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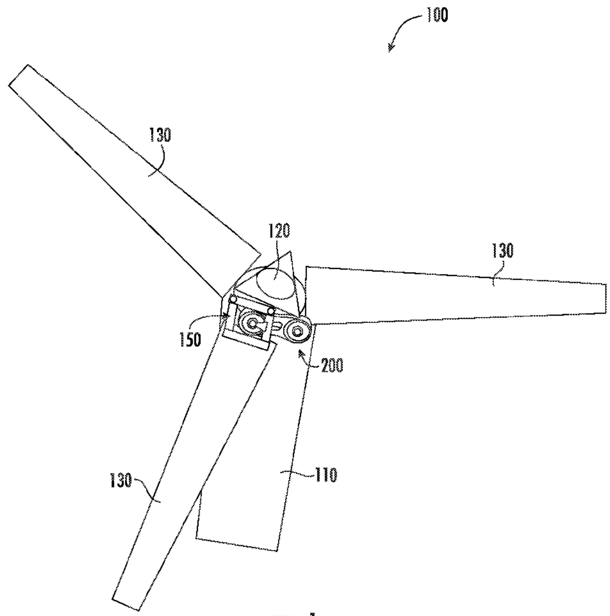

FIG. 1

(57) Abstract: Health monitoring systems, devices, and methods are used in assessing the operational health of a drive link in an aircraft. The drive link has, at each end, a magnetic sensor and a magnet for detecting relative displacement, and at least one strain gauge on the drive link for detecting a load acting on the drive link. A wand provides power, via a wireless antenna of the drive link, to be used in processing sensor signals of the drive link. The rotors are actuated through a series of prescribed movements and the signals from the sensors are recorded. After the series of prescribed movements, the data from the sensors signals is transmitted to the wand, a stiffness value is calculated for the drive link, and the stiffness value calculated is compared against a stiffness value threshold. A drive link health status is then displayed to the operator.

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HEALTH MONITORING DEVICES AND SYSTEMS FOR A LINKAGE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 62/459,865 filed February 16, 2017, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The subject matter herein generally relates to the field of health monitoring of structural components. The subject matter herein more particularly relates to systems, devices, and methods for inspecting and assessing the operational health of a linkage for rotating machinery, particularly a drive link for a rotary aircraft.

BACKGROUND

[0003] Modern day aircraft have many linkages which are subject to wear and degradation if they are not proactively monitored and replaced before failure. In some instances, a "failed" part needing to be replaced will not necessarily present an inherent safety risk, but may allow the aircraft to exhibit undesirable performance characteristics, such as excessive vibration. Elastomeric linkages are examples of such linkages, in that the elastomeric portion provides vibrational compliance and isolation characteristics, but will fatigue and "fail" long before the metal portion of the linkage will fail, which would lead to a catastrophic failure mechanism presenting a significant safety risk to many people, whether in the aircraft or on the ground. As such, while it is not vital for aircraft occupant safety to service such elastomeric components, they provide valuable and desirable performance characteristics which are quite noticeable to occupants when not present or degraded.

[0004] As such, it is common practice for conservative service intervals to be established for inspection and/or repair of such linkages in order to ensure occupant comfort and reduce operator fatigue. Unfortunately, these components are very often inaccessible and cannot be visually inspected by service personnel without time consuming disassembly of at least a part of the aircraft, thus increasing service costs and aircraft downtime due to maintenance. In fact, some such components cannot be visually evaluated for degradation at all, regardless of the ability of service personnel to visually inspect them; in such instances, it is necessary to embed sensors within these components in order to dynamically assess their performance while in motion.

[0005] One known approach to dealing with assessing the health and performance of inaccessible parts is to embed sensors in these parts which are then transmitted to the flight computer of the aircraft so as to be monitored for performance aberrations and/or degradations, indicating that service may be necessary. However, these monitoring systems require a physical connection to a power source, a data communications path, consume computational resources of the flight computer, and add to the overall weight and complexity of the aircraft. While these tradeoffs may be worth accounting for in ensuring safe operation of the aircraft, where failure of such components may compromise the safety of the occupants of the aircraft, they may not be warranted for implementing real-time monitoring of components which are primarily directed towards occupant comfort rather than safety. As such, there exists a need to provide embedded sensors within such components that do not require a connection to the aircraft power source and do not require real-time monitoring during operation of the aircraft to ensure occupant safety.

SUMMARY

[0006] In one aspect, a health monitoring system for an aircraft is provided. The health monitoring system comprises a drive link configured to connect one or more rotors to the aircraft. The drive link includes at least one magnetic sensor and magnet, at least one strain gauge, at least one wireless antenna, and an electronic and power module. The at least one magnetic sensor and magnet are located adjacent to an elastomeric member of the drive link. The at least one strain gauge located on the drive link. The electronic and power module has a processor, internal storage, and an energy supply, wherein the electronic and power module is electrically connected to the at least one magnetic sensor, the at least one strain gauge, and the at least one wireless antenna. In some embodiments, the health monitoring system further comprises a wand, which includes a grip portion on a first end of the wand, a computation module, a transponder on a second end of the wand, and a display.

[0007] In another aspect a drive link for connecting one or more rotors in a rotary aircraft is provided. The drive link comprises at least one magnetic sensor and magnet, at least one strain gauge, at least one wireless antenna, and an electronic and power module. The at least one magnetic sensor and magnet are located adjacent to an elastomeric member of the drive link. The at least one strain gauge located on the drive link. The electronic and power module includes a processor, internal storage, and an energy supply, wherein the electronic and power module is electrically connected to the at least one magnetic sensor, the at least one strain gauge, and the at least one wireless antenna.

[0008] In yet another aspect, a method of assessing a health of a drive link connecting one or more rotors to an aircraft is provided. The method comprising: manipulating a wand so that a transponder of the wand is located adjacent to a wireless antenna of the drive link; transmitting power wirelessly from the wand to the drive link; actuating the one or more rotors through one or more movements of a series of prescribed movements; recording in an internal storage of the drive link, while the one or more rotors are actuated, data in a form of sensor output signals from at least one magnetic sensor and magnet located adjacent to an elastomeric member of the drive link and from at least one strain gauge located on a surface of the drive link; transmitting the data from the internal storage to the wand using the wireless antenna; calculating a stiffness value for the drive link; comparing the stiffness value for the drive link calculated to a predetermined stiffness value threshold; and displaying a health status to an operator on a display of the wand.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a schematic illustration of a rotating blade propulsion system having a drive link, in accordance with the disclosure herein.

[0010] FIG. 2 is a perspective view of an example embodiment for a drive link, in accordance with the disclosure herein.

