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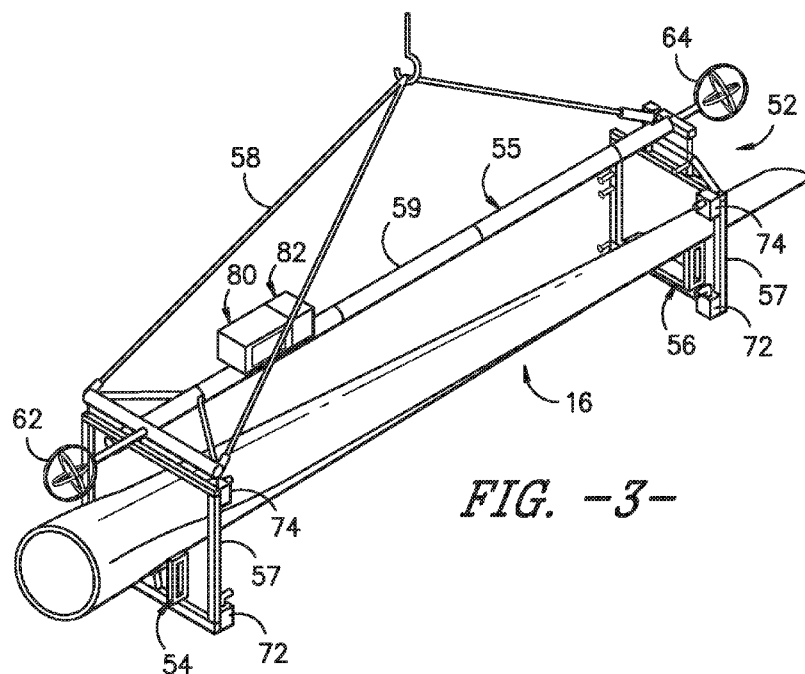
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(54) Title: LIFTING DEVICE FOR A WIND TURBINE ROTOR BLADE



(57) Abstract: A lift system (50) for a rotor blade (16) of a wind turbine includes a lifting device (52) having a structural frame body that supports at least one cradle (54, 56). The cradle(s) includes a profile that corresponds to at least one exterior surface of the rotor blade so as to receive and support at least a portion of the rotor blade. The lift system also includes a gyroscope assembly (60) coupled to the lifting device. The gyroscope assembly includes at least one gyroscope (62, 64) configured to modify an orientation of the lifting device as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind turbine.

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LIFTING DEVICE FOR A WIND TURBINE ROTOR BLADE

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Serial No.: 16/103,062 filed on August 14, 2018, which is incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates in general to wind turbines, and more particularly to lifting devices for wind turbine rotor blades.

BACKGROUND

[0003] Wind power is considered one of the cleanest, most environmentally friendly energy sources presently available, and wind turbines have gained increased attention in this regard. A modern wind turbine typically includes a tower, a generator, a gearbox, a nacelle, and one or more rotor blades. The rotor blades capture kinetic energy of wind using known airfoil principles. The rotor blades transmit the kinetic energy in the form of rotational energy so as to turn a shaft coupling the rotor blades to a gearbox, or if a gearbox is not used, directly to the generator. The generator then converts the mechanical energy to electrical energy that may be deployed to a utility grid.

[0004] The typical construction of a wind turbine involves erecting the tower and then connecting various other components to the erected tower. For example, the rotor blades may be lifted to an appropriate height and connected to the tower after erection of the tower. In some cases, each of the rotor blades is connected to a hub before lifting, and the connected rotor blades and hub are then lifted and connected to the tower as a unit. Trends towards taller towers and larger rotor diameters, however, can limit and/or preclude lifting such units to the tower due to size and/or cost. More specifically, as the rotor diameter and/or mass and hub height increases, there are few (if any) cranes that can lift such structures. Further, the sail area can become so large, that the available wind window to conduct such lifts approaches zero, i.e. the cranes cannot lift the rotor without tipping over.

[0005] Thus, current systems and methods for lifting the rotor blades involve

lifting each rotor blade uptower individually using, for example, a cradle, sling, or clamping-type blade lifting tool that is lifted using a crane. Individual rotor blades can then be connected to the hub.

[0006] Such methods typically utilize one or more tag lines connected to the lifting tool that can be held by an operator on the ground as a rotor blade is lifted uptower. As the rotor blade is lifted, however, control of the load via the tag line(s) becomes less effective. More specifically, the operator has to apply more and more force to the tag line(s) as the load is lifted with less results.

[0007] In view of the aforementioned, an improved lifting device for lifting wind turbine rotor blades uptower is desired in the art. For example, a lifting device that utilizes gyroscopic forces to maintain the X- and Y- coordinates of the lifting device during lifting and/or lowering thereof would be advantageous. In addition, a lifting device that can be lifted and/or lowered to the hub without the use of taglines would be desirable in the art.

BRIEF DESCRIPTION

[0008] Aspects and advantages of the disclosure will be set forth in part in the following description, or may be obvious from the description, or may be learned through practice of the disclosure.

[0009] In one aspect, the present disclosure is directed to a lift system for a rotor blade of a wind turbine. The lift system includes a lifting device having a structural frame body that supports at least one cradle. The cradle(s) includes a profile that corresponds to at least one exterior surface of the rotor blade so as to receive and support at least a portion of the rotor blade. The lift system also includes a gyroscope assembly coupled to the lifting device. The gyroscope assembly includes at least one gyroscope configured to modify an orientation of the lifting device as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind turbine.

[0010] In one embodiment, the gyroscope assembly may include a plurality of gyroscopes. For example, in such embodiments, the plurality of gyroscopes may include a first gyroscope and a second gyroscope. More specifically, in several embodiments, the first and second gyroscopes may be coupled to opposing ends of the structural frame body.

[0011] In further embodiments, the first and second gyroscopes may be spaced evenly from a center location of the structural frame body. In additional embodiments, tilt angles of the first and second gyroscopes may be oriented in opposing directions. In alternative embodiments, the tilt angles of the first and second gyroscopes may be oriented in the same direction.

[0012] In several embodiments, the gyroscope assembly may include a drive mechanism for spinning and/or tilting the gyroscope. For example, the drive mechanism may be a generator, an integrated motor, a separate motor, or any other suitable power device.

[0013] In particular embodiments, the gyroscope assembly may further include a controller configured to control the drive mechanism of the gyroscope so as to modify the orientation of the lifting device as the lifting device is lifted or lowered to and from the hub mounted to the tower. More specifically, in such embodiments, the controller may include a remote control, a turbine controller of the wind turbine, or a separate controller from the wind turbine.

[0014] In another embodiment, the gyroscope assembly may also include first and second sensors positioned adjacent to the first and second gyroscopes, respectively. More specifically, the first and second sensors may be communicatively coupled to the controller. In such embodiments, the controller may be configured to control the drive mechanism of the gyroscope based on sensor signals from the first and second sensors so as to modify the orientation of the lifting device. In additional embodiments, the first and second sensors may include, for example, Global Positioning Sensor (GPS) sensors, accelerometers, smart sensors, or combinations thereof, or similar.

[0015] In yet another embodiment, the lifting device may further include a root cradle for supporting a blade root of the rotor blade and a tip cradle for supporting a blade tip of the rotor blade. As such, the structural frame body may be connected to and support the root cradle and the tip cradle.

[0016] In another aspect, the present disclosure is directed to a method for controlling orientation of a lifting device for a rotor blade of a wind turbine as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind turbine. The method includes mounting a gyroscope assembly having at least one

gyroscope to a structural frame body of a lifting device. The structural frame body supports at least one cradle configured to receive the rotor blade. As such, the method includes securing the rotor blade atop the cradle(s) of the lifting device. Once the rotor blade is secured in the lifting device, the method includes lifting or lowering the lifting device between the hub and a ground location while simultaneously controlling the gyroscope(s).

