



(51) International Patent Classification:

F03D 3/00 (2006.01) F03D 80/70 (2016.01)

(21) International Application Number:

PCT/US2018/042511

(22) International Filing Date:

17 July 2018 (17.07.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/536,173 24 July 2017 (24.07.2017) US

(71) Applicant: THE BOARD OF TRUSTEES OF THE LE-  
LAND STANFORD JUNIOR UNIVERSITY [US/US];  
3000 El Camino Real, Building Five, Third Floor, Palo Al-  
to, CA 94306 (US).

(72) Inventors: BROWNSTEIN, Ian; 473 Via Ortega, Rm 161,  
Stanford, CA 94305 (US). DAVIRI, John; 473 Via Ortega,  
Rm 169, Stanford, CA 94305 (US).

(74) Agent: JACOBS, Ron et al.; 438 Cambridge Avenue, Suite  
225, Palo Alto, CA 94306 (US).

(81) Designated States (unless otherwise indicated, for every  
kind of national protection available): AE, AG, AL, AM,  
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,  
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,

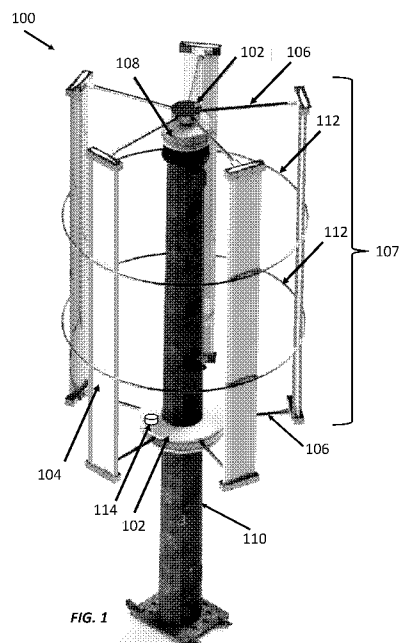
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HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,  
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,  
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OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,  
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,  
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

Published:

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

(54) Title: VERTICAL-AXIS WIND TURBINE WITH MULTI-POINT BEARING SUPPORT



(57) Abstract: A vertical axis wind turbine (VAWT) is provided that includes a vertical tower having a vertical tower axis, a generator, where the generator includes a safety release disposed to enact a free-spin mode when a power output on the generator reaches a threshold, a plurality of bearings disposed concentric to the vertical tower axis, and disposed along the vertical tower, and a rotor having a plurality of rotor arms and plurality of vertical rotor blades, where a proximal end of each the rotor arm is connected radially to the bearing, where a distal end of each blade is connected to rotor arms.



# **VERTICAL-AXIS WIND TURBINE WITH MULTI-POINT BEARING SUPPORT**

## **FIELD OF THE INVENTION**

5     The present invention relates generally to wind turbines. More specifically, it relates to structural improvements in vertical axis wind turbines.

## **BACKGROUND OF THE INVENTION**

Vertical Axis Wind Turbines (VAWT), show promise to enable cost-effective  
10   operational wind farms, however, shortcomings include reliability due to structural fatigue have been a limitation to their large-scale implantation.

Existing commercially-available VAWT designs are inherently unstable structures. Specifically, the cantilevered rotor structure above the generator induces bending  
15   loads on the generator and bearings, especially in high-wind conditions, leading to mechanical failure on time scales much shorter than experienced by the standard three-blade, horizontal-axis wind turbine (HAWT) design. These failures, combined with insufficient mechanisms to shed aerodynamic loads in high winds, makes the current portfolio of VAWT designs too unreliable and too expensive in operations and  
20   maintenance to be viable for larger implementation.

What is needed is a VAWT that is capable of sustaining adverse conditions without mechanical failure or material fatigue.

## SUMMARY OF THE INVENTION

To address the needs in the art, a vertical axis wind turbine (VAWT) is provided that includes a vertical tower having a vertical tower axis, a generator, where the generator  
5 includes a safety release disposed to enact a free-spin mode when a power output or rotational rate on the generator reaches a threshold, a plurality of bearings disposed concentric to the vertical tower axis, and disposed along the vertical tower, and a rotor having a plurality of rotor arms and plurality of vertical rotor blades, where a proximal end of each the rotor arm is connected radially to the bearing, where a distal end of  
10 each blade is connected to rotor arms.