[0011] FIG. 3 is a side view of a first example embodiment of an energizing data collection wand, in accordance with the disclosure herein.

[0012] FIG. 4 is a cross-sectional view of the first example embodiment the wand of FIG. 3, in accordance with the disclosure herein.

[0013] FIG. 5 is a side view of a second example embodiment of an energizing data collection wand, in accordance with the disclosure herein.

[0014] FIG. 6 is a side view of a third example embodiment of an energizing data collection wand, in accordance with the disclosure herein.

DETAILED DESCRIPTION

[0015] This disclosure relates to systems and methods for monitoring the health of any suitable and suitably inaccessible component without real-time health monitoring capabilities being integrated therein. Examples of such systems include manufacturing systems and drive systems. One non-limiting example of a drive system is a drive rotor of a helicopter, which has one or more drive links with elastomeric compliance elements therein. The drive system of the drive rotor of a helicopter is used hereinafter as a non-limiting example to illustrate this invention.

[0016] In some systems, these drive links are visually occluded, such that inspection of the drive link requires complete disassembly of the hub for visual inspection of these parts. In some applications, a small "sight hole" allows some visual access, but not enough to perform a full visual inspection, as required. As such, a health monitoring drive link is needed to reduce inspection cost and complexity from disassembly, while increasing reliability of the drive links, as it will be possible to extend useful service life of these parts by taking on-board performance measurements, rather than relying on an inherently less precise visual inspection replacement methodology. The health monitoring systems and methods disclosed herein are configured to be energized temporarily and to then monitor the effect of forces and movements experienced by the drive link as the rotors of the aircraft are put through a series of prescribed movements. Prescribed movements are the rotation of the rotors with actuation in the pitch direction through the limitations of the individual aircraft rotor controls. Accordingly, a health monitoring system is disclosed hereinbelow that may be operated according to a variety of methods and embodiments described herein.

[0017] FIG. 1 schematically illustrates a rotorcraft propulsion system, generally designated **100**, with a drive link, generally designated **200**, configured to connect one or more rotors **130** to the drive shaft **120** and, thus, to the aircraft. In the embodiment shown, rotors **130** are the rotor blades of an aircraft, such as a helicopter, but rotors **130** can be any suitable rotary element. Rotary motion for the drive shaft **120** is generated via the engine housed within the engine nacelle **110**. This rotary motion of the drive shaft is transferred from the drive shaft **120** into one end of the drive link **200**, through the main body of the drive link **200**, and into the rotor **130** at a motion transfer point, generally designated **150**, via the connection at the second end of the drive link **200**. The construction of the drive link **200** will be discussed further hereinbelow with respect to FIG. 2, but the illustration of the rotorcraft propulsion system **100** shown in FIG. 1 is merely an example of one embodiment capable of using such a drive link **200**, and is in no way to be construed as limiting the scope of the subject matter disclosed herein.

[0018] Referring now to FIG. 2, an example embodiment of a drive link, generally designated **200**, is shown, with the drive link **200** being configured with integrated health monitoring components (e.g., **210**, **220**, **222**, **230**, **240**). The drive link **200** comprises a portion of a health monitoring system for an aircraft, along with a wand **300**, as illustrated in FIGS. 3

and 4 and, in some embodiments, a connected device **380**. Connected device **380** may be device similar to a smartphone, a tablet PC, a notebook PC, a desktop PC, etc., and the connection may be via an interface such as a wired or wireless communications interface/protocol. The illustrated drive link **200** has a body having a first end **201**, a second end **202**, and a middle section **203**, located between and connecting the first and second ends **201** and **202**. At the first and second ends **201** and **202**, a cavity **204** is formed, with an elastomeric member **205** being disposed therein concentrically around a non-elastomeric inner member **206**. In rotorcraft applications, the non-elastomeric inner members **206** are configured to be connected to either the drive shaft **120** or the rotor **130**, with the elastomeric member **205** providing compliant force and vibrational damping behavior. The middle section **203** has a hollow cavity portion **207** formed therein. In the example embodiment of FIG. 2, each of the first and second ends **201** and **202** have an anisotropic magnetoresistive (AMR) sensor (hereinafter, "magnetic sensor") **220** and magnet **222** pair located adjacent to each elastomeric member **205** of the drive link **200** to measure relative movement, or displacement, between the respective non-elastomeric inner member **206** and the respective elastomeric member **205**. In some embodiments, the magnetic sensor **220** and the magnet **220** are located across the elastomeric member **205** such that movement of the inner member **206** relative to an outer member, such as the body of drive link **200** or an annular body installed within the cavity **204**, will cause a movement of the magnet **222** relative to the magnetic sensor **220**. In such embodiments, the body of the drive link **200** can be the middle section **203** or one of the first end **201** and the second end **202** of the drive link **200** adjacent to the magnet **222** associated with the magnetic sensor **220**. In the embodiment shown, a first of the plurality of magnetic sensors **220** and magnets **222** are located at the first end **201** of the drive link **200** and a second of the plurality of magnetic sensors **220** and magnets **222** are located at the second end **202** of the drive link **200**. In some embodiments, the magnetic sensors **220** are configured to detect relative movement between each respective magnetic sensor **220** and its corresponding magnet **222** to provide movement data to the electronic and power module **210** for storage and subsequent transmission as part of a health inspection procedure of the drive link **200**. The magnetic sensors **220** are configured, based on the relative movement detected, to generate corresponding output displacement signals from each magnetic sensor **220** to the electronic and power module **210**. In this example embodiment, the magnetic sensor **220** and magnet **222** pairs are shown as being mounted on a surface of the first and second ends **201** and **202** of the drive link **200**, respectively. In this embodiment, the magnetic sensor **220** is mounted on, or partially embedded within, a surface of the body of the drive link **200** and the magnet **222** is mounted on, or embedded within, either partially or entirely, the elastomeric member **205**. In other embodiments, the magnetic sensor **220** and magnet **222** pair can be embedded within the non-elastomeric inner member **206**, the elastomeric member **205**, and/or the body of the drive link **200**, which can include the first end **201**, the second end **202**, or the middle section **203** of the drive link **200**. A magnetic sensor **220** is mounted on the exterior surface of the drive link **200** adjacent to the perimeter of the elastomeric member **205** at the first and second ends **201** and **202** of the drive link **200**, respectively. This magnetic sensor **220** can, in other embodiments, be integrally formed within the body of the drive link **200**.