[0017] In one embodiment, the step of mounting the gyroscope assembly having the gyroscope(s) to the structural frame body may include mounting a plurality of gyroscopes to the structural frame body. More specifically, the method may include mounting a first gyroscope and a second gyroscope at opposing ends of the structural frame body.

[0018] In another embodiment, the step of controlling the gyroscope(s) may include allowing for a Z-coordinate of the structural frame body to change in a vertical direction up to predetermined altitude while maintaining an X-coordinate and a Y-coordinate of the structural frame body via the first and second gyroscopes as the lifting device is lifted or lowered between the hub and the ground location.

[0019] In further embodiments, the step of controlling the gyroscope(s) may include receiving, via a controller, a plurality of sensor signals from first and second sensors positioned adjacent to the first and second gyroscopes, respectively and controlling, via the controller, a drive mechanism of the gyroscope assembly so as to spin and/or tilt the first and second gyroscopes based on the sensor signals. More specifically, in one embodiment, the step of controlling the drive mechanism of the gyroscope assembly so as to spin and/or tilt the first and second gyroscopes based on the sensor signals may include reversing tilt angles of the first and second gyroscopes to stop and/or reverse a direction of rotation of the lifting device.

[0020] In alternative embodiments, the step of controlling the drive mechanism of the gyroscope assembly so as to spin and/or tilt the first and second gyroscopes based on the sensor signals may include tilting the first and second gyroscopes in the same direction to generate a pair of forces that counter-react load sway of the lifting device.

[0021] In yet another aspect, the present disclosure is directed to a method for controlling orientation of a lifting device for a rotor blade of a wind turbine as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind

turbine. The method includes mounting a gyroscope assembly having at least one gyroscope to a structural frame body of a lifting device. The structural frame body supports at least one cradle configured to receive the rotor blade. The method also include lifting or lowering the lifting device between the hub and a ground location while simultaneously controlling the at least one gyroscope and without using any taglines.

[0022] It should be understood that the methods described herein may further include any of the additional steps and/or features as described herein.

[0023] These and other features, aspects and advantages of the present disclosure will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the disclosure and, together with the description, serve to explain the principles of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] A full and enabling disclosure of the present disclosure, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0025] FIG. 1 illustrates a perspective view of one embodiment of a wind turbine according to the present disclosure;

[0026] FIG. 2 illustrates a side view of one embodiment of a rotor blade according to the present disclosure;

[0027] FIG. 3 illustrates a perspective view of one embodiment of a lift system according to the present disclosure;

[0028] FIG. 4 illustrates a perspective view of one embodiment of a lifting device according to the present disclosure;

[0029] FIG. 5 illustrates a perspective view of one embodiment of a gyroscope according to the present disclosure;

[0030] FIG. 6 illustrates a perspective view of one embodiment of a lift system for a rotor blade of a wind turbine, particularly illustrating first and second gyroscopes mounted at opposing ends of a lifting device of the lift system;

[0031] FIG. 7 illustrates a schematic diagram of one embodiment of a lift system

for a rotor blade of a wind turbine, particularly illustrating first and second gyroscopes mounted at opposing ends of a lifting device of the lift system and having reversed tilt angles;

[0032] FIG. 8 illustrates a schematic diagram of one embodiment of a lift system for a rotor blade of a wind turbine, particularly illustrating first and second gyroscopes mounted at opposing ends of a lifting device of the lift system and having the same tilt angles; and,

[0033] FIG. 9 illustrates a flow diagram of one embodiment of a method for controlling orientation of a lifting device for a rotor blade of a wind turbine as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind turbine according to the present disclosure.

DETAILED DESCRIPTION

[0034] Reference now will be made in detail to embodiments of the disclosure, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation of the disclosure, not limitation of the disclosure. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present disclosure without departing from the scope or spirit of the disclosure. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present disclosure covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0035] Generally, the present disclosure is directed to a lifting device for a wind turbine rotor blade and a method of controlling the ascent and descent thereof with or without a rotor blade loaded into it without the aid of tag lines or tag line crews. For example, in one embodiment, the orientation of the lifting device under is controlled by utilizing the gyroscopic effects provided by a set of gyroscopes mounted on either or both ends of the lifting device. Control of the gyroscopes can be manual, automatic, and/or combinations thereof. The same gyroscopes can also be used to counter-react wind-induced load sway.

[0036] More particularly, a gyroscope tends to maintain its position in space or in

other words, the axis, around which it is revolving, and tends to resist changes in its orientation by outside influences. Inversely, if an outside force causes a change in the position of the axis, a reacting force in a plane perpendicular to that of the outside force is being generated. The presented disclosure utilizes this gyroscopic behavior, which is also called precession. For example, the pair of gyroscopes are configured to spin in a vertical plane. More specifically, the gyroscopic wheels are suspended in a way that they can be tilted around a horizontal axis. If the gyroscopes are tilted in opposite directions, the resulting precession forces create a torque which will cause the lifting device to rotate. The force acts as long as the gyroscopes are tilted and disappears if the gyroscopes are returned to their original plane. By tilting the gyroscopes, a more direct control over the load is achieved compared to tag line input from a ground-based crew. Conversely, if the gyroscopes are titled in the same direction, a pair of force vectors which both act in the same direction thus can be used to counter-react unwanted wind-induced sway of the load.

[0037] Referring now to the drawings, FIG. 1 illustrates a perspective view of one embodiment of a wind turbine 10 according to the present disclosure. As shown, the wind turbine 10 includes a tower 12 with a nacelle 14 mounted thereon. A plurality of rotor blades 16 are mounted to a rotor hub 18, such as via the roots (discussed below) of the rotor blades, which is in turn connected to a main flange that turns a main rotor shaft (not shown). The wind turbine power generation and control components are typically housed within the nacelle 14 and/or the tower 12. The view of FIG. 1 is provided for illustrative purposes only to place the present disclosure in an exemplary field of use. It should be appreciated that the disclosure is not limited to any particular type of wind turbine configuration.

[0038] Referring to FIG. 2, a perspective view of one of the rotor blades 16 of FIG. 1 according to the present disclosure is illustrated. As shown, the rotor blade 16 includes exterior surfaces defining a pressure side 22 and a suction side 24 extending between a leading edge 26 and a trailing edge 28, and extends from a blade tip 32 to a blade root 34. The exterior surfaces may be generally aerodynamic surfaces having generally aerodynamic contours, as is generally known in the art. In some embodiments, the rotor blade 16 may include a plurality of individual blade segments aligned in an end-to-end order from the blade tip 32 to the blade root 34. Each of the

individual blade segments may be uniquely configured such that the plurality of blade segments define a complete rotor blade 16 having a designed aerodynamic profile, length, and other desired characteristics. For example, each of the blade segments may have an aerodynamic profile that corresponds to the aerodynamic profile of adjacent blade segments. Thus, the aerodynamic profiles of the blade segments may form a continuous aerodynamic profile of the rotor blade 16. Alternatively, the rotor blade 16 may be formed as a singular, unitary blade having the designed aerodynamic profile, length, and other desired characteristics.