In one aspect of the invention, the power output or rotational rate threshold is set by the operating limits of the generator to enable a free-spinning mode.

15 In a further aspect of the invention, the generator is disposed concentric with the axis of the vertical tower.

In another aspect, the invention further includes rotor blade containment rings, where the rotor blade containment rings are disposed concentric to the vertical tower axis  
20 and connected to a region between the top end and the bottom end of the vertical rotor blade, where the rotor blade containment ring is positioned to limit vertical rotor blade deformation by centripetal acceleration of the vertical blade along the mid-region when the generator is in the free-spin mode.

In yet another aspect, the invention further includes sensors, where the sensors include an RPM sensor or torque sensor. Here, the data from the sensor is received by a controller, where the controller engages and disengages the VAWT generator according to measurements by the sensors.

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In another aspect, the invention further includes downstream sensors disposed electronically downstream from the generator, where the downstream sensors can be a voltage sensor, an amperage sensor, and power sensor. Here, the data from the downstream sensor(s) is received by a controller, where the controller engages and  
10 disengages the VAWT generator according to measurements by the downstream sensors.

According to another aspect, the invention further includes a gearbox, where the gearbox is connected to generator which is not concentric with the vertical towers  
15 vertical axis.

## BRIEF DESCRIPTION OF THE DRAWINGS

**FIGs. 1-4** show a perspective view (**FIG. 1**), and cutaway views (**FIGs. 2-4**) of different embodiments VAWT's, according to the current invention.

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## DETAILED DESCRIPTION

The invention provides several vertical axis wind turbine (VAWT) design innovations that are preferably used together but could also be used independently: 1) Multi-point

bearing supports at top and bottom, or top, center region and bottom, including a generator at the top or bottom; 2) clamps at ends of blades to restrict blade bending modes; 3) hoops around blades at intermediate positions to prevent blade bending in high centrifugal loads; 4) Simple and efficient rotor release protocol in high winds.

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The current invention has various advantages, including: 1) Vastly increased structural stability from currently available VAWT designs; 2) No need for mechanical braking mechanism; 3) Simple and efficient rotor release protocol in high winds.

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The invention solves the issues of VAWT reliability by eliminating the primary sources of structural fatigue in existing VAWTs. According to one embodiment, the invention facilitates a rotor release protocol in high winds, instead of conventional electromechanical rotor braking that has proven insufficient for VAWTs. The rotor release protocol for operation in high winds cannot be implemented using existing VAWT designs due to the large bending loads they incur which lead to structural failure.

This vertical-axis wind turbine (VAWT) design can withstand the loads associated with power generation and free spin in high wind speeds. When in use, power is generated until the limits of the energy conversion device being used (e.g. permanent magnet generator, water pump, etc.) and then the turbine will be released from producing power into a free spinning condition instead of braking, preventing the highly unbalanced loading which occurs when the turbine is in a braked condition.

Embodiments of the current VAWT invention solve the problems with existing VAWT designs by eliminating the primary sources of structural fatigue. This is done using a multi-point bearing support to the tower, including supports at the top and  
5 bottom of the rotor. One or more of these bearing supports may be incorporated into the power conversion device, e.g. permanent magnet generator or water pump. This reduces the moments applied to the power conversion device by transferring load low on the tower, resulting in a net zero moment on the rotor structure. Since a portion of the thrust load is applied lower on the tower, the overall moment transferred to the  
10 tower is lower, increasing the rated wind speed of the tower foundation. Additionally, the proposed design constrains the blades from bending outward due to the large centrifugal loads when the rotor is spinning at high RPM in high winds. This is done in two ways. First, the ends of the blades are rigidly constrained. In one embodiment, hoops are installed around the blades to prevent bending between these rigid  
15 constraints. This forces blade bending to higher frequency modes, which require much larger forces to manifest.

With the implementation of these two aspects to mitigate damage to the rotor, this design can simply be electronically released by disengaging the generator, allowing  
20 the rotor to free spin in high winds when the generator would produce power beyond its rated output. When the wind speed reduces sufficiently, the system can be re-engaged electronically so that power can again be produced.

Some embodiments may include a shaft extending into the tower to the ground where power conversion generator device (e.g. permanent magnet generator, water pump, etc.) can be easily accessed.