[0019] Each of the magnetic sensors **220** are electrically connected to the electronic and power module **210**, which is disposed within the hollow cavity portion **207** of the middle section **203** of the drive link **200**. The drive link **200** comprises at least one or more strain gauge **230** that are surface mounted and located on the middle section **203** of the drive link **200** on either side of the electronic and power module **210** for detecting a load acting on the drive link **200** and measuring the strain acting on the drive link **200**, which is the load being reacted by the drive link **200,** at the locations selected for the attachment of the strain gauge(s) **230**. The strain gauges **230** are configured, based on the strain detected, to generate corresponding output load signals from each strain gauge **230** to the electronic and power module **210**. Regardless of the number of strain gauges **230** employed, in some embodiments the strain gauges are configured to provide load data correlating to a strain experienced at each strain gauge **230** of the drive link **200** while the rotors **130** are deflected during an inspection procedure. In some embodiments, two sets of full bridge strain gauges **230** are used to measure loads acting on the drive link, but any suitable number of strain gauges may be installed in order to provide a plurality of strain measurements for analysis. The drive link **200** also comprises an electronic and power module **210** which has a processor, internal storage, and an energy supply, which can be an energy storage device, such as a battery or supercapacitor. In some embodiments, the electronic and power module comprises a wireless communication chip. The wireless communication chip, the internal storage, and/or the processor can be integrated in a system-on-chip (SoC) design in order to allow for a smaller hollow cavity portion **207** to be made in the middle section **203** of the drive link **200** to accommodate the electronic and power module **210** and/or to allow for a larger energy supply. The drive link comprises at least one wireless antenna **240**. The electronic and power module **210** is also in electronic communication with the at least one wireless antenna **240** configured for one of any suitable wireless communication protocols, such as near field communication (NFC), radio frequency identification (RFID), Bluetooth®, etc. While the at least one wireless antenna **240** is shown in this embodiment as being external to the electronic and power module **210**, in some embodiments the at least one wireless antenna **240** is internal to and/or integral with the electronic and power module **210**. The internal storage of the electronic and power module **210** can be any suitable type of storage, including non-volatile (NV) RAM, flash storage, and the like. In some embodiments, the internal storage of the electronic and power module **210** is configured to store the output displacement signals from each of the magnetic sensors **220** and the output load signals from each of the strain gauges **230**. In some embodiments, the wireless antenna **240** is configured to receive power from a wireless power source, such as a power storage device **340** of wand **300**, as well as to transmit and/or receive data to/from wand **300**. Power received from the wireless power source is stored in the energy supply of the electronic and power module **210**. In other embodiments, a power receiver, such as a coiled wire, may be provided elsewhere on the drive link **200** electrically connected to the electronic and power module **210** to enable inductive charging. In the embodiment described herein, the drive link **200** is not connected to a power source onboard the example aircraft. The electronic and power module **210** is electrically connected to the at least one magnetic sensor **220**, the at least one strain gauge **230**, and the at least one wireless antenna **240**. In the embodiment shown, the electronic and power module **210** is disconnected from a power source such as an auxiliary power unit of the aircraft. In some embodiments, the energy supply of the electronic and power module **210** is configured to be connected to a power source of the aircraft.

[0020] Continuing on to FIGS. 3 through 6, three example embodiments of a wand are shown. In general, the wand is configured for wireless operation and has a grip portion **310** on a first end of the wand **300**, a computation module **350**, a display **320**, and a wireless transponder **330**, such as a wireless transmitter and receiver, on a second end of the wand **300**. These example embodiments of wands **300** are all configured to transmit power to the drive link **200** from, for example, the transponder **330** to the wireless antenna **240** of the drive link **200**. In some embodiments, the wireless antenna of the drive link **200** may be augmented and/or replaced, at least for the purposes of wireless power reception, with a magnetic coil configured to receive power via an induced magnetic field via inductive charging. In these embodiments, the wand **300** is configured to generate a magnetic field when the transponder **330** is adjacent to the magnetic coil of the electronic and power module **210**. As such, the transponder **330** is configured to wirelessly transmit power to the at least one wireless antenna **240** of the drive link **200**. Regardless of the type of wireless power transmission, the power source, such as the transponder **330**, can be turned on via a proximity sensor, such as an embedder within the wand **300** and/or the drive link **200**, a user-operated button, preferably located on the wand **300**, a signal received from the drive link **200** via the wireless communication antenna, and the like. The wand **300** also includes an internal power storage device **340** and a computation module **350**, the computation module **350** having at least a processor and a memory associated therewith. The processor and memory associated with the computation module may be located within the grip portion **310**. The computation module **350** is configured to calculate a stiffness value for the drive link **200** based on the load data and the movement data received from the drive link sensors **220**, **230**. The computation module **350** is then, in some embodiments, configured to compare the stiffness value calculated with a stored stiffness value threshold, which is a stiffness value threshold for a particular drive link retrieved from a database for use by the computation module **350**. Based on this comparison, the computation module **350** is, in some such embodiments, configured to generate an indication of drive link health that is transmitted visually, haptically, auditorily, etc., to an operator. The transmission may be, for example, on the display **320**.

[0021] Referring now specifically to the example embodiment of the wand **300** illustrated in FIG. 3, a grip portion **310** is located at a first end of the wand **300** and is configured to be held by an operator. Attached to the other end of the wand **300** is wireless transponder **330**. The transponder **330** is configured to wirelessly transmit and/or receive power to the at least one wireless antenna **240** and/or to wirelessly receive data from the at least one wireless antenna, which is in electrical communication with the electronic and power module **210** of the drive link **200**. The data received comprises, in some embodiments, movement data from the at least one magnetic sensor **220** and load data from the at least one strain gauge **230** of the drive link **200**. In some embodiments, the movement data and/or the load data are generated by a movement of one or more of the rotors **130** through one or more movements of a series of prescribed movements. In some embodiments, operator controls of the aircraft are configured to generate the movement of the one or more rotors of the aircraft through the one or more movements of the series of prescribed movements. In some other embodiments, the movement of the one or more rotors through the one or more movements of the series of prescribed movements is performed manually by an operator of the health monitoring system, which may include drive link **200**, wand **300**/**301**/**302**, and/or connected device **380**. In order to enhance the ability of an operator to place the transponder **330** adjacent to the drive link **200**, the transponder **330** may be separated from the grip portion **310** by a spacing member in the form of an elongated rigid neck **312**, which is in the form of a rod and has a hollow center portion **314** along the length of the rigid neck **312** for the passage of electrical wires **316** between the grip portion **310** and the transponder **330**. The transponder **330** is configured to communicate by any suitable wireless communication protocol, including, for example, NFC, RFID, Bluetooth®, Wi-Fi®, and the like. A display **320** is located on the grip portion **310**, with three status lights **322** being included thereon in a substantially straight line. Any suitable number and configuration of status lights **322** may be used. In some embodiments, a display screen may be used in place of, or in addition to, the three status lights **322**, and may be configured to display the same or different information signified by the three status lights **322**. In the embodiment shown, the three status lights **322** are configured to be illuminated in a predetermined pattern according to the health status of the drive link being displayed, based on the results of the inspection procedure.

