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(54) VERTICAL AXIS WIND TURBINE

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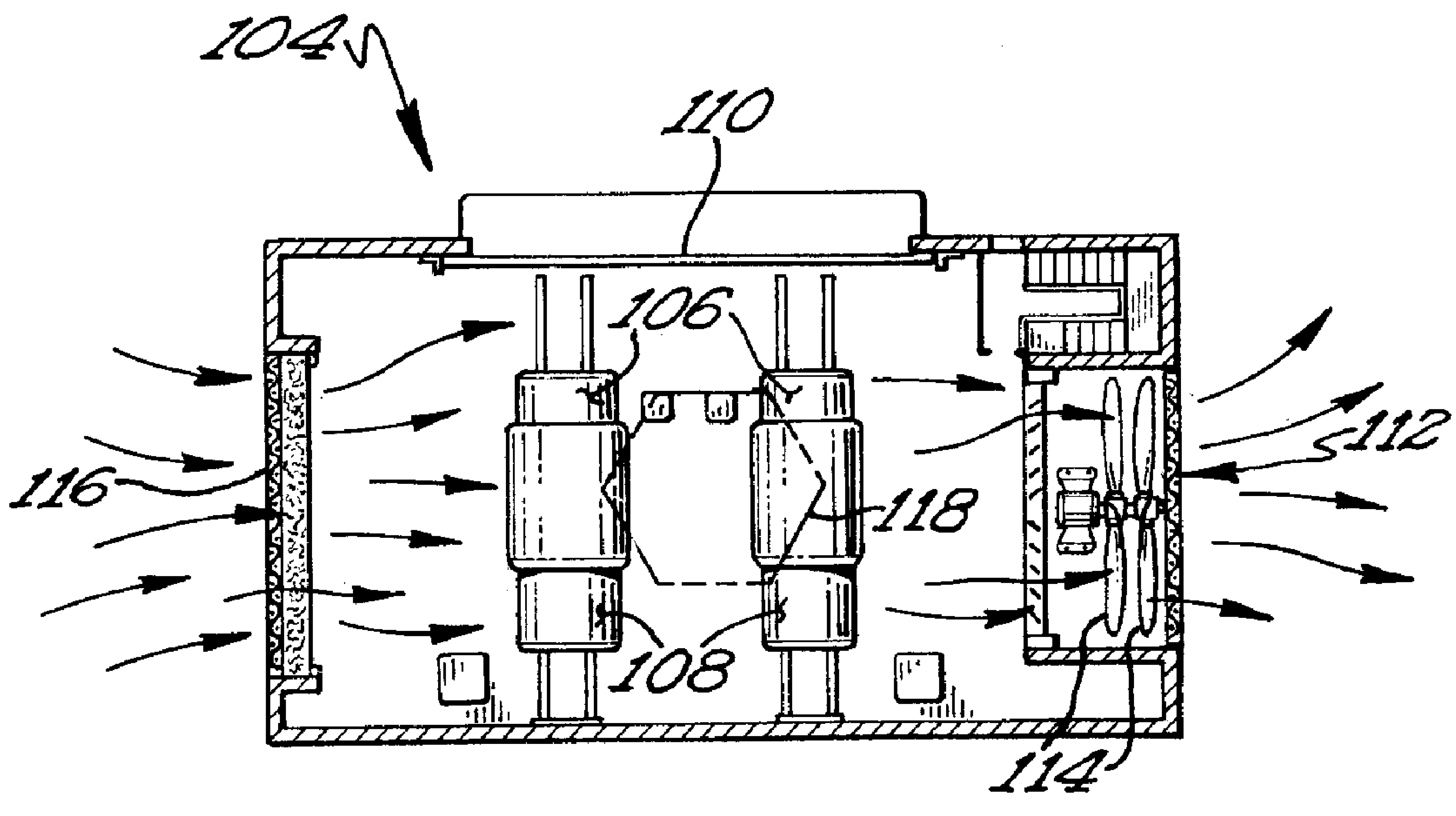
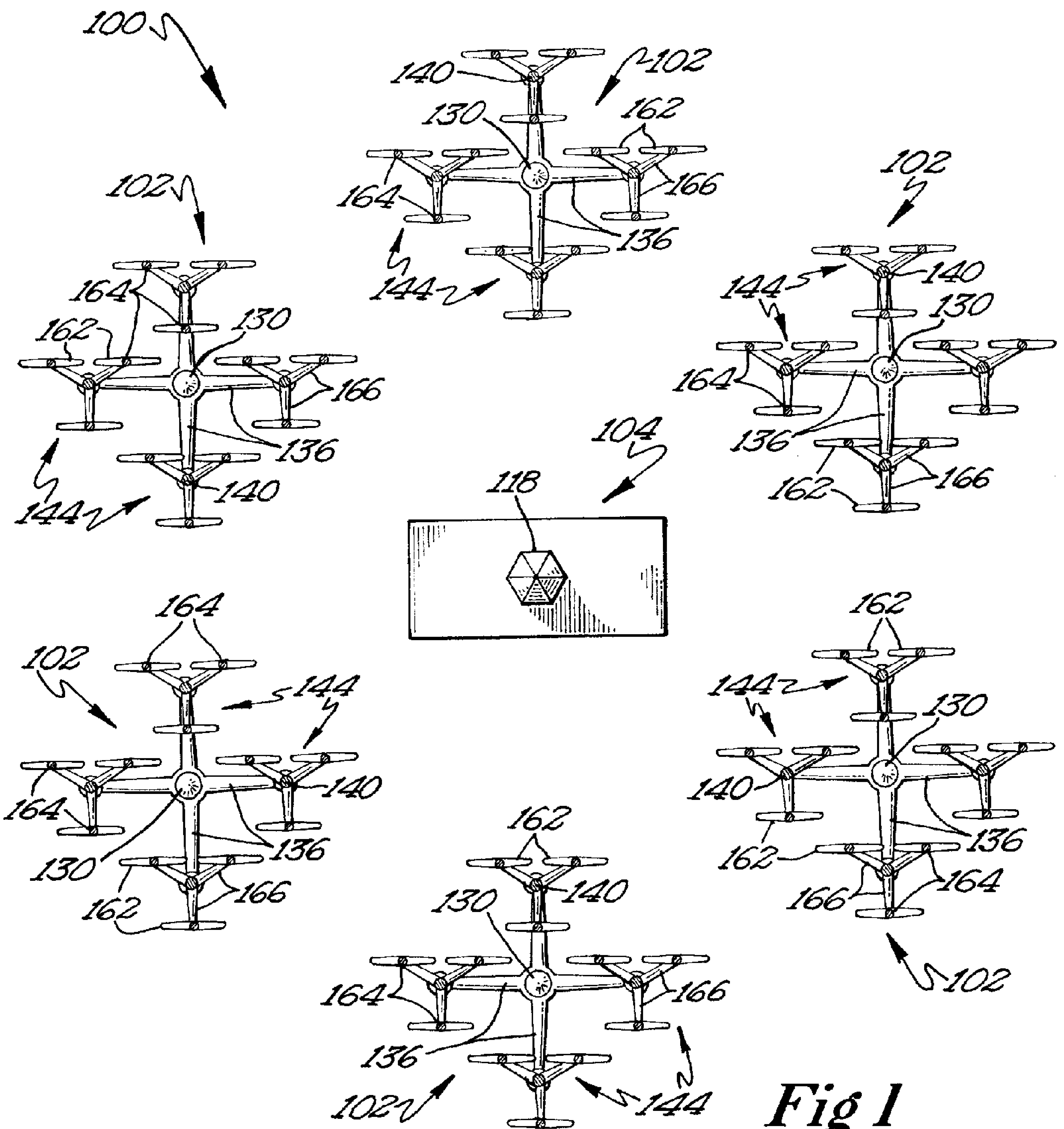
(57) **ABSTRACT**

A vertical axis sail-type wind turbine includes an array of sail-like structures that are mounted on rotating main masts. The sail-like structures can be oriented to interact with the wind. For example, when the sail-like structures are moving in a downwind direction, they are oriented to present a flat surface that is perpendicular to the wind direction. On the other hand, when the sail-like structures are moving in an upwind direction, they are oriented to present a surface that is at an angle that creates an upwind vector. The sail-like structures rotate about the sail masts, which are mounted to transverse mounting arms that are firmly mounted to a main mast. The main mast rotates, transferring power through a gear and shaft drive to hydraulic pumps in the tower. This hydraulic fluid pressure is then used to drive an electrical generator.





