

SYSTEM FOR WIND TURBINE BLADE ACTUATION

BACKGROUND

[0001] The invention generally relates to wind turbines and, more particularly, to a system for actuating wind turbine blades in the wind turbine.

[0002] Conventional wind turbine blades are controlled using various methods to enhance the structural and aerodynamic performance of the wind turbine blades. One such method may include pitch control of complete wind turbine blade to reduce structural loads and aerodynamic loads at a root of the wind turbine blade. However, the aforementioned method is limited to performing pitch control for the complete wind turbine blade and is unable to perform one or more functions associated with reducing the structural loads and the aerodynamic loads of the wind turbine blade such as local morphing of the shape of the wind turbine blade, flapping of trailing edge, and activating synthetic jets. The one or more functions help in reducing the structural loads and the aerodynamic loads in the wind turbine blade, which increases the efficiency of the wind turbine. However, conventional actuation mechanisms such as electrical drives, hydraulic, and pneumatic drives may not be feasible to perform the one or more functions of the wind turbine blades as the conventional actuation mechanisms are generally heavy and require additional power supply accessories which may create undesirable complexities and mass/weight penalties on the wind turbine.

[0003] Hence, there is a need for an improved system and method for actuating the wind turbine blades.

BRIEF DESCRIPTION

[0004] Briefly, in accordance with one embodiment, a wind turbine blade is provided. The wind turbine blade includes an active element disposed in a section of the wind turbine blade and configured to deform in a first direction from an initial position to generate torque upon activation. The wind turbine blade also includes a restoring system operatively coupled to a corresponding active element and configured to restore the corresponding active element to the initial position upon deactivation of the corresponding active element. The wind turbine blade further includes a heating unit operatively coupled to an active element and configured to selectively activate one or more corresponding active elements.

[0005] In another embodiment, a wind turbine blade including one or more torque generators is provided. The one or more torque generators include active elements formed of a shape memory alloy and disposed in a section of the wind turbine blade. The one or more torque generators are configured to deform in a first direction from an initial position to generate torque upon activation. The wind turbine blade also includes one or more torque transmitters operatively coupled to corresponding torque generators and configured to transmit the torque generated by the corresponding torque generators for performing one or more functions associated with controlling loads of the wind turbine blade in the corresponding sections of the wind turbine blade. The wind turbine blade further includes at least one restoring system operatively coupled to the corresponding torque generators and configured to restore the corresponding torque generator to the initial position upon deactivation of the corresponding torque generator. The wind turbine blade also includes a heating unit operatively coupled to one or more torque generators and configured to selectively activate one or more corresponding torque generators.

DRAWINGS

[0006] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0007] FIG. 1 is a schematic representation of a section of a wind turbine blade including an actuation system in accordance with an embodiment of the invention.

[0008] FIG. 2 is a schematic representation of a section of a wind turbine blade including another embodiment of the actuation system in accordance with an embodiment of the invention.

[0009] FIG. 3 is a schematic representation of a section of a wind turbine blade including an alternative embodiment of the actuation system of FIG. 2 in accordance with an embodiment of the invention.

[0010] FIG. 4 is a schematic representation of the flapping of the trailing edge performed by the actuation system of FIGs. 1-3 for controlling the loads in the section of the wind turbine blade in accordance with an embodiment of the invention.

[0011] FIG. 5 is a schematic representation of altering the shape of the trailing edge using the actuation systems of FIGs. 1-3 for controlling the loads in the section of the wind turbine blade in accordance with an embodiment of the invention.

[0012] FIG. 6 is a schematic representation of the flapping of the tip of the wind turbine blade performed by the actuation system of FIG. 1-3 for controlling loads in the section of the wind turbine blade in accordance with an embodiment of the invention.

[0013] FIG. 7 is a schematic representation of actuating micro-flaps in the section of the wind turbine blade performed by the actuation system of FIGs. 1-3 for controlling loads in the section of the wind turbine blade in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0014] Embodiments of the present invention include a system for actuating wind turbine blades. In at least some embodiments, the inventive apparatus may advantageously enable actuation of a section of the wind turbine blade. The actuation system includes an active element, a restoring system, and a heating unit packaged together to form the actuation system. Such a packaged actuation system is light in weight and can be disposed in any section of the wind turbine blade. Furthermore, the active element may be disposed on a torque transmitter to provide local or distributed actuation in the section of the wind turbine blade. The active element disposed on the torque transmitter may include a ring shape. Such an embodiment helps in faster heating over the conventional actuators as a small surface area is required to be heated for actuation. Furthermore, the ring shaped active elements have higher surface area over the conventional actuators, which is available for convection to provide faster cooling. As a consequence, the ring shaped active elements help in increasing frequency of actuation in the wind turbine blade. Moreover, two sets of active elements disposed on the torque transmitter and operating in opposite directions helps in better adjustment of rotational angle of the torque transmitter over the conventional actuators.

