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Hotto

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(54) **ROTATABLE BLADE APPARATUS WITH INDIVIDUALLY ADJUSTABLE BLADES**

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(52) **U.S. Cl.**
USPC **416/42**; 416/61

(58) **Field of Classification Search**
USPC .... 416/42, 61, 87, 88, 89, 98, 112, 114, 416/132 R, 113, 142, 1, 131
See application file for complete search history.

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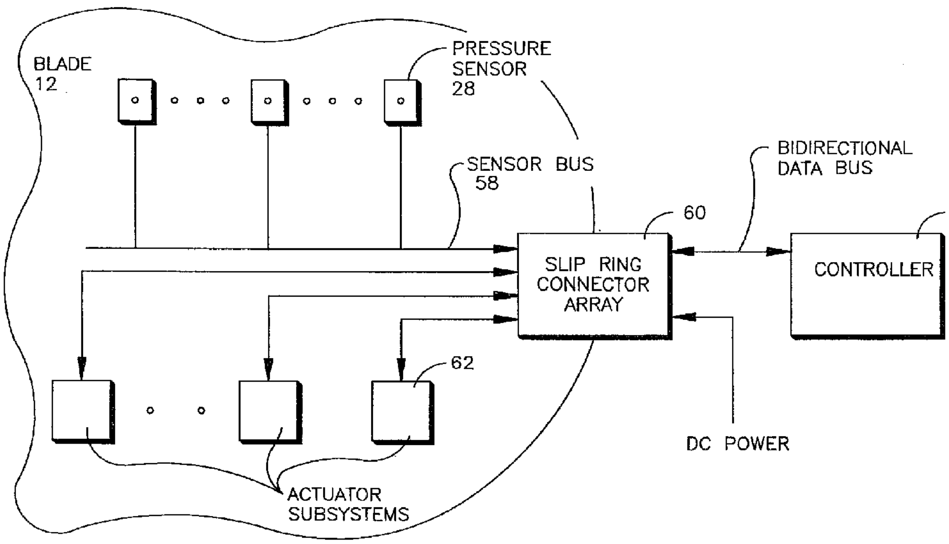
(57) **ABSTRACT**

The lengths and/or chords and/or pitches of wind turbine or propeller blades are individually established, so that a first blade can have a length/chord/pitch that is different at a given time to the length/chord/pitch of a second blade to optimize performance and/or to equalize stresses on the system.

36 Claims, 9 Drawing Sheets



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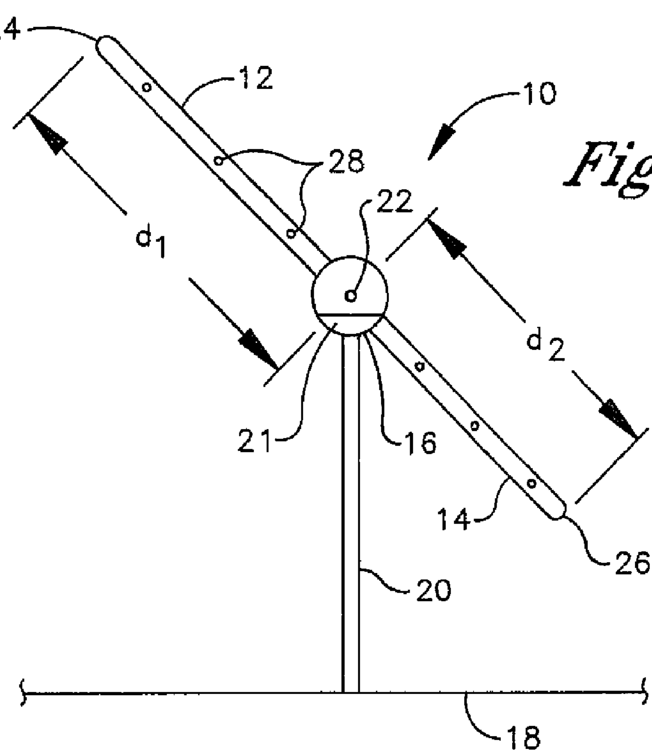


