductive coupling mechanism coupled to a portion of the insulation system at a second position along the longitudinal distance, wherein:

said fiber optic probe coupled to the structural member at a first position along the longitudinal distance; and

said target reflector coupled to the coupling mechanism.

3. The system in accordance with Claim 1, wherein the transformer further includes a structural member positioned a predetermined distance from the top ring assembly, wherein:

said fiber optic probe coupled to the structural member; and

said target reflector coupled to the top ring assembly.

4. The system in accordance with Claim 1, wherein said fiber optic probe is configured to measure a ratio of a number of photons received from said target reflector to a number of photons transmitted from said fiber optic probe.

5. The system in accordance with Claim 4, wherein said fiber optic probe comprises a tip and said target reflector comprises a mirrored surface, said tip and said mirrored surface define a gap distance therebetween, wherein the ratio of photons received from said target reflector to photons transmitted from said fiber optic probe is inversely proportional to a measurement of the gap distance.

6. The system in accordance with Claim 5, wherein the gap distance measurements are representative of a clamping force induced on the winding coil by the top ring assembly.

7. The system in accordance with Claim 5, wherein said processor is configured to receive the gap measurement signals from said fiber optic probe, the gap measurement signals representative of a position of the top ring assembly, said processor further configured to generate values of a clamping force induced on the winding coil by the top ring assembly.

8. The system in accordance with Claim 1 further comprising a display device coupled to said processor, said display device configured to display real-time force measurements induced on the winding coil by the top ring assembly while the transformer is in service.

9. A method of monitoring a transformer, the transformer including a winding coil and a top ring assembly coupled to the winding coil, the transformer further including a fiber optic probe and a target reflector positioned proximate the fiber optic probe, the target reflector configured to receive photonic signals from the fiber optic probe and reflect photonic signals toward the fiber optic probe, said method comprising:

placing the transformer in service;

generating signals representative of a position of the top ring assembly; and

generating signals representative of a clamping force induced on the winding coil by the top ring assembly, the clamping force signals related to the top ring assembly position signals.

10. The method in accordance with Claim 9, wherein generating signals representative of a position of the top ring assembly with the fiber optic probe comprises generating measurement signals representative of a gap defined by the fiber optic probe and the target reflector.

11. The method in accordance with Claim 10, wherein generating measurement signals representative of a gap defined by the fiber optic probe and the target reflector comprises generating a ratio of a number of photons received from the target reflector to a number of photons transmitted from the fiber optic probe, the photonic ratio inversely proportional to the gap distance measurements.

12. The method in accordance with Claim 11, wherein generating signals representative of a clamping force induced on the winding coil by the top ring assembly comprises:

transmitting the photonic ratio to a processor;

converting, within the processor, the photonic ratio to a gap distance measurement;

converting, within the processor, the gap distance measurement to a position measurement of the top ring assembly; and

converting, within the processor, the position measurements of the top ring assembly to clamping force measurement signals.

13. The method in accordance with Claim 12 further comprising:

transmitting the clamping force measurement signals to a display device coupled to the processor; and

displaying on the display device real-time clamping force measurements induced on the winding coil by the top ring assembly while the transformer is in service.

14. A transformer comprising:

a winding coil;

an insulation system coupled to said winding coil;

a top ring assembly coupled to said winding coil, said top ring assembly configured to induce a clamping force on said winding coil;

a monitoring system configured to monitor the clamping force, said monitoring system comprising:

a fiber optic probe configured to transmit and receive photonic signals;

a target reflector positioned proximate said fiber optic probe and configured to receive the photonic signals from said fiber optic probe and reflect the photonic signals toward said fiber optic probe; and

a processor coupled to said fiber optic probe.

15. The transformer in accordance with Claim 14, wherein said winding coil extends a longitudinal distance from said top ring assembly, said transformer further including:

a structural member positioned a predetermined radial distance from said winding coil and extending along at least a portion of the longitudinal distance, said fiber optic probe coupled to said structural member at a first position along the longitudinal distance; and

a substantially non-conductive coupling mechanism coupled to a portion of said insulation system at a second position along the longitudinal distance, said target reflector coupled to said coupling mechanism.

