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DESCRIPTION

Technical Field

[0001] This application relates generally to wind turbines, and more particularly to a molding apparatus for constructing a wind turbine blade and to a method of making a wind turbine blade using such a molding apparatus.

Background

[0002] The typical modern wind turbine includes a tower that supports a nacelle at an upper end thereof. A rotor having a central hub and one or more blades is coupled to the nacelle and converts the kinetic energy of the wind into mechanical energy, usually in the form of a rotating main shaft. The nacelle includes various components, such as a drive train and a generator, that convert the mechanical energy from the rotor into electrical energy. Wind turbines are known to generate their highest yield (i.e., operating efficiency) under predetermined aerodynamic conditions of their blades, which may have a predetermined profile for optimizing lift on the blades. As the blades are a major aspect and cost of wind turbine construction, much effort has been directed toward the efficient manufacturing of the blades.

[0003] According to one conventional process, a wind turbine blade is manufactured by disposing structural outer shell material into two mold halves and then injecting a binder, such as an epoxy resin, polyester resin, or other suitable material around the structural outer shell material while a vacuum system (e.g., vacuum bag) presses the structural outer shell material into each of the mold halves. In an alternate process, pre-impregnated composite material may be used which precludes injecting the material with a binder. In any event, after curing the binder about the structural outer shell material (e.g., a fiberglass weave), the two halves of the wind turbine blade outer shell may be coupled to one another around a structural support member or spar. The two halves of the wind turbine blade are typically coupled by adhesive material along, for example, the leading and trailing edges thereby completing blade construction.

[0004] Bringing the two halves of the blade together can be a difficult and time-consuming task. One current method to facilitate the coupling of the blade halves includes utilizing the mold halves which were used to form the blade halves. In this regard, once the blade halves are formed in their respective molds, the mold halves may be moved relative to each other to locate one mold half on top of the other mold half such that the edges (e.g., the leading and trailing edges) of the two blade halves are generally aligned with each other. The mold halves may then be brought even closer together so that the edges of the blade halves may be, for example, adhesively bonded together.

[0005] By way of example, a conventional approach for moving the mold halves relative to each other has one mold half in a fixed position and the other mold half arranged so it rotates or pivots relative to the fixed mold half so as to be positioned on top of the fixed mold half (e.g., a clamshell configuration). This rotating or pivot action is typically achieved with a fixed hinge or pivot mechanism (e.g., the pivot point or axis remains stationary during use) operatively coupled to the movable mold half and optionally coupled to the fixed mold half. In this regard, the pivot mechanism may be located adjacent the interface between the two mold halves, i.e., adjacent an upper surface of the fixed mold half.

[0006] While the manufacturing method described above is generally successful for its intended purpose, manufacturers have more recently realized certain limitations to the conventional manufacturing method. More particularly, as the size of wind turbine blades has continued to increase, the size of the molds used to make the blades has correspondingly increased. As a result, finding sufficient space within the manufacturing facility suitable for housing the blade molds has become particularly problematic. In this regard, many existing manufacturing facilities enclose an interior floor space with a ceiling having a vertical height of about 11 meters or less. Current wind turbine blade construction has chord lengths approaching about 6 meters or more and is expected to grow moving forward. The size of the molds sufficient to accommodate blade halves of this size are very large such that there is a significant concern that as the movable mold half rotates about the fixed pivot axis, the moving mold half will contact the ceiling, light fixtures, duct work, etc. adjacent the ceiling, and thereby be prevented from further movement that properly locates the movable mold half on top of the fixed mold half. Such a scenario will then prevent the complete construction of the wind turbine blade in accordance with current methodologies.

[0007] Of course one solution to this problem is to raise the ceiling height of the manufacturing facility so as to provide sufficient space to fully rotate the movable mold half. While this solution may be implemented when building a new manufacturing facility, such a solution is generally not viable for existing facilities. In this regard, the costs for raising the ceiling height of the manufacturing facility would be prohibitively high. Such a renovation may also result in a temporary shut-down of the facility, a reduction in production output, and loss of work hours, thus adding further costs and inefficiencies to the renovation project.

[0008] A representative example of the prior art is disclosed in DE202010 01462 U1, which discloses the features specified in the preamble of claim 1 of the present invention.

[0009] Accordingly, there is a need for an improved molding apparatus and associated method that allows wind turbine blades of increasing size to be manufactured in existing manufacturing facilities without undue concern of contacting the ceiling or adjacent fixtures during movement of a mold half and without the need of expensive and time-consuming renovations.

Summary

[0010] To address these and other drawbacks of conventional approaches, a method of making a wind turbine blade having a first shell half and a second shell half using a molding apparatus having a first mold half and a second mold half comprises at least partially forming the first shell half in the first mold half; at least partially forming the first shell half in the second mold half; moving the first and second mold halves relative to each other from an opened position, where respective molding surfaces of the first and second mold halves are exposed, to a closed position, where the molding surfaces of the first and second mold halves confront each other; and coupling the first shell half and the second shell half to form the wind turbine blade.

