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(54) **WIND TURBINE BLADE DRAINAGE**

Publication Classification

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(57) **ABSTRACT**

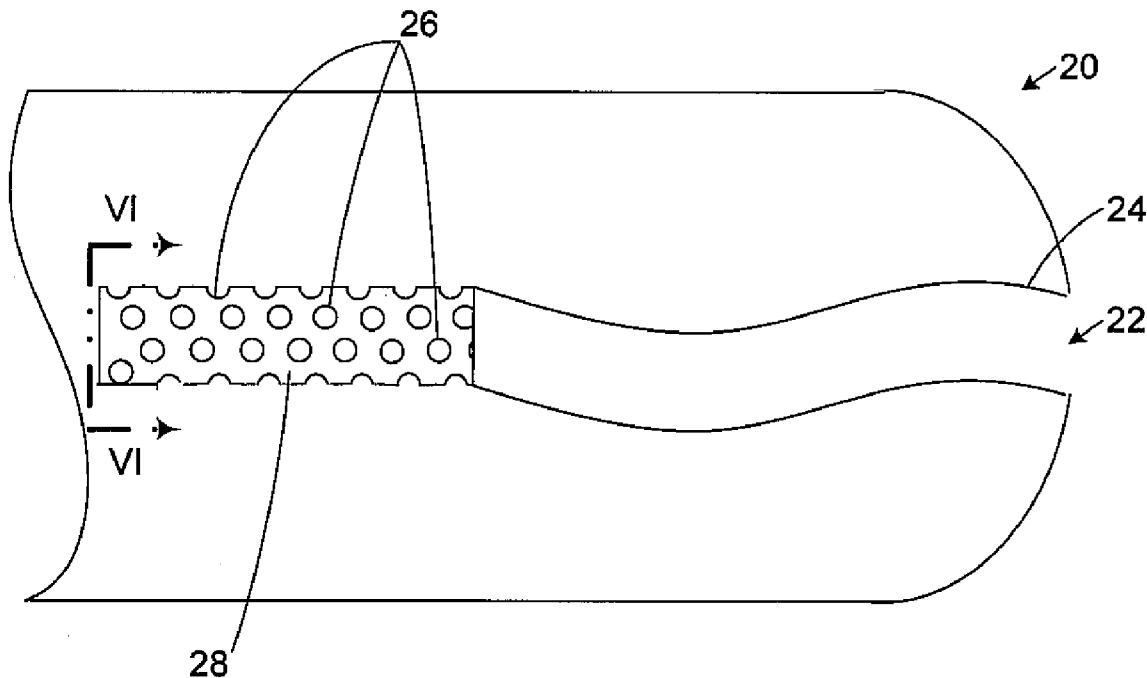
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A wind turbine includes a tower supporting a drive train with a rotor, at least one hollow blade extending radially from the rotor; a drain hole arranged in a tip portion of the blade; a baffle, arranged inside the blade and inboard of the drain hole, for impeding a flow of particulate matter to the drain hole; a flexible drain conduit arranged inside the blade for connecting to the drain hole; and a non-flexible drain conduit arranged inside the blade for connecting to the flexible drain conduit, the non-flexible conduit having a plurality of openings for receiving fluid from inside the blade.

(73) Assignee: **General Electric Company**

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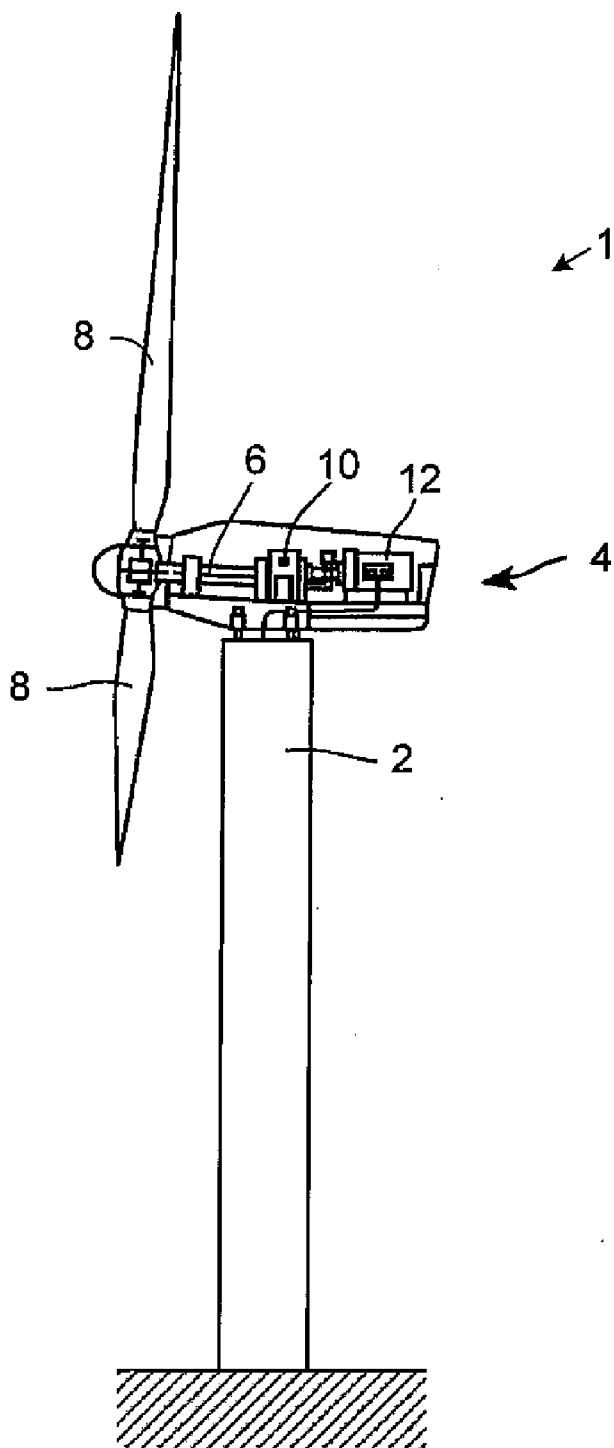