[0015] FIG. 1 is a schematic representation of a section 10 of a wind turbine blade including an actuation system 20 in accordance with an embodiment of the invention. The actuation system 20 includes a torque generator 30 disposed in the section 10 of the wind turbine blade, where the section 10 of the wind turbine blade includes a portion of the wind turbine blade. In some embodiments, the section 10 may include one segment of a segmented wind

turbine blade, where the segmented wind turbine blade is formed by combining a plurality of segments of the wind turbine blades. As used herein, the term “torque generator 30” may be defined as an element/device/apparatus/system which may be used to generate torque in the section 10 of the wind turbine blade, where the torque generated by the torque generator 30 is used to perform one or more functions in the corresponding section 10 of the wind turbine blade. In some embodiments, the torque generator 30 may include an active element which may be formed of a shape memory alloy. As used herein, the term “active element” may be defined as an element/device/component, which when energized deforms its shape in a particular direction. For purposes of explanation of FIG. 1 only, the torque generator 30 and the active element are used synonymously as only one active element is shown as the torque generator, however multiple active elements in one section may form the torque generator 30 for the corresponding section. In one embodiment, the active element 30 may include a tube shaped active element disposed along a span 40 of the section 10 of the wind turbine blade. In some embodiments, the tube shaped active element/torque generator 30 also operates as a torque transmitter. The torque generator 30 is mechanically coupled to an inner surface 50 of an airfoil 60 of the section 10 of the wind turbine blade, which further enables performing one or more functions associated with controlling the loads of the corresponding section 10 of the wind turbine blade by the torque generator 30. The actuation system 20 also includes a heating unit 70 operatively coupled to the torque generator 30 which is used to heat the torque generator 30. As used herein, the term “heating unit” may be defined as an apparatus/system/device which is disposed within the wind turbine blade or a section of the wind turbine blade and is used to increase temperature of the active element upon activation. In operation, the heating unit 70 is used to increase a temperature of the active element 30. In one embodiment, the heating unit 70 may include a cartridge heater (as shown in FIG. 1) wrapped around the active element. The heating unit 70 is operatively coupled to an energy storage device 80 which is used to provide electrical power to the heating unit 70. In one example, the energy storage device 80 may include a battery or a capacitor. Upon reaching a predefined level of temperature, the active element 30 is activated and deforms in a first direction 90 from an initial position. Such deformation of the active element 30 generates torque in the first direction 90, which is used to perform one or more functions associated with controlling loads in the corresponding section 10 of the wind turbine blade. In one embodiment, the loads may include structural loads and aerodynamic loads such as bending moment and lift of the corresponding section 10 of the wind turbine blade. The magnitude of

torque and an angle of deformation of the active element 30 may be determined based on system requirement and the nature of the function to be performed.

[0016] In one embodiment, the one or more functions may include one or more first functions and one or more second functions. In a specific embodiment, the one or more first functions may include at least one of altering a shape of the corresponding section 10 of the wind turbine blade, flapping of a trailing edge 100 of the corresponding section 10 of the wind turbine blade, or flapping of a tip (FIG. 6) of the wind turbine blade. In a more specific embodiment, altering the shape of the corresponding section 10 of the wind turbine blade comprises at least one of altering the shape of the trailing edge 100 of the corresponding section 10, or altering the shape of the tip of the wind turbine blade. In another embodiment, the one or more second functions may include at least one of activating synthetic jets, activating spoilers, or activating micro-flaps in the corresponding section 10 of the wind turbine blade. Details of the one or more functions listed above are discussed later in the specification.

[0017] Based on system requirements, the active element/torque generator 30 may be deactivated by switching off the heating unit 70 and reducing the temperature of the active element 30 below the predefined level. In one embodiment, the temperature may be reduced by convection or by using a cooling assembly (not shown). In a specific embodiment, the cooling assembly may include cooling channels which may further include a cooling fluid. The cooling assembly may be used to reduce the temperature of the active element 30 faster, thereby providing better frequency of operation of the active element 30. The actuation system 20 also includes a restoring system 110 operatively coupled to the torque generator 30 via stiffener 120, which is used to restore the initial position of the active element 30 upon cooling. In one embodiment, the restoring system 110 may include a torsion spring system. The restoring system 110 stores/absorbs energy from the torque generator 30 during activation time period and releases the stored/absorbed energy upon deactivation of the torque generator 30 to restore the torque generator 30 to the initial position.

[0018] FIG. 2 is a schematic representation of a section 130 of a wind turbine blade including another embodiment of the actuation system 140 in accordance with an embodiment of the invention. The actuation system 140 includes a torque transmitter 150 disposed along a span 160 of the section 130 of the wind turbine blade. In one embodiment, the torque transmitter 150 may include a hollow cylindrical shape. In a specific embodiment, the torque transmitter 150

may be formed of a non-shape memory (Non-SMA) material. The actuation system 140 further includes a torque generator 170 including an active element 180 disposed on the torque transmitter 150. The active element 180 disposed on the torque transmitter 150 may include at least one of a ring shape or a spring shape. In other embodiments, different shapes of the active elements 180 may be used, and which may be disposed on the torque transmitter 150. In a specific embodiment, the active elements 180 may be formed of a shape memory alloy. As used herein, shape memory alloy may be defined as “an alloy that “remembers” its original shape and that when deformed returns to its pre-deformed shape when heated.”