[0011] In an exemplary embodiment, the moving step further comprises rotating the first and second mold halves relative to each other about a pivot axis; translating the pivot axis in a first direction of translation during movement of the mold halves between the opened and closed positions; and translating the pivot axis in a second direction of translation different from the first direction during movement of the mold halves between the opened and closed directions.

[0012] In one embodiment, rotation of the first and second mold halves from the opened position to an intermediate position defines a first phase of rotation of the first and second mold halves, and rotation from the intermediate position to the closed position defines a second phase of rotation of the first and second mold halves, wherein the step of translating the pivot axis in the first direction occurs during the first phase and the step of translating the pivot axis in the second direction occurs during the second phase. In one particular embodiment, the first and second mold halves rotate through an angle θ of approximately 180° from the opened position to the closed position and the intermediate position is approximately midway through the full rotation of the mold halves.

[0013] According to the invention, one of the first or second mold halves is supported on a support surface and the pivot axis is located at a height relative to the support surface, wherein translating the pivot axis in the first direction comprises decreasing the height of the pivot axis relative to the support surface and translating the pivot axis in the second direction comprises increasing the height of the pivot axis relative to the support surface. In one exemplary embodiment, translating the pivot axis in the first direction comprises translating the pivot axis vertically downward, and translating the pivot axis in the second direction comprises translating the pivot axis vertically upward.

[0014] From a timing standpoint, in one embodiment, the rotating and translating steps occur simultaneously for at least a portion of the relative movement of the first and second mold halves. In an alternative embodiment, however, the rotating step occurs without translation and the translating step occurs without rotation. In one embodiment, the rotation of the first and second mold halves occurs around a single pivot axis.

[0015] In still a further embodiment, the molding apparatus may include a rotational prime mover and a translational prime mover, wherein rotation of the first and second mold halves relative to each other about the pivot axis is carried out by activating the rotation prime mover and translation of the pivot axis in the first and second directions is carried out by activating the translational prime mover. The molding apparatus may include a controller coupled to the rotational prime mover and the translational prime mover, wherein the rotating and translating steps are controlled by the controller and may be implemented in an automated manner, such as a timed sequence of as a function of rotational position.

[0016] In accordance with another aspect, a method of operating a molding apparatus within a manufacturing facility having a support surface to support the molding apparatus and an obstruction vertically spaced above the molding apparatus, the molding apparatus comprising a first mold half and a second mold half, the first mold half being immovably supported on the support surface and the second mold half being movable relative to the first mold half includes rotating the second mold half about a pivot axis; translating the pivot axis in a direction away from the obstruction as the second mold half moves toward the obstruction above the molding apparatus; continuing rotation of the second mold half about the pivot axis; and translating the pivot axis toward the obstruction after the second mold half has cleared the obstruction.

[0017] In another embodiment, a wind turbine includes a tower; a nacelle coupled to the tower; and a rotor coupled to the nacelle and including a hub and at least one blade extending therefrom. The at least one blade is made in accordance with the method as described above.

[0018] A molding apparatus for manufacturing a wind turbine blade having a first shelf half and a second shell half includes a first mold half for forming the first shell half of the wind turbine blade and a second mold half for forming the second shell half of the wind turbine blade. The molding apparatus further includes a turner assembly coupled to at least one of the first and second mold halves and configured to move the first and second mold halves relative to each other between an opened position and a closed position. In the opened position, the first and second shell halves are configured to be at least partially formed in the first and second mold halves. In the closed position, the first and second shell halves are configured to be coupled to each other to form the wind turbine blade. The turner assembly includes a pivot mechanism coupled to at least one of the first and second mold halves that defines a pivot axis. The pivot mechanism provides rotational movement of the first and second mold halves relative to each other about the pivot axis. The turner assembly also includes a track coupled to the pivot mechanism that defines a translation axis. The track provides translational movement of the pivot axis in a direction generally parallel to the translation axis. The track includes a first lug, a second lug spaced from the first lug, and a travel rod extending between the first and second lugs.

[0019] In an embodiment of the invention, the turner assembly includes a rotational prime mover for causing rotational movement of the first and second mold halves relative to each other about the pivot axis. Additionally, the turner assembly may include a translational prime mover for causing translational movement of the pivot axis in a direction generally parallel to the translation axis. A controller may be operatively coupled to the rotational and translational prime movers for controlling the rotational movement of the first and second mold halves relative to each other and controlling the translational movement of the pivot axis.

[0020] The translational prime mover may include an actuator coupled to the pivot mechanism and movable between an extended position and a contracted position. The actuator may be coupled to the pivot mechanism such that actuation of the actuator moves the pivot mechanism along the track and in a direction generally parallel to the translation axis. The track may be coupled to the other of the first and second mold halves and the turner assembly may include only a single pivot axis. Furthermore, in a specific embodiment, the pivot mechanism is coupled to one of the first and second mold halves and to the track. The coupling between the pivot mechanism and the one mold half provides for rotational movement of the one mold half relative to the other mold half about the pivot axis. The coupling between the pivot mechanism and the track provides for translational movement of the pivot axis in a direction generally parallel to the translation axis.