5 The term ‘multi-point bearing support’ refers to multiple points along the length of tower where the rotating rotor applies load to the tower through a bearing. This invention is meant to include at least one point of connection at each extreme of the rotor. Specifically, **FIGs. 1-4** show embodiments of different VAWT’s **100** according to the current invention, where shown are two bearing supports **102** points, a rotor  
10 system **107** that includes rotor blades **104**, and rotor arms **106**, and further shown is a generator **108**, which houses two internal SKF bearings, shown at the top of the rotor assembly in **FIG. 1**, where the purpose built ‘bearing assembly’ is shown at the bottom of the rotor assembly. Also shown is a wind turbine monopole tower **110**. The tower **110** mates to all of the bearing supports **102**, which transfer loads from the stationary  
15 tower to the rotor assembly. In this embodiment, there are two bearing supports: one at the generator **108**, which provides the top bearing **102** support and has the potential to generate electricity, and the lower dedicated bearing **102** support designed for this realization, which will be referred to as the bearing assembly. **FIG. 2** shows downstream sensors **109** disposed electronically downstream from the generator **108**,  
20 where the downstream sensors **109** can be a voltage sensor, an amperage sensor, and power sensor.

**FIG. 1** and **FIG. 2** show a pair of hoops **112**, and a single hoop **112**, respectively, disposed to support the blades in a manner to reduce deformation under high rotational velocities, where it is understood that any number of hoops can be implemented. A

sensor **114** is show in the figures connected to the bottom bearing **102**, where the sensor includes an RPM sensor and/or a torque sensor, where it is understood that the sensors can be located at other positions on the VAWT, or located external to the VAWT.

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**FIG. 4** further shows a gearbox **116**, which enables adjustment of a torque imposed on the generator according to an appropriate RPM.

According to embodiments of the invention, the bearing assembly includes:

- 10 i. Two-part collar, which adapts the 12-sided tower shape to the inner bearing sleeve.
- ii. The inner sleeve, which has a precision cut OD to press onto the ID of the lower bearing.
- iii. The lower bearing.
- 15 iv. The outer sleeve, which has a precision cut ID to press onto the OD if the lower bearing. This part, along with the outer race of the lower bearing, are the parts of the bearing assembly which rotate with the rotor assembly. In this example, the outer sleeve connects to the rotor through 5- radial holes that the bottom rotor arms bolt into.
- 20 v. The bearing cover. This part mates to the stationary two-part collar and reaches over the bearing assembly to prevent contaminates from entering the lower bearing. This helps extend lower bearings lifetime. This cover can have a number of manifestations: providing a labyrinth to complicate the path particulates would need to take to reach the bearing and/ or a sealing ring which



presses against the outer sleeve to seal the bearing off from the outside environment.

In one aspect, the rotor assembly includes:

- 5     i.    The bottom rotor arms, which reach out of the outer sleeve.
- ii.   The blade block adapters, which transfer the cylindrical top and bottom blade arms shape to the rectangular form of the blade mounting blocks.
- iii.   The blade mounting blocks, which provide a rigid clamp to the blades on both  
10       the top and bottom of the rotor. This constrains blade bending to modes within  
      these two end clamps.
- iv.    The blades.
- v.    The hoops, which further constrain blade bending to higher modes than would  
      be possible with just the blade mounting blocks.
- vi.    The top rotor arms, which connect the top blade mounting blocks to the  
15       generator hub.
- vii.   The generator hub, which connects the rotor to the generator.

In the embodiment of **FIG. 1**, the tower **110**, bearing assemblies **102**, rotor system **107**, and generator **108** are all concentric. The tower **110** is preferably made of steel  
20   or composite material and all bearing assembly **102** and rotor system **107** components are preferably made of aluminum or composite material except for the bearings **102**. The bearings **102**, and generator **108** are made of multiple internal components of various materials.

There are no practical limitations on the size of this type of turbine compared to commercial wind turbines. The physical ranges used in horizontal-axis turbines, 10W-10MW, are in-line with the current invention.

- 5 During operation, the rotor spins under aerodynamic loading. The power is converted to useful energy via at least one generator which converts that energy to useful mechanical or electrical form. In high wind speeds, the turbine can be electronically released (i.e., the rotor assembly is decoupled from the generator), allowing the rotor to free spin in high winds when the generator would produce power beyond its rated  
10 output. When the wind speed reduces sufficiently, the system can be re-engaged electronically so that power can again be produced.