Fig. 1

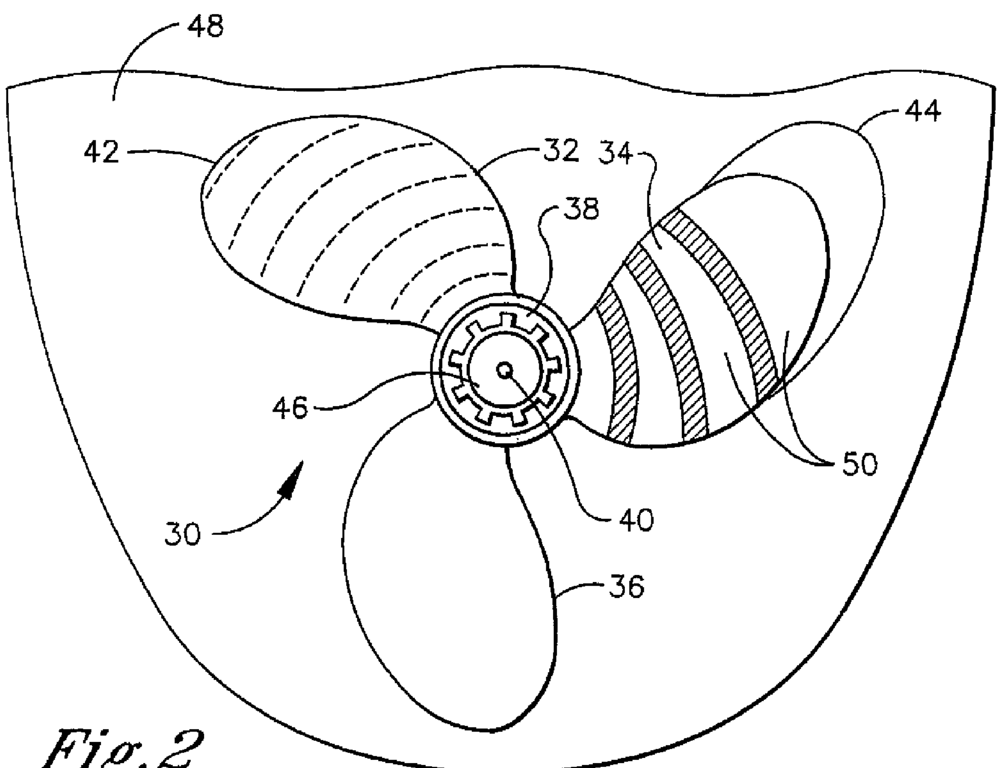


Fig. 2

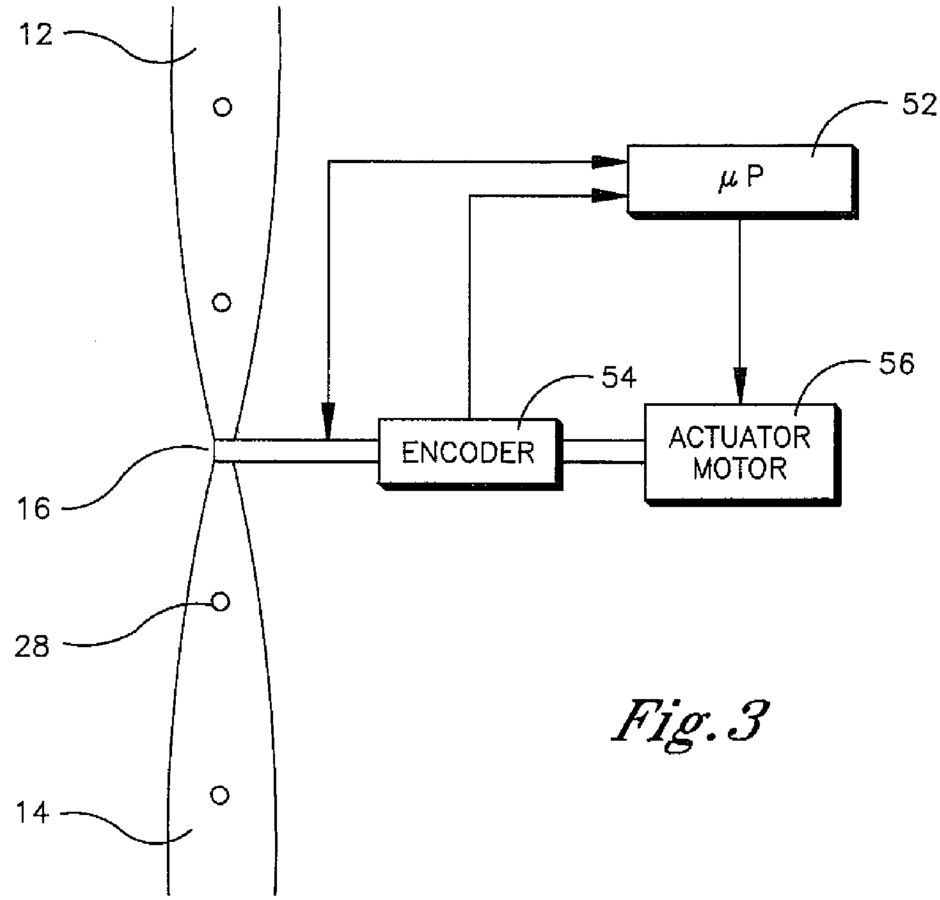