[0021] In another embodiment, a wind turbine includes a tower, a nacelle coupled to the tower, and a rotor coupled to the nacelle and including a hub and at least one blade extending therefrom. The at least one blade may be made with the molding apparatus in accordance with that described above.

<u>Brief Description of the Drawings</u>

[0022] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate various embodiments of the invention and, together with a general description of the invention given above and the detailed description of the embodiments given below, serve to explain the embodiments of the invention.

Fig. 1 is a diagrammatic perspective view of a wind turbine having a blade made with a molding apparatus in accordance with one embodiment of the invention;

Fig. 2 is a perspective view of a wind turbine blade shown in Fig. 1;

Fig. 3 is a cross-sectional view of the wind turbine blade shown in Fig. 2 taken along line 3-3;

Fig. 4 is a cross-sectional view of a molding apparatus in accordance with one embodiment of the invention and in an opened position;

Fig. 4A is an enlarged portion of Fig. 4 illustrating a turner assembly in accordance with an embodiment of the invention;

Fig. 5 is a schematic cross-sectional view illustrating an exemplary method of forming a wind turbine blade shell in a mold;

Fig. 6 is another cross-sectional view of the molding apparatus shown in Fig. 4 with one of the mold halves moved toward a closed position;

Fig. 7 is another cross-sectional view of the molding apparatus shown in Fig. 4 with one of the mold halves shown in an upright position;

Fig. 8 is another cross-sectional view of the molding apparatus shown in Fig. 4 with one of the mold halves shown in a peak position;

Fig. 9 is another cross-sectional view of the molding apparatus shown in Fig. 4 with one of the mold halves moved even further toward the closed position;

Fig. 10 is another cross-sectional view of the molding apparatus shown in Fig. 4 when in the closed position; and

Fig. 11 is a partial perspective view of the molding apparatus shown in Fig. 4.

Detailed Description

[0023] With reference to Fig. 1 and in accordance with an embodiment of the invention, a wind turbine 10 includes a tower 12, a nacelle 14 disposed at the apex of the tower 12, and a rotor 16 operatively coupled to a generator (not shown) housed inside the nacelle 14. In addition to the generator, the nacelle 14 houses miscellaneous components required for converting wind energy into electrical energy and various components needed to operate, control, and optimize the performance of the wind turbine 10. The tower 12 supports the load presented by the nacelle 14, the rotor 16, and other components of the wind turbine 10 that are housed inside the nacelle 14, and also operates to elevate the nacelle 14 and rotor 16 to a height above ground level or sea level, as may be the case, at which faster moving air currents of lower turbulence are typically found.

[0024] The rotor 16 of the wind turbine 10, which is represented as a horizontal-axis wind turbine, serves as the prime mover for the electromechanical system. Wind exceeding a minimum level will activate the rotor 16 and cause rotation in a direction substantially perpendicular to the wind direction. The rotor 16 of wind turbine 10 includes a central hub 18 and at least one blade 20 that projects outwardly from the central hub 18. In the representative embodiment, the rotor 16 includes three blades 20 at locations circumferentially distributed thereabout, but the number may vary. The blades 20 are configured to interact with the passing air flow to produce lift that causes the central hub 18 to spin about a longitudinal axis 22. The rotor 16 is mounted on an end of a main rotary shaft (not shown) that extends into the nacelle 14 and is rotatably supported therein by a main bearing assembly (not shown) coupled to the framework of the nacelle 14. The main rotary shaft is coupled to a drive train (not shown) having as an input the relatively low angular velocity main rotary shaft, and having as an output a higher angular velocity secondary rotary shaft (not shown) that is operatively coupled to the generator.

[0025] The wind turbine 10 may be included among a collection of similar wind turbines belonging to a wind farm or wind park that serves as a power generating plant connected by transmission lines with a power grid, such as a three-phase alternating current (AC) power grid. The power grid generally consists of a network of power stations, transmission circuits, and substations coupled by a network of transmission lines that transmit the power to loads in the form of end users and other customers of electrical utilities. Under normal circumstances, the electrical power is supplied from the generator to the power grid as known to a person having ordinary skill in the art.

[0026] With reference to Figs. 1-3, a wind turbine blade 20 is an elongate structure having, in an exemplary embodiment, an outer shell 24 disposed about an inner support element or spar 26. The outer shell 24 may be optimally shaped to give the blade 20 the desired aerodynamic properties to generate lift, while the spar 26 provides the structural aspects (e.g., strength, stiffness, etc.) to blade 20. The elongate blade 20 includes a first root end 28 which is coupled to the central hub 18 when mounted to rotor 16, and a tip end 30 longitudinally opposite to root end 28. As discussed above, the outer shell 24 includes a first, upper shell half 32 on the suction side of the blade 20, and a second, lower shell half 34 on the pressure side of the blade 20, the upper and lower shell halves 32, 34 being coupled together along a leading edge 36 and a trailing edge 38 located opposite one another across a width of the blade 20.

