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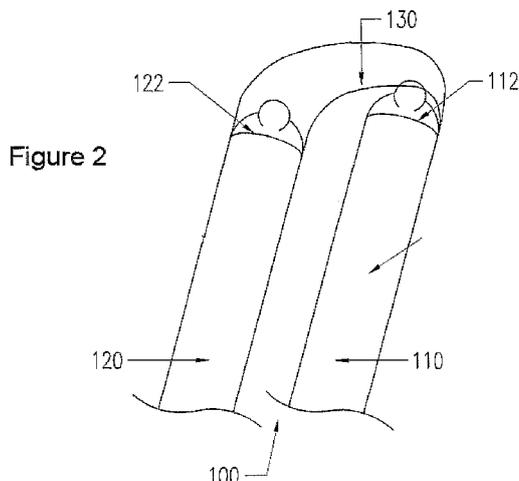
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(57) Abstract: Embodiments of the present invention provide a wind turbine blade system comprising a first blade portion coupled to a wind turbine hub; a second blade portion coupled to the wind turbine hub; and a connector that connects a tip of the first blade portion to a tip of the second blade portion. In some embodiments, each of the first blade portion and the second blade portion may be connected to the connector such that a pitch of each blade portion can be independently adjusted. The system may also include various means coupled to the hub and to the first and second blade portions to adjust a pitch of each of the first and second blades.



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## TANDEM TIP-JOINED BLADES FOR WIND TURBINES

### FIELD OF INVENTION

- 5 Embodiments of the present invention relate to the field of wind turbine generators, and particularly to turbine blades for wind turbine generators.

### BACKGROUND

- 10 Wind turbines generate electricity using wind power. The turbines generally use large blades that are designed to convert wind energy into rotational energy to drive a turbine, which produces the electricity. The blades of large commercial wind turbines can be up to 40 meters or more in length. In present wind turbines, these single blades are attached to a hub of the turbine. These blades are generally  
15 produced from a plurality of composite laminated sheets that are joined together to provide structural integrity to the blades during operation. The size and weight of the blades add to the overall cost of the turbines.

- The blades must also efficiently convert wind energy into rotational energy. They  
20 are generally designed to provide as much rotational torque as possible for a given wind condition. In some turbines, the pitch angle of the blades can be adjusted with respect to the hub in order to increase the aerodynamic efficiency of the wind turbine.

- 25 One problem with the blades is that the blade tips tend to rotate at a very high speed. This results in induced aerodynamic drag that results from tip vortices acting on the blades. The speed of the blade tips also results in the rotating blades producing a great deal of noise that can be heard from a distance. In more built-up areas, this noise is undesirable.

30

It would therefore be an improvement in the art if a system could be developed that could alleviate one or more of the problems discussed above.

**SUMMARY**

One aspect of the present invention provides a wind turbine rotor blade system  
5 comprising a first blade portion coupled to a wind turbine hub; a second blade  
portion coupled to the wind turbine hub; and a connector that connects a tip of the  
first blade portion to a tip of the second blade portion.

10 In some embodiments, each of the first blade portion and the second blade portion  
may be connected to the connector such that a pitch of each blade portion can be  
independently adjusted. The first blade portion may be coupled to the hub at a first  
point, and the second blade portion may be coupled to the hub at a second point  
that is offset by a distance in a direction perpendicular to a rotational plane of the  
wind turbine hub.

15 In alternate embodiments, the connector may be connected to the first and second  
blade tips using a ball and socket joint. In further embodiments, the connector may  
be connected to the first and second blade tips using roller bearings. The connector  
may be configured to reduce aerodynamic drag due to the formation of tip vortices.

20 In other embodiments of the wind turbine rotor blade system, the first blade portion  
may rotate in a windward plane. Similarly, the second blade portion may rotate in a  
downwind plane relative to the first blade portion.

25 An alternate aspect of the present invention provides a wind turbine for generating  
electricity, the wind turbine comprising: a plurality of rotor blade systems, each rotor  
blade system comprising: a first blade portion coupled to a wind turbine hub; a  
second blade portion coupled to the wind turbine hub; and a connector that  
connects a tip of the first blade portion to a tip of the second blade portion.

30 In alternate embodiments of the wind turbine, each of the first blade portion and the  
second blade portion may be connected to the connector such that a pitch of each  
blade portion can be independently adjusted.

In further embodiments, for each of the rotor blade systems, the first blade portion may be coupled to the hub at a first point, and the second blade portion may be coupled to the hub at a second point that is offset by a distance in a direction parallel to a rotational plane of the wind turbine hub. The connector for each rotor blade system may be connected to the first and second blade tips using a ball and socket joint. Alternately, the connector for each rotor blade system may be connected to the first and second blade tips using roller bearings. The connector may be configured to reduce aerodynamic drag due to the formation of tip vortices.