[0019] The active element 180 in the torque generator 170 may be operatively coupled to a heating unit (FIG. 1). In one embodiment, each of the active elements 180 may be wrapped in a cartridge heater and each of the cartridge heaters may be operatively coupled to an individual or a common energy storage device as shown in FIG. 1. Based on the torque requirements for performing one or more functions, the active elements 180 are selectively activated by heating the selected active elements. In one embodiment, the ring shaped active elements 180 are heated faster, when compared to whole tubes in conventional actuation systems as only a small surface area is required to be heated. The active elements 180 are deformed in a first direction 190 from an initial position to generate torque, which is transmitted to the torque transmitter 150. The torque transmitter 150 is twisted using the torque generated by the active elements 180, which further enables performing the one or more functions associated with controlling the loads in the section 130 of the wind turbine blade.

[0020] For example, if it is required to twist the torque transmitter 150 by five degrees, only one active element 182 in the middle may be activated. Similarly, if a ten degree twist is required, two active elements 184, 186 on the sides may be activated without activating the active element 182 in the middle. Furthermore, if a twenty degree twist is required, all three active elements 182, 184, 186 may be activated to provide the twenty degree twist in the torque transmitter 150. Furthermore, the twist generated by the active elements 180 in the torque transmitter 150 may vary based on shape and size of the active element 180, temperature of the active element 180 and a position of the active element 180.

[0021] The twist generated by the active element 180 in the torque transmitter 150 exerts a force on a restoring system 200 operatively coupled to the torque transmitter 150. The restoring system 200 stores/absorbs energy generated by the torque transmitter 150 and uses such

energy to restore the torque transmitter 150 to an initial shape upon deactivation of the active elements 180. Upon receiving a deactivation command from a system controller (not shown), the heating unit stops its operations and allows the active element 180 to cool down by reducing their temperatures. In one embodiment, the temperatures may be reduced by convection or by using a cooling assembly as discussed in FIG. 1. Since the surface area of the ring shaped active elements 180 is high, the active elements 180 cool faster with respect to conventional actuation systems. Upon cooling, the active elements 180 reach their initial position, thereby reducing the torque exerted on the torque transmitter 150 and simultaneously, the restoring system 200 restores the torque transmitter 150 to the initial shape. In some embodiments, the actuation system 140 may also include a holding apparatus (not shown) operatively coupled to the torque generator 170, the torque transmitter 150 or both. In one embodiment, the holding apparatus may include an active element and a mechanical element operatively coupled to the active elements 180 for holding the active elements 180 in the deformed shape. The holding apparatus may be used to hold the torque transmitter 150 in the deformed shape, while cooling the active elements 180 simultaneously. In such embodiments, once the torque transmitter 150 is deformed to a desired shape, the holding apparatus is used to hold the deformed torque transmitter 150 in such shape for a predetermined period of time. Therefore, the active elements 180 are not required to be heated constantly to keep the torque transmitter 150 in the desired shape, thereby resulting in a reduced consumption of energy.

[0022] FIG. 3 is a schematic representation of a section 210 of a wind turbine blade including an alternative embodiment of the actuation system 220 of FIG. 2 in accordance with an embodiment of the invention. The actuation system 220 in this embodiment is substantially similar to the actuation system 140 of FIG. 2 having a torque generator 170 including an active element 180, the torque transmitter 150, and the restoring system 200. The actuation system 220 further includes a first set 230 of active elements 182, 184, 186 and a second set 240 of active elements 242, 244, 246 disposed on the torque transmitter 150. The first set 230 of active elements is configured to generate torque in a clockwise direction 250 and the second set 240 of active elements are configured to generate torque in a counter-clockwise direction 260. The active elements of the first set 230 are alternatively placed with respect to the active elements of the second set 240 which enables an additional degree of freedom in twisting the torque transmitter 150. Such a configuration increases frequency and reduces delay in responding to system requirements. In one embodiment, the system requirements may include any such control

action, which includes generation of torque in opposite directions. In some embodiments, the actuation system 220 may include a plurality of torque transmitters 150, which is used to generate torque in opposite directions. In this embodiment, the first set 230 of active elements may be disposed on a first torque transmitter and the second set 240 of active elements may be disposed on a second torque transmitter such that the first set 230 disposed on the first torque transmitter generates torque in the clockwise direction and the second set 240 disposed on the second torque transmitter generates torque in the counter-clockwise direction. In another embodiment, the active elements 180 may be operatively coupled/biased to each other such that the active elements 180 in the first set 230 are able to generate torque in the clockwise direction as well as the counterclockwise direction.