[0039] The rotor blade 16 may, in exemplary embodiments, be curved. Curving of the rotor blade 16 may entail bending the rotor blade 16 in a generally flap-wise direction and/or in a generally edge-wise direction. The flap-wise direction may generally be construed as the direction (or the opposite direction) in which the aerodynamic lift acts on the rotor blade 16. The edge-wise direction is generally perpendicular to the flap-wise direction. Flap-wise curvature of the rotor blade 16 is also known as pre-bend, while edgewise curvature is also known as sweep. Thus, a curved rotor blade 16 may be pre-bent and/or swept. Curving may enable the rotor blade 16 to better withstand flapwise and edgewise loads during operation of the wind turbine 10, and may further provide clearance for the rotor blade 16 from the tower 12 during operation of the wind turbine 10.

[0040] Still referring to FIG. 2, the rotor blade 16 may further define chord 42 and a span 44. Further, as shown in FIG. 2, the chord 42 may vary throughout the span 44 of the rotor blade 16. Thus, a local chord may be defined for the rotor blade 16 at any point on the rotor blade 16 along the span 44. The exterior surfaces, as discussed above, may extend in the generally span-wise direction between the tip 32 and root 34.

[0041] Referring now to FIGS. 3 through 8, various components of a lift system 50 for a rotor blade 16 of a wind turbine 10 according to the present disclosure are illustrated. As shown in FIGS. 3 and 4, the lift system 50 includes a lifting device 52 configured to support at least a portion of the rotor blade 16. More specifically, as shown, the lifting device 52 includes at least one cradle 54, 56, which is described in more detail below. For example, as shown, the lifting device 52 includes a root cradle 54 and a tip cradle 56 for supporting portions of the blade 16 near the blade root 34

and the blade tip 32, respectively. Further, in certain embodiments, each of the cradles 54, 56 generally has a profile that corresponds to at least one of the exterior surfaces of the rotor blade 16 so as to support at least a portion of the rotor blade 16. For example, as shown in FIGS. 3 and 4, the root cradle 54 has a profile that generally corresponds to the blade root 34 of the rotor blade 16, whereas the tip cradle 56 has a profile that generally corresponds to the blade tip 32 of the rotor blade 16.

[0042] In addition, as shown in FIGS. 3 and 4, the lifting device 52 may include a structural frame body 55 for connecting and supporting the root cradle 54 and the tip cradle 56. More specifically, as shown, the structural frame body 55 may include one or more cradle supports 57 configured to support each of the root and tip cradles 54, 56, respectively. Thus, as shown, the root and tip cradles 54, 56 may be mounted to respective ends of the structural frame body 55. Further, the cradle supports 57 may be joined or coupled together via a main support 59 or beam. Thus, in additional embodiments, the lift system 50 may also include a crane (not shown) and a crane cable or sling 58 (FIGS. 3 and 4). In such embodiments, the crane may be coupled to the cable or sling 58, which is secured to the structural frame body 55 such that the crane can lift and/or lower the rotor blade 16 between the hub 18 and the tower 12. More specifically, the crane cable or sling 58 may include a synthetic fabric sling and/or a central attachment point so as to provide stability to the lifting device 52 during lifting and/or lowering.

[0043] The crane as described herein may be any suitable machine for generally lifting equipment and/or materials, such as a mobile crane, a floating crane, an aerial crane, or a fixed crane (such as a tower crane), as is generally known in the art. Further, the crane cable or sling 58 may be connected to the crane, and the crane may control movement of the crane cable or sling 58, as is generally known in the art.

[0044] Still referring to FIGS. 3-8, the lift system 50 may also include a gyroscope assembly 60 having at least one gyroscope 62 coupled to the lifting device 52. As used herein, a gyroscope generally refers to a device used for measuring or maintaining orientation and angular velocity. More specifically, as shown in FIG. 5, a perspective view of one embodiment of the gyroscope 62 is illustrated. As shown, the illustrated gyroscope 62 includes a spinning wheel 66 or disc that is mounted within a plurality of gimbals 68, 70, 72, which are pivoted supports that allow the rotation of

the wheel 66 about an axis of rotation 74 that is free to assume any orientation by itself. Thus, when rotating, the orientation of the axis 74 is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum. Accordingly, the gimbals 68, 70, 72 allow the spinning wheel 66 mounted on the innermost gimbal 68 to have an orientation remaining independent of the orientation, in space, of its support. As such, rotation of the gyroscope 62 can be used to modify an orientation of the lifting device 52 as the device 52 is lifted or lowered to and from the hub 20 mounted uptower.

[0045] In further embodiments, the gyroscope assembly 60 may include a plurality of gyroscopes 62, 64. For example, as shown particularly in FIGS. 3-4 and 6-8, the gyroscope assembly 60 may include a first gyroscope 62 and a second gyroscope 64. More specifically, as shown in the illustrated embodiments, the first and second gyroscopes 62, 64 may be coupled to opposing ends of the structural frame body 55. In addition, as shown, the first and second gyroscopes 62, 64 may be spaced evenly from a center location of the structural frame body 55 (e.g. as shown by distance r).

[0046] In several embodiments, as shown in FIGS. 3 and 4, the gyroscope assembly 60 may include a drive mechanism 80 communicatively coupled to the gyroscopes 62, 64 for spinning and/or tilting the gyroscopes 62, 64. For example, in certain embodiments, the drive mechanism 80 may be a generator, an integrated motor, a separate motor, or any other suitable power device. In addition, as shown, the gyroscope assembly 60 may further include a controller 82 configured to control the drive mechanism 80 of the gyroscopes 62, 64 so as to modify the orientation of the lifting device 52 as the device 52 is lifted or lowered to and from the hub 20. The controller 82 as described herein may be incorporated into a suitable control system of the wind turbine 10 (not shown), a handheld remote, a personal digital assistant, cellular telephone, a separate controller or computer having one or more processor(s) and associated memory devices. Further, the one or more processor(s) may include suitable processing apparatus and software for operating the gyroscope assembly 60 as desired or required.

[0047] Accordingly, as shown in FIGS. 6 and 7, the drive mechanism 80 may be configured to orient the tilt angles/directions 76, 78 of the first and second gyroscopes

62, 64 in opposing directions. Thus, as shown, the lifting device 52 can be rotated about the single suspension point (i.e. the crane hook), whereas reversing the tilt angle of the first and second gyroscopes 62, 64 is configured to generate a torque 90 (FIGS. 6 and 7) to stop and/or reverse the direction of rotation of the lifting device 52. In alternative embodiments, as shown in FIG. 8, the drive mechanism 80 may be configured to orient the tilt angles/directions 76, 78 of the first and second gyroscopes 62, 64 in the same direction. As such, rotation of the first and second gyroscopes 62, 64 is configured to generate a pair of forces 84 which can be used to counter-react load sway (as indicated by arrow 92).

[0048] Referring still to FIGS. 7 and 8, the gyroscope assembly 60 may also include first and second sensors 86, 88 positioned adjacent to the first and second gyroscopes 62, 64, respectively. More specifically, the first and second sensors 86, 88 may be communicatively coupled to the controller 82, e.g. via a wireless and/or a wired connection. In such embodiments, the controller 82 may be configured to control the drive mechanism 80 of the gyroscopes 62, 64 based on sensor signals received from the first and second sensors 86, 88 so as to modify the orientation of the lifting device 52 during a lifting or lowering procedure. In additional embodiments, the first and second sensors 86, 88 may include, for example, Global Positioning Sensor (GPS) sensors, accelerometers, smart sensors, or combinations thereof, or similar.