[0027] In accordance with an exemplary embodiment of the invention and as illustrated in Fig. 4, a molding apparatus 50 may be used to form the blades 20 of wind turbine 10. The molding apparatus 50 includes a first mold half 52 and a second mold half 54 positioned relative to each other and positioned relative to a support surface 56, such as the ground, floor, platform, etc. of a manufacturing facility. As will be explained in more detail below, the first mold half 52 is configured to be used to at least partially form the first shell half 32 and the second mold half 54 is configured to be used to at least partially form the second shell half 34. To this end, the first mold half 52 includes a contoured surface 58 at a first end 60 (e.g., an upper end) thereof generally corresponding to a negative of the contoured surface of the first shell half 32. Similarly, the second mold half 54 includes a contoured surface 62 at a first end 64 (e.g., an upper end from the perspective of Fig. 4) thereof generally corresponding to a negative of the contoured surface of the second shell half 34. The first and second mold halves 52, 54 may be formed from fiberglass reinforced with a metal frame (e.g., steel frame), as is generally understood in the art.

[0028] In accordance with an aspect of the invention, and as mentioned above, at least one of the mold halves 52, 54 is movable relative to the other such that mold halves 52, 54 may be used to couple the first and second blade shell halves 32, 34 together and thereby complete the construction of the blade 20. In an exemplary embodiment, the molding apparatus 50 may have a clamshell configuration having one fixed mold half and a second movable mold half movable relative to the fixed mold half so as to be positionable generally over the top of the fixed mold half. In this regard, the first mold half 52 may be configured to be fixed relative to the support surface 56, and the second mold half 54 may be configured to be movable relative to the first mold half 52 (and relative to support surface 56). For example, a second end 66 of the first mold half 52 may be supported by, such as by directly resting on, support surface 56. Moreover, the first mold half 52 may be secured to the support surface 56, such as by suitable fasteners and the like. It should be recognized, however, that the first mold half 52 may be fixedly supported on support surface 56 in other ways. It should also be recognized that in an alternative embodiment, the first mold half 52 may be movable and the second mold half 54 may be stationary.

[0029] With such a clamshell configuration, the second mold half 54 may be movable relative to the first mold half 52 between an opened position, illustrated in Fig. 4, for example, and a closed position, illustrated in Fig. 10, for example. In the opened position, the contoured surfaces 58, 62 of the first and second mold halves 52, 54, respectively, are exposed such that the blade shell halves 32, 34 may be at least partially formed therein in accordance with a method to be described below. For example, in the opened position, the second mold half 54 may be positioned similarly to the first mold half 52, such as with a second end 68 of the second mold half 54 being supported by, such as by directly resting on, support surface 56. The invention, however, is not so limited as the second mold half 54 may be unsupported or supported on another object when in the opened position. In the closed position, the second mold half 54 may be positioned over the top of the first mold half 52 such that the respective pairs of confronting edges 70a, 70b, 72a, 72b of the first and second shell halves 32, 34 may be generally aligned and in contact or near contact with each other so as to be coupled together (Fig. 10).

[0030] To effectuate movement of the second mold half 54 relative to the first mold half 52, the molding apparatus 50 may include a turner assembly 78, which may be positioned between the first and second mold halves 52, 54 when in the opened position, for example. In one embodiment, the turner assembly 78 includes a hinge or pivot mechanism, generally shown at 80, having a first pivot portion 82, a second pivot portion 84 and a pivot pin 86 operatively coupled to the first and second pivot portions 82, 84 and which defines a pivot axis 88. At least one of the first and second pivot portions 82, 84 is rotatable relative to the other about pivot axis 88. As illustrated in the figures, the pivot mechanism 80 may be arranged such that the pivot axis 88 extends in a direction generally parallel to the longitudinal axis 90 of the blade 20 (Fig. 3). Additionally, in an exemplary embodiment the second pivot portion 84 may be rigidly coupled to the second mold half 54, such as along a side wall 92 thereof. Accordingly, the second mold half 54 is permitted to rotate about pivot axis 88 defined by pivot mechanism 80.

[0031] Those of ordinary skill in the art will recognize various mechanisms for rotating the second mold half 54 about the pivot axis 88. For example, the molding apparatus 50 may include one or more controllable prime movers, shown schematically at 94, operatively coupled to the turner assembly 78 (or alternatively the second mold half 54) for rotating the second mold half 54 about pivot axis 88. The prime mover 94 may include, without limitation, a wide variety of motors and/or actuators arranged in such a manner as to allow controlled rotation of the second mold half 54 about pivot axis 88. Additionally, the prime mover 94 may be operatively coupled to a controller, shown schematically at 96, for controlling the prime mover 94 and thus the rotation of the second mold half 54 about pivot axis 88.