Fig. 3

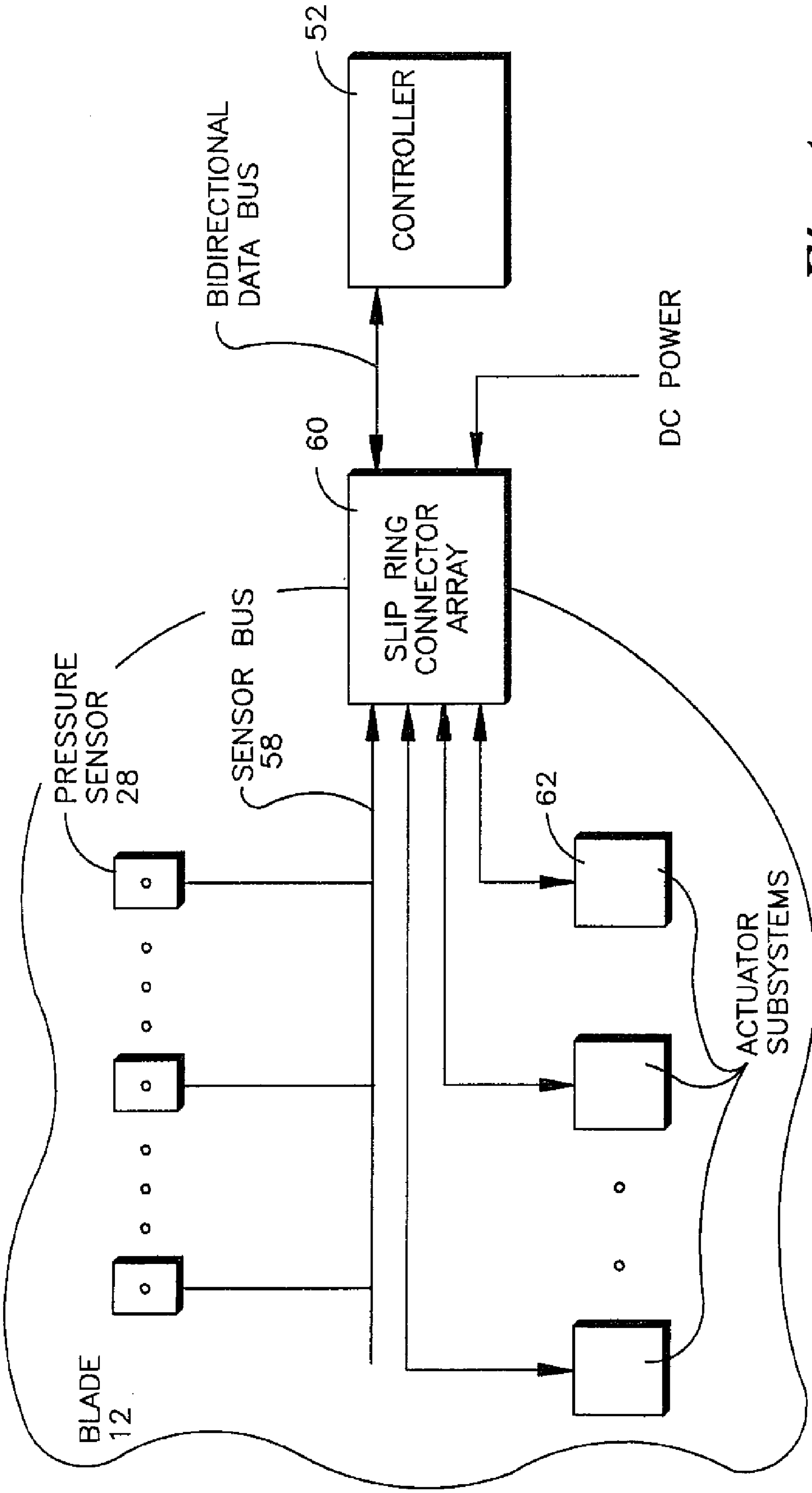
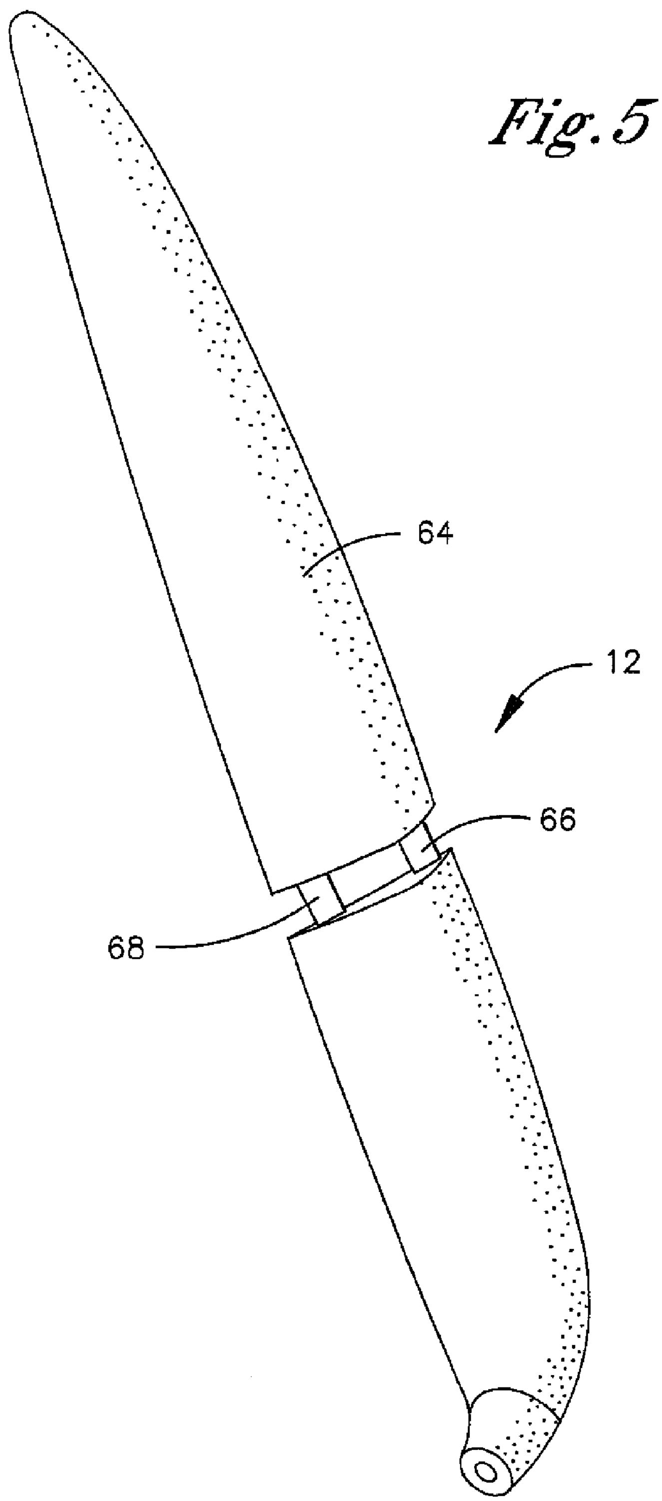