[0049] Referring now to FIG. 9, a flow diagram of one embodiment of a method 100 for controlling orientation of a lifting device for a rotor blade of a wind turbine as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind turbine is illustrated. In general, the method 100 will be described herein with reference to the wind turbine 10 and lift system 50 shown in FIGS. 1-9. However, it should be appreciated that the disclosed method 100 may be implemented with wind turbines having any other suitable configurations. In addition, although FIG. 9 depicts steps performed in a particular order for purposes of illustration and discussion, the methods discussed herein are not limited to any particular order or arrangement. One skilled in the art, using the disclosures provided herein, will appreciate that various steps of the methods disclosed herein can be omitted,

rearranged, combined, and/or adapted in various ways without deviating from the scope of the present disclosure.

[0050] As shown at (102), the method 100 may include mounting the gyroscope assembly 60 having at least one gyroscope 62 to the structural frame body 55 of the lifting device 52. For example, in one embodiment, the method 100 may include mounting the first gyroscope 62 and the second gyroscope 64 at opposing ends of the structural frame body 55. As shown at (104), the method 100 may include securing the rotor blade atop the cradle(s) of the lifting device 52. In alternative embodiments, it should be understood that the lifting device 52 may also be lifted or lowered to and from the hub without the rotor blade 16 installed therein. Once the rotor blade 16 is secured in the lifting device 52, as shown at (106), the method 100 may include lifting or lowering the lifting device 52 between the hub 20 and a ground location while simultaneously controlling the gyroscope(s) 62, 64.

[0051] More specifically, in one embodiment, the step of controlling the gyroscope(s) 62, 64 may include allowing for a Z-coordinate of the structural frame body 55 to change in a vertical direction up to predetermined altitude or height while maintaining an X-coordinate and a Y-coordinate of the structural frame body 55 via the first and second gyroscopes 62, 64 as the lifting device 52 is lifted or lowered between the hub 20 and the ground location.

[0052] In another embodiment, the controller 82 may control the gyroscope(s) 62, 64 by receiving a plurality of sensor signals from first and second sensors 86, 88 positioned adjacent to the first and second gyroscopes 62, 64, respectively, and controlling the drive mechanism 80 of the gyroscope assembly 60 so as to spin and/or tilt the first and second gyroscopes 62, 64 based on the sensor signals. More specifically, in one embodiment, the controller 82 may reverse the tilt angles of the first and second gyroscopes 62, 64 to stop and/or reverse a direction of rotation of the lifting device 52. In alternative embodiments, the controller 82 may tilt the first and second gyroscopes 62, 64 in the same direction to generate a pair of forces 84 that counter-react load sway of the lifting device 52.

[0053] This written description uses examples to disclose the disclosure, including the best mode, and also to enable any person skilled in the art to practice the disclosure, 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 include 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 languages of the claims.

WHAT IS CLAIMED IS:

1. A lift system for a rotor blade of a wind turbine, the lift system comprising:
 - a lifting device comprising a structural frame body that supports at least one cradle, the at least one cradle comprising a profile that corresponds to at least one exterior surface of the rotor blade so as to receive and support at least a portion of the rotor blade; and,
 - a gyroscope assembly coupled to the lifting device, the gyroscope assembly comprising at least one gyroscope configured to modify an orientation of the lifting device as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind turbine.
2. The lift system of claim 1, wherein the gyroscope assembly comprises a plurality of gyroscopes.
3. The lift system of claim 2, wherein the plurality of gyroscopes comprises a first gyroscope and a second gyroscope, the first and second gyroscopes being coupled to opposing ends of the structural frame body.
4. The lift system of claim 3, wherein the first and second gyroscopes are spaced evenly from a center location of the structural frame body.
5. The lift system of claim 3, wherein tilt angles of the first and second gyroscopes are oriented in opposing directions.
6. The lift system of claim 3, wherein tilt angles of the first and second gyroscopes are oriented in the same direction.
7. The lift system of any of the preceding claims, wherein the gyroscope assembly further comprises a drive mechanism for spinning and/or tilting the gyroscope, the drive mechanism comprising at least one of a generator, an integrated motor, or a separate motor.
8. The lift system of any of the preceding claims, wherein the gyroscope assembly further comprises a controller configured to control the drive mechanism of the gyroscope so as to modify the orientation of the lifting device as the lifting device is lifted or lowered to and from the hub mounted to the tower.
9. The lift system of claim 8, wherein the controller comprises at least one of a remote control, a turbine controller of the wind turbine, or a separate

controller from the wind turbine.

10. The lift system of claim 8, wherein the gyroscope assembly further comprises first and second sensors positioned adjacent to the first and second gyroscopes, respectively, the first and second sensors communicatively coupled to the controller, the controller configured to control the drive mechanism of the gyroscope based on sensor signals from the first and second sensors so as to modify the orientation of the lifting device.

11. The lift system of claim 10, wherein the first and second sensors comprise at least one of Global Positioning Sensor (GPS) sensors, accelerometers, smart sensors, or combinations thereof.

12. The lift system of any of the preceding claims, wherein the lifting device further comprises a root cradle for supporting a blade root of the rotor blade and a tip cradle for supporting a blade tip of the rotor blade, the structural frame body connecting and supporting the root cradle and the tip cradle.

13. A method for controlling orientation of a lifting device for a rotor blade of a wind turbine as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind turbine, the method comprising:

mounting a gyroscope assembly having at least one gyroscope to a structural frame body of a lifting device, the structural frame body supporting at least one cradle configured to receive the rotor blade;

securing the rotor blade atop the at least one cradle of the lifting device; and
once the rotor blade is secured in the lifting device, lifting or lowering the lifting device between the hub and a ground location while simultaneously controlling the at least one gyroscope.

14. The method of claim 14, wherein mounting the gyroscope assembly having at least one gyroscope to the structural frame body further comprises mounting a plurality of gyroscopes to the structural frame body.

15. The method of claim 15, wherein mounting the plurality of gyroscopes to the structural frame body further comprises mounting a first gyroscope and a second gyroscope at opposing ends of the structural frame body.

16. The method of claim 16, wherein controlling the at least one gyroscope further comprises allowing for a Z-coordinate of the structural frame body to change

in a vertical direction up to predetermined altitude while maintaining an X-coordinate and a Y-coordinate of the structural frame body via the first and second gyroscopes as the lifting device is lifted or lowered between the hub and the ground location.

17. The method of claim 16, wherein controlling the at least one gyroscope further comprises:

receiving, via a controller, a plurality of sensor signals from first and second sensors positioned adjacent to the first and second gyroscopes, respectively; and,

controlling, via the controller, a drive mechanism of the gyroscope assembly so as to spin and/or tilt the first and second gyroscopes based on the sensor signals.

18. The method of claim 18, wherein controlling the drive mechanism of the gyroscope assembly so as to spin and/or tilt the first and second gyroscopes based on the sensor signals further comprises reversing tilt angles of the first and second gyroscopes to stop and/or reverse a direction of rotation of the lifting device.

19. The method of claim 18, wherein controlling the drive mechanism of the gyroscope assembly so as to spin and/or tilt the first and second gyroscopes based on the sensor signals further comprises tilting the first and second gyroscopes in the same direction to generate a pair of forces that counter-react load sway of the lifting device.

20. A method for controlling orientation of a lifting device for a rotor blade of a wind turbine as the lifting device is lifted or lowered to and from a hub mounted to a tower of the wind turbine, the method comprising:

mounting a gyroscope assembly having at least one gyroscope to a structural frame body of a lifting device, the structural frame body supporting at least one cradle configured to receive the rotor blade; and,

lifting or lowering the lifting device between the hub and a ground location while simultaneously controlling the at least one gyroscope.