The minimum number of bearing connections for this invention is two. As in the case of the embodiment described above, the two bearing connections are at the extremes  
15 of the rotor, one at the bottom and one at the top. In this embodiment, the top bearing connection is the generator and the bearings are housed internally. In other embodiments, there could be additional bearing connections between the two bearing connections near the extreme of the rotor. Any of the bearing connections can act as a generator, either mechanical or electrical.

20

In further embodiments, the invention is configured to convert rotation energy to mechanical power and heat using a generator which uses electro-mechanical forcing to heat a conductive metal which is transferred out of the turbine via working fluid.

Alternatively, the rotating turbine can spin a mechanical device to frictionally heat a working fluid.

According to the current invention, integrated power electronics include a control  
5 algorithm that accomplishes generator disconnect and reconnect, and optimize the  
controller to avoid overloading of the generator. An optimized controller is integrated  
with the VAWT of the current invention, which includes variable frequency AC  
buses. In one embodiment, the controller is optimized to minimize the number of  
disconnect and reconnect events under gusting wind conditions, while maximizing  
10 power generation and avoiding overloading of the generator.

As mentioned previously, the ability to disconnect the turbine from the load in high  
winds significantly simplifies the power generation protocol. In particular, the wild  
three-phase AC power generated by the VAWT is connected to an inverter, which can  
15 be included in the generator. When the inverter detects that the generator voltage has  
reached the maximum that can be accommodated for the associated current draw (i.e.  
due to rapid rotation in high winds), the inverter is programmed to automatically  
disconnect the generator from the electrical load (e.g. a central electrical bus). In one  
embodiment, an electromagnetic RPM sensor on the rotor detects when the turbine  
20 has slowed to an acceptable speed again (i.e. after the high-wind event has subsided),  
at which point the inverter reconnects the generator to the electrical load and power  
generation resumes.

The present invention has now been described in accordance with several exemplary

embodiments, which are intended to be illustrative in all aspects, rather than restrictive. Thus, the present invention is capable of many variations in detailed implementation, which may be derived from the description contained herein by a person of ordinary skill in the art.

5

All such variations are considered to be within the scope and spirit of the present invention as defined by the following claims and their legal equivalents.

## CLAIMS

What is claimed:

- 1) A vertical axis wind turbine (VAWT) comprising:
  - a) a vertical tower comprising a vertical tower axis;
  - 5       b) a generator, wherein said generator comprises a safety release disposed to enact a free-spin mode when a power output on said generator reaches a threshold;
  - c) a plurality of bearings disposed concentric to said vertical tower axis, and disposed along said vertical tower; and
  - 10       d) a rotor comprising a plurality of rotor arms and plurality of vertical rotor blades, wherein a proximal end of each said rotor arm is connected radially to said bearing, wherein a distal end of each blade is connected to rotor arms.
- 15       2) The VAWT of claim 1, wherein said power threshold is set by the operating limits of said generator or a rotation rate of said rotor.
- 3) The VAWT of claim 1, wherein said generator is disposed concentric with said axis of said vertical tower.
- 20       4) The VAWT of claim 1 further comprises rotor blade containment rings, where said rotor blade containment rings are disposed concentric to said vertical tower axis and connected to a region between said top end and said bottom end of said vertical rotor blade, wherein said rotor blade

containment ring is positioned to limit vertical rotor blade deformation by centripetal acceleration of said vertical blade along said mid-region when said generator is in said free-spin mode.