FIG. 1
(PRIOR ART)

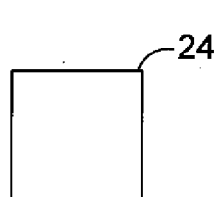
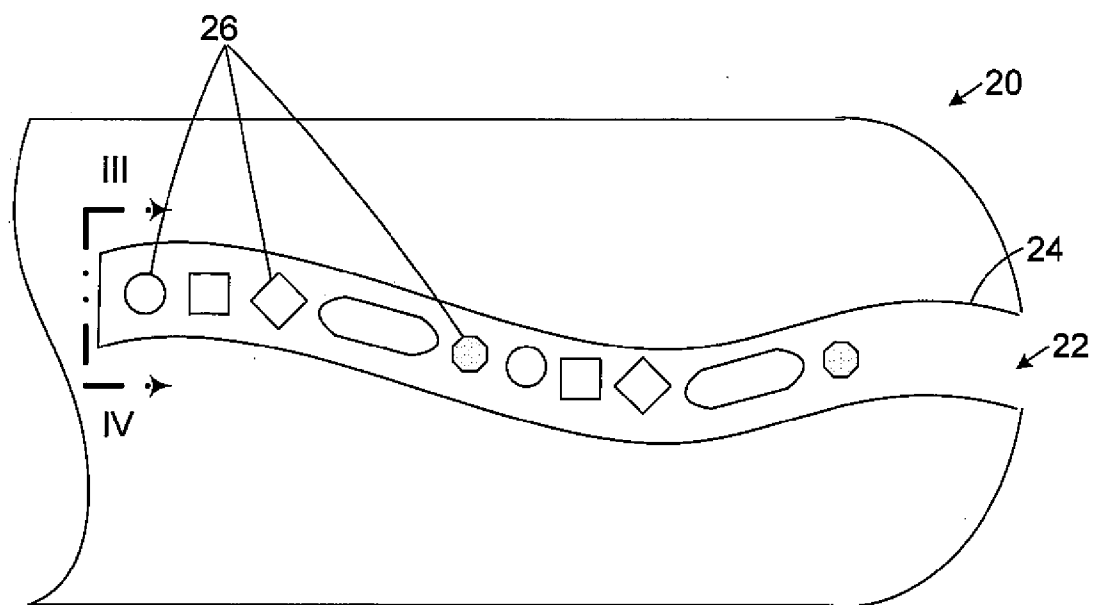