In some embodiments, the first blade portion may rotate in a windward plane and the second blade portion may rotate in a downwind plane relative to the first blade portion.

An alternate aspect of the present invention provides a method for producing a wind turbine rotor blade system, the method comprising the steps of: coupling a first blade portion to a wind turbine hub; coupling a second blade portion to the wind turbine hub; and connecting a tip of the first blade portion to a tip of the second blade portion.

In some embodiments, the connecting step may be performed such that a pitch of each blade portion can be independently adjusted.

In further embodiments, the first blade portion may be coupled to the hub at a first point, and the second blade portion may be coupled to the hub at a second point that is offset by a distance in a direction parallel to a rotational plane of the wind turbine hub.

In other embodiments, the connecting step may further comprise connecting the first and second blade tips using a ball and socket joint. Alternately, the connecting step may further comprise connecting the first and second blade tips using roller bearings.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Embodiments of the invention will be better understood and readily apparent to one  
5 of ordinary skill in the art from the following written description, by way of example  
only, and in conjunction with the drawings, in which:

Figure 1 illustrates a perspective view of a wind turbine generator equipped with the  
10 tandem blade system of the present invention;

Figure 2 illustrates a perspective view of an end portion of one embodiment of a  
tandem blade system according to the present invention;

Figure 3 illustrates a side view of one embodiment of an endplate to join the blade  
15 tips of the two blades of the tandem blade system of Figures 1 and 2;

Figure 4 illustrates a side view of an alternate embodiment of an endplate for joining  
the blade tips of the tandem blade system of Figure 2;

Figure 5 illustrates a top view of one embodiment of a means to adjust a pitch angle  
20 of the tandem blade system of Figure 2;

Figure 6 illustrates a top view of an alternate embodiment of a means to adjust a  
25 pitch angle of the tandem blade system of Figure 2; and

Figure 7 is a flow chart illustrating one method of producing the tandem blade  
system of Figures 2-6.

**30 DETAILED DESCRIPTION**

Figure 1 illustrates a perspective view of one embodiment of a wind power  
generator, designated generally as reference numeral 10, that is capable of using a

tandem blade system according to the present invention. Figure 2 illustrates a perspective view of an end portion of one embodiment of a tandem blade system 100. The wind power generator 10 includes a plurality of tandem blade systems 100 mounted on a hub 410 (Figure 5). The hub 410 is rotatably attached to a generator  
5 20 that produces electricity when the hub 410 rotates as a result of air currents acting on the tandem blade systems 100. The generator 20 is coupled to a tower 30 having a sufficient height to allow the tandem blade systems 100 to rotate freely when the wind blows.

10 While the generator 10 illustrated in Figure 1 shows three tandem blade systems 100 connected to the hub 410, it is understood that two or more tandem blade systems may be used. The embodiments of the generator 10 and tandem blade system 100 shown and described are provided by way of example only.

15 Figure 2 illustrates a perspective view of an end portion of one embodiment of the tandem blade system 100. The system 100 includes a first blade portion 110 and a second blade portion 120. The first blade portion 110 has blade tip 112, while the second blade portion 120 has a blade tip 122. The blade tips 112, 122 are joined together using an endplate or connector 130. The endplate 130 provides a smooth  
20 and continuous extension of the blade tip profile of the blade tips 112, 122.

Figure 3 illustrates a side view of one embodiment of the endplate 130 joining the blade tips 112, 122 of the two blade portions 110, 120 of the tandem blade system 100 of Figure 1. In this embodiment, a ball 114 is coupled to the blade tip 112, while  
25 a ball 124 is coupled to the blade tip 122. A corresponding socket 132 connects the endplate 130 to the ball 114 of the blade 110. Similarly, a corresponding socket 134 connects the endplate 130 to the ball 124 of the blade portion 120. The balls 114, 124 and sockets 132, 134 allow the blade portions 110, 120 to move with respect to the end plate 130. This will be discussed in more detail below with reference to  
30 Figures 4 and 5.

In some embodiments, the balls 114, 124 may be coupled to the blade tips 112, 122 by various means. For example, the balls 114, 124 may be integrally formed as part

of the blade portions 110, 120 during the manufacturing process. In this embodiment, the blade portions 110, 120 and balls 114, 124 respectively, may be made from various composite materials known to those of skill in the art. Alternately, the balls 114, 124 may be coupled to the blade tips 112, 122 using, for example, various types of adhesives. In some embodiments, the adhesives may include Polyurethane (PU) or Epoxy glue.