[0032] As can be appreciated by one of ordinary skill in the art, the controller 96 may include one or more processors that manipulate signals (analog and/or digital) based on operational instructions that are stored in a memory. The controller 96 may further include an Input/Output (I/O) interface employing a suitable communication protocol for communicating with prime mover 94 and a data port to allow communication between the controller and/or a network or other device, such as a computer and/or data storage device. The controller 96 may include a human machine interface (HMI) operatively coupled to the processor and include output devices, such as alphanumeric and/or graphical displays, a touch screen, and other visual indicators, and input devices and controls, such as an alphanumeric keyboard, a pointing device, keypads, pushbuttons, control knobs, etc., capable of accepting commands or input from the operator and transmitting the entered input to the processor. The processor may operate under the control of an operating system, and executes or otherwise relies upon computer program code or logic embodied in various computer software applications to read data from and transmit instructions or signals to the various components operatively coupled to the controller 96.

[0033] In accordance with one aspect of the invention, the pivot mechanism 80 is not relegated to being in a fixed position relative to the support surface 56, or to other fixed components of the molding apparatus 50, such as the first mold half 52. Instead, the turner assembly 78 may be configured such that the pivot mechanism 80 may be movable relative to, for example, the support surface 56 or the first mold half 52. As will be discussed in more detail below, the ability to move the pivot mechanism 80, and more particularly the ability to move pivot axis 88, provides certain benefits that address some of the drawbacks of current molding devices discussed above.

[0034] To effectuate the movement of the pivot mechanism 80, the turner assembly 78 may include a track 110 that operates as a guide or otherwise at least partially controls the movement of the pivot mechanism 80. The track 110 may be coupled to a fixed object, such as the support surface 56 or the first mold half 52, as is illustrated in Figs. 4 and 4A. In one embodiment, the track 110 may be configured to permit movement of the pivot mechanism 80 along a generally linear translation path having a translation axis 112 and defining two generally opposed directions of movement along that axis. More particularly, in one embodiment, the translation axis 112 may be generally perpendicular to the longitudinal axis 90 of the blade 20. For example, the translation axis 112 may be generally vertically oriented such that the pivot mechanism 80 is movable along track 110 in a generally upwardly and downwardly direction and relative to, for example, support surface 56.

[0035] In the exemplary embodiment, the track 110 may include a pair of spaced apart supports or lugs 114, 116 and a travel rod 118 extending therebetween and having an axis that is at least parallel to (and perhaps coaxial with) the translation axis 112. The lugs 114, 116 may be coupled to the first mold half 52, such as on a side wall 120 thereof. As shown in Fig. 4, the side walls 120, 92 of the first and second mold halves 52, 54, respectively, may be configured to confront each other when the molding apparatus 50 is in the opened position with the turner assembly 78 disposed therebetween. Lug 114 may be positioned adjacent the first end 60 of the first mold half 52, and the lug 116 may be positioned adjacent the second end 66 of the first mold half 52 so that rod 118 defines a sufficiently long travel path to achieve the purposes as more fully described below.

[0036] In accordance with this aspect of the invention, the pivot mechanism 80 may be movably coupled to the track 110. In this regard, the first pivot portion 82 may include a bushing or collar 122 which is mounted about the travel rod 118 such that movement of the first pivot portion 82, and thus the pivot mechanism 80, is limited to movement along the rod 118 and along translation axis 112. The collar 122 may include additional features that facilitate the movement of the collar 122 along the rod 118. For example, the collar 122 may include various bearings, seals, lubricants (e.g., grease, oils etc.), or other devices that facilitate such movement. The rod 118 may also include lubricants to reduce the friction and ease movement of the collar 122 along the rod 118. In any event, it should be understood that the collar/rod arrangement limits movement of the pivot mechanism 80 along a linear path defined by travel rod 118 and directed along translation axis 112.

[0037] To move the pivot mechanism 80 along the travel rod 118, the turner assembly 78 may include a second prime mover operatively coupled to, for example, the pivot mechanism 80. As illustrated in Figs. 4 and 4A, in one embodiment, the prime mover may include an actuator, generally shown at 124, which is operatively coupled to the pivot mechanism 80 for moving the pivot mechanism 80 along travel rod 118. In this regard, the actuator 124 may include a first end 126 that remains fixed. For example, the first end 126 may be coupled to the support surface 56 or to the first mold half 52. This coupling may also be achieved by a swivel connector 128 so as to allow greater degrees of freedom in its movements during use. The actuator 124 may further include a second end 130 coupled to the pivot mechanism 80, such as at first pivot portion 82 and via a suitable connector as known to those of ordinary skill in the art. The actuator 124 is configured to move between an extended position (Fig. 4A) and a contracted position (Fig. 7). In the extended position, the first and second ends 126, 130 are separated by a first distance, and in the contracted position, the first and second ends 126, 130 are separated by a second distance less than the first distance.

[0038] As shown in Figs. 4 and 4A, when the actuator 124 is in the extended position, the collar 122 is adjacent lug 114 of track 110. In this position, the pivot mechanism 80, and more particularly the pivot axis 88 thereof, may be at its highest position (e.g., vertical position) relative to support surface 56. In contrast to this, and as shown in Fig. 7, when the actuator 124 is in the contracted position, the collar 122 is adjacent the lug 116 of track 110. In this position, the pivot mechanism 80, and more particularly the pivot axis 88 thereof, may be at its lowest position (e.g., vertical position) relative to support surface 56. To control the actuator 124, and thus the position of the pivot mechanism 80 along track 110, actuator 124 may be operatively coupled to a suitable controller, such as controller 96 as schematically shown in Fig. 4A. It should be realized, however, that the actuator 124 may be coupled to its own controller, separate from the controller that controls the rotation of the second mold half 54 about pivot axis 88.