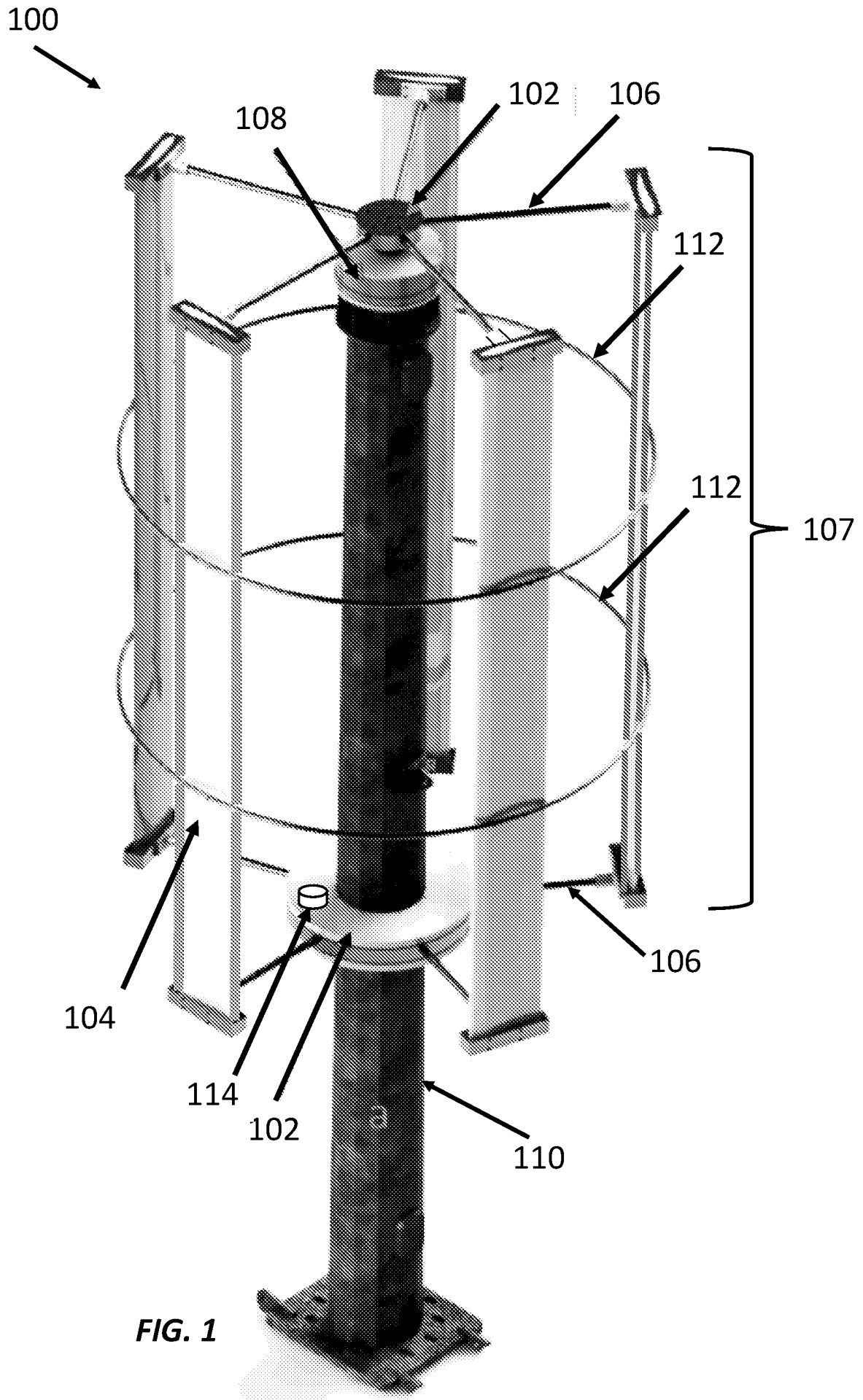
5           5) The VAWT of claim 1 further comprising sensors, wherein said sensors are selected from the group consisting of an RPM sensor and torque sensor.