52
CONTROLLER
BIDIRECTIONAL
DATA BUS
60
DC POWER
SLIP RING
CONNECTOR
ARRAY
SENSOR BUS
PRESSURE
SENSOR
28
SENSOR
58
62
ACTUATOR
SUBSYSTEMS
BLADE
12

Fig. 4

Fig. 5



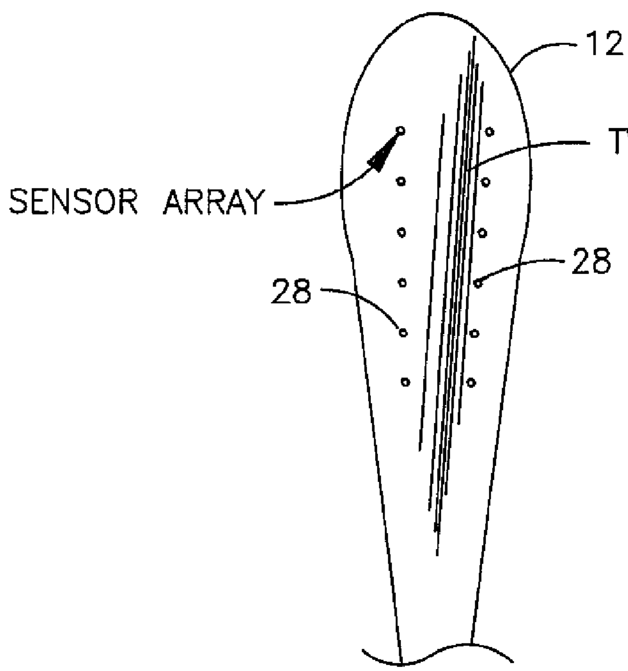


Fig. 6

BLADE WITH SENSOR ARRAY

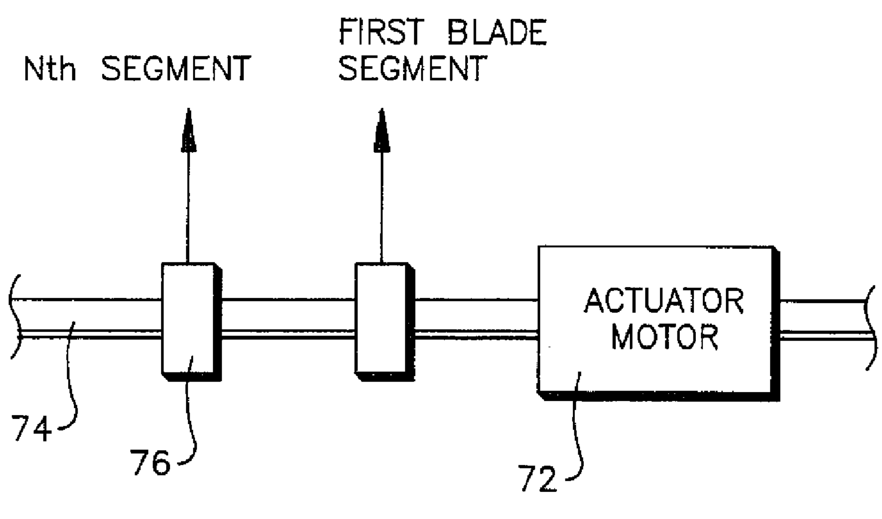


Fig. 7

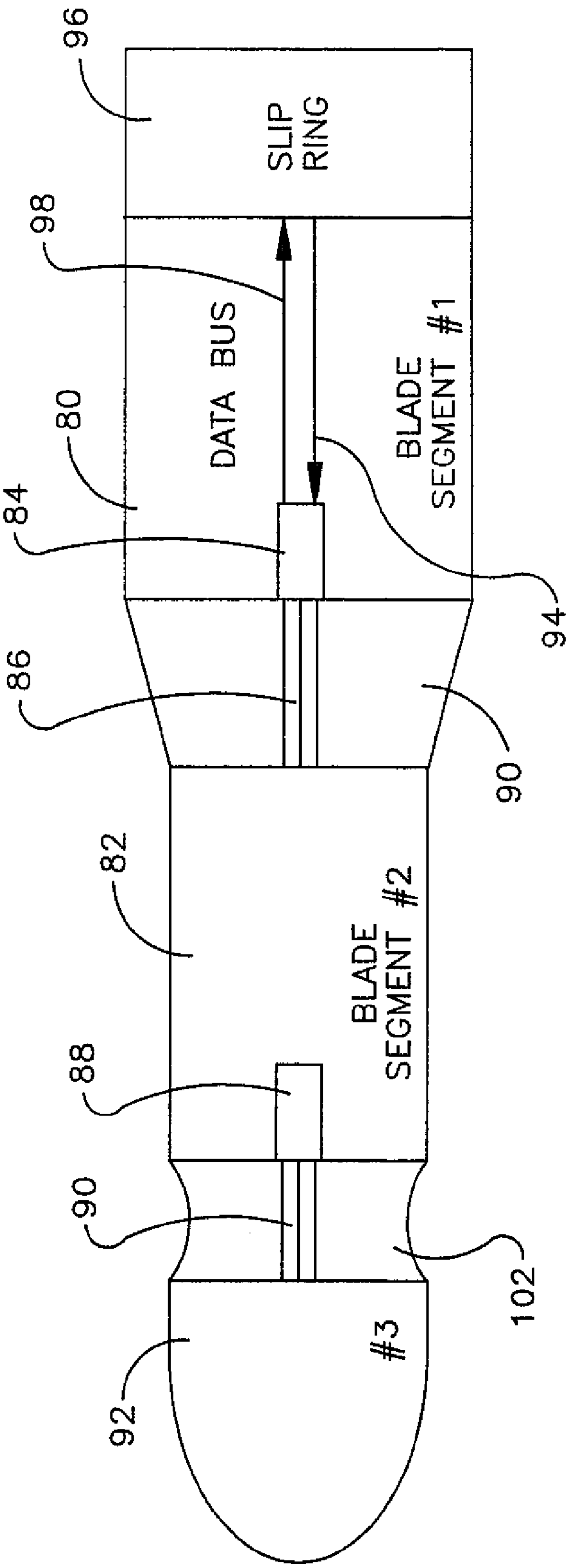

96
SLIP RING
98
DATA BUS
BLADE SEGMENT #1
80
84
94
86
90
82
BLADE SEGMENT #2
88
90
102
#3
92

Fig. 8

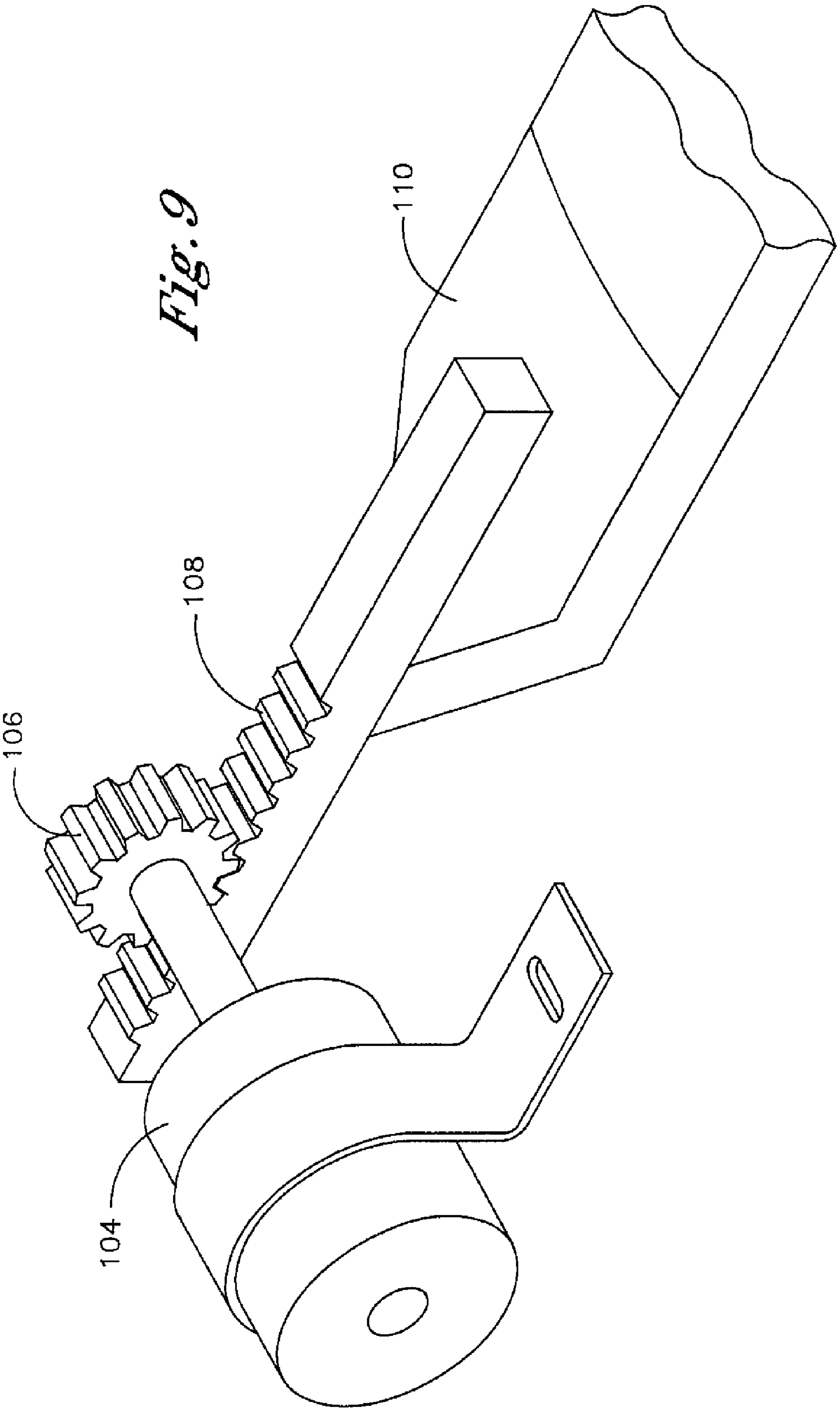


Fig. 9

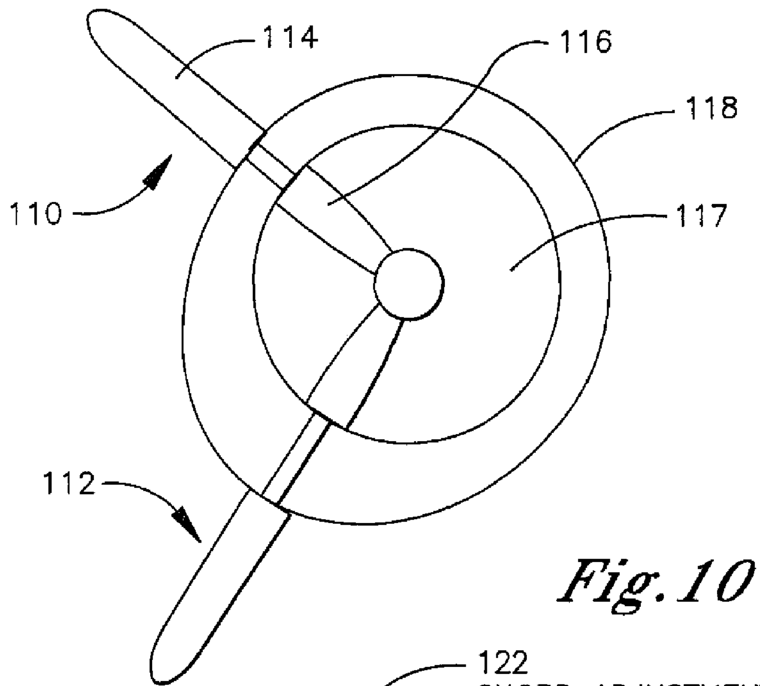


Fig. 10

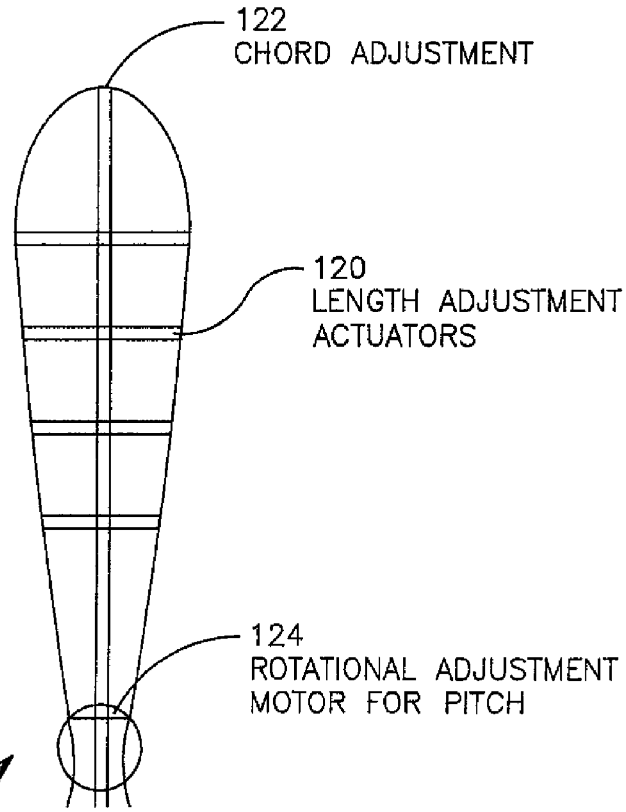


Fig. 11

BLADE ILLUSTRATING ROTATIONAL, LENGTH AND CHORD ADJUSTMENT POINTS

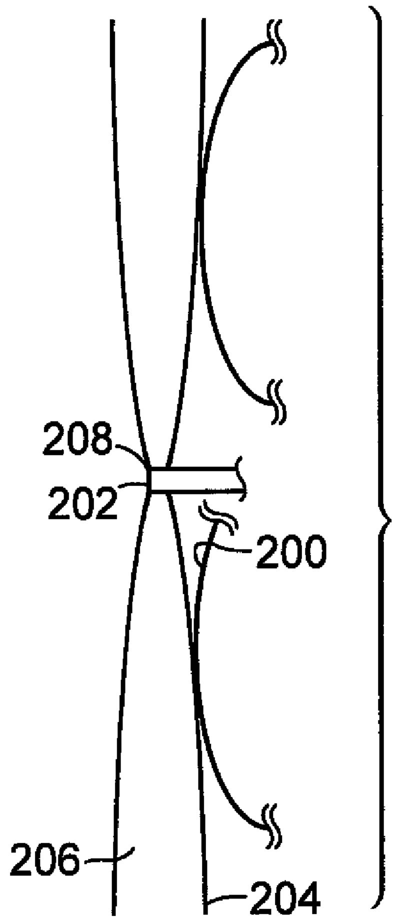


Fig. 12

ROTATABLE BLADE APPARATUS WITH INDIVIDUALLY ADJUSTABLE BLADES

FIELD OF THE INVENTION

The present invention relates generally to rotatable blades for wind turbines, and more particularly to blade assemblies for wind turbines and propellers in which the parameters of chord, length, and pitch can be individually adjusted for each blade.

BACKGROUND OF THE INVENTION

Variable pitch propellers have been provided in which the pitch of all blades can be simultaneously changed as appropriate to, e.g., reduce cavitation depending on the speed of rotation of the blades. An example of such a system is disclosed in U.S. Pat. No. 5,733,156, incorporated herein by reference.

In the wind turbine art, U.S. Pat. No. 6,972,498, incorporated herein by reference, provides a wind turbine blade assembly in which the lengths of the blades may be simultaneously changed to account for changing wind speed, imbalances, and control system loads. As understood herein, it would be desirable, for each blade individually, to establish the length and/or chord and/or pitch of the blade.

SUMMARY OF THE INVENTION

A wind turbine blade assembly or a propeller blade assembly has at least first and second blades coupled to a rotor defining an axis of rotation. The tip of the first blade is positioned a first distance from the axis of rotation at a first time, while the tip of the second blade is positioned a second distance from the axis of rotation at the first time, with the first and second distances not being equal.