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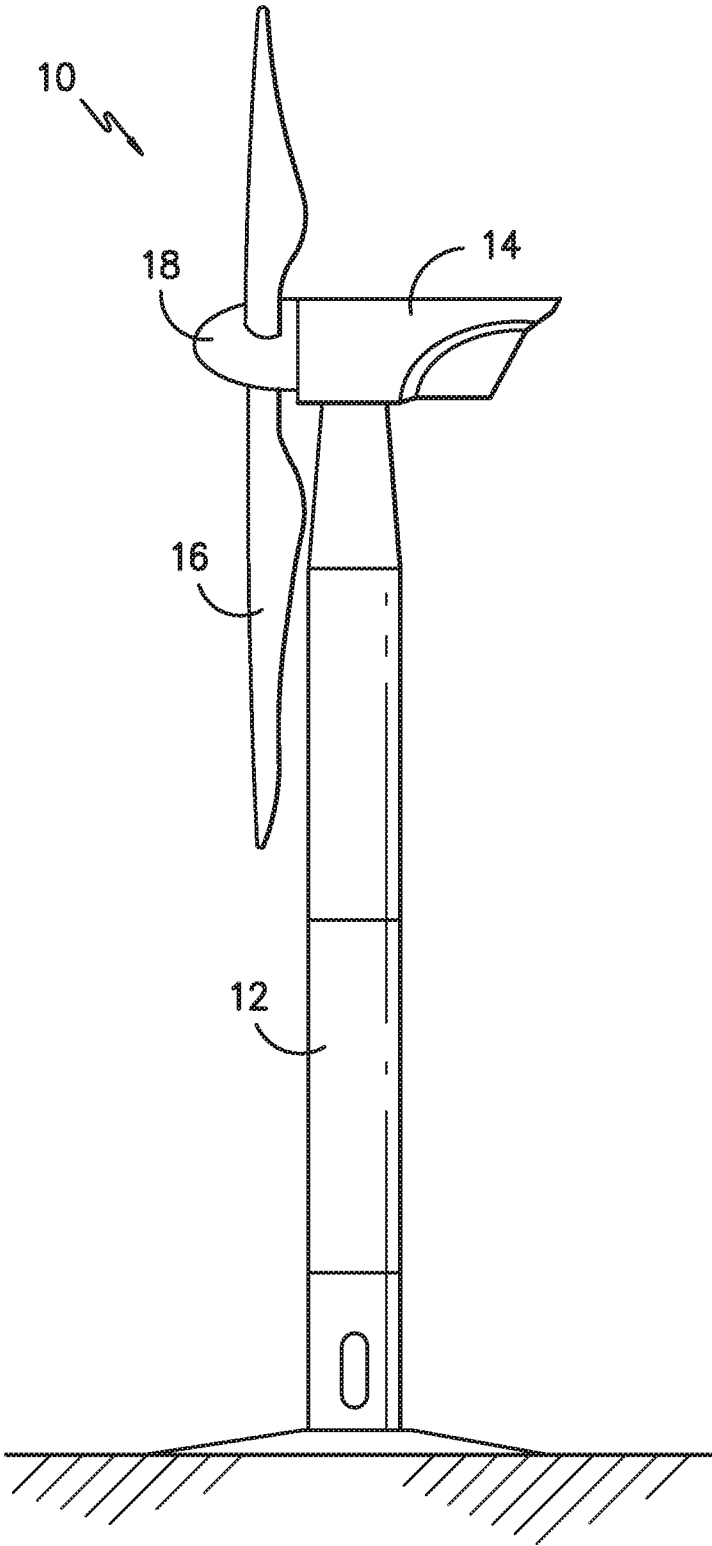
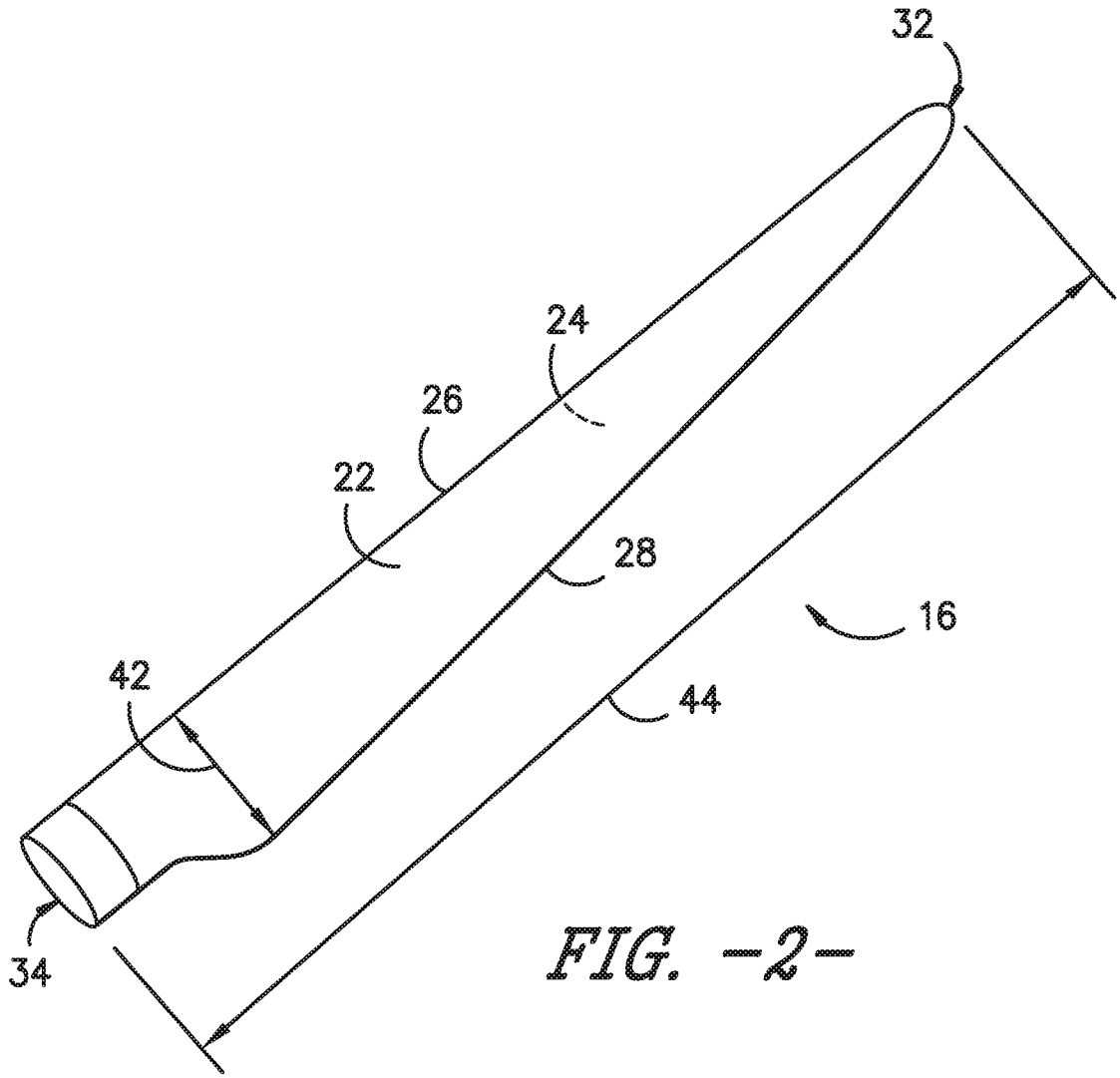