FIG. 2

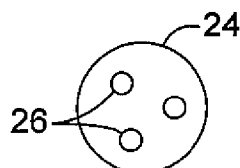


FIG. 3

FIG. 4

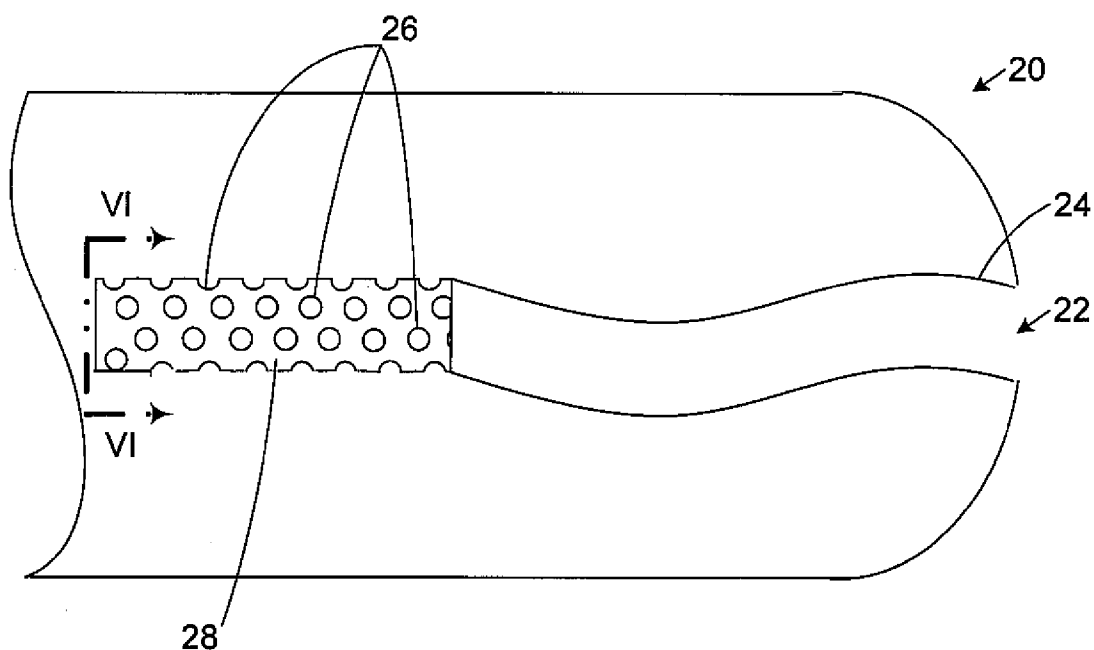


FIG. 5

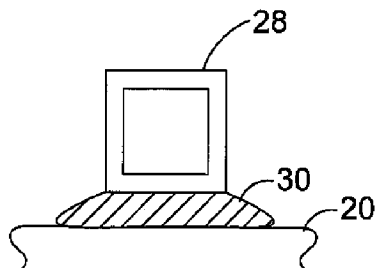


FIG. 6

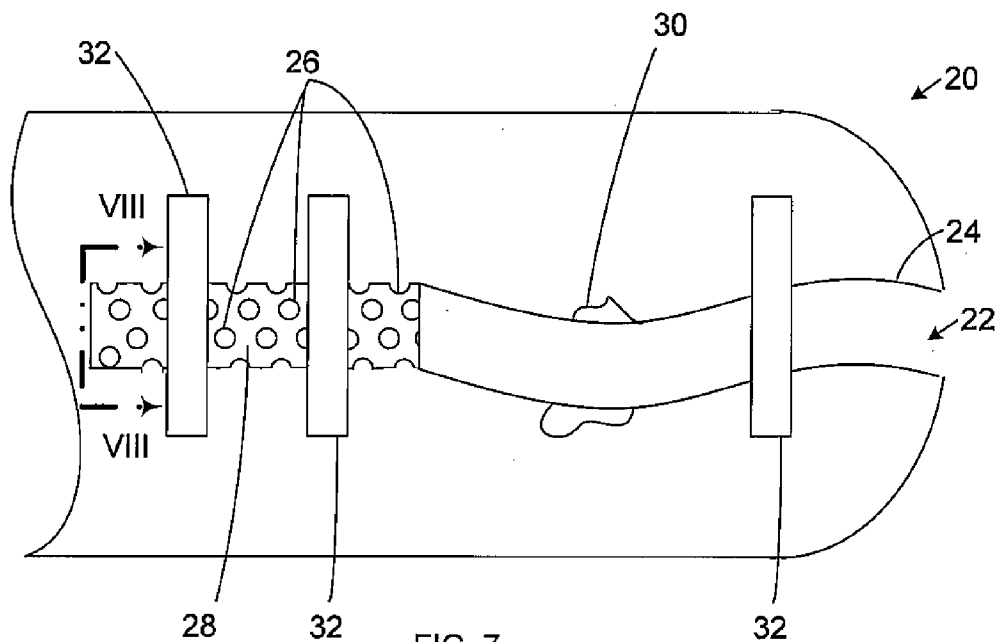


FIG. 7

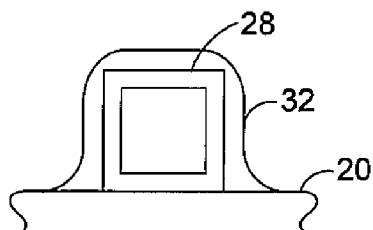


FIG. 8

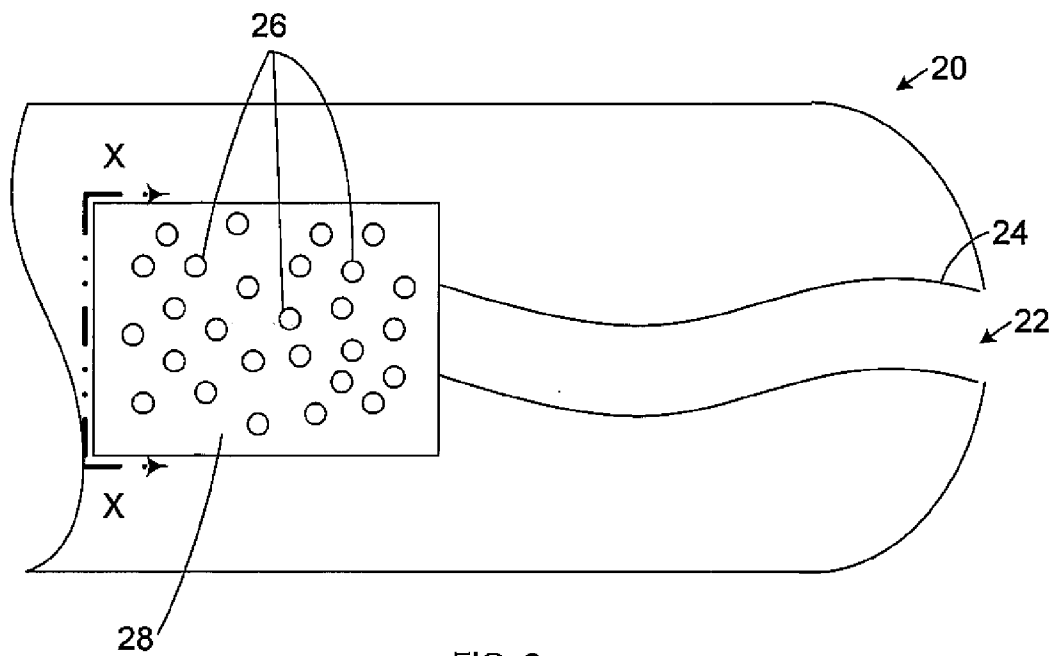


FIG. 9

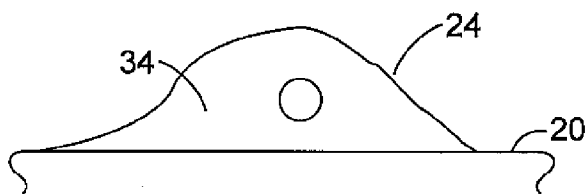


FIG. 10