[0023] In continuation to the aforementioned example of FIG. 2, if the system requirement at time T1 is to twist the torque transmitter 150 by five degrees, the active element in the first set 230 may be activated to twist the torque transmitter 150 by five degrees. Furthermore, in time T2 if the system requirement is to twist the torque transmitter 150 by three degrees, which is two degrees lesser than the twist in time T1, the active element 242 in the second set 240 may be activate to twist the torque transmitter 150 in the counter-clockwise direction 260 to reduce the twist of the torque transmitter 150 from five degrees to three degrees. In this situation, the active element from first set 230 and the active element from the second set 240 are in an activated state simultaneously and the torque transmitter 150 directly shifts from five degrees to three degrees. In contrast to this embodiment, the active elements of FIG. 2 are required to first cool down and reach its initial position, thereby reducing the twist of the torque transmitter 150 to zero degrees and then the process of activation is re-initiated to achieve a three degree twist in the torque transmitter 150.

[0024] FIG. 4 is a schematic representation 300 of the flapping of the trailing edge 310 performed by the actuation system of FIGs. 1-3 for controlling the loads in the section of the wind turbine blade in accordance with an embodiment of the invention. In this embodiment, the trailing edge 310 of the section of the wind turbine is mechanically coupled to the airfoil 320 of the section of the wind turbine blade using a hinge 330. The actuator systems of FIGs. 1-3 apply torque at the hinge 330 which enables movement of the trailing edge 310 in an upward or a downward direction. Such movement of the trailing edge 310 modifies a camber of the airfoil 320 and a lift of the section of the wind turbine blade.

[0025] FIG. 5 is a schematic representation of a first function 350 of altering the shape of a trailing edge 360 using the actuation systems of FIGs. 1-3 for controlling the loads in the section of the wind turbine blade in accordance with an embodiment of the invention. In this embodiment, the trailing edge 360 is integrated with the airfoil 370 in contrast to the embodiment of FIG. 4. In this embodiment, the torque transmitter (FIGs. 1-3) applies a force on the trailing edge 360 of the section of the wind turbine blade to alter the shape of the trailing edge 360 of the section of the wind turbine blade based on the system requirements for controlling the loads of the section of the wind turbine blade. Similarly, the shape of the tip may also be altered based on the system requirements for controlling the loads of the section of the wind turbine blade.

[0026] FIG. 6 is a schematic representation of a first function 400 of the flapping of the tip of the wind turbine blade performed by the actuation system of FIG. 1-3 for controlling loads in the section of the wind turbine blade in accordance with an embodiment of the invention. In this embodiment, the wind turbine blade includes a segmented tip 410, which is mechanically coupled to the wind turbine blade using a hinge 420. Such a configuration enables the tip 410 to pitch independently from a remaining wind turbine blade 430. The torque transmitter (FIGs. 1-3) upon activation of the active element exerts a force on the hinge 420, which in turn moves the tip 410 in an upward or a downward direction. Such movement of the tip 410 modifies a load associated with a lift of the wind turbine blade.

[0027] FIG. 7 is a schematic representation of a second function 450 for actuating micro-flaps in the section of the wind turbine blade performed by the actuation system of FIGs. 1-3 for controlling loads in the section of the wind turbine blade in accordance with an embodiment of the invention. This embodiment includes micro flaps 460, which include small deployable flaps disposed parallel to the trailing edge 470 in the section of the wind turbine blade. Such micro-flaps 460 are actuated in the section of the wind turbine blade using the actuation system of the FIGs. 1-3. The torque generator (FIGs. 1-3) generates the torque which is used by the torque transmitter (FIGs. 1-3) to actuate the micro-flaps 460 in the corresponding section of the wind turbine blade. Such deployment of the micro-flaps 460 creates an additional camber increasing lift which helps in controlling the loads of the section of the wind turbine blade. Similarly, spoilers and synthetic jets in the leading edge of the airfoil may be actuated to control loads in the section of the wind turbine blade. Furthermore, the actuation system of FIGs. 1-3 may also be used to perform circulation control.

[0028] It is to be understood that a skilled artisan will recognize the interchangeability of various features from different embodiments and that the various features described, as well as other known equivalents for each feature, may be mixed and matched by one of ordinary skill in this art to construct additional systems and techniques in accordance with principles of this disclosure. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

[0029] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

CLAIMS:

1. A wind turbine blade comprising:

an active element disposed in a section of the wind turbine blade and configured to deform in a first direction from an initial position to generate torque upon activation;

a restoring system operatively coupled to a corresponding active element and configured to restore the corresponding active element to the initial position upon deactivation of the corresponding active element; and

a heating unit operatively coupled to one or more active elements and configured to selectively activate one or more corresponding active elements.
2. The wind turbine blade of claim 1, wherein the active element is formed of a shape memory alloy.
3. The wind turbine blade of claim 1, wherein the active element comprises a tube.
4. The wind turbine blade of claim 1, wherein the active element comprises at least one of a ring shape and a spring shape.
5. The wind turbine blade of claim 4, wherein the active element is disposed on a torque transmitter, wherein the torque transmitter is configured to transmit the torque generated by the active element to perform one or more functions associated with controlling loads in the section of the wind turbine blade.
6. The wind turbine blade of claim 5, wherein the active element comprises a first set of active elements and a second set of active elements, wherein the first set of active elements is configured to generate torque in a clockwise direction and the second set of active elements is configured to generate torque in a counter-clockwise direction.
7. The wind turbine blade of claim 6, wherein the active elements of the first set are disposed alternatively with respect to the active elements of the second set on the torque transmitter.
8. The wind turbine blade of claim 4, wherein the one or more functions comprise one or more first functions and one or more second functions.