16. The transformer in accordance with Claim 14, wherein said transformer further includes a structural member positioned a predetermined distance from said top ring assembly, wherein:

said fiber optic probe coupled to the structural member; and

said target reflector coupled to the top ring assembly.

17. The transformer in accordance with Claim 14, wherein said fiber optic probe is configured to measure a ratio of a number of photons received from said target reflector to a number of photons transmitted from said fiber optic probe.

18. The transformer in accordance with Claim 17, wherein said fiber optic probe comprises a tip and said target reflector comprises a mirrored surface, said tip and said mirrored surface define a gap distance therebetween, wherein the ratio of photons received from said target reflector to photons transmitted from said fiber optic probe is inversely proportional to a measurement of the gap distance.

19. The transformer in accordance with Claim 18, wherein the gap distance measurements are representative of a clamping force induced on said winding coil by said top ring assembly.

20. The transformer in accordance with Claim 18, wherein said processor is configured to receive gap measurement signals from said fiber optic probe, the gap measurement signals representative of a position of said top ring assembly, said processor further configured to generate values of a clamping force induced on said winding coil by said top ring assembly, said monitoring system further comprising a display device coupled to said processor, said display device configured to display real-time force measurements induced on said winding coil by said top ring assembly while said transformer is in service.

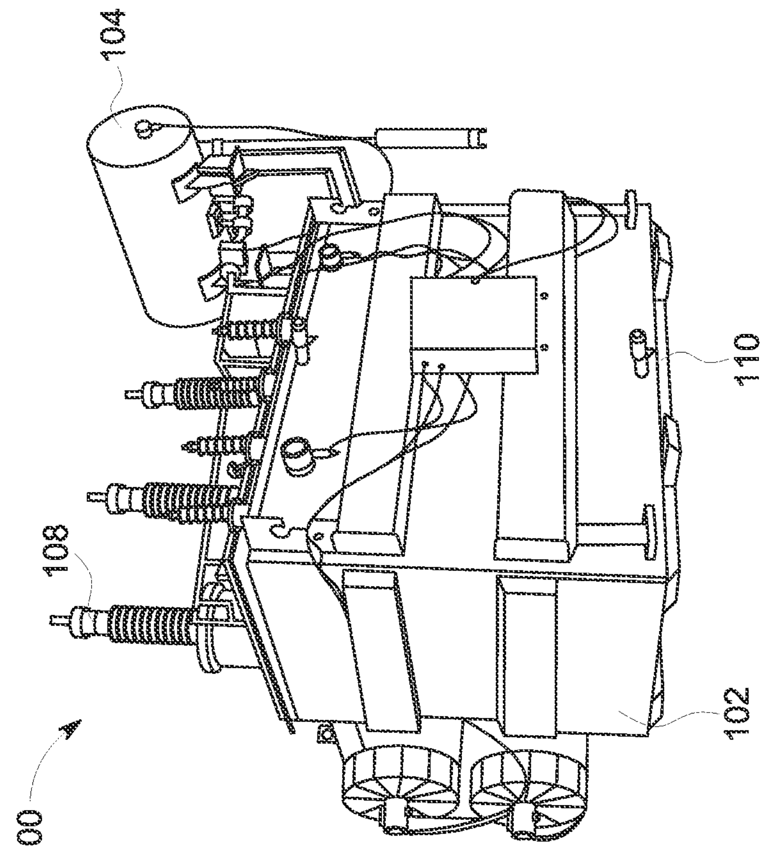
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FIG. 1