100
102
104
118
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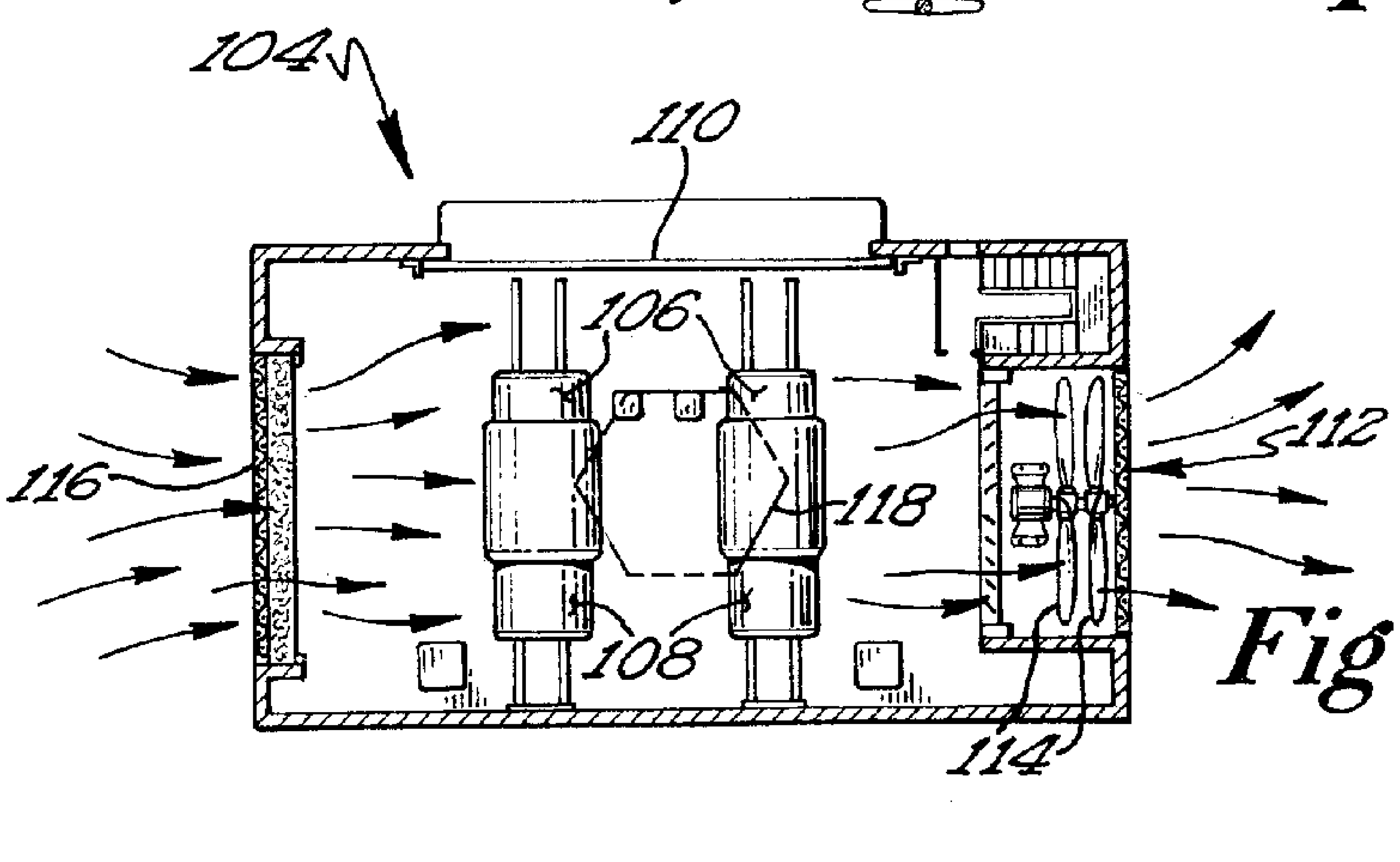
136
140
144
162
164
166

Fig 1



104
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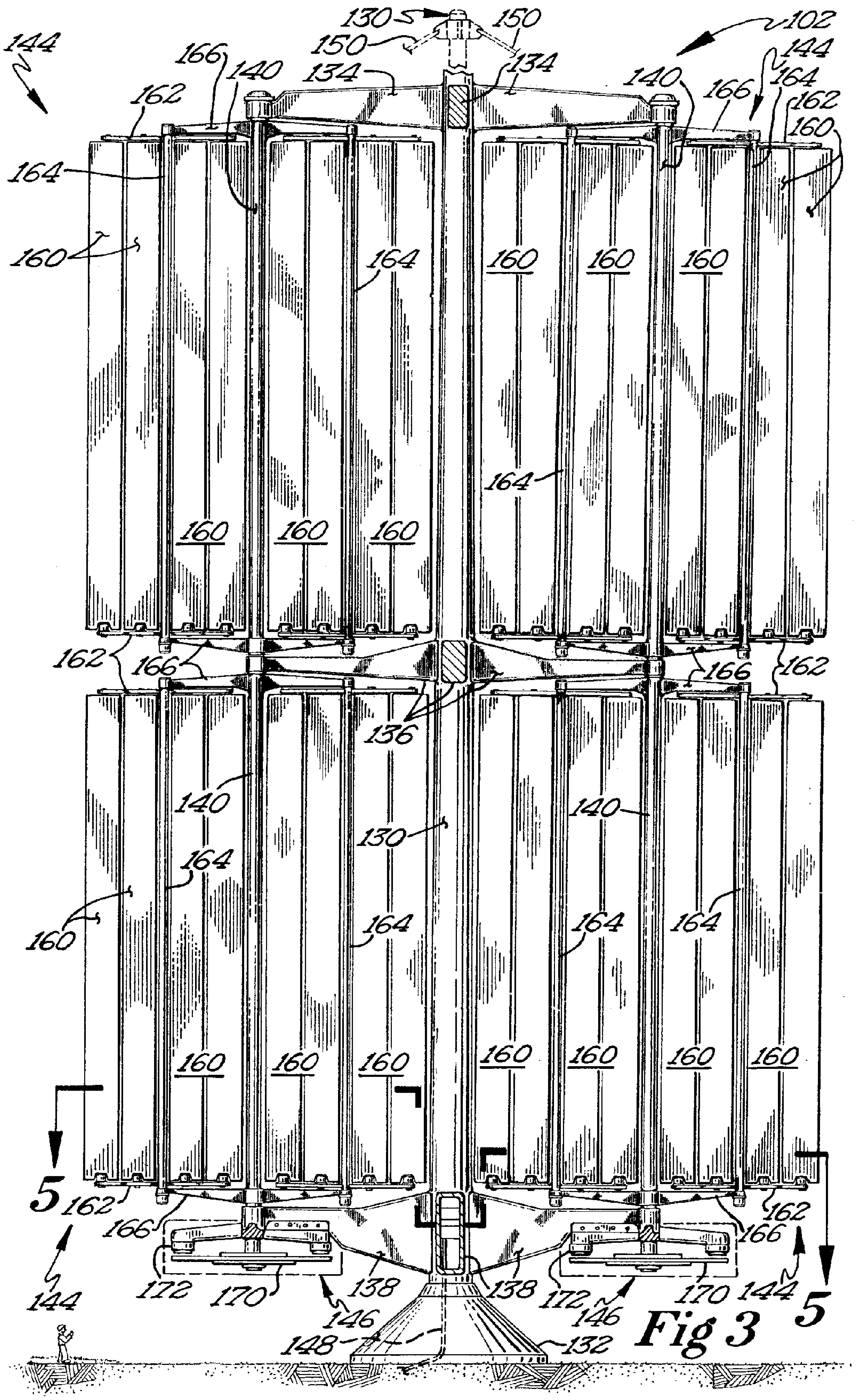
114