Figure 4 illustrates a side view of an alternate embodiment of an endplate or connector 230 joining the blade tips 112, 122 of the two blade portions 110, 120 of the tandem blade system 100 of Figure 1. In this embodiment, a post 115 is coupled to the blade tip 112, while a post 125 is coupled to the blade tip 122. A first roller bearing 116 is used to connect the post 115 to a corresponding opening 232 in the endplate 230. Similarly, a second roller bearing 126 is used to connect the post 125 to a corresponding opening 234 in the endplate 230. Each of the roller bearings 116, 126 allow the blade portions 110, 120 to move slightly with respect to the end plate 130. This will be discussed in more detail below with reference to Figures 5 and 6.

In some embodiments, the posts 115, 125 may be coupled to the blade tips 112, 122 by various means. For example, the posts 115, 125 may be integrally formed as part of the blade portions 110, 120 during the manufacturing process. In this embodiment, the blade portions 110, 120 and posts 115, 125 may be made from various composite materials known to those of skill in the art. Alternately, the posts 115, 125 may be coupled to the blade tips 112, 122, respectively using, for example, various types of adhesives, as previously discussed.

Figure 5 illustrates a top view of one embodiment of a means, designated generally as reference numeral 400, to adjust a pitch of the tandem blade system 100 of Figure 1. As shown in Figure 5, each of the blade portions 110, 120 are pivotally connected to a hub 410 of a wind turbine generator (not shown). The first blade portion 110 is capable of pivoting about an axis 412 that extends along the length of the first blade portion 110. Similarly, the second blade portion 120 is capable of pivoting about an axis 414 that extends along the length of the second blade portion

120. The pitch of the blade portions 110, 120 can be adjusted by pivoting the blade portions 110, 120 about the respective axes 412, 414. In this embodiment, a hydraulic cylinder 430 connected to each of the blade portions 110, 120 provides the force required to pivot the blades. For the purposes of illustration, the hydraulic cylinder 430 is shown extending beyond the periphery of the hub 410. However, it is understood that, in some embodiments, the hydraulic cylinder 430 may be completely contained within the hub 410.

In some embodiments, the pitch angle of the blades 110, 120 can be changed within a range of from about -10 degrees to about +30 degrees. The pitch angle may be adjusted, for example, depending on the wind speed, in order to provide for the efficient conversion of wind energy into rotational torque.

In operation, the hydraulic cylinder 430 exerts a linear force on a first shaft 432. The first shaft 432 is pivotally coupled to the second blade 120 at connection point 434. Similarly, the first shaft 432 is connected to a second shaft 432a that extends between connection point 434 and a connection point 436 on first blade portion 110. In some embodiments, the shaft 432 may be a single piece. In these embodiments, a pin or other connector attached to each of the first and second blade portions 110, 120 may extend through the shaft 432 to provide the rotational force. In some embodiments, the pitching system is controlled as a function of the wind speed. The pitch angle of the blades may be adjusted for maximum aerodynamic efficiency, as well as to regulate power production and maintain rated power.

In this embodiment, the hub 410 rotates in a direction indicated by arrow 420. However, it is understood that the system 100 may be adapted to rotate in the other direction as well. In this orientation, the first blade portion 110 is in the downwind plane from the second blade portion 120, which is in the windward plane. In one embodiment, the first axis 412 and the second axis 414 are slightly offset from each other in a direction parallel to a rotational plane of the wind turbine 10. This offset is shown as reference numeral 416. In some embodiments, there may also be an offset in a direction that is perpendicular to the rotational plane of the wind turbine 10. It is understood that other offsets may also be used, both parallel and perpendicular to the

rotational plane of the wind turbine 10, depending on the type of wind turbine 10 to which the system 100 is attached.

Figure 6 illustrates a top view of an alternate embodiment of a means, designated  
5 generally as reference numeral 500, to adjust a pitch of the tandem blade system  
100 of Figure 1. As shown in Figure 6, each of the blade portions 110, 120 are  
pivotally connected to a hub 510 of a wind turbine generator (not shown). The first  
blade portion 110 is capable of pivoting about an axis 512 that extends along the  
length of the first blade portion 110. Similarly, the second blade portion 120 is  
10 capable of pivoting about an axis 514 that extends along the length of the second  
blade portion 120. The pitch of the blade portions 110, 120 can be adjusted by  
pivoting the blade portions 110, 120 about the respective axes 512, 514.

In this embodiment, the blade portion 110 includes a ring gear 538 on an inside  
15 surface. A corresponding pinion gear 536 can then be driven to pivot the blade  
portion 110. Similarly, the blade portion 120 includes a ring gear 534 on an inside  
surface. A corresponding pinion gear 532 can then be driven to pivot the blade  
portion 120.

20 While the embodiments of a tandem blade pitching system of Figures 5 and 6  
illustrate a hub attachment for a single tandem blade, it is understood that similar  
structure may be found on all of the tandem blade systems 100 attached to the hub.