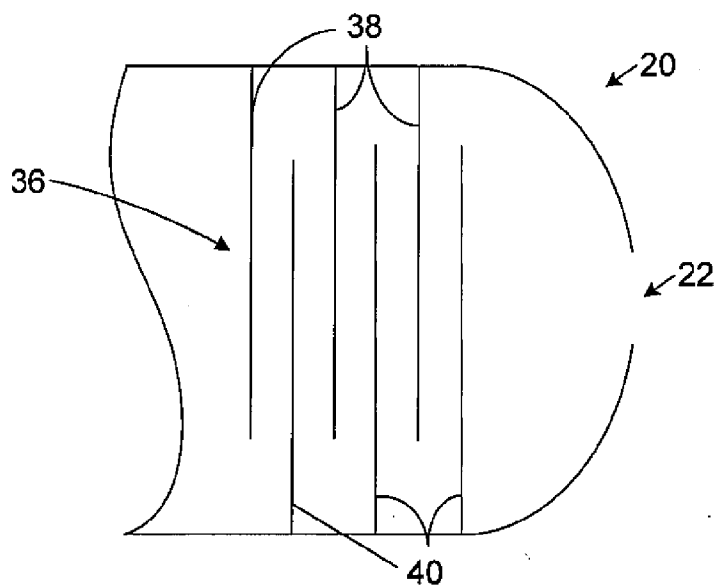


FIG. 11

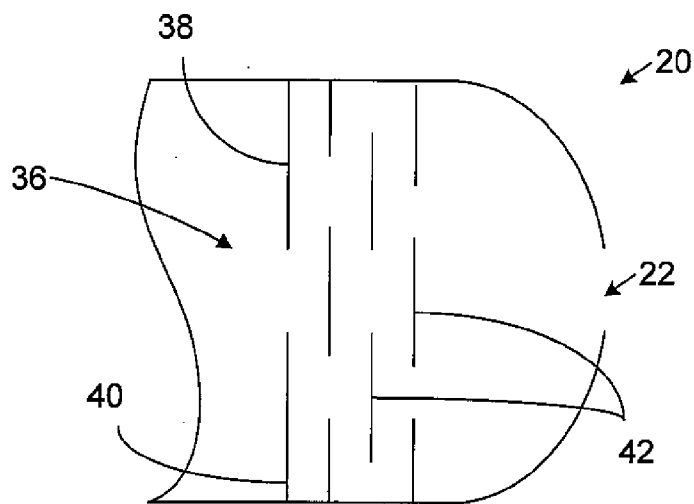


FIG. 12

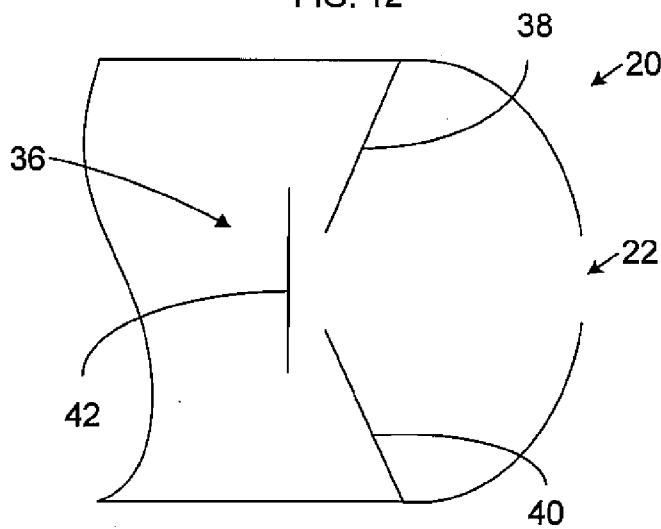


FIG. 13

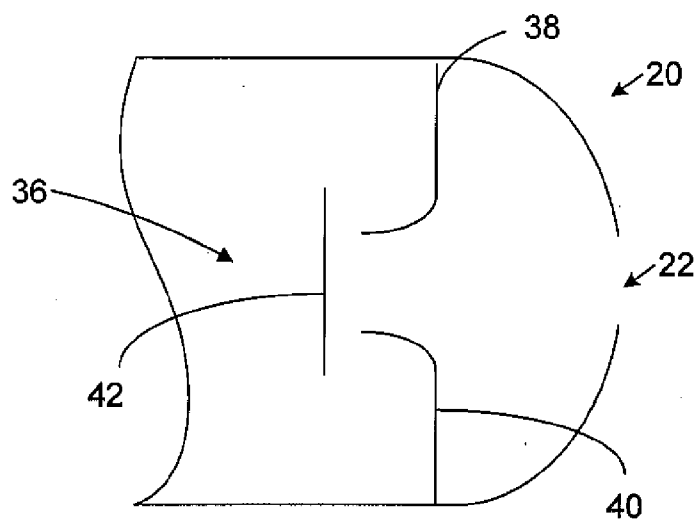


FIG. 14

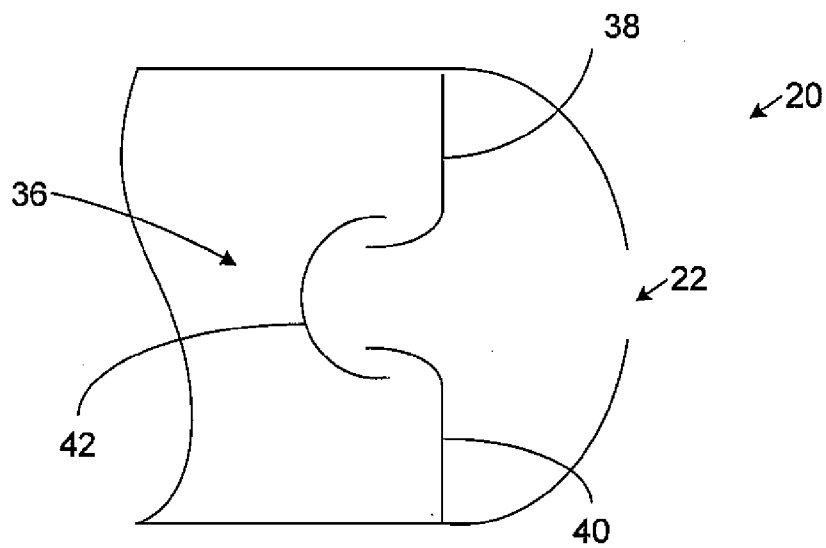


FIG. 15

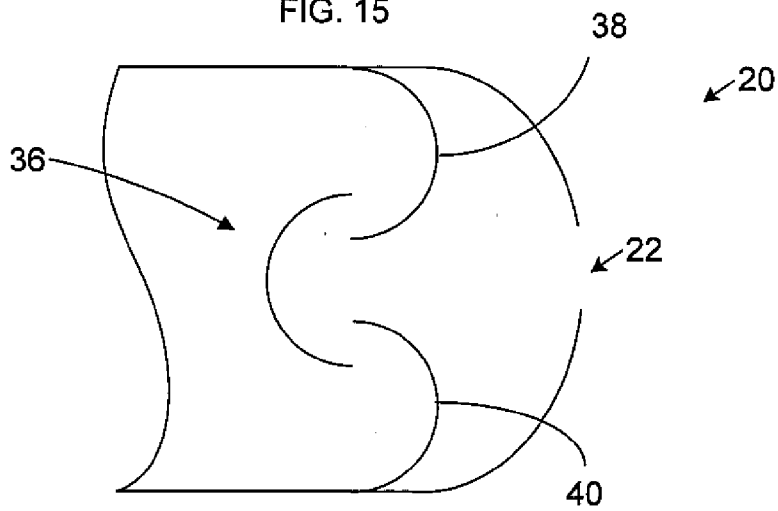


FIG. 16

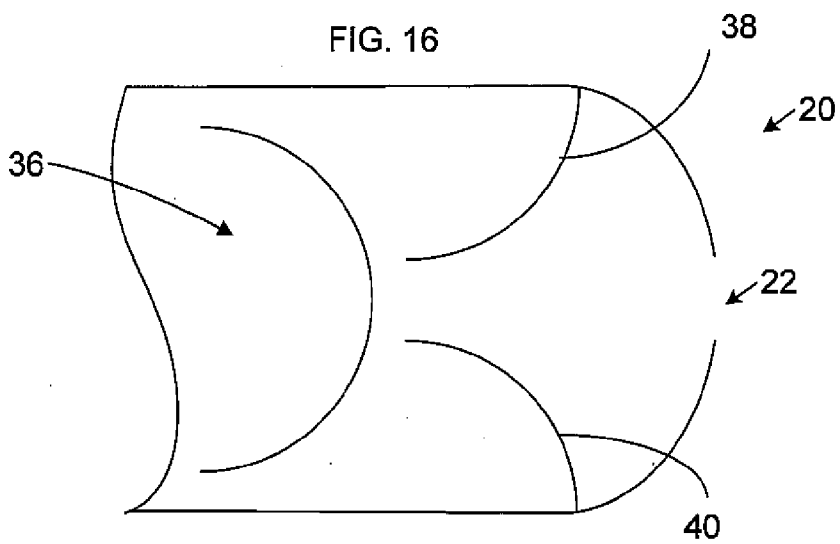


FIG. 17

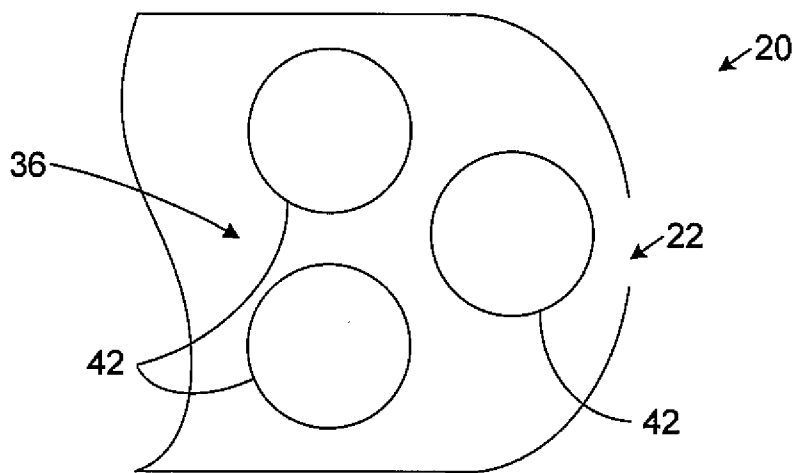