[0022] In FIG. 4, a cross-sectional view of the example embodiment of the wand **300** of FIG. 3 is shown and to clearly illustrate the internal components of the wand **300** the display is not illustrated. It can be seen in FIG. 4 that the grip portion **310** houses a power storage device **340** in electrical communication with the computation module **350**, also housed within the grip portion **310**. The computation module **350** has at least a processor and a memory. The memory is configured at least to store data, such as stiffness value thresholds, associated with the types of components, such as drive links **200** that are compatible with inspection via the wand **300**, to store the calculated stiffness values and/or the sensor data from the components actually tested, to store instructions for executing the inspection method, as well as other potential identifying information retrieved from the component. Potentially identifying information may include a part number and/or serial number. The processor is configured to do any or all of the following functions: control a discharge of the power storage device **340**, control a discharge of the transponder **330**, process the data and signals received from the drive link via the transponder **330**, to calculate a stiffness value from the sensor data received, to retrieve a stored stiffness value threshold from the memory, to compare the calculated stiffness value with the stored stiffness value threshold, and to output a result to the display **320**. In this example, the result may include the health status of drive link **200**. In some aspects, the processor is configured to perform predictive failure analysis of the remaining useful life of the component being inspected, with the result of the predictive failure analysis, including the remaining useful life, being displayed to the operator and stored in the memory.

[0023] In some embodiments, the wand **300** is configured to have an external communication port configured for data and/or power transfer. The external communication port may be or be something similar to a universal serial bus. The data transfer functionality may include importing updates to wand software and/or firmware. The power transfer functionality may be used for charging the power storage device **340** or, in instances where the power storage device **340** may be degraded, for operating the wand without a power storage device **340**. In other embodiments, the processor is configured to have communication protocol functionality to be able to communicate with the component being tested, but the computation module **350** may also have a separate communications module for such functionality. It can be further seen that the computation module **350** is connected to the transponder **330** of the wand **300**. In some embodiments, transponder **330** comprises an NFC antenna. Although an NFC antenna is contemplated, any antenna or device configured for wireless power and/or data transmission may be used in lieu of an NFC antenna.

[0024] Referring to FIG. 5, a second embodiment of the wand, generally designated **301**, is illustrated. As was the case with the first embodiment of FIGS. 3 and 4, the wand **301** of FIG. 5 has a grip portion **310**, and a transponder **330**. However, in this embodiment the transponder **330** is spaced apart by a flexible neck **360** rather than a rigid neck **312**, as was illustrated and described relative to FIG. 3. This flexible neck **360** provides enhanced maneuverability and more accurate placement of the transponder **330** of the wand **301** so as to be closer to the drive link **200** than is possible using the wand **300** of FIGS. 3 and 4 with the rigid neck **312**. In some aspects, this flexible neck **360** is a structure capable of being electrically and/or mechanically controlled by an operator via an input on the grip portion **310**, so that the flexible neck **360** can articulate around obstructions with the operator's input. In some further aspects, proximity sensors can be installed so as to automate the articulation of the flexible neck **360** in order to avoid obstructions. The wand of FIG. 5 is illustrated with a digital status display **370**. In the embodiment shown, the digital status display **370** comprises a screen **374** and a light **372** separate from the display. Preferably, light **372** is a light emitting diode (LED) light **372**, but may be any light source capable of providing a visual cue to the operator. The screen **374** and the light **372** are configured to present information to the operator concerning the operation of the wand **301** and/or the health of the drive link undergoing inspection.

[0025] Referring now to FIG. 6, the wand, generally designated **302**, is configured similar to the wand **300** of FIG. 3, but incorporates the digital status display **370** of the wand **301** shown in FIG. 5 to provide enhanced data presentation capabilities. While the wand **302** is shown with a rigid neck **312** separating the transponder **330** from the grip portion **310**, it is contemplated that the flexible neck **360** from FIG. 5 can be incorporated in the embodiment of the wand **302** of this embodiment. The wand **302** of FIG. 6 is further in electronic communication with a connected device **380** via an interface as defined above. The wand **302** according to this embodiment is wirelessly connected to the connected device **380**, but the wand **302** may be connected via a wired connection to the connected device **380** for more secure data transmission. The connected device **380** is, in some embodiments, configured to query a database remote from the connected device **380** or stored onboard the connected device **380** to receive a stored stiffness value threshold for use by the computation module **350**. In some embodiments, the database comprises a plurality of calculated stiffness values and/or stiffness value thresholds for the drive link and the wand **302** or the connected device **380** is configured to display a remaining useful life for the drive link. In this embodiment, the display screen **382** for the connected device **380** is used as the main display of information to be presented to the operator of the wand **302**, with the digital status display **370** being used as a supplemental screen to present the same or other data to the operator during inspection of a drive link or other suitable component. Other data may include operational instructions to the operator. In such embodiments where the connected device **380** is configured as the main display, the display screen **382** of the connected device **380** is configured to present the health status of the drive link **200** and other associated information for the drive link to the operator. Other associated information includes, but is not limited to, the date of last inspection, predictive failure analysis data, and other pertinent information an operator needs or wants to know.

[0026] While the embodiments of FIGS. 3 through 6 are provided merely for purposes of illustration, the features included in each of these embodiments may be combined in any possible combination, as would be readily understood by those having ordinary skill in the art.

[0027] Before the inspection process is initiated, the electronic and power module **210** of the drive link **200** will be wirelessly powered via the wand **300, 301, 302**. When placed adjacent to the wireless antenna **240** or power receiver, the wand will wirelessly transmit power via the transponder **330** to the wireless antenna **240**, which converts the wireless power into electrical energy that is stored in an energy supply of the drive link **200** such as the electronic and power module **210**. The energy supply of the drive link **200** is configured to provide a specified amount of operational time before the energy supply of the drive link **200** will be depleted. That specified amount of operational time is defined by the operator's need and the capacity to store energy. An example of a specified amount of operational time might be 10 minutes, 20 minutes, 30 minutes, and on up to an hour or more.