Figure 7 shows a flow chart illustrating one embodiment of a method, designated  
25 generally with reference numeral 600, for producing the tandem blade system of  
Figures 2-6. The method 600 includes a first step of coupling a first blade portion  
110 to a wind turbine hub 410, 510, as shown with reference numeral 602. The next  
step is to couple a second blade portion 120 to the wind turbine hub 410, 510, as  
shown with reference numeral 604. The final step in the method 600 is connecting a  
30 tip of the first blade portion 110 to a tip of the second blade portion 220, as shown  
with reference numeral 606.

As discussed above, the connecting step may optionally be performed such that a pitch of each blade portion 110, 120 can be independently adjusted. Additional alternatives may include coupling the first blade portion 110 to the hub at a first point, and coupling the second blade portion 120 to the hub at a second point that is  
5 offset by a distance in a direction parallel to a rotational plane of the wind turbine hub.

Also as discussed above with reference to Figures 2-6, the connecting step may include connecting the first and second blade tips using a ball and socket joint.  
10 Alternately, the connecting step may include connecting the first and second blade tips using roller bearings.

Embodiments of the present invention provide several advantages over traditional single blade wind power generators. First, the system provides for increased structural  
15 efficiency. By having two blades rotating in tandem and joined at the tip end, the overall structure is very strong and stiff. Hence, each blade can be made much thinner, especially at the root end, thereby saving on material costs.

Another advantage is that the overall aerodynamic efficiency is improved. The tip-joint  
20 structure behaves like a closed winglet, and therefore reduces aerodynamic induced drag due to tip vortices or tip losses. This will in turn improve the overall efficiency in power generation of the wind turbine. The increased number of blades also allows the tip speed of the wind turbine blades to be reduced since the blades can be made shorter for the same rated power production. Hence, the noise emission of the blades can be  
25 significantly reduced.

The improvement in structural stiffness may be determined by detailed structural and aero-elastic analysis. The aerodynamic design of the two blades can also be further optimized to benefit from constructive interference between the windward and downwind  
30 blades. The improvement in aerodynamic efficiency can be calculated by obtaining the improved lift-to-drag coefficient of the tandem blades compared to a single blade. For the same rated power production and tip-speed ratio, the length of the tandem blades can thus be reduced, resulting in a corresponding lower tip speed. This provides greater

efficiency in power generation for a given blade length and rotational speed, as well as a reduction in the amount of noise produced by the wind turbine.

5 It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

**CLAIMS**

1. A wind turbine rotor blade system comprising:
  - a first blade portion coupled to a wind turbine hub;
  - 5 a second blade portion coupled to the wind turbine hub; and
  - a connector that connects a tip of the first blade portion to a tip of the second blade portion.
  
- 10 2. The wind turbine blade system of claim 1, wherein each of the first blade portion and the second blade portion is connected to the connector such that a pitch of each blade portion can be independently adjusted.
  
- 15 3. The wind turbine blade system of claims 1 or 2, wherein the first blade portion is coupled to the hub at a first point, and the second blade portion is coupled to the hub at a second point that is offset by a distance in a direction parallel to a rotational plane of the wind turbine hub.
  
- 20 4. The wind turbine blade system of any one of the previous claims, wherein the connector is connected to the first and second blade tips using a ball and socket joint.
  
- 25 5. The wind turbine blade system of any one of the previous claims, wherein the connector is connected to the first and second blade tips using roller bearings.
  
- 30 6. The wind turbine blade system of any one of the previous claims, wherein the connector is configured to reduce aerodynamic drag due to the formation of tip vortices.
  
7. The wind turbine blade system of any one of the previous claims, wherein the first blade portion rotates in a windward plane and the second blade portion rotates in a downwind plane relative to the first blade portion.

8. A wind turbine for generating electricity, the wind turbine comprising:  
a plurality of rotor blade systems, each rotor blade system comprising:  
a first blade portion coupled to a wind turbine hub;  
a second blade portion coupled to the wind turbine hub; and  
5 a connector that connects a tip of the first blade portion to a tip  
of the second blade portion.
9. The wind turbine of claim 8, wherein each of the first blade portion and the  
10 second blade portion is connected to the connector such that a pitch of each  
blade portion can be independently adjusted.
10. The wind turbine of claims 8 or 9, wherein, for each of the rotor blade  
systems, the first blade portion is coupled to the hub at a first point, and the  
15 second blade portion is coupled to the hub at a second point that is offset by  
a distance in a direction parallel to a rotational plane of the wind turbine hub.
11. The wind turbine of any one of claims 8-10, wherein the connector for each  
rotor blade system is connected to the first and second blade tips using a ball  
and socket joint.  
20
12. The wind turbine of any one of claims 8-10, wherein the connector for each  
rotor blade system is connected to the first and second blade tips using roller  
bearings.
- 25 13. The wind turbine of any one of claims 8-12, wherein the connector is  
configured to reduce aerodynamic drag due to the formation of tip vortices.
14. The wind turbine of any one of claims 8-13, wherein the first blade portion  
rotates in a windward plane and the second blade portion rotates in a  
30 downwind plane relative to the first blade portion.
15. A method for producing a wind turbine rotor blade system, the method  
comprising the steps of:

coupling a first blade portion to a wind turbine hub;  
coupling a second blade portion to the wind turbine hub; and  
connecting a tip of the first blade portion to a tip of the second blade  
portion.

5

16. The method of claim 15, wherein said connecting step is performed such that  
a pitch of each blade portion can be independently adjusted.

10

17. The method of claims 15 or 16, wherein the first blade portion is coupled to  
the hub at a first point, and the second blade portion is coupled to the hub at  
a second point that is offset by a distance in a direction parallel to a rotational  
plane of the wind turbine hub.

15

18. The method of any one of the claims 15-17, wherein the connecting step  
further comprises connecting the first and second blade tips using a ball and  
socket joint.

20

19. The method of any one of the claims 15-17, wherein the connecting step  
further comprises connecting the first and second blade tips using roller  
bearings.

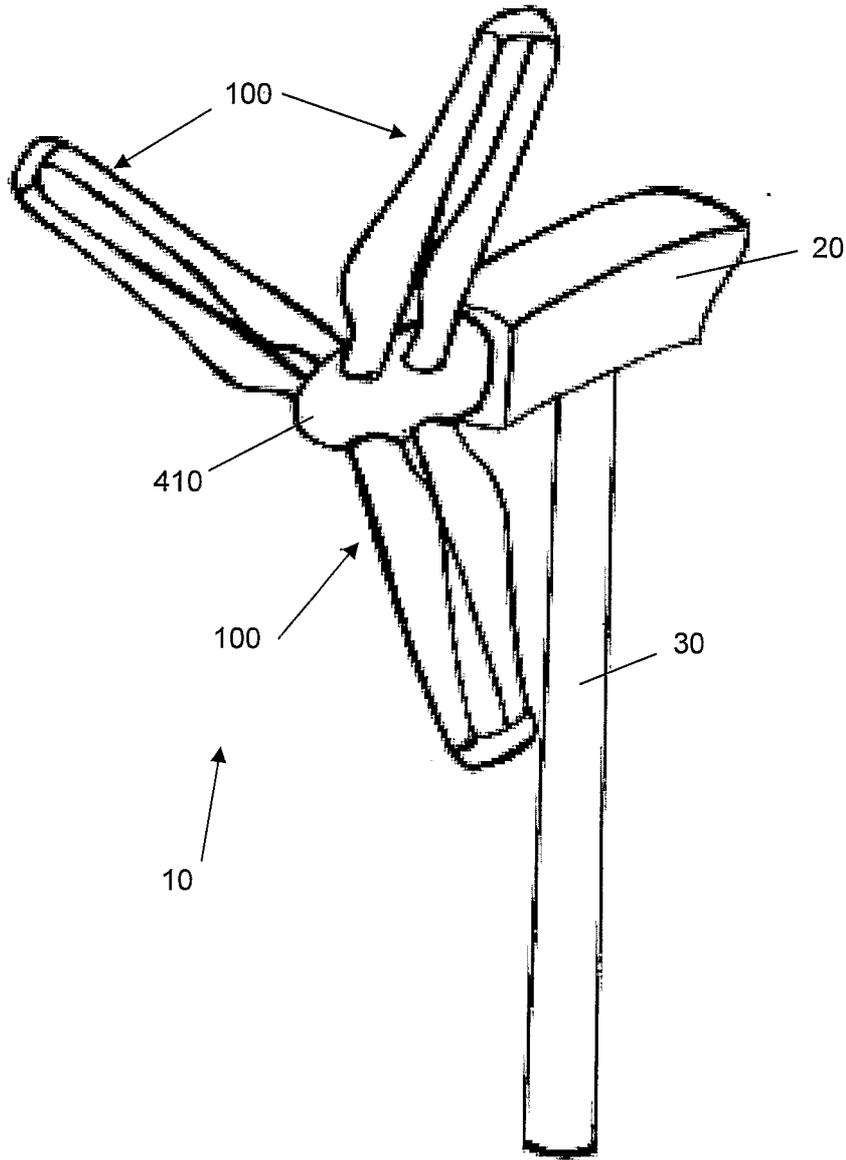


Figure 1

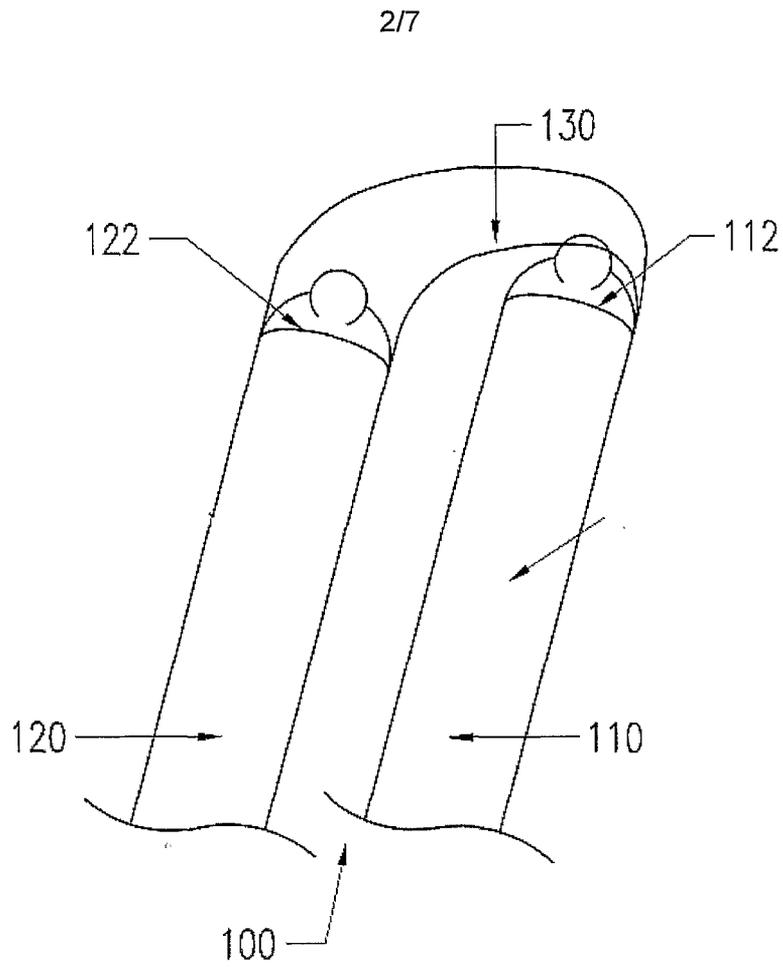


Figure 2

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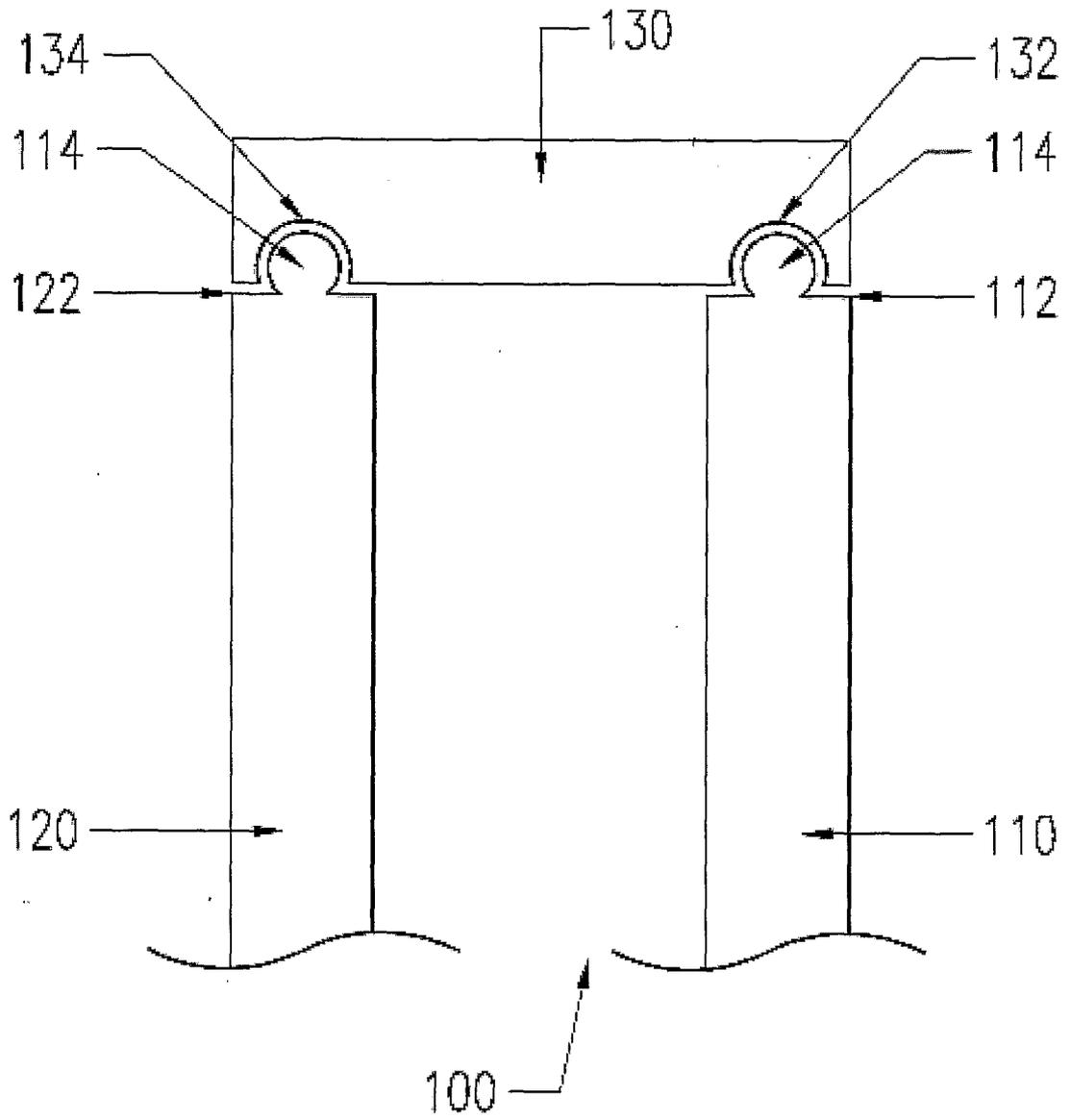