In some implementations, at least one blade has respective plural parts telescoping relative to each other along the length of the blade. Each blade defines a respective length, and the lengths are different from each other at least at the first time. An actuator can telescope one part of a blade relative to another part of the blade. In some aspects plural actuators can be provided to telescope plural parts. The actuator may be supported on the blade and may receive power through a slip ring. Or, the blades can move longitudinally as they ride against a cam surface. The lengths of the blades may be established based on respective pressure signals representative of fluid pressure on the blades, and/or based on respective angular positions of the blades.

In another aspect, a wind turbine blade assembly or a propeller blade assembly has at least first and second blades coupled to a rotor defining an axis of rotation. The first blade defines a first chord at a first time, the second blade defines a second chord at the first time, and the first and second chords are not equal.

In still another aspect, a wind turbine blade assembly or a propeller blade assembly has at least first and second blades coupled to a rotor defining an axis of rotation. The first blade defines a first pitch at a first time, the second blade defines a second pitch at the first time, and the first and second pitches are not equal.

In another aspect, a method for operating a wind turbine includes establishing a first value for a first parameter of a first blade at a first time, and establishing a second value for the first parameter of a second blade at the first time. According to this aspect, when the blades are disposed in wind, they rotate to cause the wind turbine to produce electrical power.

In another aspect, a wind turbine has an upright support, a rotor coupled to the support, and at least first and second blades coupled to the rotor to cause it to rotate when wind passes the blades. Each blade has first and second configurations. The first configuration of the first blade is identical to the first configuration of the second blade and the second configuration of the first blade is identical to the second configuration of the second blade. As set forth further below, the first blade assumes the first configuration at a first time and the second blade assumes the second configuration at the first time.

The details of the present invention, both as to its structure and operation, can best be understood in reference to the accompanying drawings, in which like reference numerals refer to like parts, and in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of a wind turbine in accordance with present principles;

FIG. **2** is a schematic view of a vessel propeller in accordance with present principles;

FIG. **3** is a block diagram showing control elements in accordance with one embodiment;

FIG. **4** is a block diagram showing control elements in accordance with another embodiment;

FIG. **5** is a perspective view of a blade in the extended configuration;

FIG. **6** is a plan view of a blade, showing one preferred non-limiting pressure sensor disposition on the blade;

FIG. **7** is a block diagram of one actuator embodiment, in which a single motor moves plural blade segments;

FIG. **8** is a block diagram of one actuator embodiment, in which respective motors move respective blade segments;

FIG. **9** is a perspective view of a non-limiting actuator;

FIG. **10** is an elevational view of an alternative cam-based system;

FIG. **11** is a plan view showing that the present principles, in addition to being applied to change the length of a blade, may also be applied in changing the chord and/or pitch of the blade; and

FIG. **12** is a view of a cam-based system for adjusting blade pitch, with portions of the caroming surface broken away for clarity.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to FIG. **1**, a wind turbine blade assembly is shown, generally designated **10**, which includes first and second blades **12**, **14** that are coupled to a rotor **16**, it being understood that present principles apply to two, three, or more blades. The rotor **16** is rotatably supported above the surface **18** of the earth by an upright support **20**, which holds the blades **12**, **14** in a vertical plane above the earth's surface as shown. In accordance with principles known in the art, wind flowing past the blades causes them to turn to thereby cause an associated generator, shown schematically at **21**, to generate electric power.

The rotor **16** defines an axis **22** of rotation, and in accordance with disclosure below at least the first blade **12** and preferably both blades **12**, **14** can be moved between a long configuration and a short configuration, as well as to intermediate configurations therebetween, and the blade **12** is not constrained to be in the same configuration as the second blade **14**. Thus, to illustrate, FIG. **1** shows that the blade **12** has a blade tip **24** that can be configured to be a relatively long distance d_1 from the axis **22** of rotation. Simultaneously, the tip **26** of the second blade **14** can be configured to be a second distance d_2 from the axis **22** of rotation, with the distances d_1, d_2 being unequal when present principles are applied. For purposes that will shortly become clear, one or more pressure sensors **28** can be disposed on one or both blades **12**, **14**. Alternatively, wind speed sensors on the blades **12**, **14** or elsewhere can be used.

As set forth further below, the principles outlined herein in terms of variable length also apply to variable pitches and chords, so that in addition to or in lieu of different lengths, the pitches and/or chords of the respective blades **12**, **14** may be different from each other at the same point in time. It is to be further understood that the assembly **10** may also, at other times, embody conventional operating principles wherein the blades **12**, **14** are identically configured in length, chord, and pitch.

FIG. **2** shows that the present principles can also be applied to a propeller blade assembly **30** that has at least first and second blades **32**, **34**, and potentially additional blades **36**, coupled to a rotatable rotor **38** that defines an axis **40** of rotation. The tip **42** of the first blade **32** can be configured to be a first distance from the axis **40** of rotation and simultaneously the tip **44** of the second blade **34** can be configured to be a further distance from the axis **40** of rotation than is the tip **42** of the first blade **32**. A shaft **46** of a waterborne vessel **48** can hold the blades **32**, **34**, **36** in a vertical plane (at neutral vessel pitch) as shown.

As set forth further below, the principles outlined herein in terms of variable length also apply to variable pitches and chords, so that in addition to or in lieu of different lengths, the pitches and/or chords of the respective blades **32**, **34**, **36** may be different from each other at the same point in time. It is to be further understood that the assembly **30** may also, at other times, embody conventional operating principles wherein the blades are identically configured in length, chord, and pitch.

For illustration purposes the disclosure below focuses on a wind turbine application, it being understood that the principles embodied therein may be applied to the propeller assembly **30**, in which, e.g., the blade **34** has plural portions **50** that can telescope or otherwise move in the axial dimension of the blade **34** relative to each other (and, as stated above, potentially can also move relative to each other in the chord dimension).

FIGS. **3** and **4** show various system configurations for controlling the lengths (and/or chords and/or pitches) of the blade **12**, and preferably also of the blade **14**. A controller or processor **52** can receive input from the pressure sensors **28** on the blades and/or from an encoder **54** that outputs a signal representing the angular position of the rotor **16**. The controller or processor **52** controls an actuator with motor **56** to establish the length (and/or chord and/or pitch) of the blades. The motor may be a stepper motor or other appropriate motor, and as set forth further below may be located within the blade **12** or outside the blade **12**. From time to time herein, "actuator" may be used to refer to both a motor and the linkages that couple the motor to the movable blade portions, and to just the linkages themselves.

In some implementations, the length of each blade **12**, **14** is established based on its angular position. Thus, in non-limiting embodiments a blade can assume the long configuration when at the top dead center position (pointing straight up vertically from the rotor) and the short configuration in the opposite position, and can have intermediate lengths when moving therebetween. In terms of the two blade application of FIG. **1**, the first blade **12** is in the long configuration at the same time the second blade **14** is in the short configuration.