FIG. 18

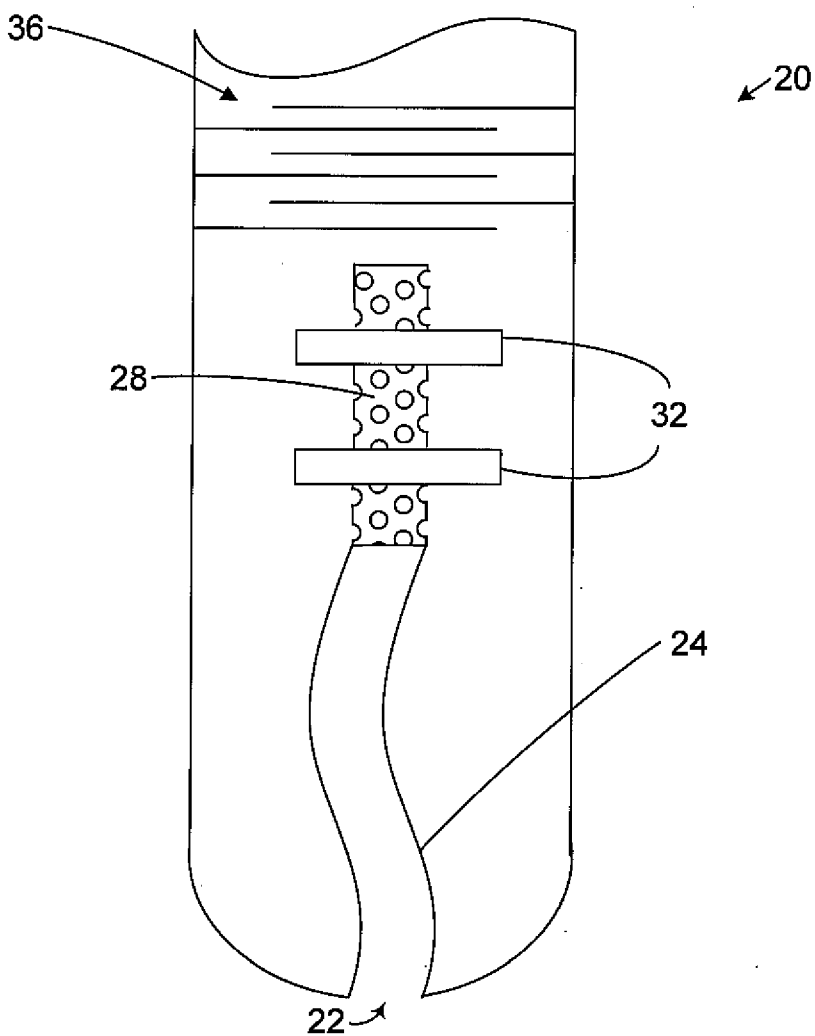


FIG. 19

WIND TURBINE BLADE DRAINAGE

BACKGROUND OF THE INVENTION

[0001] 1. Technical Field

[0002] The subject matter described here generally relates to fluid reaction surfaces with specific blade structures that are apertured or permeable, and, more particularly, to clog-resistant drains for wind turbine blades.