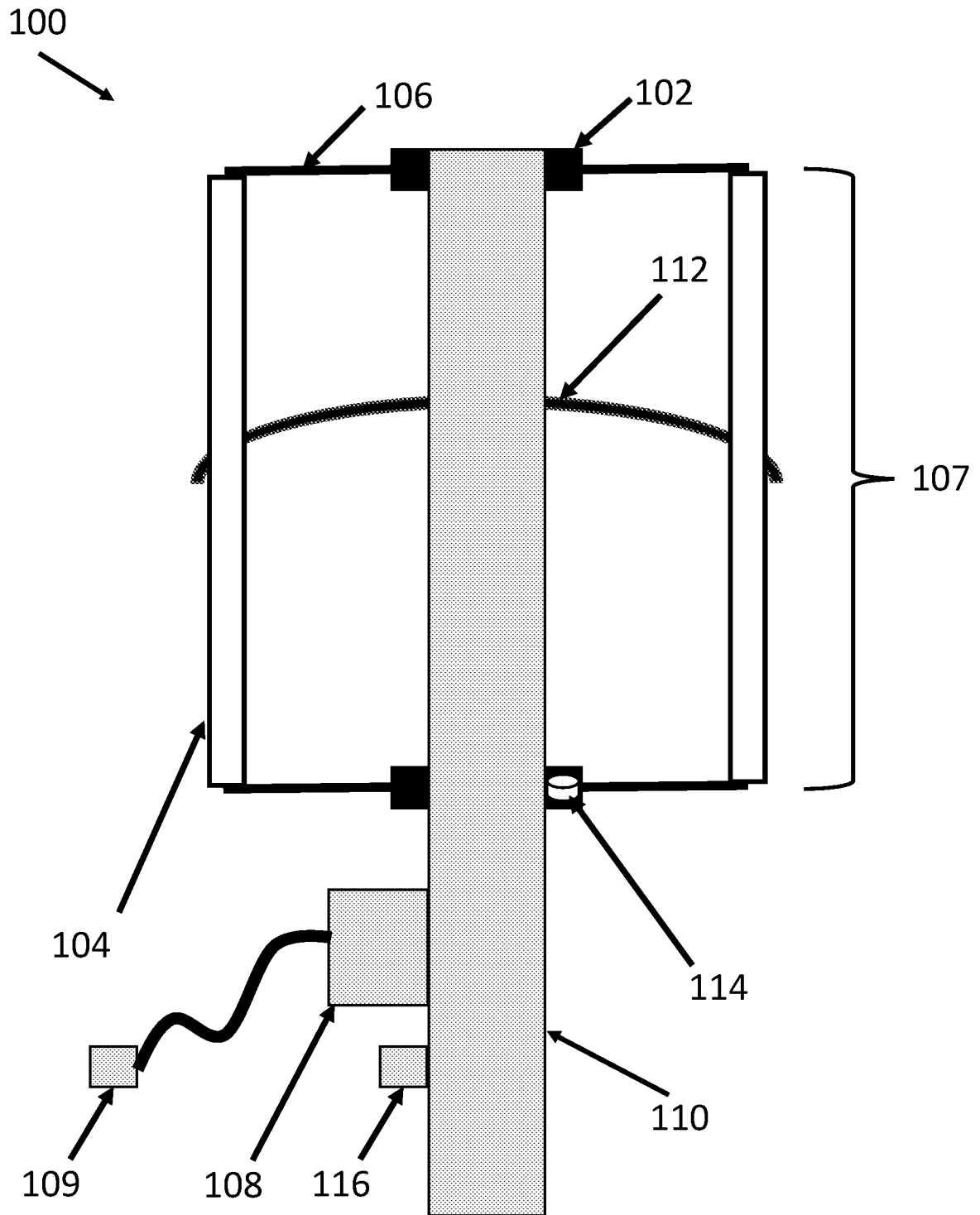
6) The VAWT of claim 5, wherein said data from said sensor is received by a controller, where said controller engages and disengages said  
10           VAWT generator according to measurements by said sensors.

7) The VAWT of claim 1 further comprising downstream sensors disposed electronically downstream from said generator, wherein said downstream sensors are selected from the group consisting of a voltage sensor, an  
15           amperage sensor, and power sensor.

8) The VAWT of claim 7, wherein said data from said downstream sensor is received by a controller, where said controller engages and disengages said VAWT generator according to measurements by said  
20           downstream sensors.