[0028] A method of inspecting drive link **200** is also provided. The method comprises a step of an operator manipulating wand **300**, **301**, **302** so that the transponder **330** of the wand **300**, **301**, **302** is located adjacent to the wireless antenna **240** and/or power receiver of the drive link **200**. The method comprises, in some embodiments, a step of transmitting power wirelessly from the wand **300**, **301**, **302** to the drive link **200** to be stored in an energy supply of the drive link **200**. The method comprises, in some embodiments, a step of receiving, at the wand **300**, **301**, **302**, a signal from the drive link **200** that the energy supply of the drive link **200** is charged for the inspection process to proceed. The method comprises, in some embodiments, a step of displaying the signal to the operator via the wand **300**, **301**, **302**. The method comprises, in some embodiments, a step of actuating one or more rotors **130** of an aircraft or rotorcraft through one or more of a series of prescribed movements. In some such embodiments, the operator actuates the rotor(s) associated with the drive link **200** through a series of prescribed movements. In some embodiments, the actuation of the rotors is done manually by the operator. In some other embodiments, the actuation of the rotors is performed by manipulating an operator control of the aircraft such as the flight controls in the cockpit of the aircraft. The method comprises, in some embodiments, a step of, during the actuation of the rotors **130**, whether manually or via a control input, detecting, using the sensors, loads acting on and movement of the drive link **200** relative movement between the components of the drive link **200**, and transmitting this load and movement data to the electronic and power module **210**. The method comprises, in some embodiments, a step of recording in the internal storage of the electronic and power module **210** of the drive link **200**, while the one or more rotors **130** are actuated, data in a form of sensor output signals from at least one magnetic sensor and magnet located across an elastomeric member of the drive link **200** and from at least one strain gauge located on a surface of the drive link **200**. In some embodiments, the sensor output signals from the at least one magnetic sensor and the at least one strain gauge correspond to a displacement and load experienced by and/or within the drive link **200**. The method comprises, in some embodiments, re-inserting the transponder of the wand **300**, **301**, **302** so as to be located adjacent to the wireless antenna **240** after the rotors **130** have come to rest. The method comprises, in some embodiments, a step of transmitting the data from the drive link **200** from the internal storage of the electronic and power module **210** to the wand **300**, **301**, **302** via the transponder of the wand **300**, **301**, **302** using the wireless antenna **240**. The method comprises, in some embodiments, a step of calculating a stiffness value for the drive link **200**. In some embodiments, the calculations for determining the stiffness of the drive link **200** are performed by the wand **300**, **301**, **302**, but these calculations can be performed by the processor of the drive link **200** in some other embodiments. The method comprises, in some embodiments, a step of comparing the stiffness value for the drive link **200** calculated to a predetermined stiffness value threshold associated with the type of drive link **200** being inspected. In some such embodiments, this stiffness value threshold is stored within the internal storage of the wand **300**, **301**, **302**. The method comprises, in some embodiments, a step of displaying a health status, such as "healthy," "replace soon," or "replace immediately," for the drive link **200** to an operator on a display of the wand. In some embodiments, the display comprises a plurality of status lights that are illuminated in a predetermined pattern according to the health status being displayed.

[0029] In some aspects, the method can include connecting the wand **300**, **301**, **302** to a connected device **380**, such as illustrated in FIG. 6, which is connected to a database for storing and transmitting calculated stiffness values associated with the drive link **200**. In some aspects, the database contains a plurality of stiffness values and/or stiffness value thresholds for drive links **200**. This database is configured to provide data suitable for performing predictive failure analysis, so that a remaining useful life of the drive link **200** can be calculated. In some embodiments, the connected device **380** is configured as a primary display for the wand **300**, **301**, **302** to present the health status and other associated information to the operator. In some such embodiments, the connected device **380** is configured to calculate or receive a remaining useful life of the drive link **200**. While the steps recited hereinabove are recited in a given order, it is contemplated that one or more steps can be omitted and/or the steps can be performed in another order without deviating from the subject matter disclosed herein.

[0030] The embodiments described herein are examples only and are not limiting. Many variations and modifications of the systems, apparatus, and processes described herein are possible and are within the scope of the disclosure. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.

CLAIMS

What is claimed is:

1. A health monitoring system for an aircraft, the health monitoring system comprising:

a drive link configured to connect one or more rotors to the aircraft, the drive link including:

at least one magnetic sensor and magnet, which are located adjacent to an elastomeric member of the drive link;

at least one strain gauge located on the drive link;

at least one wireless antenna; and

an electronic and power module includes a processor, internal storage, and an energy supply, wherein the electronic and power module is electrically connected to the at least one magnetic sensor, the at least one strain gauge, and the at least one wireless antenna.

2. The health monitoring system of claim 1, further comprising a wand, the wand including:

a grip portion on a first end of the wand;

a computation module;

a transponder on a second end of the wand; and

a display.

3. The health monitoring system of claim 2, wherein the transponder is configured to wirelessly transmit power to the at least one wireless antenna, and the transponder is configured to wirelessly receive data from the at least one wireless antenna.

4. The health monitoring system of claim 3, wherein:

the data received comprises movement data from the at least one magnetic sensor and load data from the at least one strain gauge, and

the computation module is configured to calculate a stiffness value for the drive link based on the data received, to compare the stiffness value calculated with a stored stiffness value threshold, and to generate an indication of drive link health to an operator on the display.

5. The health monitoring system of claim 4, wherein the movement data and the load data are generated by a movement of one or more rotors through one or more movements of a series of prescribed movements.

6. The health monitoring system of claim 5, wherein operator controls of the aircraft are configured to generate the movement of the one or more rotors through the one or more movements of the series of prescribed movements.

7. The health monitoring system of claim 5, wherein the movement of the one or more rotors through the one or more movements of the series of prescribed movements is performed manually by an operator of the health monitoring system.

8. The health monitoring system of claim 4, wherein the wand is in electronic communication with a connected device via an interface.

9. The health monitoring system of claim 8, wherein the connected device is configured to be a main display of information to an operator of the health monitoring system.

10. The health monitoring system of claim 8, wherein the connected device is configured to query a database to receive the stored stiffness value threshold.

11. The health monitoring system of claim 10, wherein the database comprises a plurality of calculated stiffness values for the drive link and wherein the wand or the connected device is configured to display a remaining useful life for the drive link.

12. The health monitoring system of claim 8, wherein the interface is wired or wireless.

13. The health monitoring system of claim 1, wherein the electronic and power module is disconnected from a power source of the aircraft.

14. A drive link for connecting one or more rotors in a rotary aircraft, the drive link comprising:

at least one magnetic sensor and magnet, which are located adjacent to an elastomeric member of the drive link;

at least one strain gauge located on the drive link;

at least one wireless antenna; and

an electronic and power module including a processor, internal storage, and an energy supply, wherein the electronic and power module is electrically connected to the at least one magnetic sensor, the at least one strain gauge, and the at least one wireless antenna.