[0003] 2. Related Art

[0004] A wind turbine is a machine for converting the kinetic energy in wind into mechanical energy. If that mechanical energy is used directly by machinery, such as to pump water or to grind wheat, then the wind turbine may be referred to as a windmill. Similarly, if the mechanical energy is further transformed into electrical energy, then the turbine may be referred to as a wind generator or wind power plant.

[0005] All wind turbines use one or more airfoils in the form of a "blade" to generate lift and capture momentum from moving air that is then imparted to a rotor. Each blade is typically secured at its "root" end, and then "spans" radially "outboard" to a free, "tip" end. The front, or "leading edge," of the blade connects the forward-most points of the blade that first contact the air. The rear, or "trailing edge," of the blade is where airflow that has been separated by the leading edge rejoins after passing over the suction and pressure surfaces of the blade. A "chord line" connects the leading and trailing edges of the blade in the direction of the typical airflow across the blade. The length of a chord line is simply referred to as the "chord."

[0006] Wind turbines are typically categorized according to the vertical or horizontal axis about which the blades rotate. One so-called horizontal-axis wind generator is schematically illustrated in FIG. 1. This particular configuration for a wind turbine 1 includes a tower 2 supporting a drive train 4 with a rotor 6 that is covered by a protective enclosure referred to as a "nacelle." The blades 8 are arranged at one end of the rotor 6 outside the nacelle for driving a gearbox 10 and electrical generator 12 at the other end of the drive train 4 inside the nacelle.

[0007] Wind turbine blades are typically hollow in order to reduce their weight. Consequently, water vapor will sometimes condense inside the blade where it can wreak havoc on the balance of the rotor, freeze and crack the blade structure, cause steam explosions when rapidly heated by lightning strikes, or simply flow down the blade and into the nacelle. Wind turbine blades are therefore typically provided with a drain hole at their tip. However, since the relatively high tip speeds of modern turbines can cause air moving over the tip opening to vibrate or whistle, these blade tip drain openings are typically limited to about six millimeters in diameter. At that small size, any extraneous material left inside the blade after manufacturing, or that comes loose during normal operation, can easily clog the drain hole, especially when propelled by centrifugal force along the length of the span.

[0008] Various approaches have been suggested for draining liquids from turbine blades. For example, an English-language abstract of European Patent Publication No. 1,607,623 describes a rotor blade for a wind turbine with one or more drainage apertures having a diameter of five millimeters and a net, gauze, or felt in the hollow space adjacent to each aperture. U.S. Patent Publication No. 2007/0086897 discloses a wind turbine blade with an eight to fifteen millimeter wide bore located in the root area and within five centimeters of an enclosure member for strengthening the root and

enclosing the blade. U.S. Pat. No. 6,979,179 discloses a wind turbine blade in which a drain passage is formed of a longitudinal bore in a lightening receptor, where the longitudinal bore communicates with the inner cavity of the blade through openings in the lightening receptor.

[0009] However, these and other related wind turbine blade drainage techniques can suffer from various drawbacks. For example, the net or gauze can become clogged with fine sediment, grease, or resin particles that are flushed from inside the blade. Any relatively large bores in the blade, especially near the root, require additional strengthening with corresponding additional material and weight. Similarly, the metallic materials that are required for lightening receptors can be relatively heavy and sometimes difficult to properly align and fit with the drain hole through the surface of the blade.

BRIEF DESCRIPTION OF THE INVENTION

[0010] These and other drawbacks of such conventional approaches are addressed here by providing, in various configurations, a hollow blade for a wind turbine including a flexible drain conduit arranged inside the blade for connecting to a drain hole through a surface of the blade. Also provided is a hollow blade for a wind turbine, including a drain hole through a surface of the blade; and a baffle, arranged inside the blade and inboard of the drain hole, for impeding a flow of particulate matter to the drain hole. In another configuration, the subject matter disclosed here relates to a wind turbine, including a tower supporting a drive train with a rotor; at least one hollow blade extending radially from the rotor; a drain hole arranged in a tip portion of the blade; and a baffle, arranged inside the blade and inboard of the drain hole, for impeding a flow of particulate matter to the drain hole. The wind turbine may also include a flexible drain conduit arranged inside the blade for connecting to the drain hole; and a non-flexible drain conduit arranged inside the blade for connecting to the flexible drain conduit where the non-flexible conduit has a plurality of openings for receiving fluid from inside the blade.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Various aspects of this technology will now be described with reference to the following figures ("FIGS.") which are not necessarily drawn to scale, but use the same reference numerals to designate corresponding parts throughout each of the several views.

[0012] FIG. 1 is a schematic illustration of a conventional wind turbine.

[0013] FIG. 2 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0014] FIG. 3 is a schematic cross-sectional view taken along section line III-IV in FIG. 2.

[0015] FIG. 4 is an alternate schematic cross-sectional view taken along section line III-IV in FIG. 2.

[0016] FIG. 5 is a schematic cross-sectional illustration of a tip of a Wind turbine blade for use with the wind turbine shown in FIG. 1.

[0017] FIG. 6 is a schematic cross-sectional view taken along section line VI-VI in FIG. 5.

[0018] FIG. 7 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0019] FIG. 8 is a schematic cross-sectional view taken along section line VIII-VIII in FIG. 7.

[0020] FIG. 9 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0021] FIG. 10 is a schematic cross-sectional view taken along section line X-X in FIG. 9.