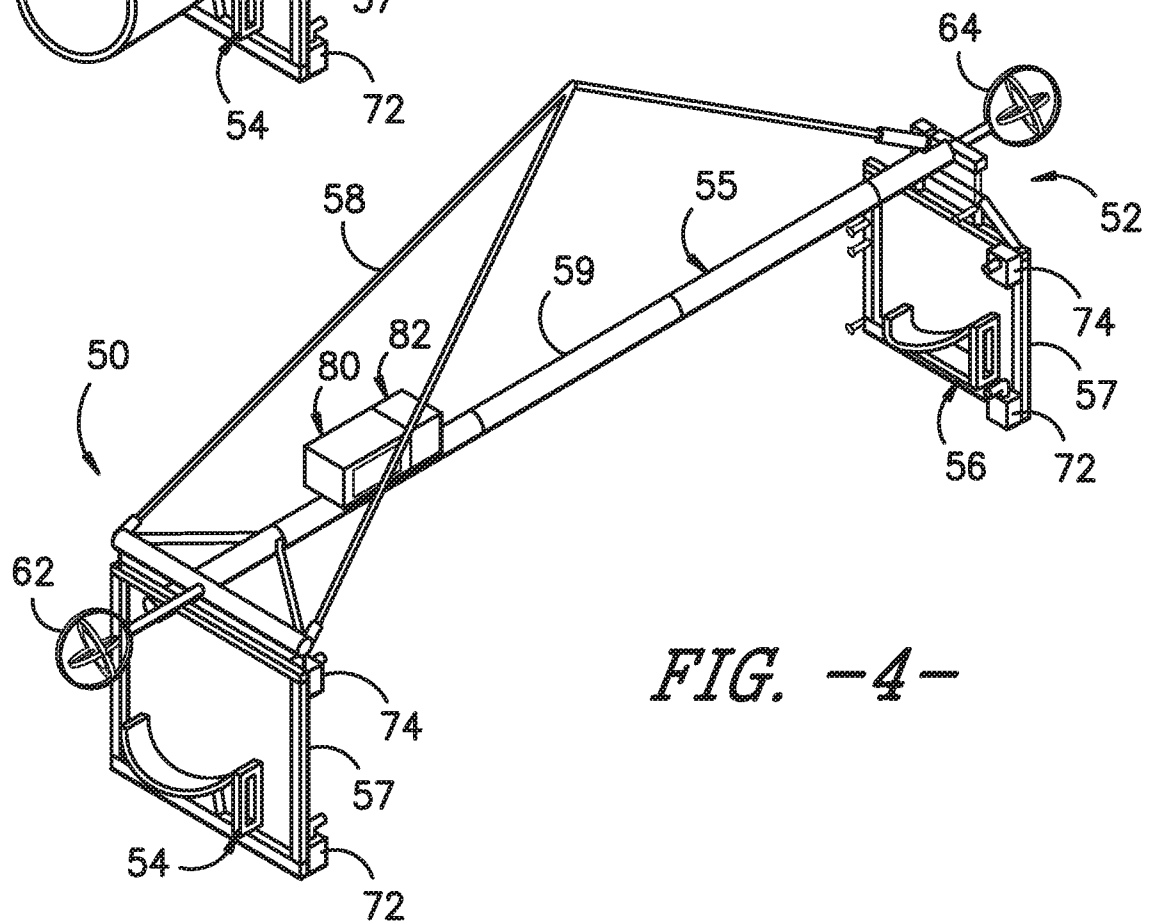
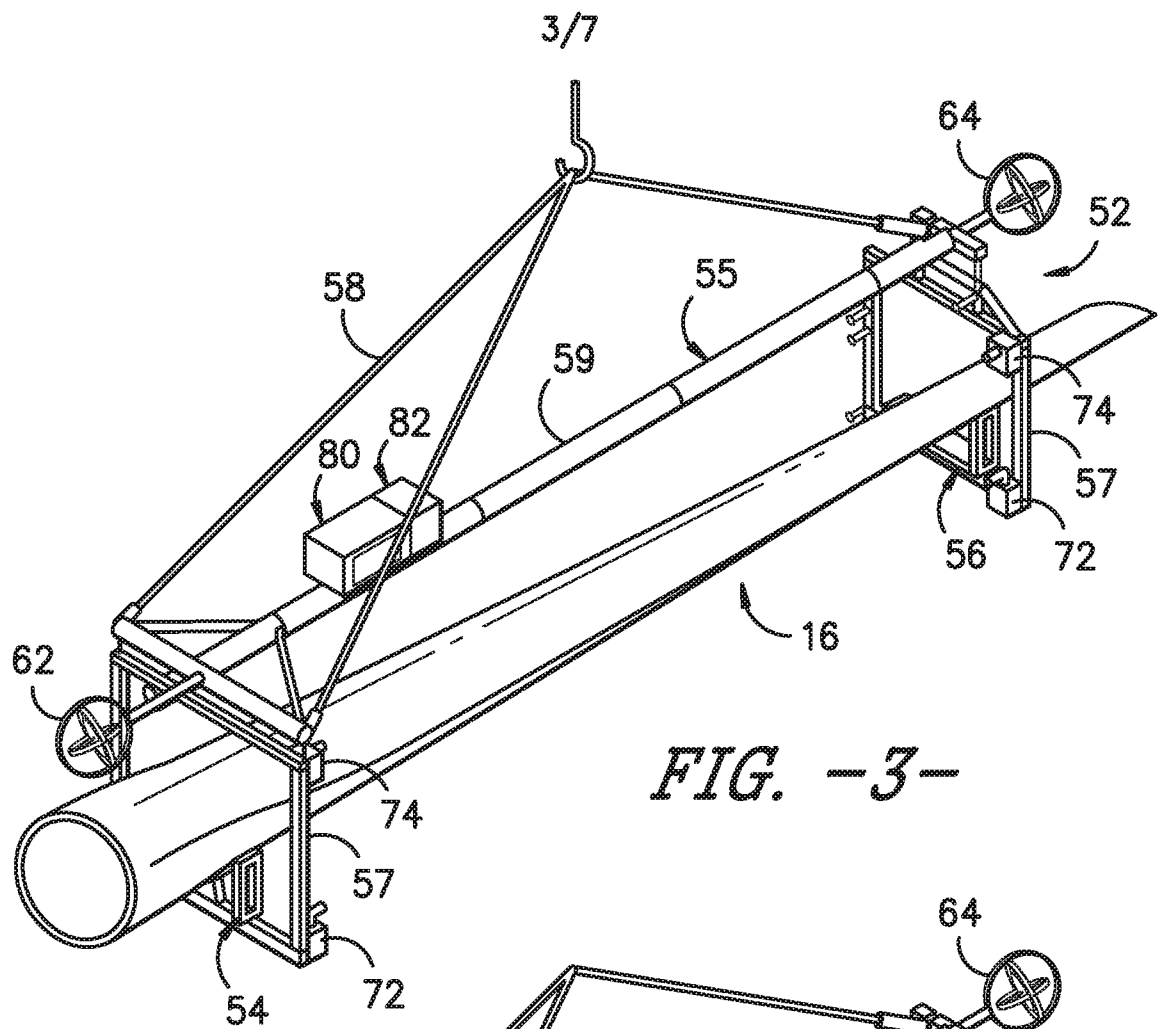
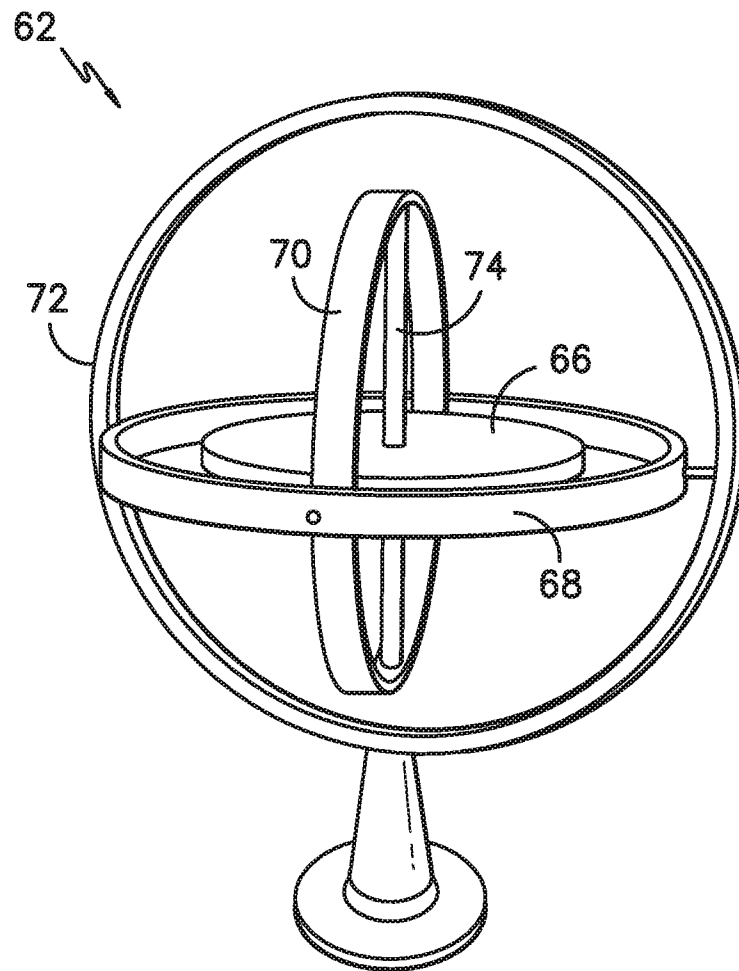