9. The wind turbine blade of claim 8, wherein the one or more first functions comprise at least one of altering a shape of the corresponding section of the wind turbine blade, flapping of a trailing edge of the corresponding section of the wind turbine blade, and flapping of a tip of the wind turbine blade.

10. The wind turbine blade of claim 9, wherein altering the shape of the corresponding section of the wind turbine blade comprises at least one of altering the shape of the trailing edge of the corresponding section, and altering the shape of the tip of the wind turbine blade.

11. The wind turbine blade of claim 8, wherein the one or more second functions comprises activating synthetic jets, activating spoilers, or activating micro-flaps in the corresponding section of the wind turbine blade.

12. The wind turbine blade of claim 1, wherein the heating unit comprises a cartridge heater.

13. The wind turbine blade of claim 12, wherein the cartridge heater is operatively coupled to an energy storage device.

14. The actuation system of claim 1, wherein the restoring system comprises a torsion spring system.

15. A wind turbine blade comprising:

one or more torque generators comprising an active element formed of a shape memory alloy and disposed in a section of the wind turbine blade, wherein the one or more torque generators are configured to deform in a first direction from an initial position to generate torque upon activation;

one or more torque transmitters operatively coupled to corresponding torque generators and configured to transmit the torque generated by the corresponding torque generators for performing one or more functions associated with controlling loads of the wind turbine blade in the corresponding sections of the wind turbine blade;

at least one restoring system operatively coupled to the corresponding torque generators and configured to restore the corresponding torque generator to the initial position upon deactivation of the corresponding torque generator; and

a heating unit operatively coupled to one or more torque generators and configured to selectively activate one or more corresponding torque generators.

16. The wind turbine blade of claim 15, wherein the torque generator comprises a first set of ring shaped active elements disposed on the corresponding torque transmitter for generating torque in a clockwise direction.

17. The wind turbine blade of claim 16, further comprising a second set of ring shaped active elements disposed on the corresponding torque transmitter for generating torque in a counter-clockwise direction.

18. The wind turbine blade of claim 15, wherein the one or more functions comprises one or more first functions comprising at least one of altering a shape of the corresponding section of the wind turbine blade, flapping of a trailing edge of the corresponding section of the wind turbine blade, and flapping of a tip of the wind turbine blade.

19. The wind turbine blade of claim 15, wherein the one or more functions comprises one or more second functions comprising at least one of activating synthetic jets, activating spoilers, and activating micro-flaps in the corresponding section of the wind turbine blade.

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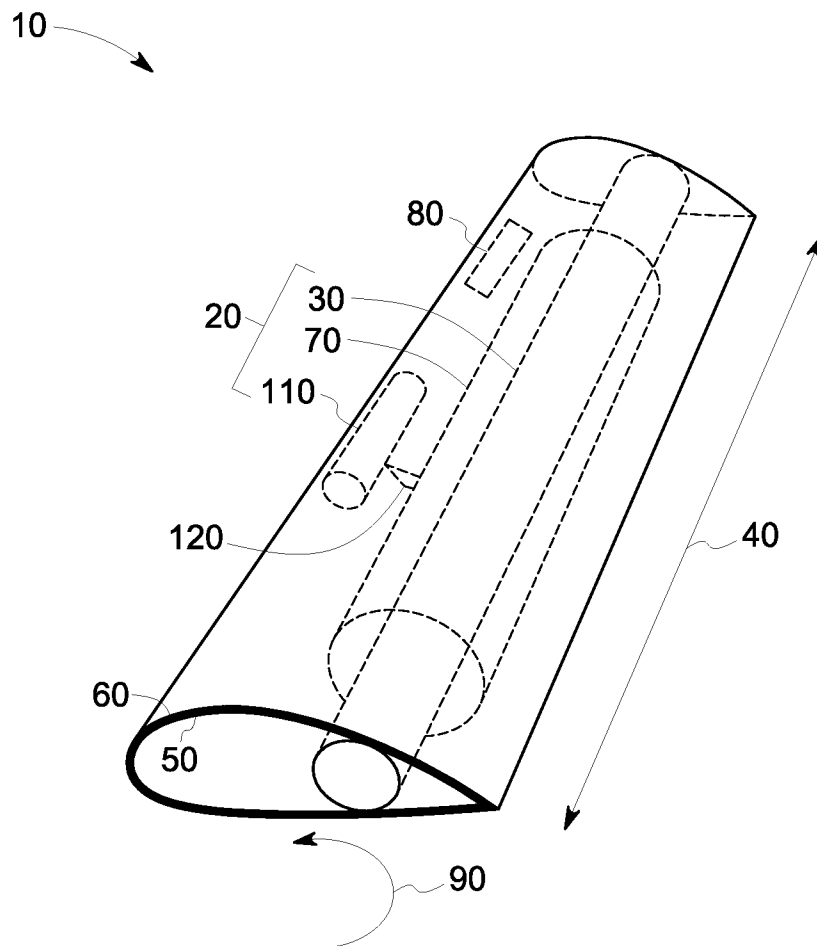