Fig 2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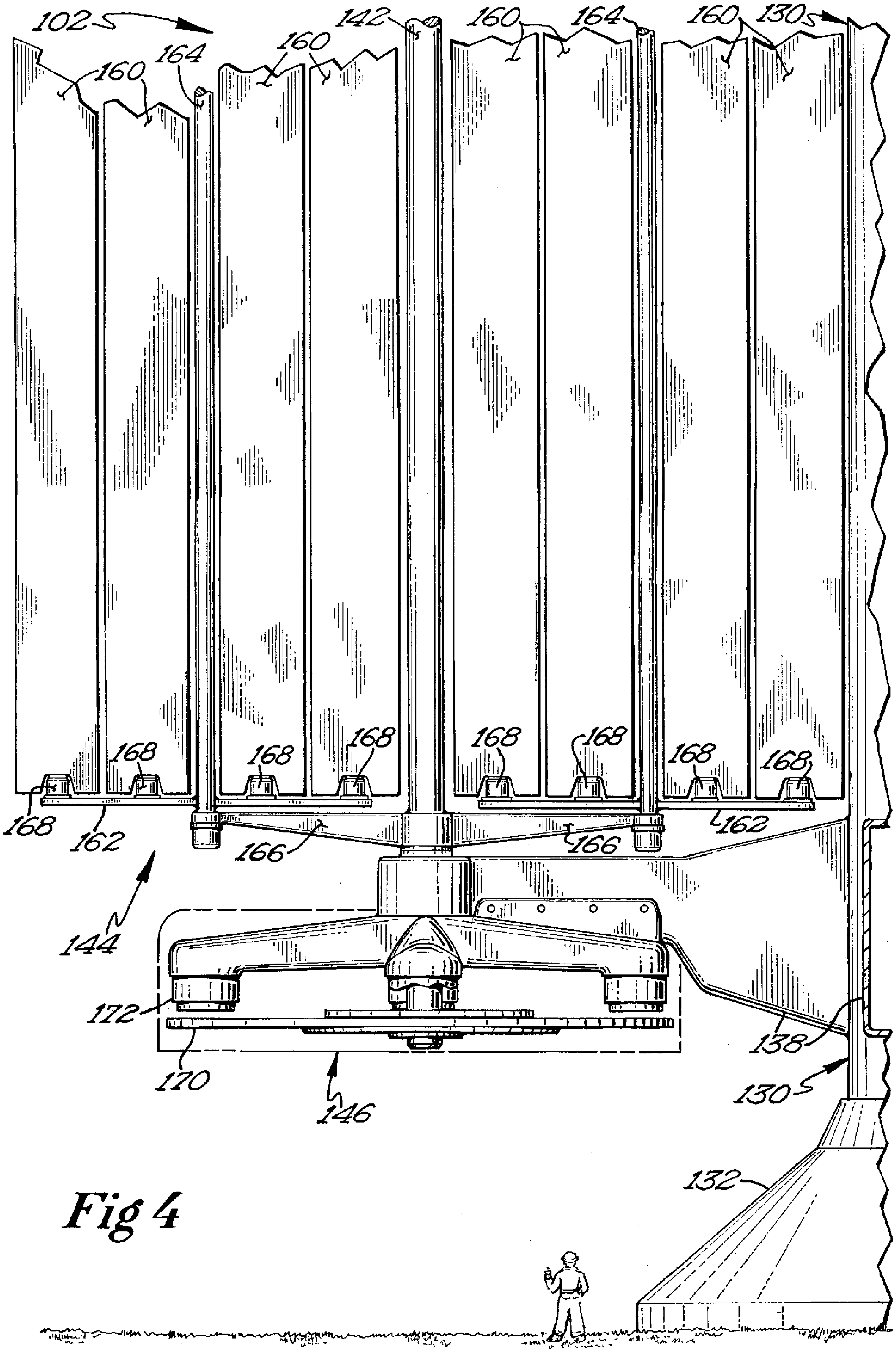
132
5
Fig 3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146
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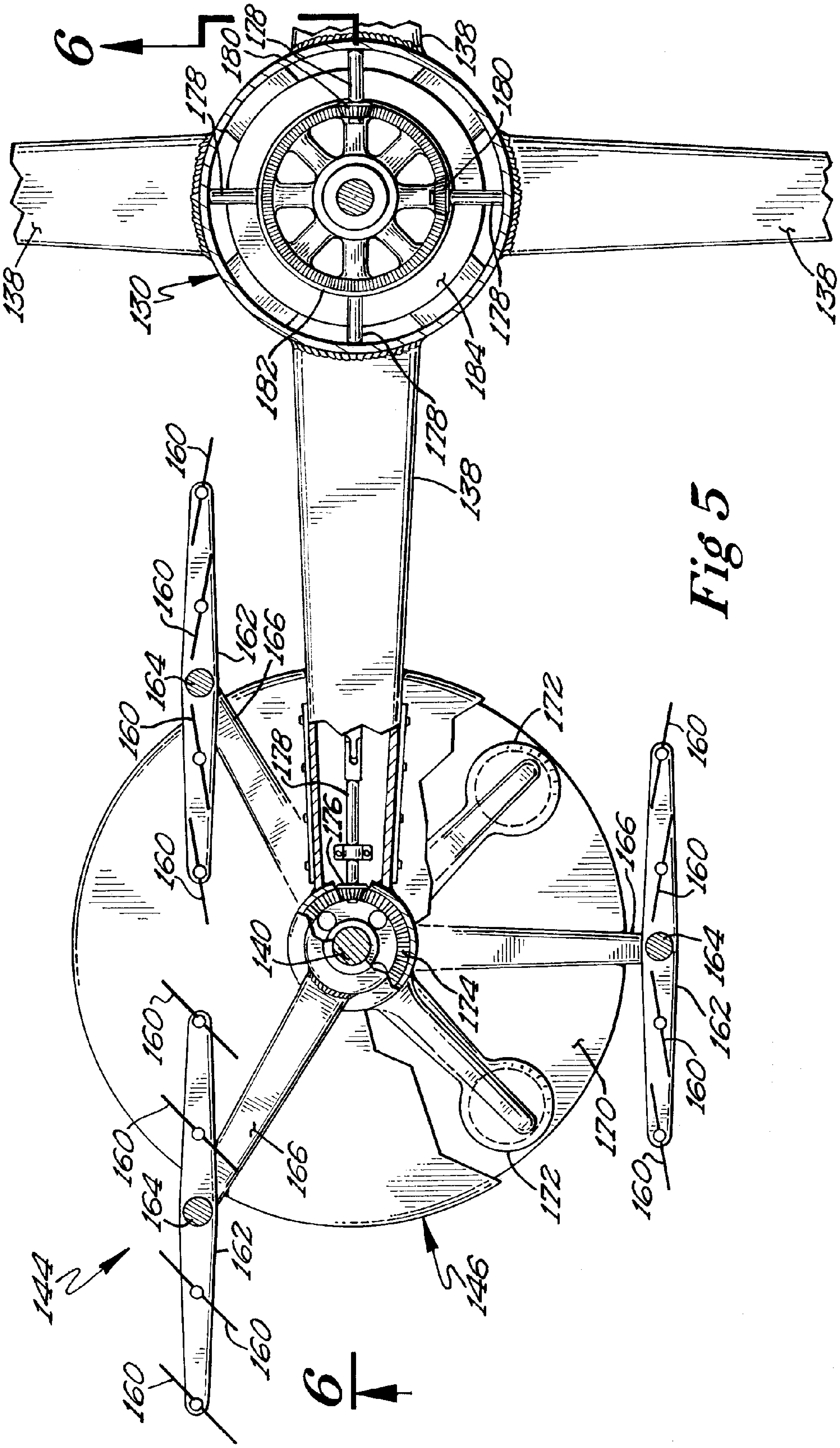
130
132

Fig 4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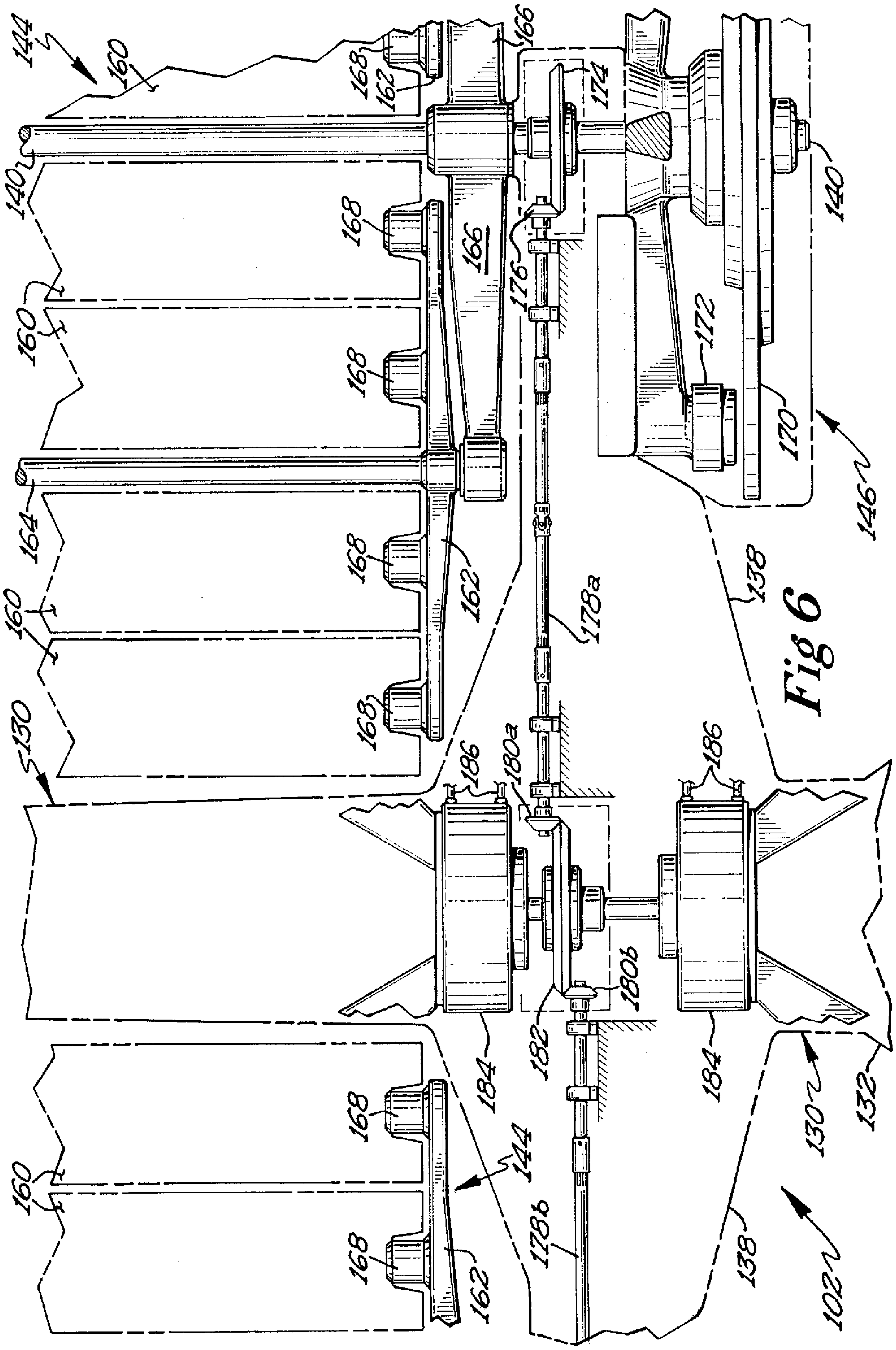
160
144
146
6