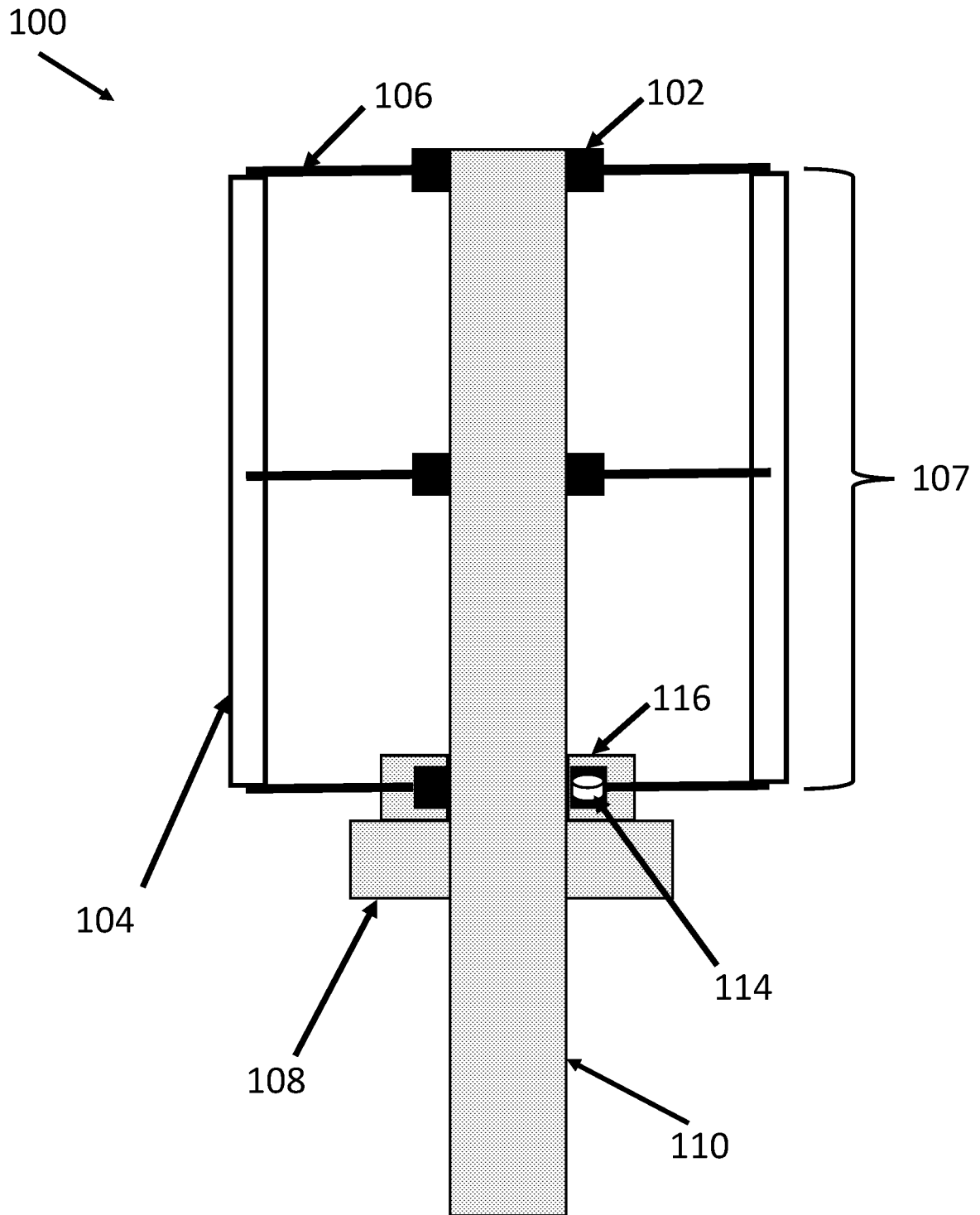
9) The VAWT of claim 1 further comprising a gearbox, wherein said gearbox is connected to said generator.