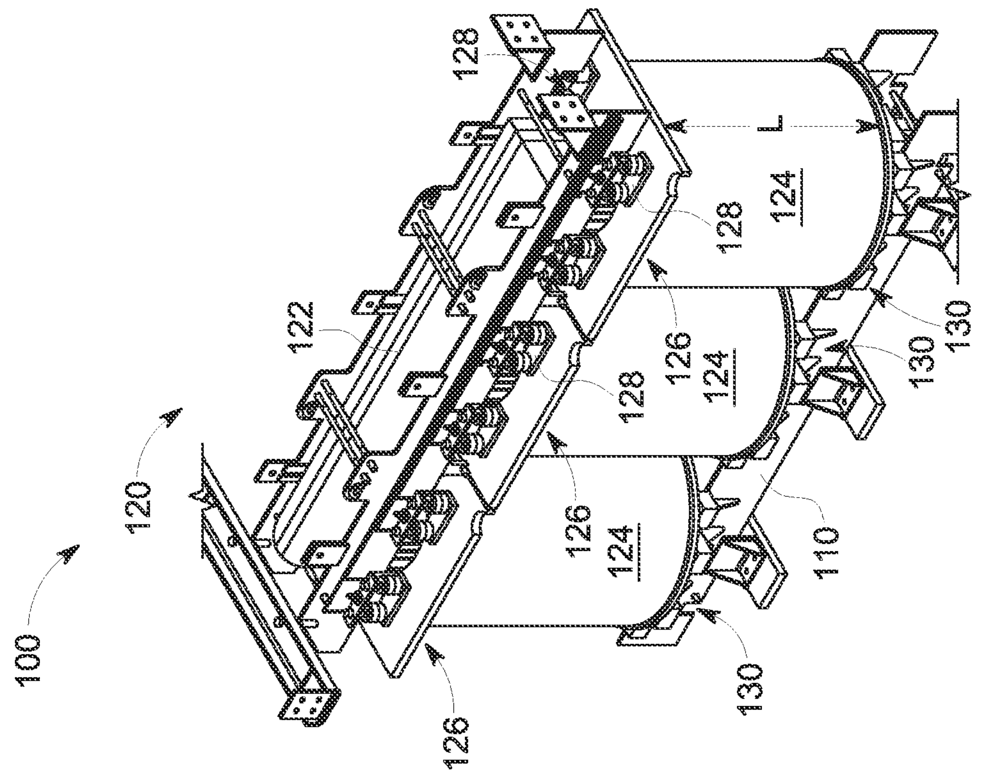
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FIG. 2