[0022] FIG. 11 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0023] FIG. 12 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0024] FIG. 13 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0025] FIG. 14 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0026] FIG. 15 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0027] FIG. 16 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0028] FIG. 17 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0029] FIG. 18 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

[0030] FIG. 19 is a schematic cross-sectional illustration of a tip of a wind turbine blade for use with the wind turbine shown in FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

[0031] FIGS. 2-19 are schematic cross-sectional illustrations of various configurations for a tip portion of a wind turbine blade 20 for use with the wind turbine 1 shown in FIG. 1. For example, the blade 8 shown in FIG. 1 may be modified to include any of the features of the various configurations of the blades 20 illustrated in FIGS. 2-19, and/or combinations of those features.

[0032] In FIG. 2, the wind turbine blade 20 is provided with a drain hole 22 for draining fluids that may accumulate inside the blade. A flexible drain conduit (or drain line) 24 is arranged inside the turbine blade 20 and connected to the drain hole 22 at one end. The flexibility of the drain conduit 24 allows it to be easily positioned and/or attached inside the blade 20. For example, the flexible drain conduit may be loosely coiled near the tip of the blade 20 and/or secured to an internal surface of the blade 20 by various techniques including fastening, laminating and/or adhesive bonding. The drain hole 24 may also be provided with a coupling, spigot, nozzle, or other feature (not shown) for receiving an end of the flexible drain conduit 24. Alternatively, the (butt) end of the flexible drain conduit 24 may be welded, glued, or otherwise adhered to the perimeter of the drain hole 22 inside the blade 20.

[0033] In the configuration shown in FIG. 2, the flexible drain conduit 24 includes one or more openings 26 for receiving fluid from inside the blade 20. These openings help to prevent particulate material from accumulating inside the flexible drain conduit 24 and/or otherwise clogging the fluid

flow path through the drain hole 22. Therefore, an internal dimension at each of the openings 26 is typically smaller than an internal dimension of the conduit. However, the openings 26 in the drain conduit 24 may be formed in a variety of sizes, configurations, and shapes including round, square, diamond-shaped, quadrilateral, slot-shaped, elliptical, octagonal, and/or a variety of other shapes. If one of the openings 26 becomes clogged by particulate matter, then the remaining openings 26 will continue to allow fluid flow through the drain hole 24.

[0034] The shape of the flexible drain conduit 24 may also be arranged in various configurations. For example, FIGS. 3 and 4 are alternate schematic cross-sectional views taken along section line III-IV in FIG. 2 showing rectangular and tubular cross-sections of the flexible drain conduit 24, respectively. However, the flexible drain conduit 24 may also be provided in a variety of other shapes and the size of the conduit 24 may change along its length. For example, the flexible conduit 24 may be larger at its free end. The free end of the flexible drain conduit 24 may also be closed, as illustrated in FIG. 3, open, or partially open as illustrated in FIG. 4. In the tubular flexible drain conduit configuration of FIG. 4, the free end of the tubular (or any other shape) flexible drain conduit 24 is provided with one or more openings 26 which may have other shapes, sizes, or configurations. As in FIG. 2, the round openings 26 in the end of the tubular flexible drain conduit 24 shown in FIG. 4 are also smaller than the outer diameter of the tubular flexible drain conduit 24 shown in FIG. 4.

[0035] Turning to FIG. 5, the turbine blade 20 may also be further provided with a non-flexible conduit 28 for connecting to the flexible drain conduit 24. For example, the non-flexible conduit 28 may be formed from fiberglass, polyvinyl chloride, wood, metal, or other relatively rigid material. In FIG. 5, the non-flexible conduit 28 includes one or more openings 26 for receiving fluid from inside the blade 20. The flexible drain conduit 24 may also be provided with openings (not shown in FIG. 5). These openings also help to prevent particulate material from accumulating inside the non-flexible drain conduit 28, flexible drain conduit 24, and/or otherwise obstructing the fluid flow path through the drain hole 22. In this configuration, and the flexible drain conduit 24 is particularly useful for connecting the end of the non-flexible conduit 28 with the drain hole 22. The flexibility of the drain conduit 24 thus accommodates for any errors in the position or alignment of the non-flexible drain conduit 28 and improves the manufacturability of the blade 20.

[0036] FIGS. 6-8 illustrate various techniques for securing the non-flexible conduit 28 to an internal surface of the blade 20. However, similar techniques may also be used for securing the flexible drain conduit 24 inside the blade 20.

[0037] FIG. 6 is a schematic cross-sectional view taken along section line VI-VI in FIG. 5 while FIG. 8 is a schematic cross-sectional view taken along section line VI-VII in FIG. 7. In FIG. 6, the rectangular non-flexible conduit 28 is adhered to an internal surface of the blade 20 by an adhesive 30. For example, the adhesive 30 may include a resin which is used to impregnate the fiberglass, carbon fiber, or other material of the body of the blade 20. In FIG. 8, the non-flexible conduit 28 is secured to the internal surface of the blade 20 by straps 32. The straps 32 may be fastened, adhered, bonded, or otherwise secured to the internal surface of the blade 20 by a variety of techniques. For example, the straps

32 may be strips of fiberglass, carbon fiber, or other material which are resin-impregnated and bonded to the internal surface of the blade **20**.

[0038] FIGS. **9** and **10** illustrate another embodiment of a hollow blade **20** for a wind turbine **1** in which the non-flexible conduit **28** is integrally-formed into an internal surface of the blade **20**. FIG. **10** is a cross-section taken along section line X-X in FIG. **9**, and illustrates a pocket space **34** formed by the non-flexible conduit **28** over the internal surface all of the blade **20**. For example, where the blade **20** is formed through a resin impregnated fiberglass transfer molding process, the non-flexible conduit **28** may be formed from a resin-impregnated fiberglass layer which is spaced from the internal surface of the blade. Once the top surface of the non-flexible conduit is formed and hardened, then openings **26** may be drilled or otherwise machined in the exterior surface of the non-flexible conduit **28**. The flexible conduit **24** then aids in aligning and connecting the non-flexible conduit **28** with the drain hole **22**. The flexible conduit **24** may also be replaced and/or supplemented with an extension of the non-flexible conduit **26** or a separate non-flexible conduit leading to the drain hole **22**.