[0039] In one embodiment, the actuator 124 may be configured as a hydraulic actuator. However, this is merely exemplary as other actuators, such as mechanical linear actuators (e.g., screw jack, ball screw, roller screw actuators, etc.), pneumatic actuators, electro-mechanical actuators, or other actuators known to those of ordinary skill in the art, may be used to facilitate movement of the pivot mechanism 80 along the travel rod 118. Accordingly, aspects of the invention should not be limited to any particular type of actuator.

[0040] With the molding apparatus 50, including the turner assembly 78, described from a structural and functional standpoint, use of the molding apparatus 50 to manufacture a wind turbine blade 20 will now be described. For purposes of description, use of the molding apparatus 50 will be described from an initial position of when the mold halves 52, 54 are in the opened position, as shown in Fig. 4. A coordinate system may be defined to aid in the description of the movement of the second mold half 54. In this regard, an x-coordinate axis may be defined which locates the pivot axis 88 relative to a reference point or plane, such as, for example, the support surface 56. A θ-coordinate direction may also be defined which provides an indication of the rotation of the second mold half 54 about the pivot axis 88.

[0041] In this regard, a first reference plane 170 may be defined which is fixed in space and a second reference plane 172 may be defined which moves with rotation of the second mold half 54. The angle between these two planes may be defined to be the θ coordinate. In one embodiment, the first reference plane 170 may be parallel to the support surface 56 (e.g., generally horizontal) and the second reference plane 172 may be generally aligned with a surface of the second mold half 54. The two reference planes 170, 172 may be coplanar when in the opened position such that θ has an initial value of approximately zero. It should be recognized, however, that other coordinate systems may be used to describe the movement of the second mold half 54 toward the closed position, and the invention is not limited to that used herein.

[0042] In this initial position, the actuator 124 may be in or near its fully extended position such that the pivot axis 88 may be located a distance $x = h_1$ from the support surface 56. It is contemplated that the distance h_1 may be as much as 3 to 5 meters and is expected to increase as wind turbine designs further evolve. As noted above, in the opened position, the contoured surfaces 58, 62 of mold halves 52, 54 are exposed such that the first and second shell halves 32, 34 may be at least partially formed using the mold halves 52, 54. In this regard, Fig. 5 is a schematic illustration of an exemplary process used to form the first and second shell halves 32, 34 using the molding apparatus 50.

[0043] As illustrated in this figure, the blade 20 is defined by a composite laminate 140 made up of a fiber material such as glass fiber, carbon fiber, or other material or combination of materials known to those of ordinary skill in the art of manufacturing wind turbine blades. In a specific embodiment, the method includes the use of a plurality of layers 142 of a resin-impregnated fiber fabric. Alternatively, the method may include using layers 142 that are dry (i.e., resin-free), with resin being injected into the forming process and directed toward the layers 142. A vacuum bag 144 may be applied over the composite laminate 140 and a vacuum source 146 is actuated to evacuate excess air and resin from the layers 142. A heat source (not shown) may then be used to cure the resin resulting in formation of the composite laminate 140.

[0044] The method may include placing a release agent 148 such as a liquid release coating, a wax, or a solid barrier (e.g., Teflon® tape) over a tool, schematically shown at 150. In the instant application, the tool 150 would include the contoured surfaces 58, 62 of the first and second mold halves 52, 54. An optional layer (not shown) of release material (e.g., film) may then be applied over the release agent 148. In addition, a first optional layer of peel ply 152 may be applied over the release material layer, if present, or directly over the release agent 148. Next, several layers 142 of the fiber fabric may be placed over one another (e.g., stacked) to define an assembly of layers 142 and resin, until a desired, predetermined thickness is reached. Once the desired thickness of the assembly is reached, a second optional peel ply 154 made, for example, of nylon or some other tightly woven fabric impregnated with a release agent, may be applied over the formed assembly.

[0045] Once the second optional peel ply 154 is in place, a layer 156 of release film may be applied thereover. In the embodiment of Fig. 5, a breather or bleeder material layer 158 may then be applied over the second optional peel ply 154, which is configured to absorb excess resin and let gases escape during formation of the composite laminate 140. The breather or bleeder material layer 158 also provides a continuous air path for pulling of the vacuum and prevents direct contact between the resin and the vacuum bag 144. With continued reference to Fig. 5, the vacuum bag 144 may be placed over the above-mentioned layers and secured in place against the tool 150 via a securing element 160, such as a bag sealant tape, and the vacuum source 146 actuated. Actuation of the vacuum source 146 is effective to pull the bag 144 toward the tool 150, i.e., pull the assembly of layers 142 toward the contoured surfaces 58, 62 of mold halves 52, 54 so as to give shape to the first and second shell halves 32, 34. The vacuum source 146 is also effective to remove air as well as excess resin from the assembly of layers 142 and resin. In a subsequent step, the resulting assembly is allowed to cure or at least partially cure within the mold halves 52, 54.