Fig 5


144
160
168
162
166
140
174
176
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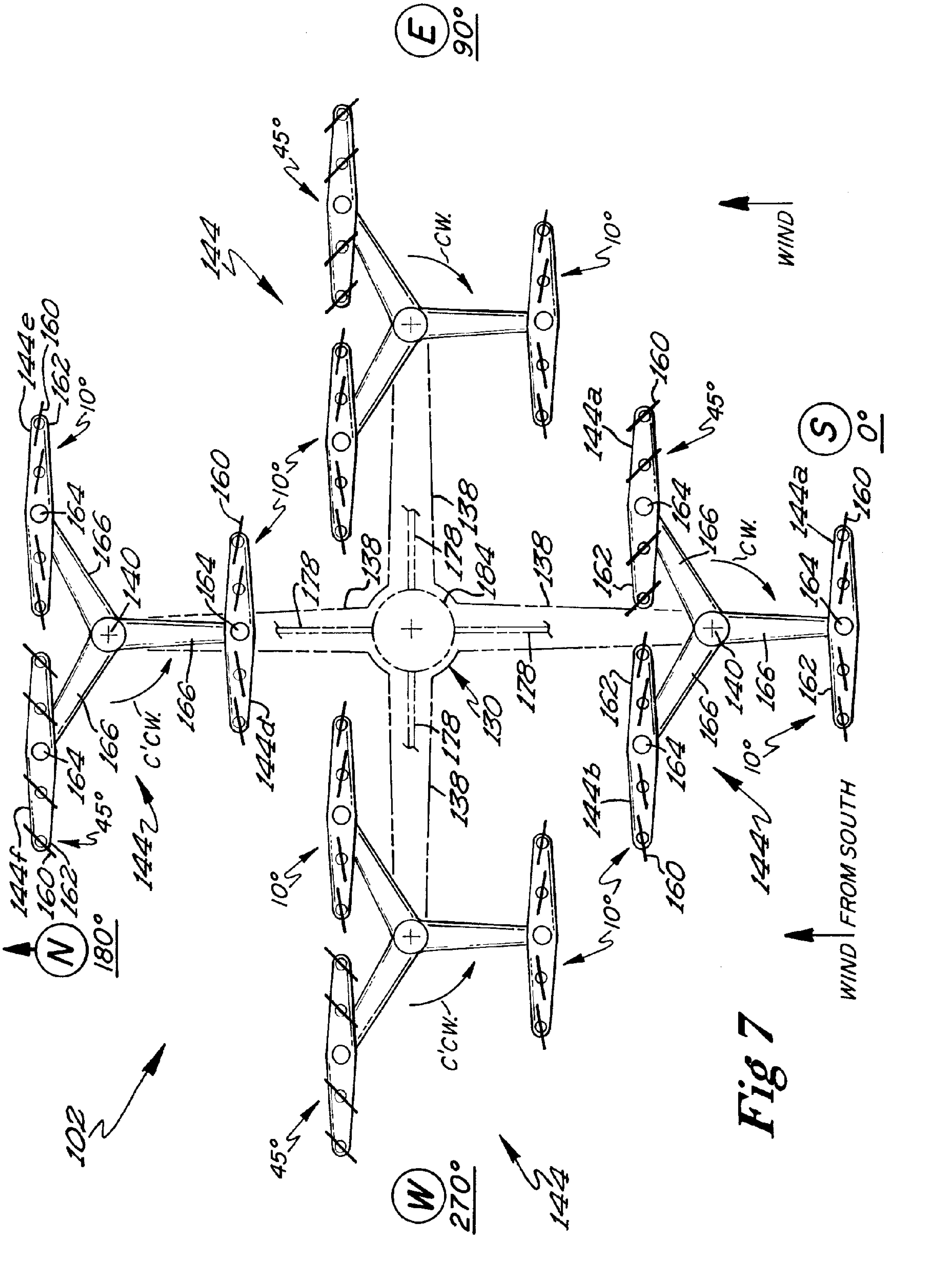
146
164
178a
138
130
186
180a
180b
182
184
132
178b
102

Fig 6



E
90°
S
0°
N
180°
W
270°
WIND
WIND FROM SOUTH
102
130
138
140
144
144a
144b
144d
144e
144f
160
162
164
166
178
184
45°
10°
CW.
C'CW.