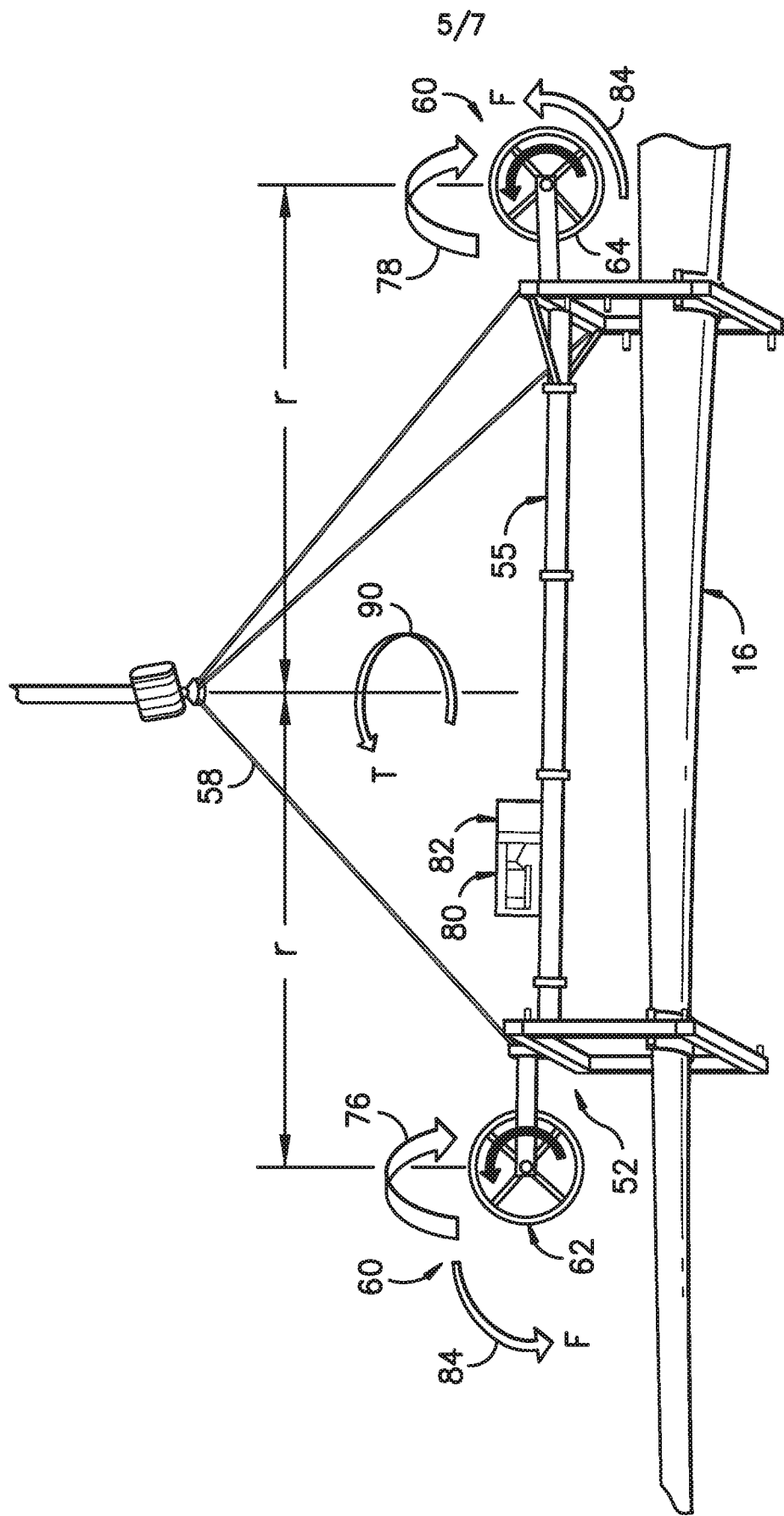
FIG. -1-

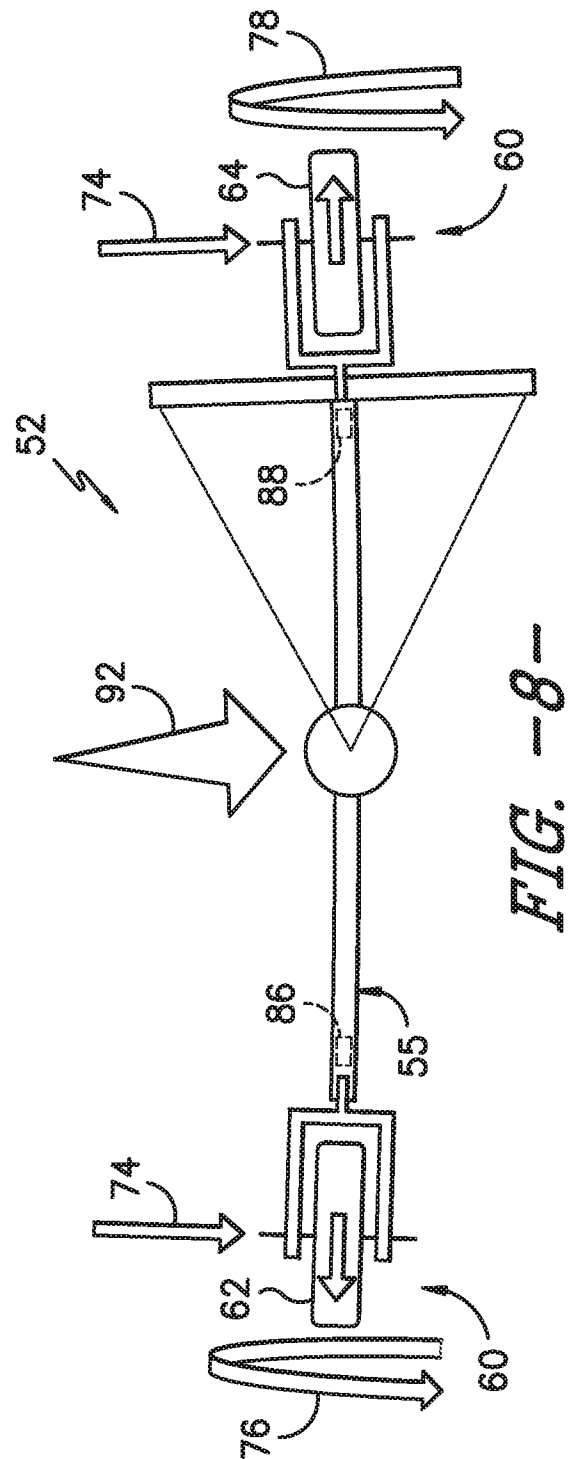
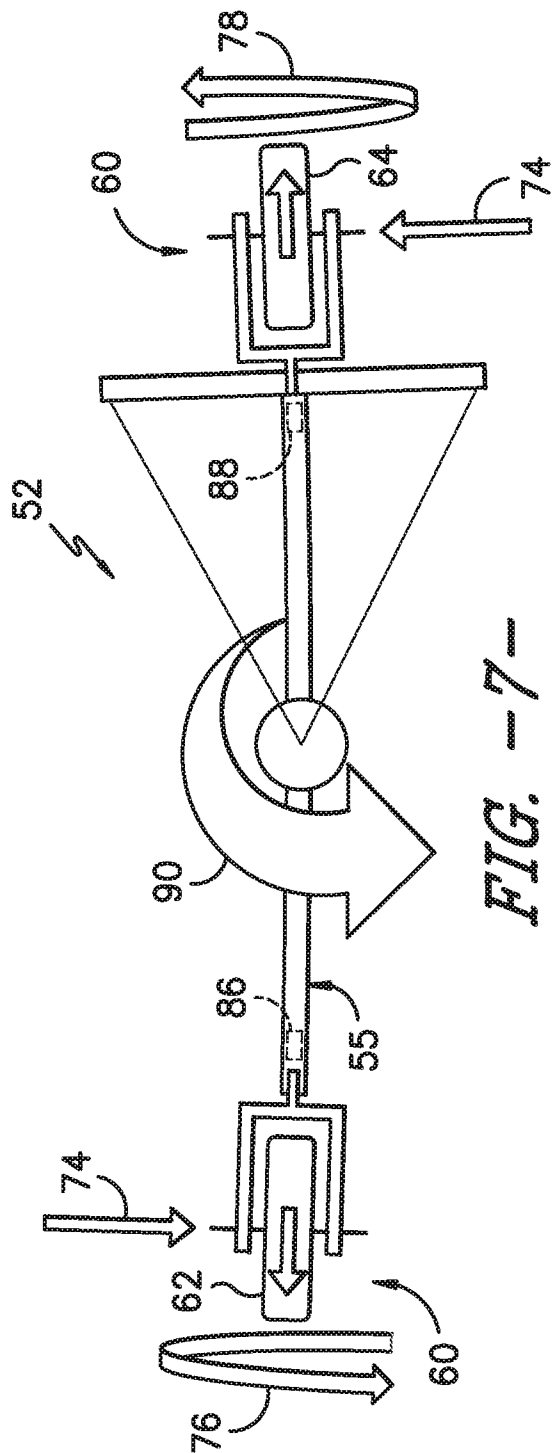




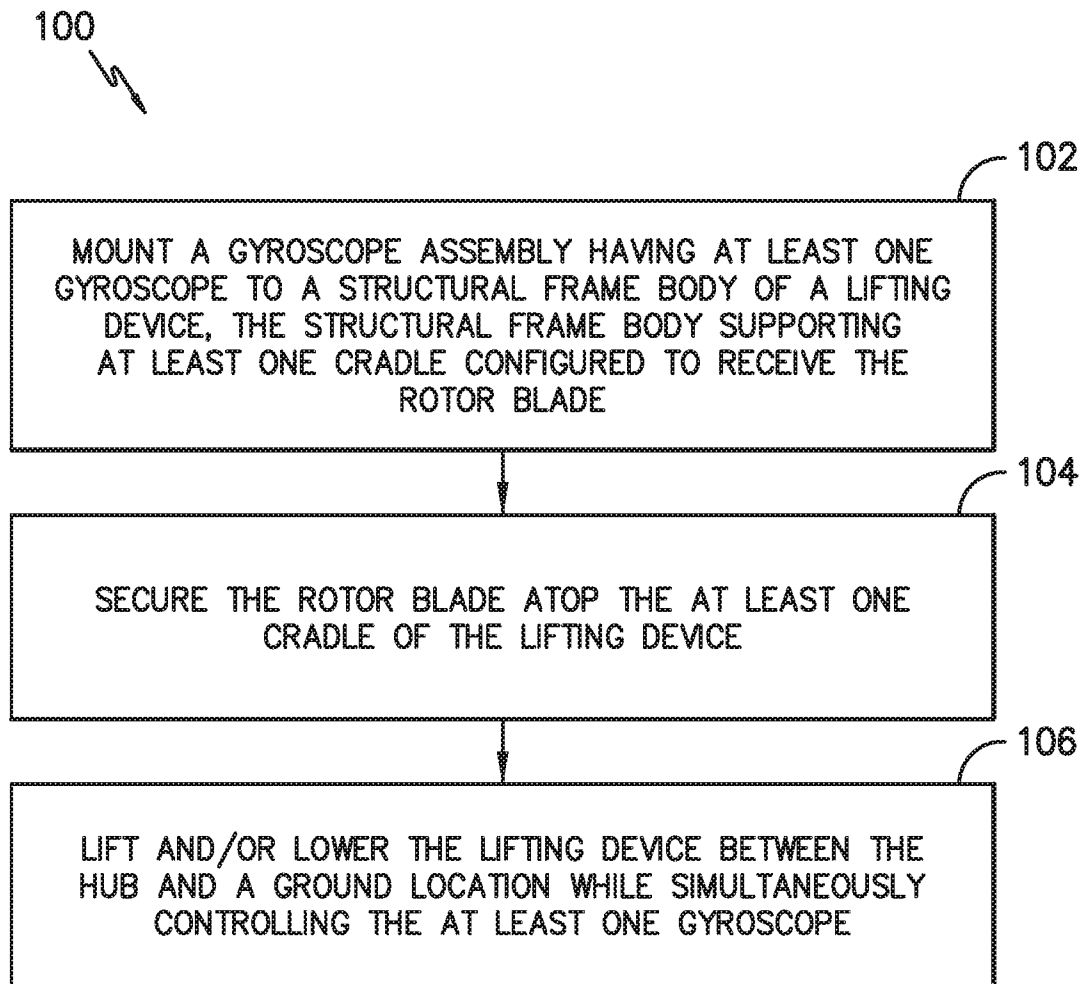
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*FIG. -5-*





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*FIG. -9-*

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/046453

A. CLASSIFICATION OF SUBJECT MATTER

INV. B66C1/10 B66C13/08 F03D13/10
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)

B66C F03D

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)

EP0-Internal, WPI Data

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Y	abstract; figures	1-12, 14-19
Y	----- WO 2017/136428 A1 (GEN ELECTRIC [US]) 10 August 2017 (2017-08-10) paragraph [0032] - paragraph [0033]; figures paragraph [0035]	1-12, 14-19
X	----- JP 2016 210607 A (KAJIMA CORP) 15 December 2016 (2016-12-15) abstract; figures	1,7-9, 13,20
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Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

15 November 2019

Date of mailing of the international search report

22/11/2019

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/046453

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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