Figure 3

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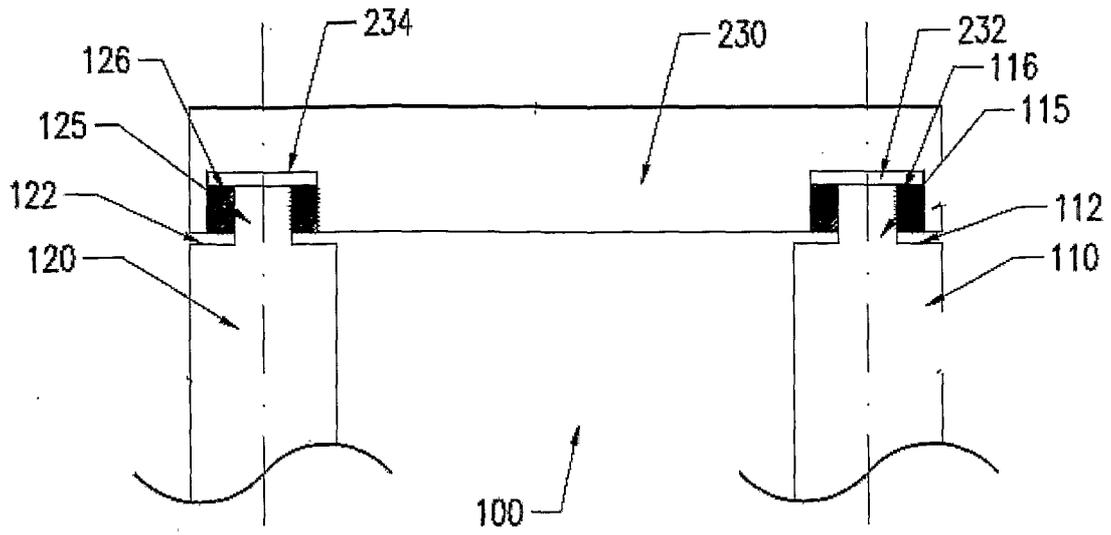