FIG. 1

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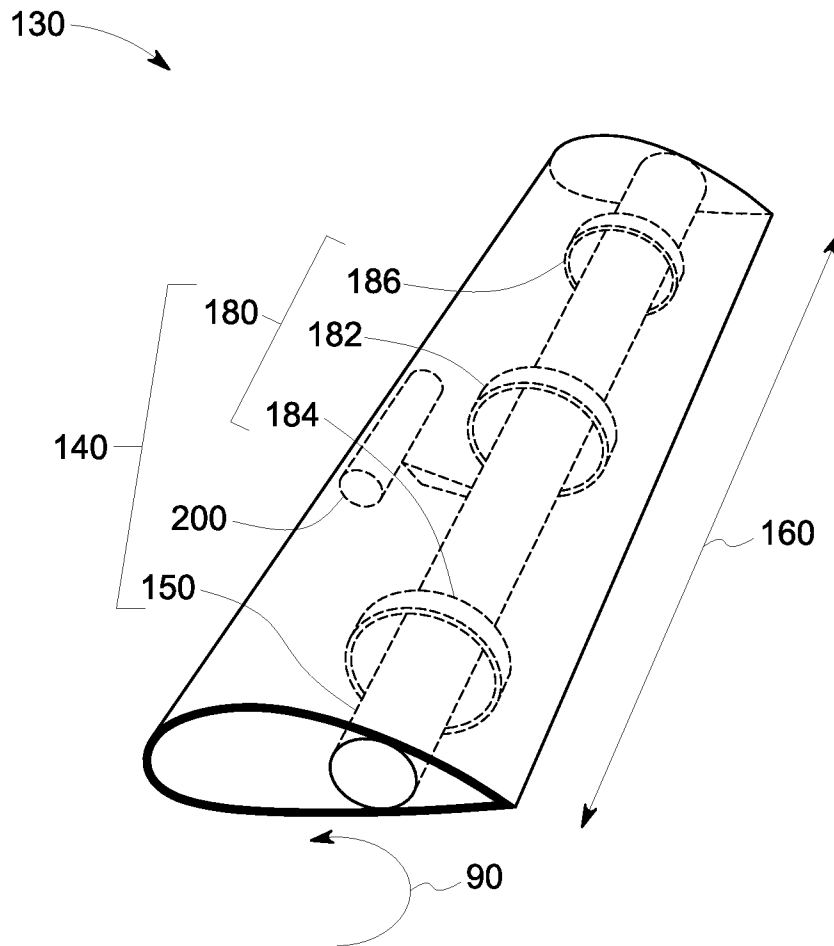