Fig 7

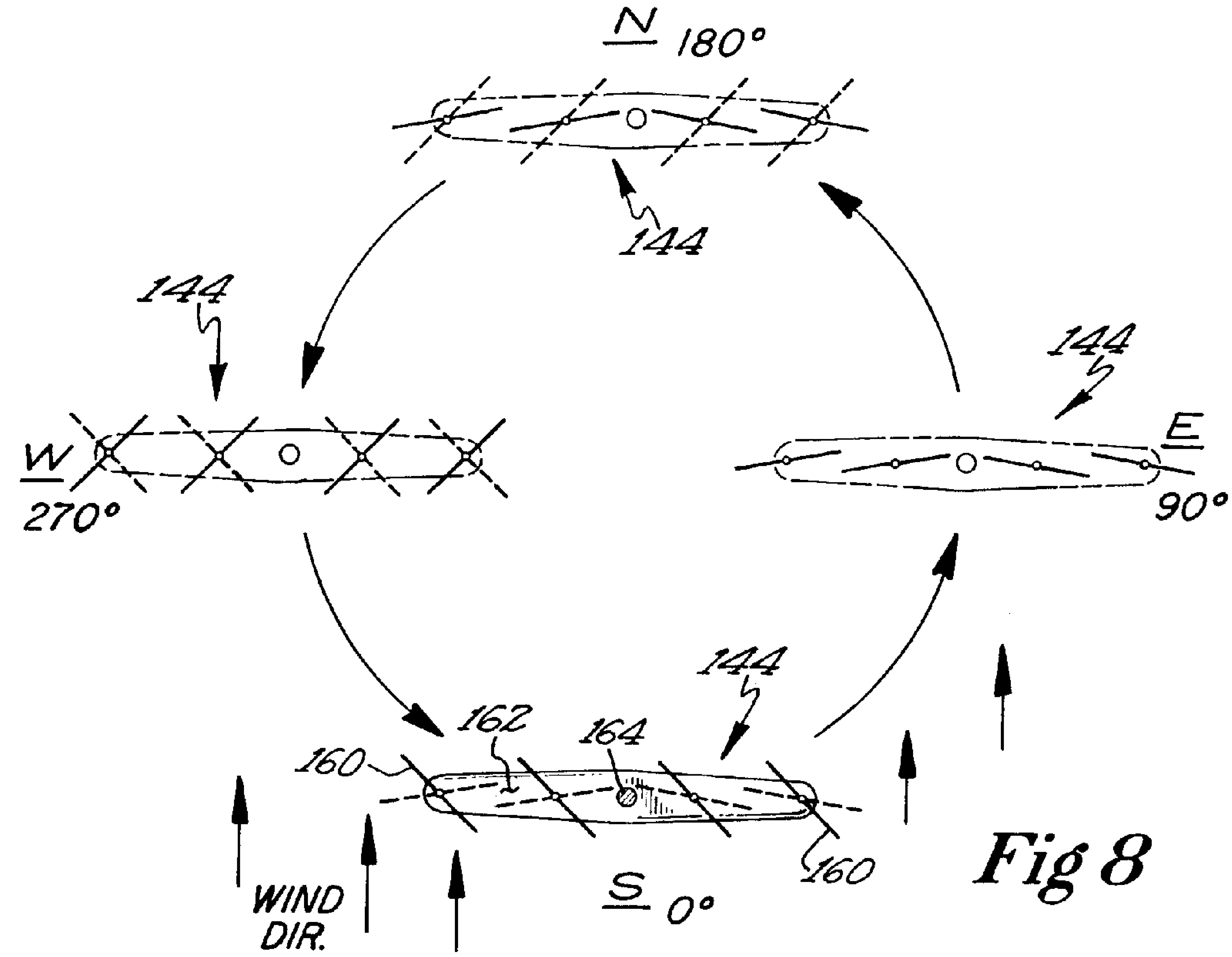

N 180°
144
144
144
W
270°
E
90°
144
162
164
160
160
WIND
DIR.
S 0°

Fig 8

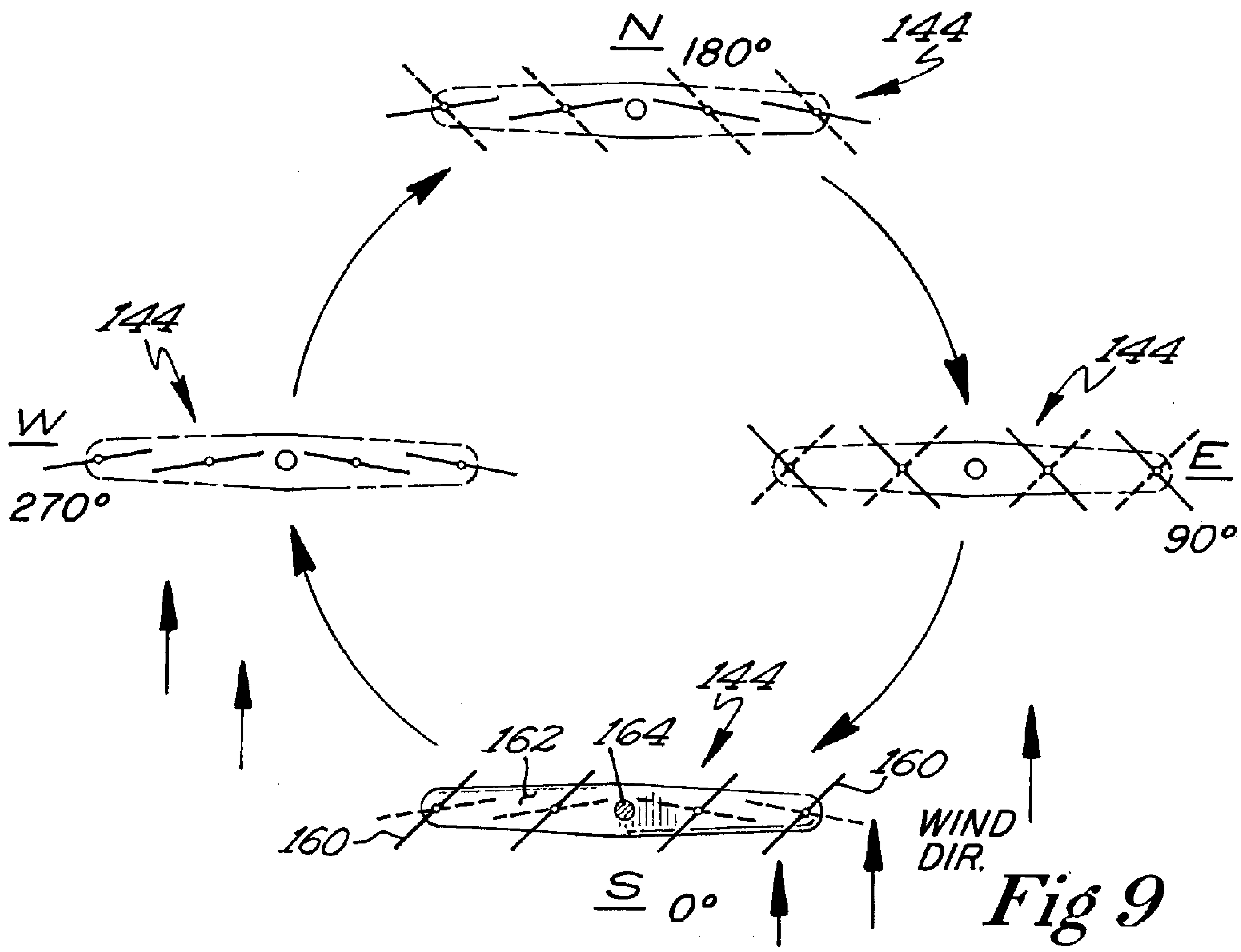

N 180°
144
144
144
W
270°
E
90°
144
162
164
160
160
WIND
DIR.
S 0°

Fig 9

VERTICAL AXIS WIND TURBINE

TECHNICAL BACKGROUND

[0001] The disclosure relates generally to electrical power generation. More particularly, the disclosure relates to the generation of electricity using wind power.

BACKGROUND

[0002] Wind turbines are known in the art for converting wind power to electrical energy. Typically, wind turbines rotate around a horizontal axis. Such wind turbines are known as horizontal axis wind turbines and have a main rotor shaft and a generator mounted on top of a tower. A gearbox may be used to convert the slow rotation of the blades into a faster rotation that is more suitable for generating electrical power. Horizontal axis wind turbines must be pointed into the wind, for example, by a wind vane or a wind sensor coupled with a servo motor.

[0003] While horizontal axis wind turbines are the most common type of wind turbine, they suffer from certain drawbacks. For example, horizontal axis wind turbines are typically velocity-governed. That is, the power that they generate is dependent on the velocity of the rotating blades. Thus, they generate low amounts of power at low wind speeds. Indeed, at sufficiently low wind speeds, the blades do not rotate at all. At high wind speeds, on the other hand, the power generated is limited by a phenomenon known as the Betz limit. Accordingly, the efficiency of velocity-governed wind turbines is limited at both low and high wind speeds. Other drawbacks that are particularly evident at high speeds include, for example, high noise levels and large numbers of birds killed by blade tips rotating at extremely high velocities. In addition, increasing the speed of the rotating blades in order to extract more energy from the wind creates centrifugal forces that impart cyclic stresses, thereby leading to fatigue of the blades, axles, and bearing material. These stresses are particularly problematic under gusty or changing wind conditions.

[0004] Some wind turbines, known as vertical axis wind turbines, rotate around a vertical axis. One example of a vertical axis wind turbine is a Darrius or "egg beater" type wind turbine. In such wind turbines, the main rotor shaft runs vertically, as contrasted with the horizontal rotor shafts of horizontal axis wind turbines. Unlike horizontal axis wind turbines, vertical axis wind turbines can incorporate the generator and gearbox near the bottom of the structure. As a result, the tower does not need to support the generator and gearbox, and the turbine does not need to be pointed into the wind. Some conventional vertical axis wind turbines also suffer from some drawbacks, such as a pulsating torque produced during each revolution. In addition, mounting vertical axis turbines on towers is relatively difficult. As a result, vertical axis turbines typically operate in the slower, more turbulent air flow near the ground. With the air flow slower and more turbulent relative to higher altitudes; vertical axis wind turbines may extract energy from wind less efficiently than horizontal axis wind turbines. In addition, vertical axis wind turbines, like horizontal axis wind turbines, are typically velocity-governed and suffer from many of the same problems exhibited by horizontal axis wind turbines, including, for example, efficiency limitations at both high and low wind speeds and stresses imparted by centrifugal forces.

SUMMARY OF THE DISCLOSURE

[0005] According to various example embodiments, a vertical axis sail-type wind turbine includes an array of sail-like structures that are mounted on rotating sail masts. The sail-like structures can be oriented to interact with the wind. For example, when the sail-like structures are moving in a downwind direction, they are oriented to present a flat surface that is perpendicular to the wind direction. On the other hand, when the sail-like structures are moving in an upwind direction, they are oriented to present a surface that is at an angle that creates an upwind vector. The sail-like structures rotate about the sail masts, which are mounted to transverse mounting arms that are firmly mounted to a main mast. The main mast transfers power through a gear and shaft drive to hydraulic pumps in the tower. This hydraulic fluid pressure is then used to drive an electrical generator.

[0006] One embodiment is directed to a wind turbine. At least two transverse mounting arms are mounted on and supported by a main tower. A sail assembly is mounted between the at least two transverse mounting arms. The sail assembly comprises a main mast defining a vertical axis of rotation. At least two sail arms are mounted on and supported by the main mast. A sail is mounted between the at least two sail arms. The sail is configured to rotate about the vertical axis of rotation in response to wind. A hydraulic pump is configured and arranged to generate a hydraulic output in response to rotation of the sail about the vertical axis of rotation.

[0007] In another embodiment, a wind turbine arrangement includes a number of wind turbines. Each wind turbine includes a main tower and at least two transverse mounting arms mounted on and supported by the main tower. A sail assembly is mounted between the at least two transverse mounting arms. The sail assembly comprises a main mast defining a vertical axis of rotation. At least two sail arms are mounted on and supported by the main mast. A sail is mounted between the at least two sail arms. The sail is configured to rotate about the vertical axis of rotation in response to wind. Each wind turbine is configured to generate a hydraulic output in response to rotation of the sail about the vertical axis of rotation. The hydraulic outputs of the wind turbines are linked together. A hydraulic pump is configured to receive the linked hydraulic outputs of the wind turbines and to drive an electrical generator. The hydraulic pump and the electrical generator may be housed in a control building, along with other components, such as a microprocessor-based system for controlling the operation of the wind turbine arrangement.

[0008] Another embodiment is directed to a wind turbine comprising a main tower. Transverse mounting arms are mounted on and supported by the main tower. Sail assemblies are mounted between at least two of the transverse mounting arms. Each sail assembly has a main mast defining a vertical axis of rotation and at least two sail arms mounted on and supported by the main mast. Sails are mounted between the sail arms. The sails are configured to rotate about the vertical axis of rotation in response to wind. A hydraulic pump is configured and arranged to generate a hydraulic output in response to rotation of the sails of the sail assemblies about the vertical axes of rotation.

[0009] Various embodiments may provide certain advantages. The wind turbine disclosed herein is torque-governed rather than velocity-governed and can therefore generate power at a wide range of wind speeds. Also, compared to the blades in a horizontal axis wind turbine, the sail-like structures of the vertical axis wind turbine disclosed herein are less susceptible to flexion and extension under even gusty or changing wind conditions. Thus, the need for maintenance and replacement parts is significantly reduced. In addition, the wind turbine disclosed herein can extract energy from the wind in both downwind and upwind directions. Also, the wind turbine is both laterally and vertically scalable to enable power generation on a larger scale than has previously been realized, particularly with horizontal axis wind turbines.