Figure 4

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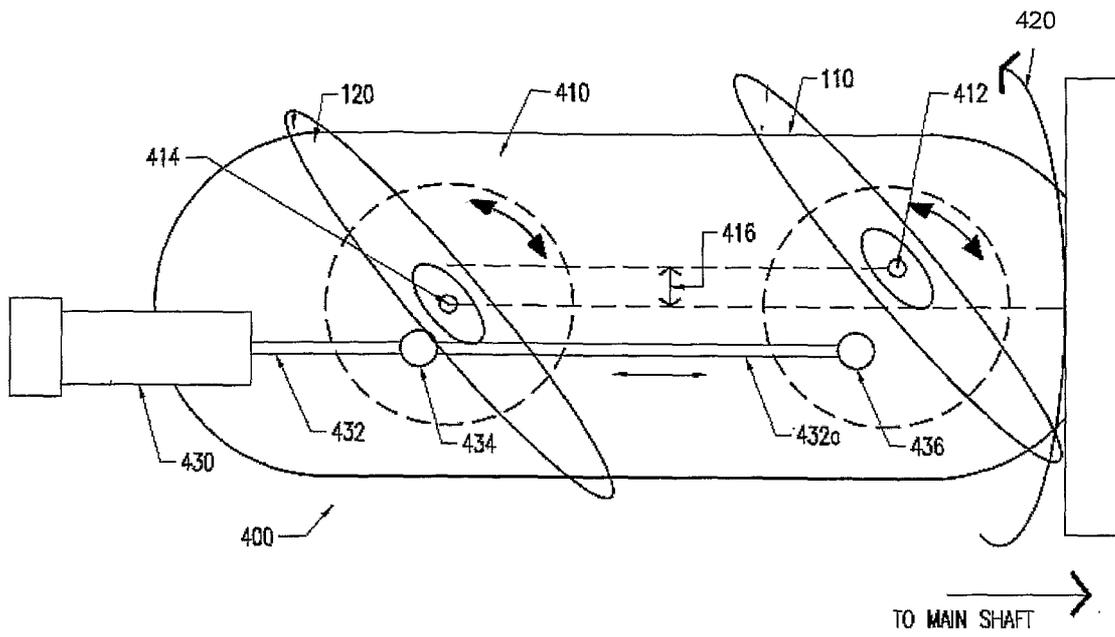


Figure 5

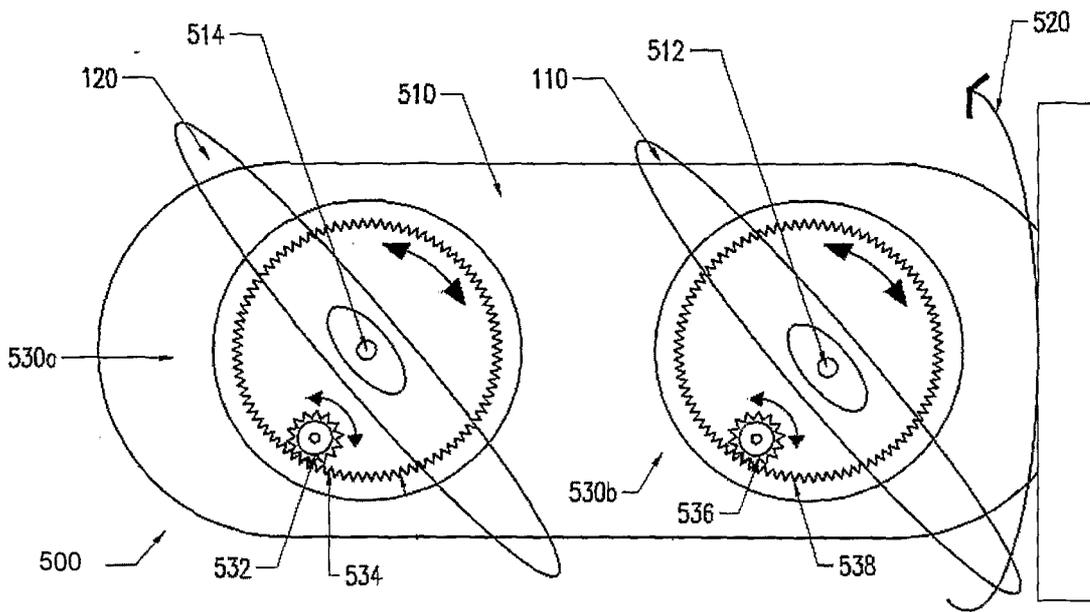


Figure 6

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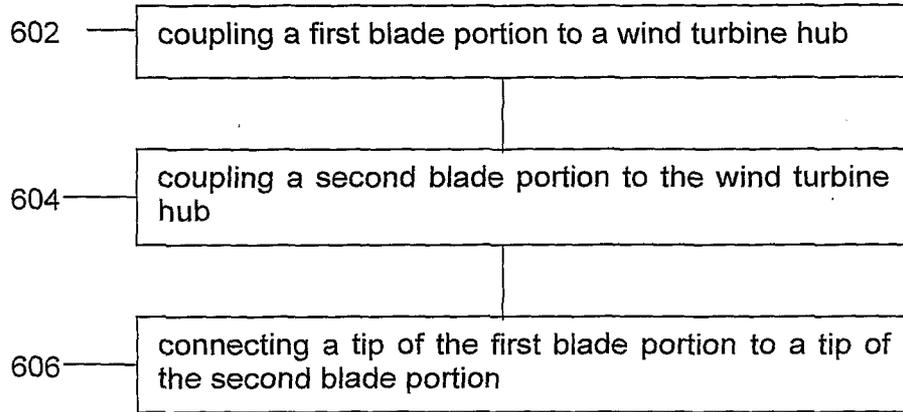


Figure 7