15. The drive link of claim 14, wherein the at least one wireless antenna is configured to receive power from a wireless power source and to transmit data to a wand wirelessly, and wherein the power received is stored in the energy supply.

16. The drive link of claim 14, wherein the at least one strain gauge is a plurality of strain gauges.

17. The drive link of claim 14, wherein the at least one magnetic sensor and magnet are a plurality of magnetic sensors and magnets, with a first of the plurality of magnetic sensors and magnets being located at a first end of the drive link and a second of the plurality of magnetic sensors and magnets being located at a second end of the drive link.

18. The drive link of claim 17, wherein the plurality of magnetic sensors and magnets are configured to detect relative displacement and generate corresponding output displacement signals, wherein the plurality of strain gauges are configured to detect a load acting on the drive link and generate corresponding output load signals, and wherein the internal storage of the electronic and power module is configured to store the output displacement signals and the output load signals.

19. A method of assessing a health of a drive link connecting one or more rotors to an aircraft, the method comprising:

manipulating a wand so that a transponder of the wand is located adjacent to a wireless antenna of the drive link;

transmitting power wirelessly from the wand to the drive link;

actuating the one or more rotors through one or more movements of a series of prescribed movements;

recording in an internal storage of the drive link, while the one or more rotors are actuated, data in a form of sensor output signals from at least one magnetic sensor and magnet located adjacent to an elastomeric member of the drive link and from at least one strain gauge located on a surface of the drive link;

transmitting the data from the internal storage to the wand using the wireless antenna;

calculating a stiffness value for the drive link;

comparing the stiffness value for the drive link calculated to a predetermined stiffness value threshold; and

displaying a health status to an operator on a display of the wand.

20. The method of claim 19, wherein the sensor output signals from the at least one magnetic sensor and the at least one strain gauge correspond to a displacement and load.

21. The method of claim 19, wherein the actuating of the one or more rotors is performed manually by the operator or by manipulating an operator control of the aircraft.

22. The method of claim 19, wherein the wand is in communication with a connected device, which is configured to query a database containing a plurality of stiffness values for drive links.

23. The method of claim 22, wherein the connected device is configured as a primary display for the wand to present the health status and other associated information to the operator, and wherein the connected device is configured to calculate or receive a remaining useful life of the drive link.

24. The method of claim 19, wherein the display comprises a plurality of status lights that are illuminated in a predetermined pattern according to the health status being displayed.