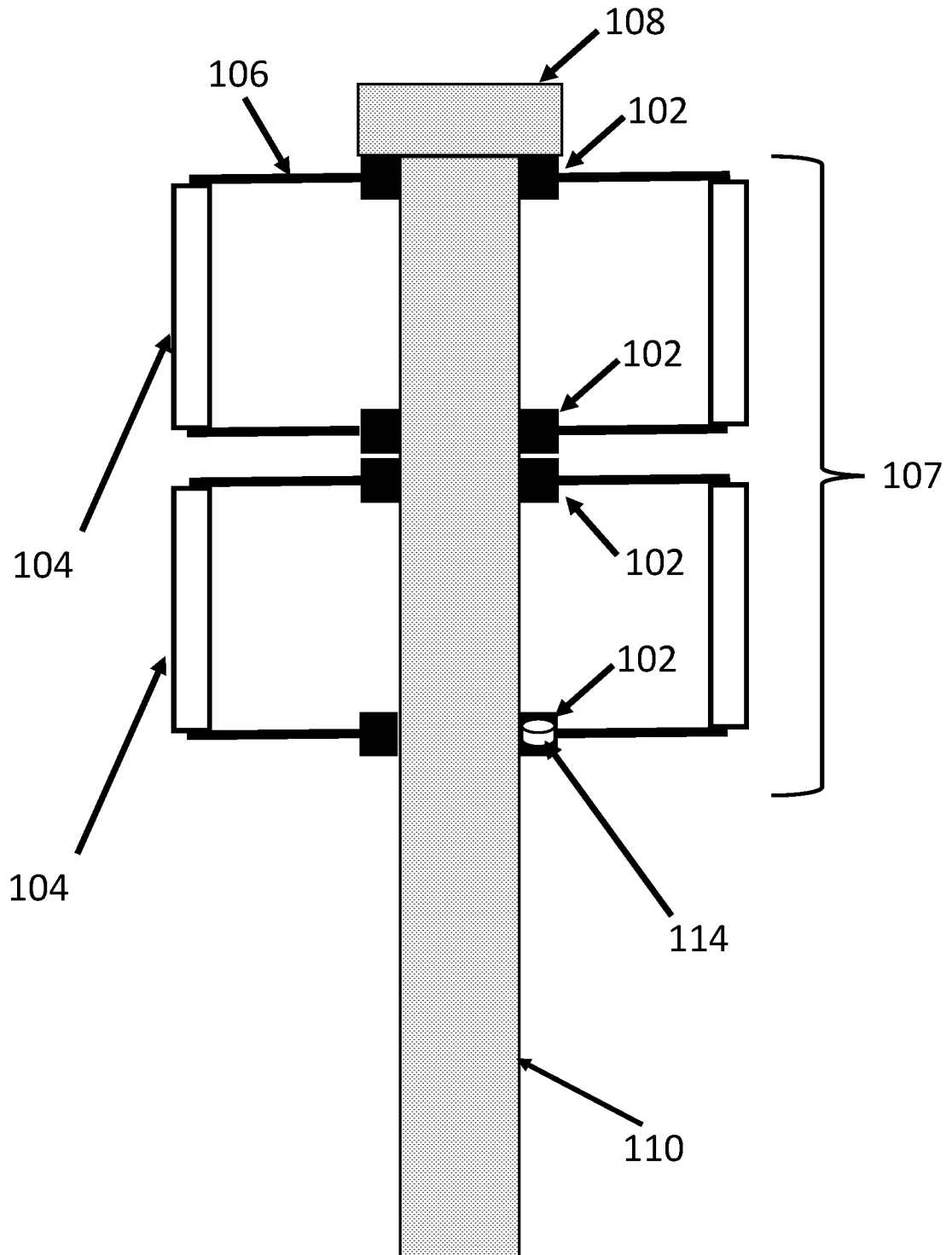
**FIG. 2**





**FIG. 3**

100



**FIG. 4**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 18/42511

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F03D 3/00, F03D 80/70 (2018.01)

CPC - F03D 3/005, F03D 80/70

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)

See Search History Document

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

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## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                              | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 4,609,827 A (NEPPLE) 02 September 1986 (02.09.1986), entire document, especially Fig 1, 3; col 5, ln 25-40; col 7, ln 21-49; col 9, ln 62-67; col 10, ln 1-4, 15-31; col 11, ln 23-26, 33-35 | 1-9                   |
| Y         | US 8,487,470 B2 (GRASSMAN) 16 July 2013 (16.07.2013), entire document, especially Fig 1-2; col 4, ln 63-67; col 5, ln 1-5, 8-14, 36-41                                                          | 1-9                   |
| Y         | US 8,421,263 B2 (WILSON, JR. et al.) 16 April 2013 (16.04.2013), entire document, especially Fig 1; col 3, ln 12-16; col 5, ln 23-26                                                            | 4                     |
| Y         | US 9,528,498 B2 (BARDIA) 27 December 2016 (27.12.2016), entire document, especially Fig 1A, 2, 4D; col 3, ln 24-27, 47-51; col 4, ln 16-21, 31-35, 40-45; col 7, ln 59-67; col 8, ln 1-4, 42-53 | 6-8                   |
| A         | US 7,230,348 B2 (POOLE) 12 June 2007 (12.06.2007), entire document                                                                                                                              | 1-9                   |
| A         | US 4,293,279 A (BOLIE) 06 October 1981 (06.10.1981), entire document                                                                                                                            | 1-9                   |
| A         | US 2007/0189889 A1 (YOKOI) 16 August 2007 (16.08.2007), entire document                                                                                                                         | 1-9                   |



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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