[0046] In an alternative embodiment of the method described above, when the layers 142 are not pre-impregnated with resin, but are instead dry layers of fiber, a resin distribution system (not shown) may be placed in communication with the layers 142 under the vacuum bag 144 and used to distribute resin to the layers 142. It should be recognized that the method of forming the first and second shell halves 32, 34 using the mold halves 52, 54 as described above is merely exemplary. Those of ordinary skill in the art will recognize a host of other or related methodologies which may be used to form the shell halves 32, 34 in the mold halves 52, 54. These alternative methodologies remain within the scope of the present invention. No matter what particular method is used to form the first and second shell halves 32, 34, at the end of this step, the at least partially formed (e.g., at least partially cured) shell halves 32, 34 may be positioned in their respective mold halves 52, 54, with the mold halves 52, 54 in their opened position, as shown in Fig. 4.

[0047] The next step in accordance with the method includes moving the second mold half 54 so as to be positioned over top of the first mold half 52, i.e., move the second mold half 54 toward the closed position. As eluded to above, in an advantageous aspect of the invention, this movement has two separate components, each component being separately controllable (i.e., each component being independently controlled). The first component is the rotation of the second mold half 54 about the pivot axis 88 (indicated by the θ coordinate). As noted above, this movement may be achieved by prime mover 94 under, for example, the control of controller 96. The second component is the movement of the pivot mechanism 80, including the pivot axis 88, along the translation axis 112 defined by the travel rod 118 of track 110 (indicated by the x coordinate). As noted above, this movement may be achieved by actuator 124 under, for example, the control of controller 96.

[0048] From a broad perspective, the pivoting movement of the second mold half has two portions or phases. The first phase has the second mold half moving toward the ceiling of the manufacturing facility such that a gap distance therebetween is decreasing. The second phase has the second mold half moving away from the ceiling of the manufacturing facility such that a gap distance therebetween is increasing. In accordance with an aspect of the invention, during the first phase of the rotation, the pivot axis may be shifted downwardly to provide additional space for rotation of the mold half and thereby avoid contact with the ceiling of the facility. During the second phase of the rotation, however, the pivot axis may be shifted back upwardly so that the second mold half may properly mate with the first mold half in the closed position. Figs. 4 and 6-10 illustrate a progression of the second mold half 54 as it is moved from the opened position to the closed position, as will now be described.

[0049] As the actuator 124 is in or near its fully extended position when in the opened position, the initial movement of the second mold half 54 may be solely rotational through, for example, actuation of prime mover 94. Of course, depending on what supports the second mold half 54 when in the opened position and/or the design of track 110, it may be possible to move the second mold half 54 along translation axis 112, such as upwardly away from support surface 56, prior to or simultaneous with the initial rotation of the second mold half 54 about pivot axis 88. In any event, as illustrated in Fig. 6, as the second mold half 54 is rotated, a clearance or gap g_1, taken in a direction generally parallel to the translation axis 112, forms between the second mold half 54 and the support surface 56. This gap distance g_1 represents the distance the pivot axis 88 could be translated along the travel rod 118 in a generally downwardly direction before the second mold half 54 would contact the support surface 56. The primary point, however, is that rotation of the second mold half 54 creates sufficient space for the downward movement of the pivot axis 88.

[0050] With this in mind, as the second mold half 54 continues to rotate toward the closed position, the pivot mechanism 80, and thus the pivot axis 88, may be moved along the travel rod 118 in a direction along the translation axis 112 and in, for example, a generally downwardly direction toward the support surface 56. As noted above, this may be achieved by controlling actuator 124, and more particularly, moving actuator 124 away from its extended position and toward is contracted position. In an exemplary embodiment, the movement of the pivot mechanism 80 along travel rod 118 occurs simultaneously with the rotation of the second mold half 54 about the pivot axis 88, i.e., both the first and second components of the movement occur together for at least for a portion of the movement of the second mold half 54. In an alternative embodiment, however, the components of the movement may be separated such that only a single component is occurring at any one time. By way of example, in this methodology, the second mold half 54 would: i) rotate without any translational movement; ii) stop rotating; iii) translate without rotational movement; iv) stop translating, and continue in a similar sequence so as to achieve the desired result in accordance with the invention.

[0051] No matter whether the translational movement and the rotational movement occur simultaneously or in separate, discrete steps in accordance with aspects of the invention, in one embodiment, the actuator 124 should be moving toward its contracted position prior to the second mold half 54 reaching its upright position (e.g., $\theta \cong 90°$). This position is illustrated in Fig. 7 wherein the pivot axis 88 is now located at a height $x = h_2$ above the support surface 56, which is less than h_1. More particularly, in accordance with an aspect of the invention, the downward translational movement of the pivot mechanism 80 is coordinated with the rotational movement of the second mold half 54 such that the second mold half 54 does not contact the ceiling 176 of the manufacturing facility or other fixtures, such as lights, duct work, etc. (not shown), adjacent the ceiling 176. Those of ordinary skill in the art will recognize how to coordinate these movements so as to achieve this particular objective. These coordinated movements may be done manually, such as through controller 96. Alternatively, the coordinated movements may be programmed into controller 96 and executed in an automated manner.