[0010] Additional objects, advantages, and features will become apparent from the following description and the claims that follow, considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a plan view of a wind turbine arrangement according to one embodiment.

[0012] FIG. **2** is a plan view of a portion of the wind turbine arrangement of FIG. **1**.

[0013] FIG. **3** is an elevational view of a wind turbine forming part of the wind turbine arrangement of FIG. **1**, according to another embodiment.

[0014] FIG. **4** is an elevational view of a portion of the wind turbine of FIG. **3**.

[0015] FIG. **5** is a sectional view taken along lines **5-5** of FIG. **3**, showing certain details of the wind turbine of FIG. **3**.

[0016] FIG. **6** is a sectional view taken along lines **6-6** of FIG. **5**, showing certain details of the wind turbine of FIG. **3**.

[0017] FIG. **7** is a diagrammatic top plan view of a wind turbine showing selected sail positions with a given wind direction, according to another embodiment.

[0018] FIG. **8** is a diagrammatic top plan view of a wind turbine showing transitions between sail positions as the sail rotates in one direction.

[0019] FIG. **9** is a diagrammatic top plan view of a wind turbine showing transitions between sail positions as the sail rotates in another direction.

DESCRIPTION OF VARIOUS EMBODIMENTS

[0020] According to various example embodiments, a vertical axis sail-type wind turbine includes an array of sail-like structures that are mounted on rotating sail masts. When the sail-like structures are moving in a downwind direction, they are oriented to present a flat surface that is perpendicular to the wind direction. When the sail-like structures are moving in an upwind direction, they are oriented to present a surface that is at an angle that creates an upwind vector. The sail-like structures rotate about the sail masts, which are mounted to transverse mounting arms that are firmly mounted to a main mast. The main mast transfers power through a gear and shaft drive to hydraulic pumps in the tower. This hydraulic fluid pressure is then used to drive an electrical generator. The use of a hydraulic power transfer eliminates the transmission and planetary gear system that are characteristic of many conventional wind turbines.

[0021] In the following description, numerous specific details are set forth in order to provide a thorough understanding of various embodiments. It will be apparent to one skilled in the art that some embodiments may be practiced without some or all of these specific details. In other instances, well known components and process steps have not been described in detail.

[0022] Various embodiments may be described in the general context of processor-executable instructions, such as program modules, being executed by a processor. Generally, program modules include routines, programs, objects, components, data structures, etc., that perform particular tasks or implement particular abstract data types. The invention may also be practiced in distributed processing environments in which tasks are performed by remote processing devices that are linked through a communications network or other data transmission medium. In a distributed processing environment, program modules and other data may be located in both local and remote storage media, including memory storage devices.

[0023] Referring now to the drawings, FIG. **1** is a top plan view of a wind turbine array **100** according to one embodiment. The wind turbine array **100** is illustrated in FIG. **1** as including six wind turbines **102**. Persons of ordinary skill in the art will appreciate that the wind turbine array **100** may include more or fewer wind turbines **102** than are illustrated in FIG. **1**, and that the wind turbines **102** may be arranged in a configuration that is either similar to or different from the configuration shown in FIG. **1**.

[0024] The wind turbine array **100** also includes a control building **104**. The control building **104** is illustrated as being located proximate the geographic center of the wind turbine arrangement **100**. Locating the control building **104** in this position facilitates monitoring the operation of the wind turbines **102**. In addition, in this configuration, the control lines and hydraulic fluid lines between the various wind turbines **102** and the control building **104** can be made substantially uniform. In this way, the control and hydraulic fluid lines between any individual wind turbine **102** and the control building **104** are prevented from being excessively long. However, persons of ordinary skill in the art will appreciate that the control building **104** may be located in another position relative to the wind turbine arrangement **100**.

[0025] FIG. **2** is a plan view illustrating the control building **104**. The control building **104** includes two generators **106** and two hydraulic pumps **108** that are hydraulically coupled with the wind turbines **102** via hydraulic fluid lines (not shown). It will be appreciated by those of ordinary skill in the art that the control building **104** may incorporate more or fewer generators **106** and hydraulic pumps **108** than are shown in FIG. **2**. In some embodiments, the control building **104** may have a door **110** that is sized and arranged to allow the generators **106** to be pulled out on wheels should the need to replace or service the generators **106** arise.

[0026] When the wind turbines **102** extract mechanical energy from wind, hot hydraulic fluid is pumped through the hydraulic fluid lines at high pressure to the control building

104. The hydraulic fluid outflows from the various wind turbines **102** are combined into a single hydraulic fluid line using pressure equalizers (not shown) to equalize the fluid pressure in the hydraulic fluid outflows from the various wind turbines **102**. Equalizing the fluid pressure in this way prevents hydraulic fluid from flowing backward through the hydraulic fluid lines. By linking hydraulic outputs, the same number of generators can be used for multiple towers in a wind farm, thereby facilitating expansion of the wind farm. A splitter (not shown) splits the hydraulic fluid output of the combined hydraulic fluid line into multiple lines that drive the generators **106**.

[0027] The hydraulic fluid drives the generators **106**, thereby generating electrical power as the wind turbines **102** rotate in response to the wind. As the hydraulic fluid drives the generators **106**, its fluid pressure decreases, while its temperature remains hot. The hot hydraulic fluid output by the generators **106** is then cooled, for example, using a cooling system **112**. The cooling system **112** may incorporate exhaust fans **114**, a radiator, and an intake filter **116**. Air from the outside environment is drawn in under negative pressure by the exhaust fans **114** through the intake filter **116**. The air cools the hydraulic fluid and is returned to the outside environment. The cooled hydraulic fluid is then returned to the wind turbines **102**.

[0028] The control building **104** also includes a control tower **118**, which may be located on an upper floor of the control building **104**. The control tower **118** may have a hexagonal profile as shown in FIG. **2** to facilitate monitoring the operation of the wind turbines **102**. Alternatively, the control tower **118** may have a circular or substantially circular profile. The control tower **118** controls and monitors various aspects of the operation of the wind turbine array **100**, including, for example, the hydraulic system, the individual wind turbines **102**, and the generator output.

[0029] The control tower **118** incorporates a microprocessor-based system (not shown) that executes software to control the operation of the wind turbine array **100**. The microprocessor-based system is typically configured to operate with one or more types of processor readable media. Processor readable media can be any available media that can be accessed by the microprocessor-based system and includes both volatile and nonvolatile media, removable and non-removable media. By way of example, and not limitation, processor readable media may include storage media and communication media. Storage media includes both volatile and nonvolatile, removable and nonremovable media implemented in any method or technology for storage of information such as processor-readable instructions, data structures, program modules, or other data. Storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile discs (DVDs) or other optical disc storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store the desired information and that can be accessed by the microprocessor-based system. Communication media typically embodies processor-readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism and includes any information delivery media. The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media includes wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared, and other wireless media. Combinations of any of the above are also intended to be included within the scope of processor-readable media.

[0030] According to certain embodiments, the microprocessor-based system obtains and interprets real-time input parameters relating, for example, to the wind velocity and direction, the rotation of the sails, power generation, and hydraulic fluid pressure levels. Based on these input parameters, the microprocessor-based system adjusts various aspects of the operation of the wind turbine array **100**. For example, the microprocessor-based system may adjust the orientation of the sails to obtain maximum power in both downwind and upwind movements. In addition, the microprocessor-based system maintains a substantially constant rotational speed of the wind turbines at, for example, **20** revolutions per minute, by adjusting the load on the generators **106**. To accomplish this adjustment, the microprocessor-based system may adjust the armature strength upward or downward in real time.

[0031] FIG. **3** is an elevational view of one of the wind turbines **102** forming part of the wind turbine array **100**. The wind turbine **102** includes a main tower **130** supported on a base **132**. In one embodiment, the main tower is approximately 250 feet tall. A main mast is bearing mounted to the main tower **130** via transverse mounting arms **134**, **136**, and **138**. The main tower **130**, which remains substantially stationary during operation of the wind turbine **102**, supports transverse mounting arms **134**, **136**, and **138**, which also remain substantially stationary during operation of the wind turbine **102**. Rotatable main masts **140** are mounted on and supported between transverse mounting arms **134** and **136** and transverse mounting arms **136** and **138**, respectively. In addition, a third main mast (not visible in FIG. **3**) is mounted on and supported between each pair of transverse mounting arms, such that each pair of transverse mounting arms is associated with three main masts and three sails. The rotatable main masts define vertical axes of revolution. Sails **144** are mounted to the main masts and rotate about the axes of revolution defined by the main masts **140**. The structure and operation of the sails **144** are described more fully below in connection with FIG. **4**. Four such assemblies of sails **144** and main masts **140** are mounted at 90 degree intervals around the main tower **130**.

[0032] Near the bottom of the wind turbine **102**, flywheel assemblies **146** maintain a constant rotational velocity and provide gyroscopic stabilization for the rotating sail assemblies and provide a braking surface for four hydraulic brakes. The structure and operation of the flywheel assemblies **146** are described more fully below in connection with FIG. **5**.

[0033] According to some embodiments, the wind turbine **102** is both horizontally and vertically scalable to promote efficiently capturing the mechanical energy contained in the wind. The wind turbine **102** may be horizontally scaled by increasing the width of the sails **144**. Additionally, the wind turbine **102** may be vertically scaled by adding one or more further levels of sails **144**. As the wind turbine **102** is constructed to great heights, guywires **150** may be used to stabilize the wind turbine **102**.