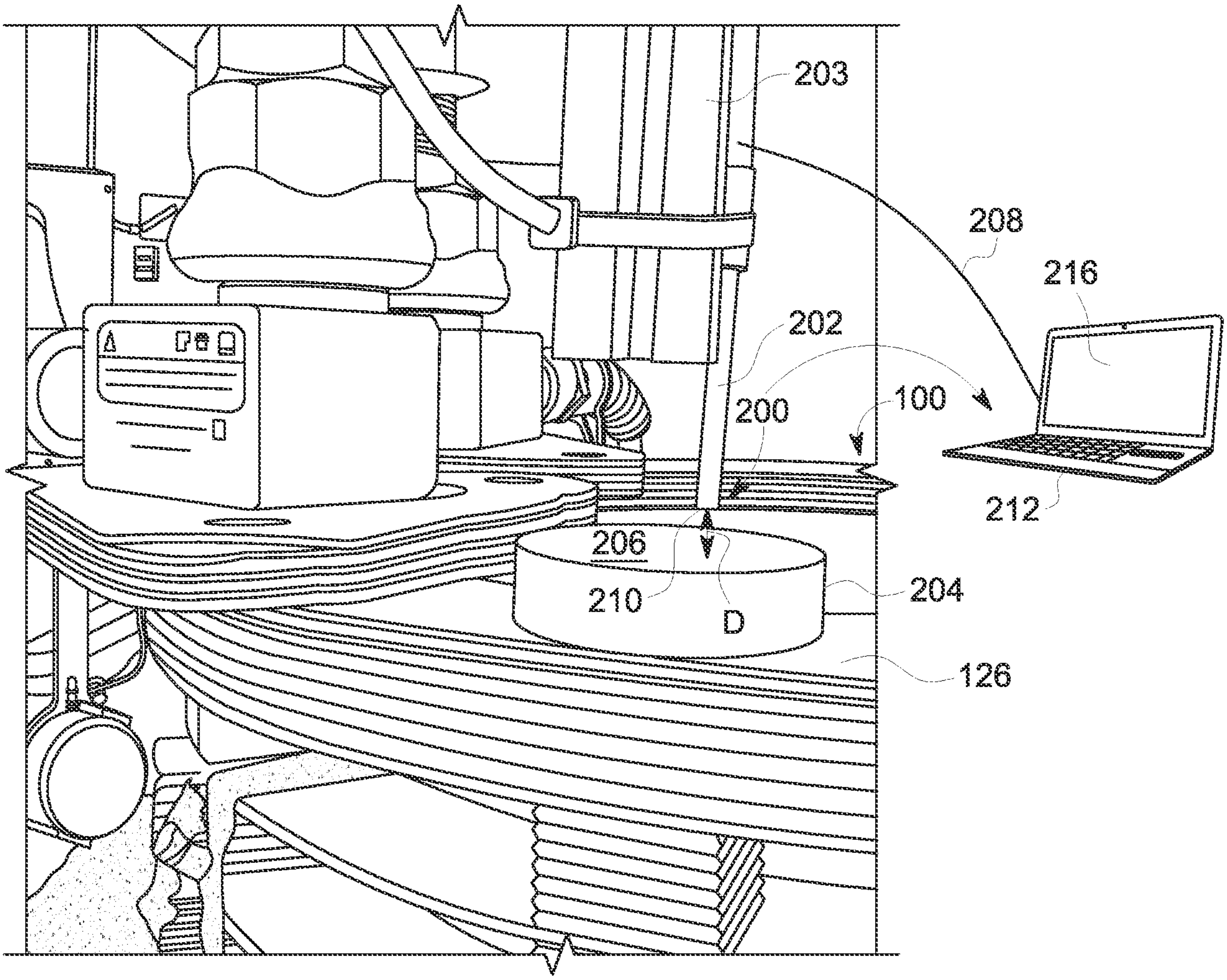
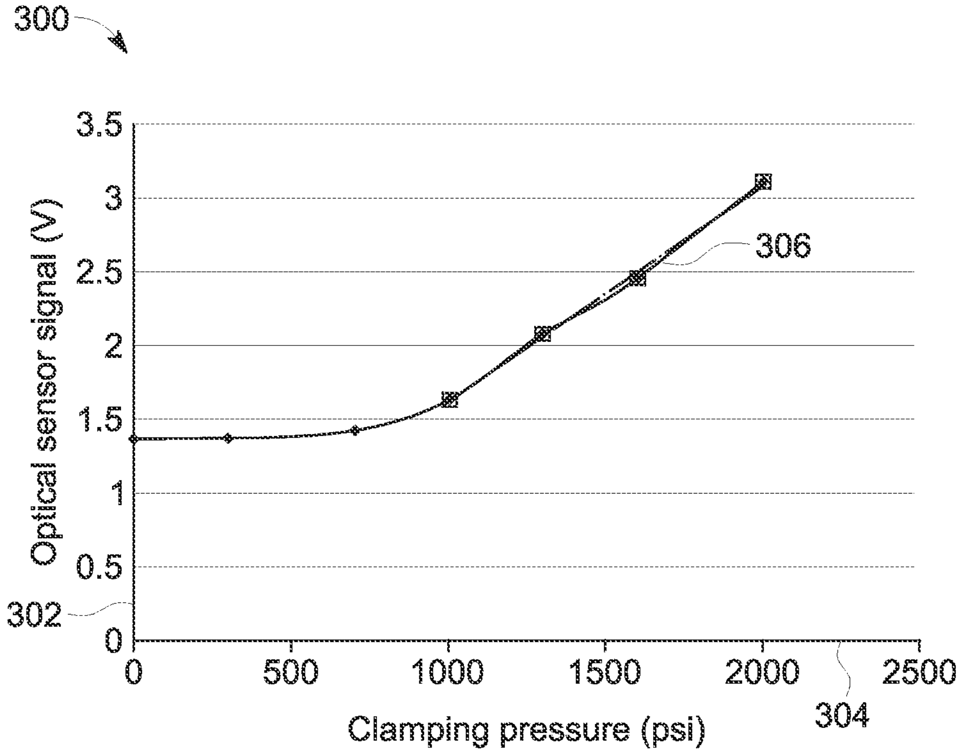