[0039] In addition to the flexible and non-flexible drain conduits **24** and **28** discussed above, the blade **28** may also be provided with a baffle, arranged inside the blade and inboard of the drain hole **22**, for in restricting the flow of particular matter to the drain hole. For example, various wind turbine blade baffle configurations are illustrated in FIGS. **11-18**. However, other baffle configurations may also be implemented.

[0040] For example, as illustrated in FIG. **11**, the baffle **36** may include one or more first flow deflectors **38** extending from a leading edge of the blade **20** and/or one or more second flow deflectors **40** extending from the opposite, trailing edge of the blade **20**. In FIG. **11**, each of the flow deflectors **38** and **40** extends from one edge substantially across the entire chord, except for a flow space at one end. In FIG. **12**, some of the first and second flow deflectors are shorter than those illustrated in FIG. **11**, and there are third flow deflectors **42** spaced from the leading and the trailing edge of the blade **20**. In FIG. **13**, the first and second flow deflectors **38** and **40** are angled inboard from their respective leading and trailing edges, while the third flow deflector **42** extends substantially along a chord which is substantially perpendicular to the leading and trailing edges of the blade **20**. However, others of the flow deflectors **38-42** may also be aligned with the chord or angled in the inboard and/or outboard directions.

[0041] In FIG. **14**, the end portions of the first flow deflector **38** and the second flow deflector **40** are curved inboard toward a third flow deflector **42** which also extends substantially along a chord that is perpendicular to the leading and trailing edges. In FIGS. **15** and **16**, the ends of these third flow deflector **42** have been curved toward a tip of the blade so that a convex portion of the third flow deflector **42** is oriented toward the inboard direction on blade **20**. In FIG. **16**, the first and second flow deflector **38** and **40** have been curved toward a root of the blade **20**, so that a convex portion of the flow deflectors **38** and **40** is oriented toward a tip portion of the blade. In FIG. **17**, the radius of curvature for each of the first, second, and third flow deflectors **38**, **40**, and **42** has been increased and the third flow deflector **42** has been oriented with a convex portion facing the inboard direction of the blade **20**. In FIG. **18**, each of the flow deflectors **42** is provided with

a generally cylindrical shape. However, a variety of other shapes may also be used including triangular, rectangular, pentagonal, et cetera.

[0042] FIG. **19** illustrates another embodiment of a wind turbine blade **20** which includes the baffle **36** configuration illustrated in FIG. **11** and the flexible conduit **24** and nonflexible drain conduit **28** configuration illustrated in FIG. **7**. Combinations of other baffle and/or conduit configurations, including ones not explicitly shown in these Figures, are also within the scope of this disclosure.

[0043] It should be emphasized that the embodiments described above, and particularly any "preferred" embodiments, are merely examples of various implementations that have been set forth here to provide a clear understanding of various aspects of this technology. These embodiments may be modified without substantially departing from scope of protection defined solely by the proper construction of the following claims.

What is claimed is:

1. A hollow blade for a wind turbine comprising a flexible drain conduit arranged inside the blade for connecting to a drain hole through a surface of the blade.

2. The blade recited in claim **1**, wherein the flexible drain conduit includes a plurality of openings for receiving fluid from inside the blade.

3. The blade recited in claim **2**, wherein an internal dimension of each of the openings is smaller than an internal dimension of the conduit.

4. The blade recited in claim **3**, wherein the conduit is tubular.

5. The blade recited in claim **3**, wherein a shape of the openings is selected from the group consisting of round, quadrilateral, square, slotted, and octagonal.

6. The blade recited in claim **3**, wherein the conduit is secured to an internal surface of the blade.

7. The blade recited in claim **6** wherein the flexible conduit is laminated to an internal surface of the blade.

8. The blade recited in claim **6**, wherein the flexible conduit is adhesively bonded to an internal surface of the blade.

9. The blade recited in claim **1**, further comprising a non-flexible drain conduit arranged inside the blade for connecting to the flexible drain conduit, the non-flexible conduit having a plurality of openings for receiving fluid from inside the blade.

10. The blade recited in claim **9** wherein the non-flexible drain conduit is laminated to an internal surface of the blade.

11. The blade recited in claim **9** wherein the non-flexible conduit is adhered to an internal surface of the blade.

12. The blade recited in claim **9** wherein the non-flexible conduit is integrally-formed with an internal surface of the blade.

13. A hollow blade for a wind turbine, comprising a drain hole through a surface of the blade; and a baffle, arranged inside the blade and inboard of the drain hole, for impeding a flow of particulate matter to the drain hole.

14. The wind turbine blade recited in claim **13**, wherein the baffle comprises

- a first deflector extending from a leading edge of the blade; and
- a second deflector extending from a trailing edge of the blade.

15. The wind turbine blade recited in claim **14**, wherein the baffle further comprises a third deflector spaced apart from the leading and trailing edges of the blade.

16. The wind turbine blade recited in claim **15**, wherein at least a portion of at least one of the deflectors curves toward a root of the blade.

17. The wind turbine blade recited in claim **13**, further comprising:

a flexible drain conduit arranged inside the blade for connecting to the drain hole; and

a non-flexible drain conduit arranged inside the blade for connecting to the flexible drain conduit, the non-flexible conduit having a plurality of openings for receiving fluid from inside the blade.

18. A wind turbine, comprising:

a tower supporting a drive train with a rotor;

at least one hollow blade extending radially from the rotor;

a drain hole arranged in a tip portion of the blade; and

a baffle, arranged inside the blade and inboard of the drain hole, for impeding a flow of particulate matter to the drain hole.

19. The wind turbine recited in claim **18**, wherein the baffle comprises

a first deflector extending from a leading edge of the blade; a second deflector extending from a trailing edge of the blade; and

a third deflector spaced apart from the leading and trailing edges of the blade.

20. The wind turbine recited in claim **18**, further comprising

a flexible drain conduit arranged inside the blade for connecting to the drain hole; and

a non-flexible drain conduit arranged inside the blade for connecting to the flexible drain conduit, the non-flexible conduit having a plurality of openings for receiving fluid from inside the blade.

* * * * *