[0034] FIG. **4** is an enlarged elevational view of a lower portion of the wind turbine **102**. Among other structures, FIG. **4** illustrates the sails **144** in greater detail. It should be noted that, while two sails **144** are visible in FIG. **4**, each main mast, such as the main mast **140** shown in FIG. **4**, preferably has three sails **144** mounted thereon. Each sail **144** includes a number of vanes **160** mounted between two crossbeams, one of which is shown as sail arm **162** in FIG. **4**, and the other of which is not visible in FIG. **4**. Preferably, each sail **144** includes two vanes **160** on each side of the sail **144**, promoting symmetry and thereby enabling the sail **144** to balance itself. Also mounted between these two crossbeams is a sail mast **164**. The sail masts **164** are mounted on a crossbeam **166**, which is itself fixedly mounted to the main mast **140**.

[0035] The vanes **160** can be rotated using individual hydraulic servo motors **168**. In this way, the orientation of the sails **144** is precisely controlled by the hydraulic servo motors **168** as the sails **144** rotate about the axes of rotation defined by the sail masts. In particular, the vanes **160** are oriented to create a flat surface perpendicular to the wind direction when a sail **144** is moving downwind. When the sail **144** is moving upwind, the vanes **160** are oriented to create a surface at an angle that creates an upwind vector.

[0036] FIG. **7** illustrates one particular scheme according to which the vanes **160** may be rotated. In order to avoid unnecessarily complicating the disclosure of the operation of the vanes **160**, only a selected set of orientations is disclosed herein in connection with FIG. **7**. In the example shown in FIG. **7**, a wind originates from the south, indicated at the bottom of FIG. **7**.

[0037] In response to the wind from the south, certain sail assemblies will rotate clockwise, while others opposed 180 degrees will rotate counterclockwise. In both cases, there are four possible transition points at which the orientation of the vanes **160** may change. These transition points occur at 90 degree intervals throughout the 360 degree rotational cycle. Whether a given sail assembly rotates clockwise or counterclockwise, transitions will occur at the 0 degree and 180 degree points. Further, if the sail assembly is rotating clockwise, a transition will also occur at the 90 degree point, but not at the 270 degree point. On the other hand, if the sail assembly is rotating counterclockwise, a transition will occur at the 270 degree point, but not at the 90 degree point.

[0038] FIG. **8** illustrates the transition points when the sail assembly rotates counterclockwise with a wind from the south. At each transition point, solid lines indicate the position of the vanes immediately before the transition point, while dashed lines indicate the position of the vanes immediately after the transition point. Immediately before the 0 degree point, the vanes are oriented at a 45 degree angle. As the sail assembly rotates counterclockwise through the 0 degree point, the vanes are oriented essentially flat, e.g., at 10 degree angles canted toward the sail mast. No transition occurs at the 90 degree point, but as the sail assembly rotates through the 180 degree point, the vanes change in orientation from an essentially flat angle to a 45 degree angle. As the sail assembly rotates through the 270 degree point, the vanes change orientation again, this time from a 45 degree angle to a 45 degree angle in an opposite direction. The vanes remain in this orientation until the sail assembly rotates through the 0 degree point.

[0039] FIG. **9** illustrates the transition points when the sail assembly rotates clockwise with a wind from the south. At each transition point, solid lines indicate the position of the vanes immediately before the transition point, while dashed lines indicate the position of the vanes immediately after the transition point. Immediately before the 0 degree point, the vanes are oriented at a 45 degree angle. As the sail assembly rotates clockwise through the 0 degree point, the vanes are oriented essentially flat, e.g., at 10 degree angles canted toward the sail mast. No transition occurs at the 270 degree point, but as the sail assembly rotates through the 180 degree point, the vanes change in orientation from an essentially flat angle to a 45 degree angle. As the sail assembly rotates through the 90 degree point, the vanes change orientation again, this time from a 45 degree angle to a 45 degree angle in an opposite direction. The vanes remain in this orientation until the sail assembly rotates through the 0 degree point.

[0040] As a particular example, the sail assembly located at the south position on FIG. **7** rotates clockwise. The sail **144***a* at the 0 degree position initially has its vanes **160** oriented inward toward the center of the sail **144***a* at a 10 degree angle so as to present a substantially flat surface perpendicular to the wind direction. This orientation promotes capturing the mechanical energy of the wind, and is maintained as the sail **144***a* rotates clockwise through the 270 degree position. As the sail **144***a* continues to rotate clockwise through the 180 degree position, however, the sail **144***a* transitions from moving downwind to moving upwind. Accordingly, as the sail **144***a* rotates through the 180 degree position, the vanes **160** are rotated to a 45 degree orientation, so as to create an upwind vector. In this way, energy may be captured during both the downwind movement and the upwind movement. This vane orientation is maintained until the sail **144***a* rotates through the 90 degree position, at which point the vanes **160** are rotated to a 45 degree orientation in the opposite direction, such that the upwind vector is maintained. This new orientation is maintained until the sail **144***a* rotates through the 0 degree position, at which point the vanes **160** return to the orientation shown in the sail **144***a* at the 0 degree position. The sail assembly located at the east position on FIG. **7** also rotates clockwise, like the sail assembly located at the south position. Accordingly, the movement of the vanes **160** is similar between these two sail assemblies.

[0041] As another example, the sail assemblies located at the north and west positions on FIG. **7** rotate counterclockwise and likewise exhibit similar movement of the vanes **160**. In this case, turning to the sail assembly located at the north position on FIG. **7**, the sail **144***d* at the 0 degree position initially has its vanes **160** oriented inward toward the center of the sail **144***d* at a 10 degree angle so as to present a substantially flat surface perpendicular to the wind direction. This orientation promotes capturing the mechanical energy of the wind, and is maintained as the sail **144***d* rotates counterclockwise through the 90 degree position. As the sail **144***d* continues to rotate counterclockwise through the 180 degree position, however, the sail **144***d* transitions from moving downwind to moving upwind. Accordingly, as the sail **144***d* rotates through the 180 degree position, the vanes **160** are rotated to a 45 degree orientation, so as to create an upwind vector. In this way, energy may be captured during both the downwind movement and the upwind movement. This vane orientation is maintained until the sail **144***d* rotates through the 270 degree position, at which point the vanes **160** are rotated to a 45 degree orientation in the opposite direction, such that the upwind vector is maintained. This new orientation is maintained until the sail **144***d* rotates through the 0 degree position, at which point the vanes **160** return to the orientation shown in the sail **144***d* at the 0 degree position.

[**0042**] In some embodiments, the hydraulic servo motors **168** are further controlled by the microprocessor-based system, which analyzes real-time sensor-obtained information on wind speed, wind direction, sail position, and sail mast position. The microprocessor-based system then continuously moves the vanes and sails using the hydraulic servo motors to resist the maximum wind force. The microprocessor-based system is also programmed to cause the wind turbine **102** to generate increased torque, rather than increased velocity, as the wind speed increases.

[**0043**] The generator **106** is driven by a hydraulic motor that is connected to the hydraulic pumps from the mainsail masts. The microprocessor-based system uses real-time sensor monitoring of wind velocity, hydraulic fluid output pressure, and generator field output power to continuously adjust the armature strength to maintain the mainsail mast and armature of the generators **106** of FIG. **2** at a constant speed, for example, 20 revolutions per minute. The generator field is wound so as to create a 60 Hz AC current when the armature is maintained at 20 revolutions per minute. This power can then be stepped up via a transformer to transmission voltage and uplinked to a power grid.

[**0044**] As the sails **144** rotate, asymmetric power loading on the main masts during downwind versus upwind rotation would cause a lateral oscillation in at least two directions. This problem is resolved by the following means: First, downwind sail rotations on opposite sides of the main tower **130** are counter-rotating. For example, in FIG. **7**, the north sail assembly and the south sail assembly rotate in opposite directions. Similarly, the east and west sail assemblies rotate in opposite directions. As a result, equal and opposite oscillation forces on the main tower **130** are generated.

[**0045**] Second, the flywheel assemblies **146** at the lower end of each main mast serve as a gyroscope preventing any remaining oscillation forces and generating a smooth, constant power output. FIG. **5** is a sectional view taken along lines **5-5** of FIG. **3**. While only one flywheel assembly **146** is visible in FIG. **5**, it will be appreciated that the wind turbine **102** includes four flywheel assemblies **146** surrounding the lower end of the main tower **130**. Each flywheel assembly **146** acts as a gyroscope to resist extraneous oscillation forces. With four flywheel assemblies **146** surrounding the lower end of the main tower **130**, the main tower is extremely stable.

[**0046**] Each flywheel assembly **146** includes a flywheel **170**, which may be approximately 12 feet in diameter. The flywheel **170** has an upper surface that also serves as a brake disk for hydraulic brakes **172**. In one embodiment, the flywheel assembly **146** has four hydraulic brakes **172**, two of which are visible in FIG. **5**. The flywheel **170** is weighted to contain four times the energy of one main mast revolution.