In addition to or in lieu of using angular position to establish the lengths of the blades, the lengths of the blades can depend on respective pressure signals from the sensors **28**, which are representative of fluid pressure on the blades. In this embodiment, the controller or processor **52** establishes blade length both to optimize performance while minimizing load imbalances on the rotor by, e.g., establishing blade lengths that result in equal pressures on both blades **12**, **14** while providing optimum length based on wind speed, to ensure that the blades rotate as fast as feasible while remaining below angular velocity limits.

FIG. **4** shows further details of the controls of one illustrative non-limiting embodiment. As shown, the pressure sensors **28** on the blade **12** are electrically connected to a sensor bus **58** within the blade. The bus **58** is connected to the controller or processor **52** through a slip ring connector array **60**, which, in accordance with slip ring principles known in the art, permits relative rotational movement between the blade **12** and the controller **52** while maintaining electrical connectivity between them. A bidirectional data bus **59** can be provided between the slip ring connector array **60** and the controller **52** to permit the controller **52** to receive pressure signals and to output control signals to the actuators discussed below.

More particularly, electrical power, as well as control signals from the controller **52**, is also provided through the slip ring to one or more actuator subsystems **62**, each of which can include a respective motor and a respective linkage that connects the actuator to a respective blade portion to move the blade portion. Alternatively, a single motor may be provided within the blade **12** and linked through gears or other linkages as set forth further below to move each of plural individual actuator subsystems that, in such a circumstance, would include only linkages to respective blade portions.

FIGS. **5-8** show further details of non-limiting implementations of the present blade. As shown in FIG. **5** and using the first blade **12** as an example, the blade can have plural portions **64** that move relative to each other in the length dimension of the blade, it being understood that similar principles apply to expand and contract the blade in the chord dimension. As shown at **66**, an actuator linkage can be coupled to two adjacent substantially rigid hollow blade portions **64** to move the blade portions relative to each other. In the embodiment shown in FIG. **5**, the blade portions abut each other along their transverse edges in the short configuration, with facing transverse edges of adjacent blade portions being distanced from each other in the long configuration and, if desired, a flexible membrane **68** (portions of which are removed in FIG. **5** to show the linkage **66**) can enclose the space between the portions.

FIG. **6** shows that the pressure sensors **28** can be arranged in two lines along the length of the blade **12**, with one line of sensors being disposed on a first side of the "twist" **70**, or blade surface aspect change line, and with a second line of sensors being disposed on the opposite side of the twist as shown.

FIG. **7** shows that in some implementations, a single motor **72** can be provided in the blade **12** to turn a lead screw **74** or equivalent structure, with plural nuts **76** or equivalent linking structure riding on the lead screw **74** and connected to respective blade portions to move the blade portions.

In contrast, FIG. **8** shows that each of plural movable blade portions **80**, **82** can house its own respective motor and linkage that connects the blade portion to the distally successive blade portion. Thus, the blade portion **80** has a motor **84** with linkage **86** that extends between the blade portions **80**, **82** to move the medial blade portion **82** outward from the proximal blade portion **80**. Likewise, the medial blade portion **82** supports a motor **88** with associated linkage **90** extending to a distal blade portion **92**, to move the distal blade portion **92** outward from the medial blade portion **82**. Additional blade portions with motors and linkages may be provided. As mentioned earlier, power can be supplied to the motors through a power line **94** and slip ring assembly **96**, and data and control signals can be exchanged through the slip ring assembly **96** and data bus **98** within the blade **12**.

As also shown in FIG. **8**, instead of using a flexible membrane **68** (FIG. **5**) between adjacent blade portions, each adjacent blade portion can, in the short configuration, be partially nested within the immediately proximal portion. Accordingly, in the short configuration the sub-portion **100** (with parts broken away in FIG. **8** to expose the linkage **86**) of the medial blade portion **82** is nested within the proximal blade portion **80**, whereas in the long configuration shown the sub-portion **100** is telescoped distally beyond the proximal portion **80**. All portions of the blade in this embodiment can be substantially rigid. Similarly, a sub-portion **102** (part of which is removed in FIG. **8** to expose the linkage **90**) of the distal blade portion **92** is nested within the medial portion **82** in the short configuration and is telescoped distally beyond the medial portion **82** in the long configuration.

FIG. **9** shows an illustrative non-limiting example of one of the motor actuators shown in FIG. **8**. A motor **104** such as DC motor is affixed to one blade portion (not shown) to turn a pinion gear **106**, which translates rotational motion to longitudinal (with respect to the blade) translational movement of a rack **108**. The rack **108** is affixed to the successive blade portion **110**, to move it toward and away the blade portion that supports the motor **104**.

When the length of the blade is sought to be changed only based on angular position, FIG. **10** shows that instead of using motor actuators, each blade **110**, **112** of a wind turbine or propeller can have proximal and distal portions **114**, **116** that telescope relative to each other as the blade, which is attached to a rotor **117**, rotates past a cam **118** on which a part of the blade between the portions **114**, **116** ride. The contour of the surface of the cam is established to establish the desired length-to-angular position relationship. Other mechanisms, including gearing, can be employed.

Other mechanisms for moving a blade are disclosed in U.S. Pat. No. 6,972,498, modified as appropriate to permit the individual establishment of the length of each blade, independently of other blades, as described above.

FIG. **11** schematically illustrates that individual blade configuration may be independently established not just in the length dimension by length adjustment actuators **120** but alternatively or additionally in the chord dimension by chord adjustment actuators **122** and/or in the pitch dimension by a pitch adjustment actuator **124**, which rotates the blade about its hub using, as non-limiting examples, the mechanisms described in U.S. Pat. No. 5,733,156. In any case, it is to be appreciated that the length and/or chord and/or pitch of each blade of the present wind turbine or propeller can be established independently of the length and/or chord and/or pitch of one or more other blades as necessary to equalize fluid pressure on the blades, to optimize performance by, e.g., attaining an optimum speed of rotation, and in the case of propellers to lower the rudder profile as necessary to avoid cavitation or even to assist in turning the vessel.

FIG. **12** shows a view similar to that of FIG. **3** with the addition of a camming surface **200**, the contoured surface of which faces outwardly relative to a rotor **202** to bear against an inner surface **204** of a blade **206**, which is rotatably coupled at its root **208** to the rotor **202** to rotate as the blade rides against the surface **200**.