FIG. 3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2
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2500
304
Clamping pressure (psi)

FIG. 4

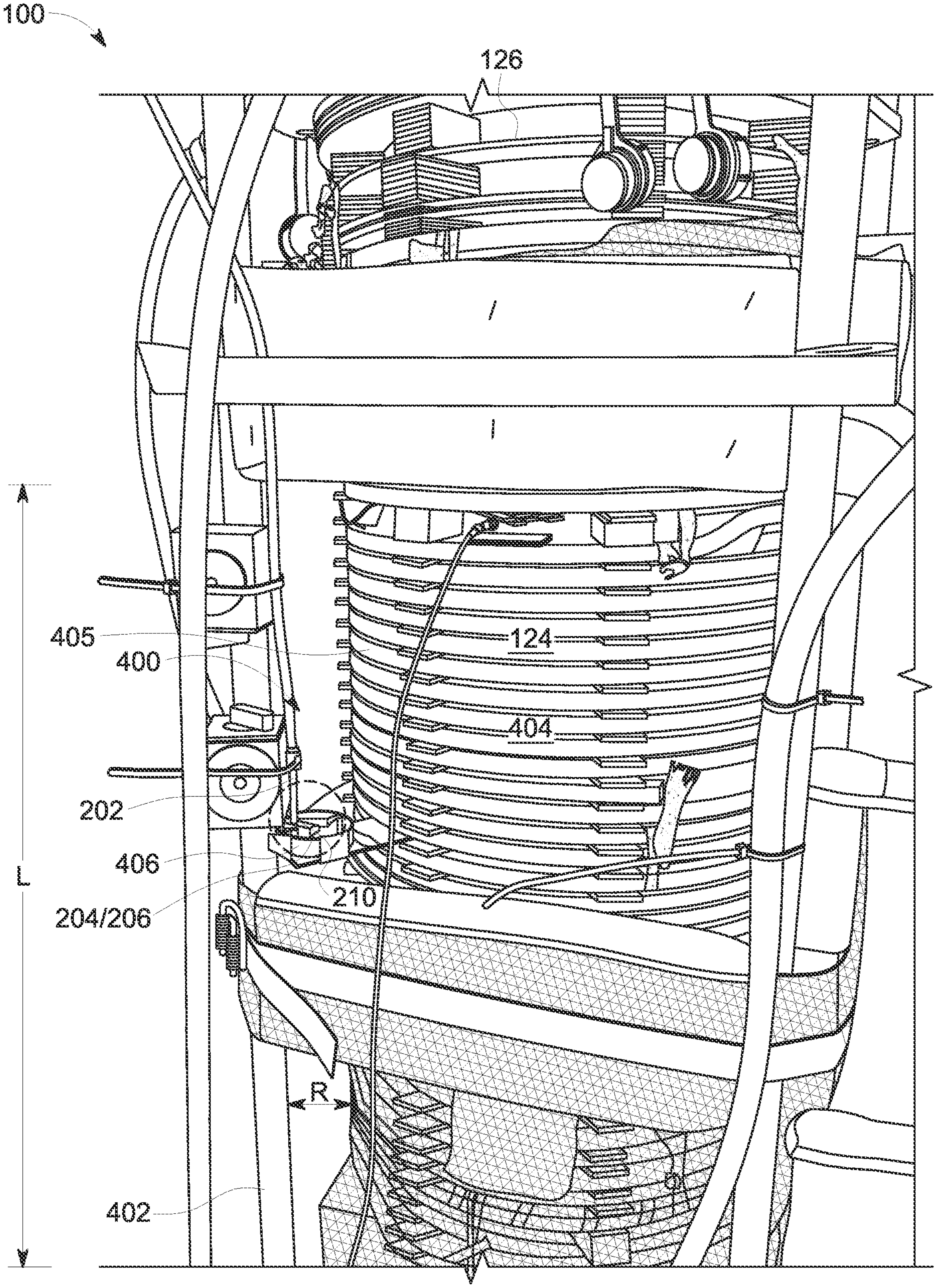
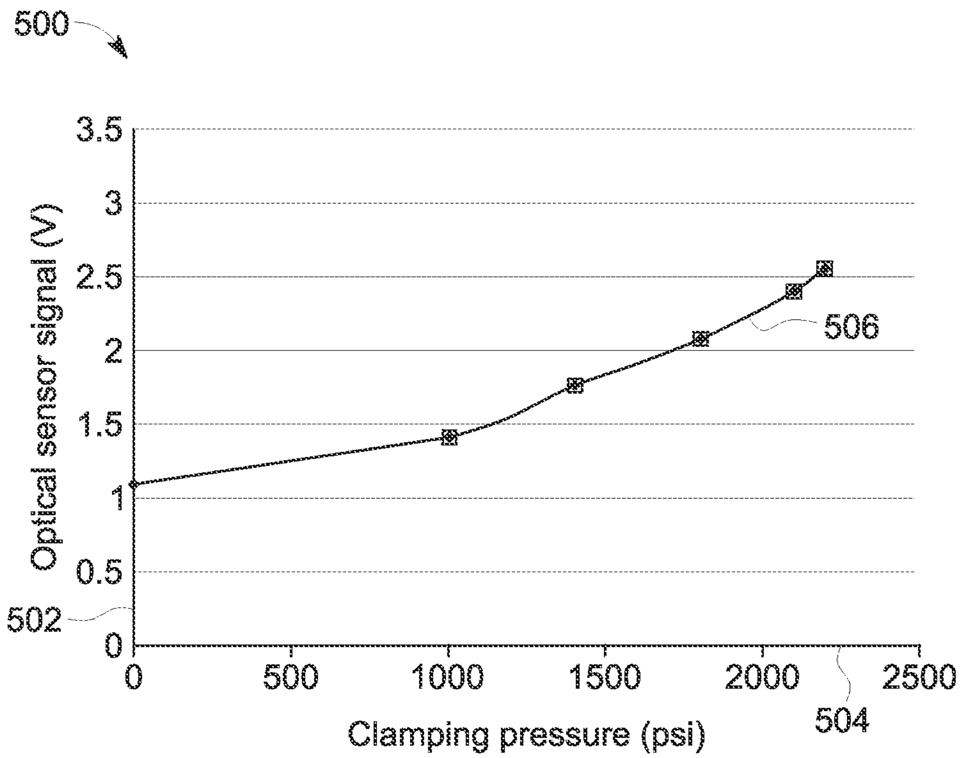


FIG. 5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2
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1
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0
Optical sensor signal (V)
506
502
0
500
1000
1500
2000
2500
504
Clamping pressure (psi)

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/040149

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R19/25 G01B11/02
ADD.

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)
G01R G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2012/247229 A1 (WOODCOCK DAVID J [US]) 4 October 2012 (2012-10-04) paragraph [0023] - paragraph [0024]	3-20

X	WO 2005/033643 A2 (SABEUS PHOTONICS INC [US]; SCHMIDT SIEGMAR [US]) 14 April 2005 (2005-04-14)	1,2
Y	abstract	3-20

X	US 5 276 501 A (MCCLINTOCK JOSEPH A [US] ET AL) 4 January 1994 (1994-01-04)	1,2
Y	abstract; column 1, line 7	3-20

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

☒ See patent family annex.

* Special categories of cited documents :

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search 14 October 2014	Date of mailing of the international search report 23/10/2014
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Malcoci, Andrei

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2014/040149

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