[**0047**] FIG. **5** also illustrates an example drive mechanism for transferring the mechanical energy extracted from the wind by the sails **144** to the hydraulic pumps contained in the main tower **130**. These hydraulic pumps are in turn hydraulically coupled to hydraulic motors in the control building **104**. As the sails **144** rotate about the rotational axis defined by the main mast **140**, they drive a ring gear **174**, which interacts with a pinion gear **176** affixed to a shaft **178** to cause the shaft **178** to rotate. In some embodiments, the shaft **178** is capable of expanding and contracting without adversely affecting the operation of the gears **174** and **176**. This capability may be provided by a slip fitting or spline joint, as shown in FIG. **5**, or by a universal joint, which would be considerably more expensive to implement than a slip fitting.

[**0048**] As the shaft **178** rotates, a pinion gear **180** at the opposite end of the shaft **178** relative to the gear **176** rotates and drives a double ring gear **182** in the main tower **130**. The double ring gear **182** drives the hydraulic pumps (not shown in FIG. **5**) at the base of the main tower **130**. In addition, linking the outputs of the sail assemblies in this way maintains synchronization between the rotating sail assemblies. The hydraulic pumps are coupled to hydraulic motors in the control building **104**, which drive the generators **106** in the control building **104**, thereby generating electrical energy.

[**0049**] FIG. **6** is a sectional view taken along lines **6-6** of FIG. **5**. As shown in FIG. **6**, the shafts **178***a* and **178***b* that are driven by sail assemblies on opposite sides of the main tower **130** rotate in opposite directions. Accordingly, to ensure that the rotation of the gears **180***a* and **180***b* causes the double ring gear **182** to rotate in a single direction, the gears **180***a* and **180***b* are located on opposite sides of the double ring gear **182**. That is, while the gear **180***a* is located above the double ring gear **182**, the gear **180***b* is located below the double ring gear **182**. As the double ring gear **182** rotates, it drives hydraulic pumps **184**. Ports **186** on the hydraulic pumps **184** permit the inflow and outflow of hydraulic fluid from the hydraulic pumps **184**. Hydraulic fluid is conveyed to the control building **104** via a hydraulic fluid line **148** of FIG. **3**, which is located underground proximate the base **132** to wind turbine **102**.

[**0050**] As demonstrated by the foregoing discussion, various embodiments may provide certain advantages, particularly when compared with horizontal axis wind turbines. With the vertical axis, the wind turbine described herein is both laterally and vertically scalable. For example, by stacking sails vertically with guywire stabilization, the wind turbine can be built to heights of up to 1000 feet. At such high altitudes with higher wind speeds and greater laminar flow, significantly more power can be generated than with horizontal axis wind turbines, which cannot use guywires. In addition, the need for certain structures at the top of the wind turbine, such as the transmission, generator, and yaw mechanism characteristic of horizontal axis wind turbines, is avoided, thereby promoting stability and facilitating repair. The reduced number of mechanical parts may result in a lower initial cost, lower operating costs, greater reliability, and lower cost per kilowatt hour.

[**0051**] In addition, the use of sails may realize a number of advantages relative to both horizontal axis wind turbines and conventional vertical axis wind turbines. Because the sails move symmetrically, for example, the wind turbine is particularly stable, especially in view of the use of the flywheel/gyroscope for balancing. Further, sails can extract far greater wind energy relative to lift-type wind turbines.

Gusty or changing wind loads at different tower heights do not cause bending or torturing of sails as they do to propellers on horizontal axis wind turbines. As a result, even under high wind conditions, the sails cannot hit the main tower as propellers can.

[0052] The relatively slow rotation speed (20 rpm) of the sails may also produce a number of advantages. Torque generating sails revolving at only 20 rpm will generate significantly less noise as compared with propeller driven wind turbines, whose wingtip velocity can exceed 180 mph and create a noise in excess of 90 dB. Also, because of their low speed, the sails will be visible to birds that can avoid flying into them. By contrast, millions of birds are killed each year by high speed propeller tips that cannot be seen by birds.

[0053] It will be understood by those who practice the embodiments described herein and those skilled in the art that various modifications and improvements may be made without departing from the spirit and scope of the disclosed embodiments. The scope of protection afforded is to be determined solely by the claims and by the breadth of interpretation allowed by law.

What is claimed is:

1. A wind turbine comprising:

a main tower;

at least two transverse mounting arms mounted on and supported by the main tower;

a sail assembly mounted between the at least two transverse mounting arms, the sail assembly comprising

a main mast defining a vertical axis of rotation,

at least two sail arms mounted on and supported by the main mast, and

a sail mounted between the at least two sail arms, the sail configured to rotate about the vertical axis of rotation in response to wind; and

a hydraulic pump configured and arranged to generate a hydraulic output in response to rotation of the sail about the vertical axis of rotation.

2. The wind turbine of claim 1, wherein the sail comprises a plurality of vanes configured to be rotated to a first orientation when the sail is moving in an upwind direction and to a second orientation when the sail is moving in a downwind direction.

3. The wind turbine of claim 2, wherein the sail further comprises a plurality of servo motors configured to selectively rotate the vanes to the first and second orientations.

4. The wind turbine of claim 3, further comprising a microprocessor-based system configured to control operation of the vanes.

5. The wind turbine of claim 1, wherein the sail assembly comprises:

three pairs of sail arms; and

three sails each mounted between a corresponding pair of sail arms.

6. The wind turbine of claim 1, further comprising a flywheel assembly operatively coupled to the sail assembly.

7. The wind turbine of claim 6, wherein the flywheel assembly is sized and configured to function as a gyroscope.

8. The wind turbine of claim 6, further comprising a plurality of hydraulic brakes, and wherein the flywheel is configured to act as a brake disk for the hydraulic brakes.

9. The wind turbine of claim 1, further comprising a pill block bearing drive mechanism configured and arranged to drive the hydraulic pump in response to movement of the sails.

10. The wind turbine of claim 1, wherein the pill block bearing drive mechanism comprises a shaft arrangement having a variable effective length.

11. The wind turbine of claim 10, wherein the shaft arrangement comprises a plurality of segments arranged in a slip fitting arrangement.

12. The wind turbine of claim 10, wherein the shaft arrangement comprises a plurality of segments connected to one another via a universal joint.

13. The wind turbine of claim 1, further comprising a plurality of guywires affixed to an upper portion of the main tower.

14. A wind turbine arrangement comprising:

a plurality of wind turbines each comprising

a main tower,

at least two transverse mounting arms mounted on and supported by the main tower, and

a sail assembly mounted between the at least two transverse mounting arms, the sail assembly comprising

a main mast defining a vertical axis of rotation,

at least two sail arms mounted on and supported by the main mast, and

a sail mounted between the at least two sail arms, the sail configured to rotate about the vertical axis of rotation in response to wind,

each wind turbine configured to generate a hydraulic output in response to rotation of the sail about the vertical axis of rotation, wherein the hydraulic outputs of the wind turbines are linked together;

an electrical generator, and

a hydraulic pump configured to receive the linked hydraulic outputs of the wind turbines and to drive the electrical generator.

15. The wind turbine arrangement of claim 14, wherein the electrical generator and the hydraulic pump are housed in a control building.

16. The wind turbine arrangement of claim 15, wherein the control building comprises a pressure equalizer configured to equalize fluid pressures between the linked hydraulic outputs of the wind turbines.

17. The wind turbine arrangement of claim 15, wherein the control building comprises:

a plurality of electrical generators;

a plurality of hydraulic pumps; and

a splitter arrangement to split the linked hydraulic outputs of the wind turbines among the plurality of hydraulic pumps.

18. The wind turbine arrangement of claim 14, wherein the sail comprises a plurality of vanes configured to be rotated to a first orientation when the sail is moving in an upwind direction and to a second orientation when the sail is moving in a downwind direction.

19. The wind turbine arrangement of claim 18, wherein the sail further comprises a plurality of servo motors configured to selectively rotate the vanes to the first and second orientations.

20. The wind turbine arrangement of claim 14, wherein each wind turbine further comprises a flywheel assembly operatively coupled to the sail assembly.

21. The wind turbine arrangement of claim 20, wherein the flywheel assembly is sized and configured to function as a gyroscope.

22. The wind turbine arrangement of claim 20, further comprising a plurality of hydraulic brakes, and wherein the flywheel is configured to act as a brake disk for the hydraulic brakes.

23. The wind turbine arrangement of claim 14, wherein each wind turbine further comprises a pill block bearing drive mechanism configured and arranged to drive the hydraulic pump in response to movement of the sails.

24. The wind turbine arrangement of claim 23, wherein the pill block bearing drive mechanism comprises a shaft arrangement having a variable effective length.

25. The wind turbine arrangement of claim 14, wherein each wind turbine further comprises a plurality of guywires affixed to an upper portion of the main tower.

26. A wind turbine comprising:

a main tower;

a plurality of transverse mounting arms mounted on and supported by the main tower;

a plurality of sail assemblies mounted between at least two of the transverse mounting arms, each sail assembly comprising

a main mast defining a vertical axis of rotation,

at least two sail arms mounted on and supported by the main mast, and

a sail mounted between the at least two sail arms, the sail configured to rotate about the vertical axis of rotation in response to wind; and

a hydraulic pump configured and arranged to generate a hydraulic output in response to rotation of the sails of the sail assemblies about the vertical axes of rotation.

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