While the particular ROTATABLE BLADE APPARATUS WITH INDIVIDUALLY ADJUSTABLE BLADES is herein shown and described in detail, it is to be understood that the subject matter which is encompassed by the present invention is limited only by the claims. For instance, the principles described herein could be applied to airplane propellers and to helicopter rotor blades.

What is claimed is:

1. A wind turbine blade assembly comprising:

at least first and second blades coupled to a rotatable rotor defining an axis of rotation, the first blade having a first blade tip being a first distance from the axis of rotation at a first time, the second blade having a second blade tip being a second distance from the axis of rotation at the first time, the first and second distances not being equal, wherein the distances are based on respective angular positions of the blades relative to the rotor independently of forces on the blades, the first distance being longer than the second distance, the first blade tip being at top dead center relative to the rotor at the first time, wherein the first blade has at least one of: its pitch, or its chord, being different from that of the second blade at the first time.

2. The assembly of claim **1**, wherein at least one blade has respective plural parts telescoping relative to each other along the length of the blade, each blade defining a respective length, the lengths being different from each other at least at the first time.

3. The assembly of claim **2**, comprising at least one actuator telescoping at least one part of a blade relative to another part of the blade.

4. A wind turbine blade assembly comprising:

at least first and second blades coupled to a rotatable rotor defining an axis of rotation, the first blade having a first blade tip being a first distance from the axis of rotation at a first time, the second blade having a second blade tip being a second distance from the axis of rotation at the first time, the first and second distances not being equal, wherein the distances are based on respective angular positions of the blades relative to the rotor independently of forces on the blades, the first distance being longer than the second distance, wherein at least one blade has respective plural parts telescoping relative to each other along the length of the blade, each blade defining a respective length, the lengths being different from each other at least at the first time, at least one actuator telescoping at least one part of a blade relative to another part of the blade, wherein at least one blade has at least three parts and at least two actuators telescoping respective parts.

5. The assembly of claim **3**, comprising a movable actuator.

6. The assembly of claim **5**, wherein the actuator is supported on the blade and receives power through a slip ring.

7. The assembly of claim **1**, wherein the blades move as they ride against a cam surface.

8. The assembly of claim **1**, comprising an upright support holding the blades in a vertical plane above the earth's surface.

9. A wind turbine blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade defining a first pitch at a first time, the second blade defining a second pitch at the first time, the first and second pitches not being equal, wherein the pitches are based on respective angular positions of the blades with respect to the rotor, a motor being coupled to at least one blade to establish the pitch of the blade.

10. The assembly of claim **9**, comprising an upright support holding the blades in a vertical plane above the earth's surface.

11. A wind turbine blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade defining a first pitch at a first time, the second blade defining a second pitch at the first time, the first and second pitches not being equal, wherein the pitches are based on respective angular positions of the blades with respect to the rotor, wherein the first blade has at least one of: its chord, or its length, being different from that of the second blade at the first time.

12. A wind turbine blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade defining a first pitch at a first time, the second blade defining a second pitch at the first time, the first and second pitches not being equal, wherein the pitches are based on respective angular positions of the blades with respect to the rotor, wherein the pitches are established based on respective pressure signals representative of fluid pressure on the blades.

13. A propeller blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade having a first blade tip being a first distance from the axis of rotation at a first time, the second blade having a second blade tip being a second distance from the axis of rotation at the first time, the first and second distances not being equal, the first distance being longer than the second distance, the first blade tip being at top dead center relative to the rotor at the first time, wherein at least one blade has respective plural parts telescoping relative to each other along the length of the blade, each blade defining a respective length, the lengths being different from each other at least at the first time, comprising at least one actuator telescoping at least one part of a blade relative to another part of the blade, comprising a motor moving at least a portion of an actuator.

14. The assembly of claim **13**, wherein at least one blade has at least three parts and at least two actuators telescoping respective parts.

15. The assembly of claim **13**, wherein the motor is supported on the blade and receives power through a slip ring.

16. The assembly of claim **13**, wherein the blades move as they ride against a cam surface.

17. The assembly of claim **13**, comprising a waterborne vessel shaft holding the blades in a vertical plane.

18. The assembly of claim **13**, wherein the first blade has at least one of: its pitch, or its chord, being different from that of the second blade at the first time.

19. The assembly of claim **13**, wherein the lengths are established based on respective pressure signals representative of fluid pressure on the blades.

20. The assembly of claim **13**, wherein the distances are based on respective angular positions of the blades.

21. A propeller blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade defining a first chord at a first time, the second blade defining a second chord at the first time, the first and second chords not being equal, a waterborne vessel shaft holding the blades in a vertical plane.

22. The assembly of claim **21**, wherein at least one blade has respective plural parts telescoping relative to each other along the chord dimension of the blade.

23. The assembly of claim **22**, comprising at least one actuator telescoping at least one part of a blade relative to another part of the blade.

24. The assembly of claim **23**, wherein at least one blade has at least three parts and at least two actuators telescoping respective parts.

25. The assembly of claim **23**, comprising a movable actuator.

26. The assembly of claim **25**, wherein the actuator is supported on the blade and receives power through a slip ring.

27. The assembly of claim **21**, wherein the blades move as they ride against a cam surface.

28. The assembly of claim **21**, wherein the first blade has at least one of: its pitch, or its length, being different from that of the second blade at the first time.

29. A propeller blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade defining a first chord at a first time, the second blade defining a second chord at the first time, the first and second chords not being equal, wherein the chords are established based on respective pressure signals representative of fluid pressure on the blades.

30. The assembly of claim **21**, wherein the chords are based on respective angular positions of the blades.

31. A propeller blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade defining a first pitch at a first time, the second blade defining a second pitch at the first time, the first and second pitches not being equal, no other blade defining the first pitch at the first time other than the first blade, a waterborne vessel shaft holding the blades in a vertical plane.

32. The assembly of claim **31**, comprising an actuator coupled to at least one blade to establish the pitch of the blade.

33. The assembly of claim **31**, wherein the blades move as they ride against a cam surface.

34. A propeller blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade defining a first pitch at a first time, the second blade defining a second pitch at the first time, the first and second pitches not being equal, no other blade defining the first pitch at the first time other than the first blade, wherein the first blade has at least one of: its chord, or its length, being different from that of the second blade at the first time.

35. A propeller blade assembly comprising:

at least first and second blades coupled to a rotor defining an axis of rotation, the first blade defining a first pitch at a first time, the second blade defining a second pitch at the first time, the first and second pitches not being equal, no other blade defining the first pitch at the first time other than the first blade, wherein the pitches are established based on respective pressure signals representative of fluid pressure on the blades.

36. The assembly of claim **31**, wherein the pitches are based on respective angular positions of the blades with respect to the rotor.

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