FIG. 2

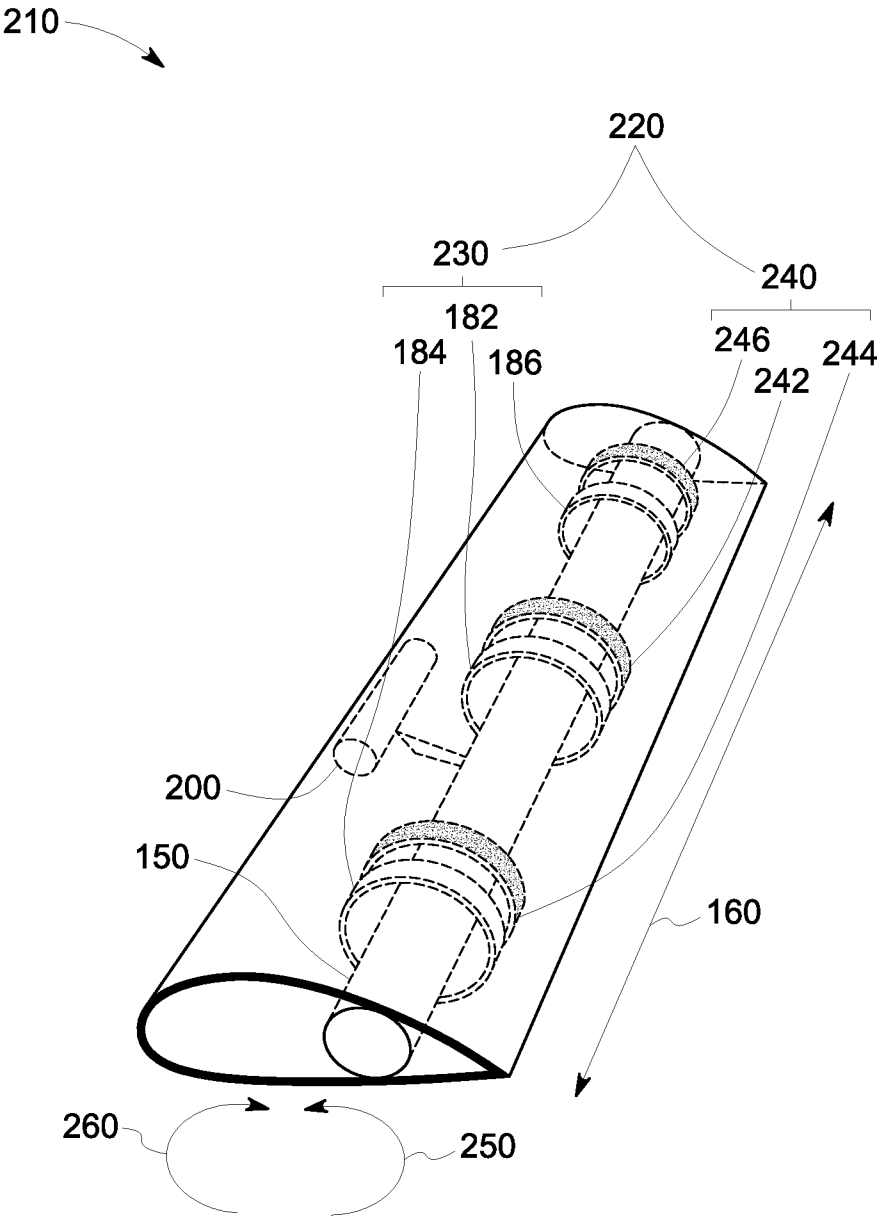


FIG. 3

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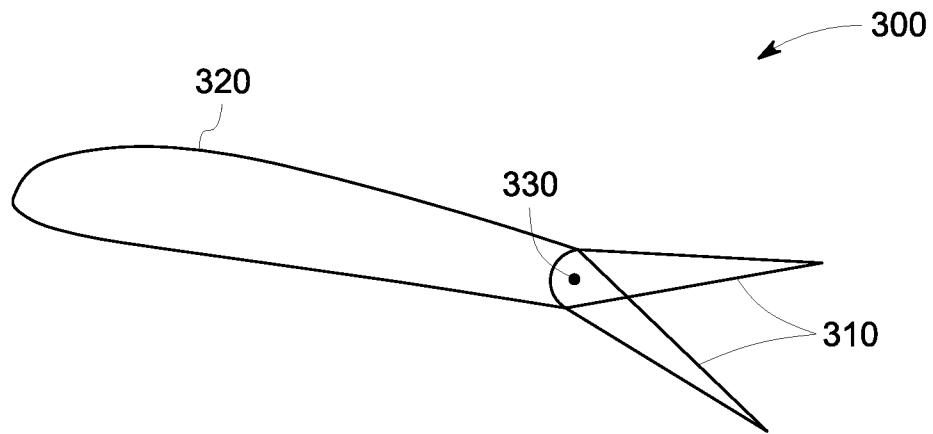