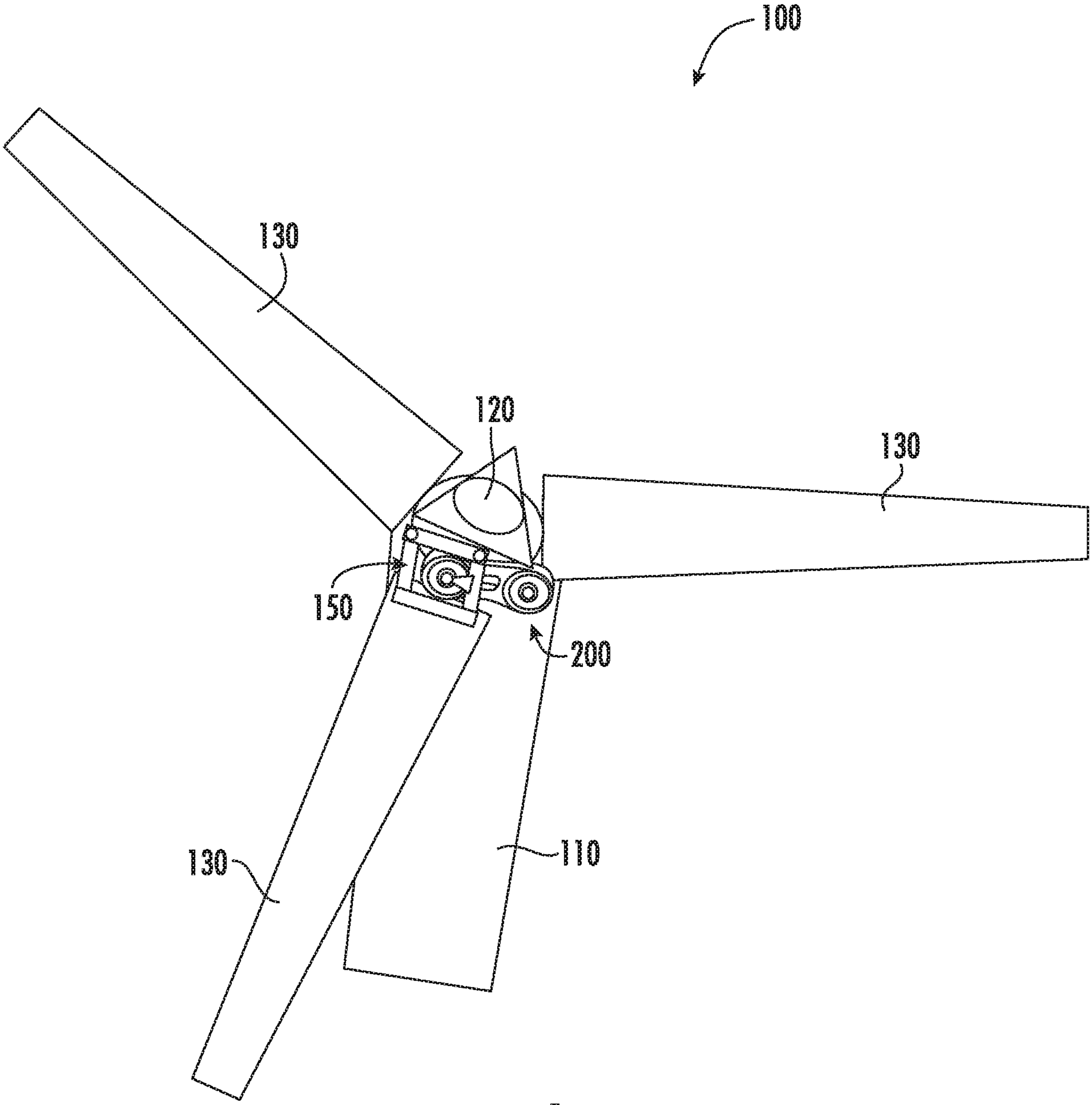

FIG. 1

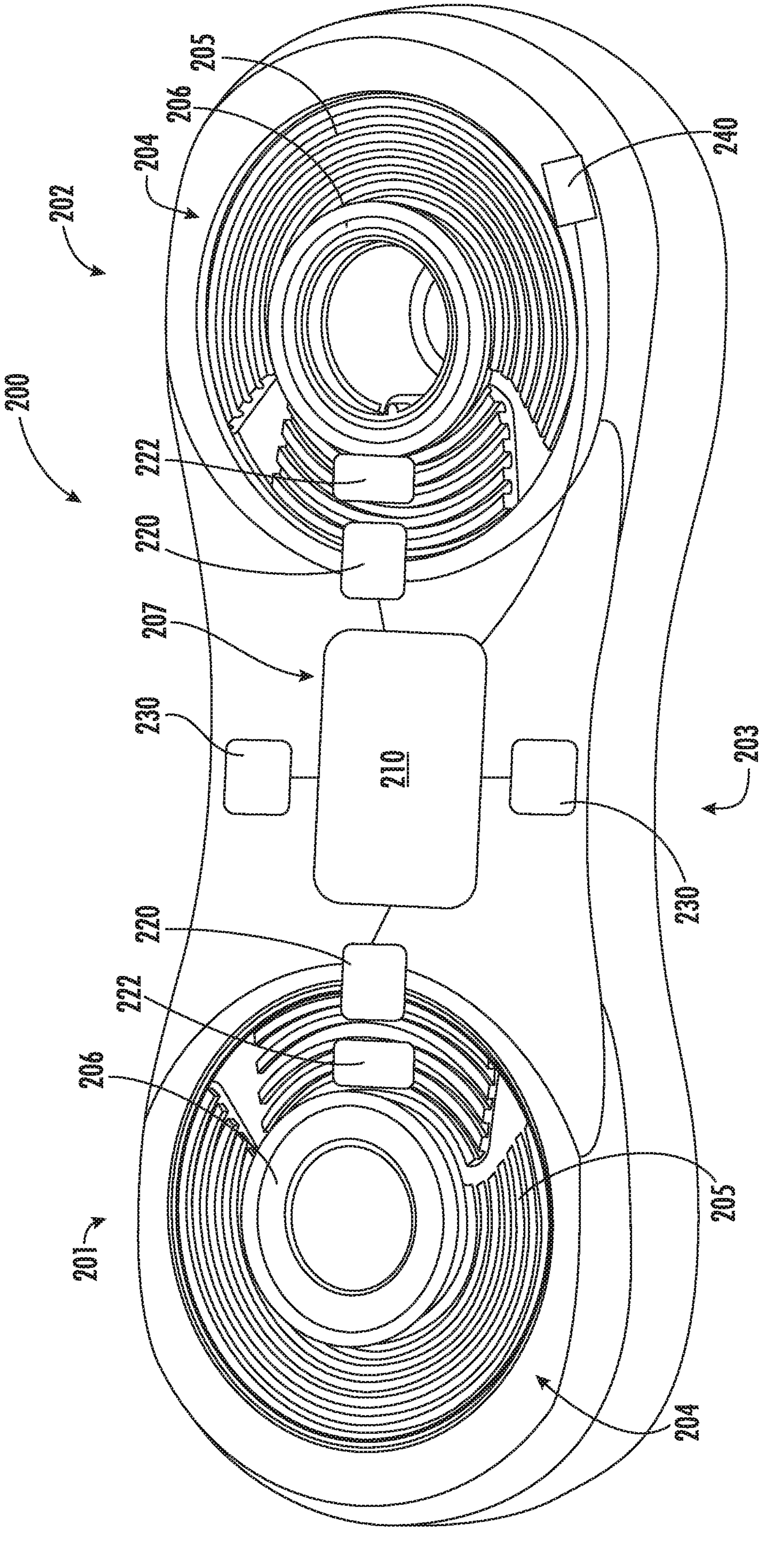

FIG. 2

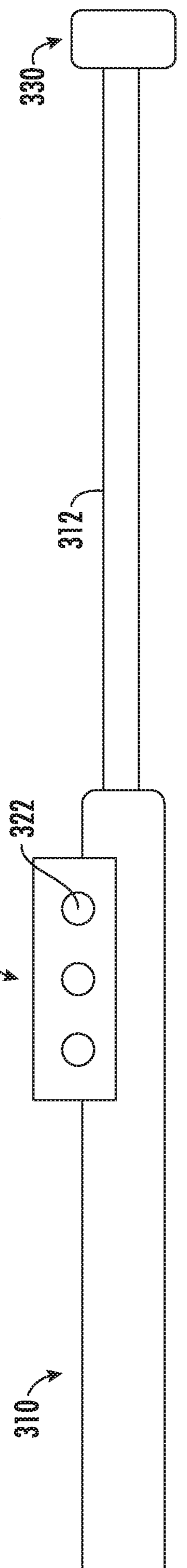

FIG. 3

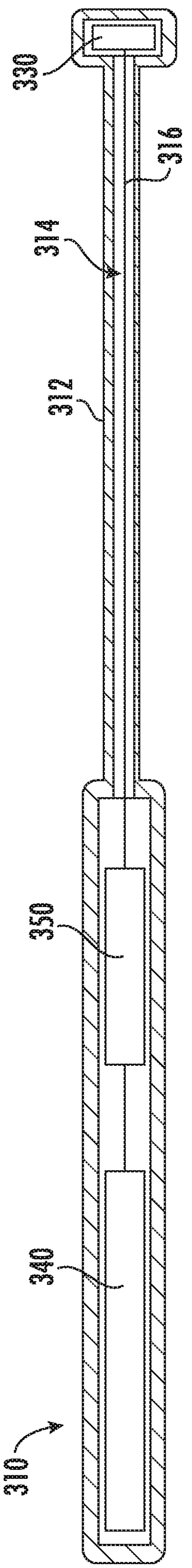

FIG. 4

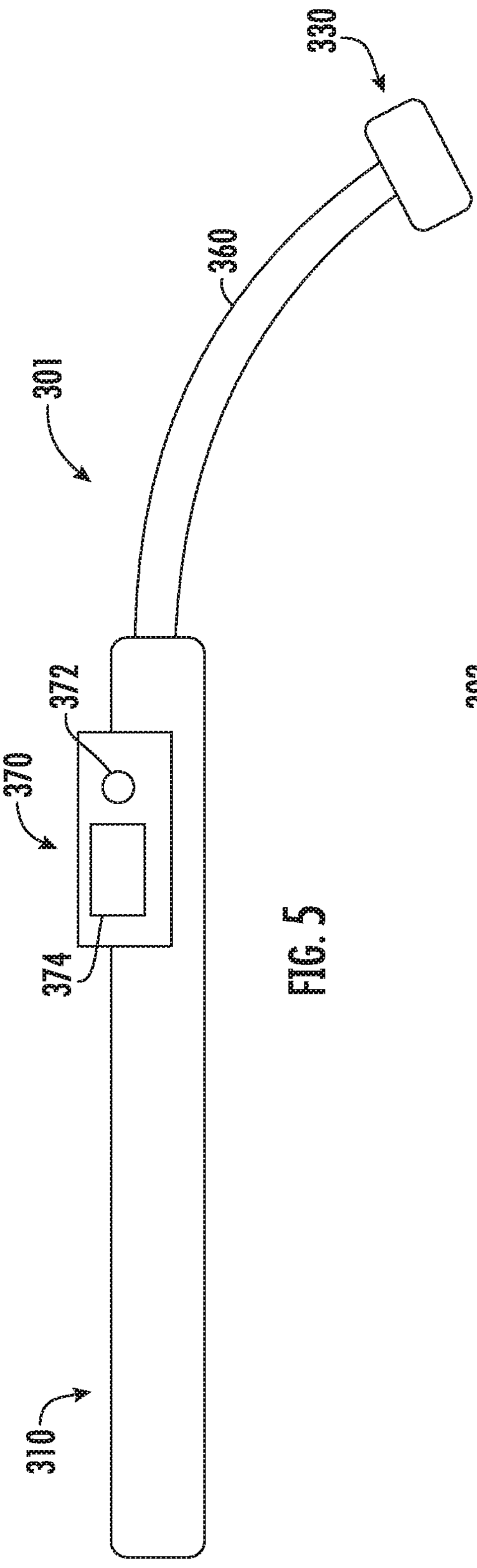

FIG. 5

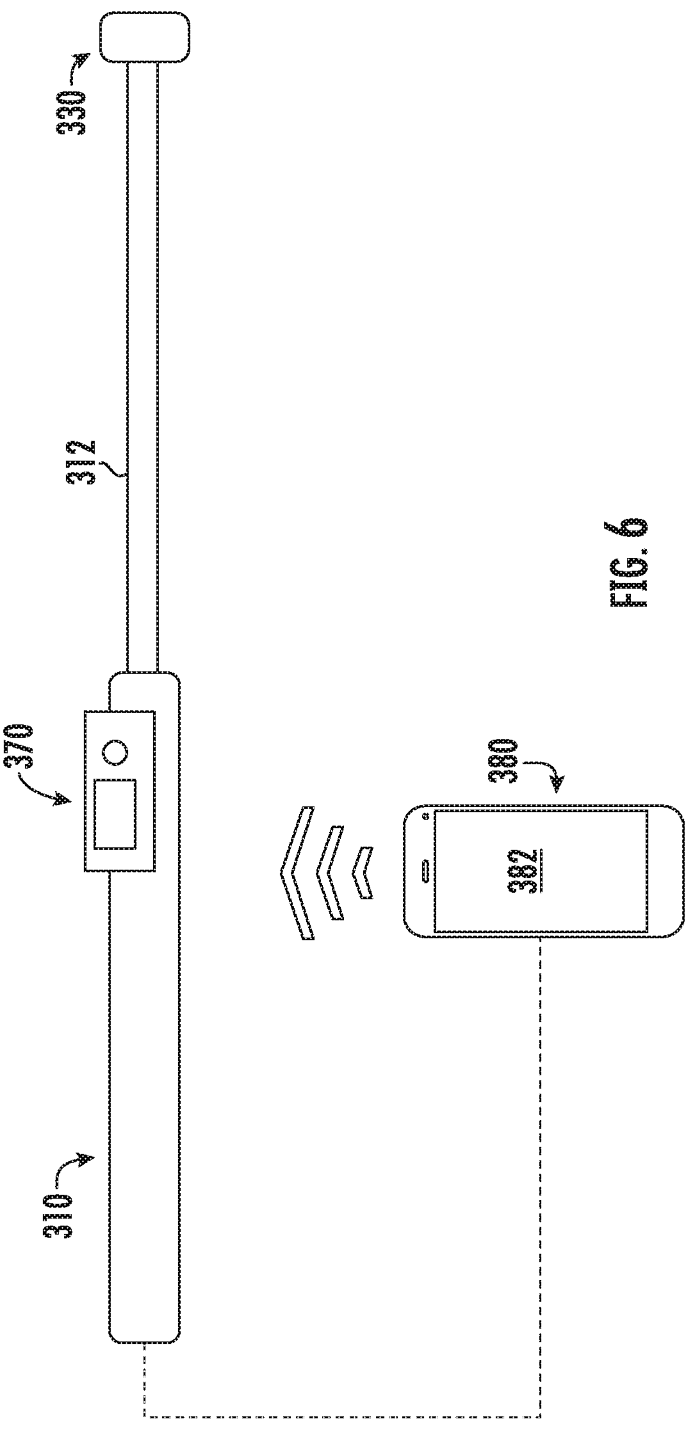

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/018287

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01M5/00 B64C27/00 B64C27/51 F16F9/32
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)
G01M B64C F16F

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.
X Y A	US 2015/369328 A1 (SAUTIER PASCAL [FR] ET AL) 24 December 2015 (2015-12-24) paragraph [0001] - paragraph [0005]; claims 1,2,4,5,6,7,9,10,12,13,14; figures 2,3,5 paragraph [0016] - paragraph [0045] paragraph [0088] - paragraph [0131] -----	1,14, 16-18 2,3,13, 15 4-12, 19-24
Y A	US 2002/154029 A1 (WATTERS DAVID G [US] ET AL) 24 October 2002 (2002-10-24) paragraph [0002] - paragraph [0003]; figures 1,2a,3a paragraph [0008] - paragraph [0013] paragraph [0044] - paragraph [0047] paragraph [0058] - paragraph [0060] paragraph [0068] - paragraph [0081] paragraph [0115] ----- -/--	2,3,13, 15 1,4-12, 14,16-24

[X] Further documents are listed in the continuation of Box C.

[X] 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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 April 2018	20/04/2018

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/256055 A1 (JOLLY MARK R [US] ET AL) 11 October 2012 (2012-10-11) paragraph [0002] - paragraph [0003]; figures 1b,2a,2b paragraph [0020] - paragraph [0022] paragraph [0028] - paragraph [0038] -----	1-24
A	US 7 343 265 B2 (LOCKHEED CORP [US]) 11 March 2008 (2008-03-11) column 1, line 19 - column 1, line 57; figures 1,2,3,4,13,14,15 column 2, line 12 - column 3, line 2 column 4, line 1 - column 4, line 25 column 6, line 26 - column 7, line 21 -----	1-24

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2018/018287

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