FIG. 4

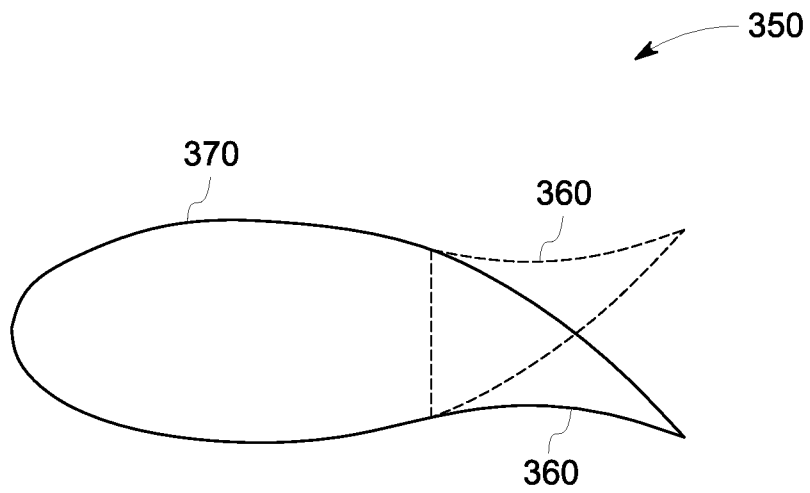


FIG. 5

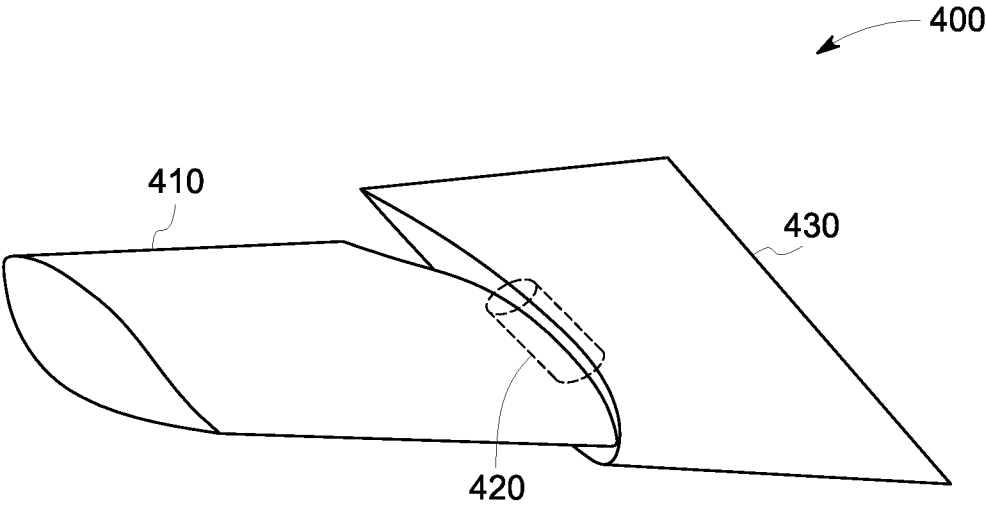


FIG. 6

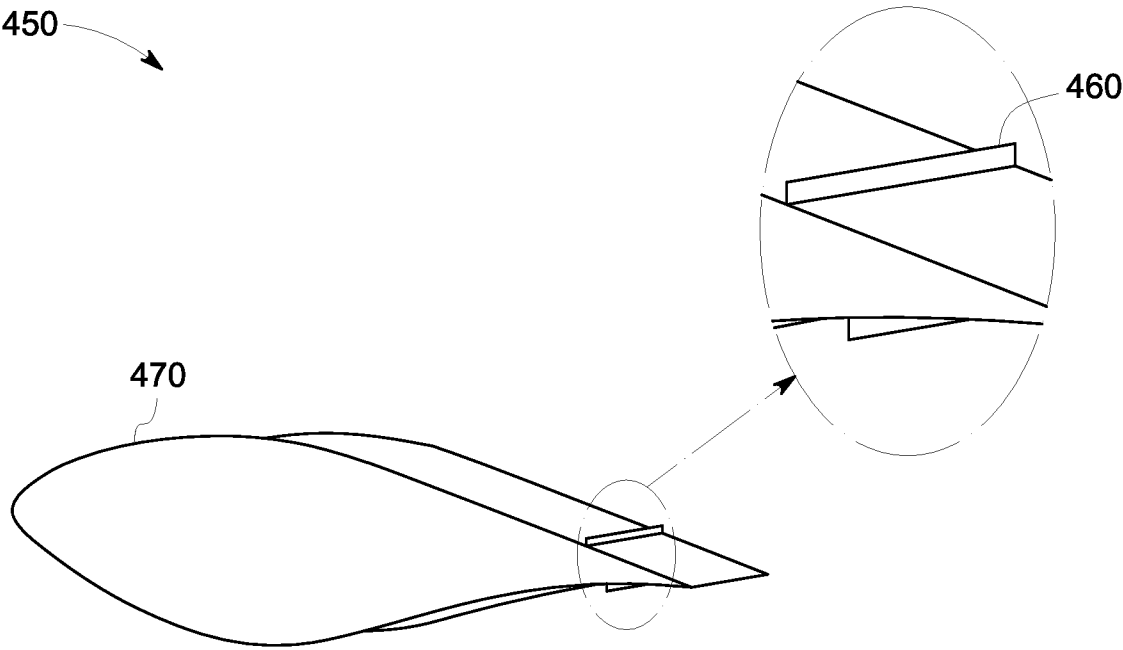


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/025839

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D7/02 F03D1/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F03D

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 378 115 A2 (GEN ELECTRIC [US]) 19 October 2011 (2011-10-19) abstract paragraph [0015] - paragraph [0019] paragraph [0021] - paragraph [0023]; figures 1,2,3,4,5,6,7 -----	1-5, 8-10, 12-15,18
X	WO 2010/093621 A1 (UNIV WEST VIRGINIA [US]; SMITH JAMES E [US]; PERTL FRANZ A [US]; ANGLE) 19 August 2010 (2010-08-19) abstract paragraph [0100] paragraph [0107] - paragraph [0115]; figures 17,18,19,21 ----- -/--	1-19



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

7 December 2015

Date of mailing of the international search report

14/12/2015

Name and mailing address of the ISA/

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Westermayer, Philipp

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/025839

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/134812 A1 (NANUKUTTAN BIJU [IN] ET AL) 31 May 2012 (2012-05-31) abstract paragraph [0005] - paragraph [0006] paragraph [0026] - paragraph [0027] paragraph [0047] - paragraph [0051]; figures 1,2,7,8,9 -----	1-19
A	US 2011/042524 A1 (HEMMELGARN CHRISTOPHER DOUGLAS [US] ET AL) 24 February 2011 (2011-02-24) abstract paragraph [0039] - paragraph [0040] paragraph [0191] - paragraph [0198]; figures 14,19,20 -----	1-19

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/025839

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 2378115	A2	19-10-2011	CN 102220935 A	19-10-2011
			EP 2378115 A2	19-10-2011
			US 2011255974 A1	20-10-2011

WO 2010093621	A1	19-08-2010	US 2012003090 A1	05-01-2012
			US 2012014792 A1	19-01-2012
			WO 2010093621 A1	19-08-2010
			WO 2010093624 A1	19-08-2010
			WO 2010093628 A1	19-08-2010

US 2012134812	A1	31-05-2012	NONE	

US 2011042524	A1	24-02-2011	US 9033283 B1	19-05-2015
			US 2011042524 A1	24-02-2011