[0052] In any event, when the second mold half 54 is in the upright position, the second mold half 54 may be separated from the ceiling 176 (or fixtures) by a gap g_2. Referring back to Fig. 4, curves 178 and 180 show the path of travel of points P_1 and P_2, respectively, in the event the pivot axis 88 remains fixed (relative to that shown in Fig. 4) with the actuator 124 in the extended position. By comparing these curves to the positions shown in Figs. 7 and 8 (discussed below), it is clear that but for the pivot axis 88 moving downwardly, the second mold half 54 would contact the ceiling 176 as it rotates toward the closed position. However, because the pivot axis 88 is able to move downwardly, by moving the actuator 124 toward the contracted position, the second mold half 54 does not contact the ceiling 176 and the points P_1 and P_2 are located safely below the ceiling 176. It is contemplated that the amount of travel of the pivot mechanism 80 along travel rod 118 as the actuator 124 moves between its extended and contracted positions may be between about 1 meter and about 2 meters. However, this amount may vary depending on the specific application.

[0053] Depending on the particular configuration of the second mold half 54, as the second mold half 54 continues to be rotated toward the closed position, the gap between the second mold half 54 and the ceiling 176 may reach a minimum, as illustrated in Fig. 8. This minimum gap g_{min} exists when that portion of the second mold half 54 furthest from the pivot axis 88, identified by the distance R_{max} in Fig. 4 (and in the instant case that portion or point being coterminous with the point P_2), is vertically aligned with the pivot axis 88. This peak position may represent the maximum vertical height of the second mold half 54 during its movement to the closed position. Certainly in this position, the actuator 124 should be in a fully contracted configuration to provide the best opportunity for the second mold half 54 to clear the ceiling 176. The position of the second mold half 54 from that shown in Fig. 4 to that shown in Fig. 8 represents the first phase of the rotation where the distance between the second mold half 54 and the ceiling 176 decreases. As described, the pivot axis 88 may be moved downwardly during this phase.

[0054] Fig. 9 illustrates the second mold half 54 after it has passed the upright position and the peak positions shown in Figs. 7 and 8, respectively. In this regard, as the second mold half 54 moves further toward the closed position, the gap g_3 between the second mold half 54 and the ceiling 176 starts to increase (i.e., the second mold half 54 moves away from the ceiling 176). However, in order to allow the second mold half 54 to properly mate up with the first mold half 52, the pivot axis 88 may have to be moved upwardly and back towards its original position, i.e., moved so that the pivot axis 88 is generally aligned with the interface between the first and second mold halves 52, 54 when in the closed position, as shown in Fig. 10. For example, as illustrated in Fig. 9, the pivot axis 88 may have a height $x = h_3$ relative to the support surface 56 which may be greater than h_2 but less than h_1. As one can imagine, if the pivot axis 88 were not moved upwardly toward its original position, the second mold half 54 might contact the first mold half 52 prematurely and certainly not in a configuration wherein the second mold half 54 is positioned over top of the first mold half 52 such that the edges 70a, 70b, 72a, 72b of first and second shell halves 32, 34 are in contact or near contact with each other so as to be coupled together.

[0055] Similar to the above, the pivot mechanism 80, and thus the pivot axis 88, may be moved along the travel rod 118 in a direction along the translation axis 112 and in, for example, a generally upwardly direction away from the support surface 56. As noted above, this may be achieved by controlling actuator 124, and more particularly, moving actuator 124 from its contracted position toward its extended position. In an exemplary embodiment, the upward movement of the pivot mechanism 80 along travel rod 118 may occur simultaneously with the rotation of the second mold half 54 about the pivot axis 88, i.e., both the first and second components of the movement occur together for at least a portion of the movement of the second mold half 54. In an alternative embodiment, however, the components of the movement may be separated such that only a single component is occurring at any one time. In accordance with an aspect of the invention, the upward movement of the pivot mechanism 80 may be coordinated with the rotational movement of the second mold half 54 such that the second mold half 54 does not prematurely contact the first mold half 52. Those of ordinary skill in the art will recognize how to coordinate these movements so as to achieve this particular objective. These coordinated movements may be done manually, such as through controller 96. Alternatively, the coordinated movements may be programmed into controller 96 and executed in an automated manner.

[0056] Fig. 10 illustrates the mold halves 52, 54 when in the closed position ($\theta \cong 180°$). In this position, the pivot axis 88 has been moved back to approximately its original position (e.g., a height $x = h_1$ relative to support surface 56) by moving the actuator 124 back to its extended or to its nearly extended position. In the closed position, the second mold half 54 is positioned overtop the first mold half 52 such that the edges 70a, 70b, 72a, 72b are in contact or near contact with each other. Accordingly, these edges, which may represent the leading and trailing edges 36, 38 of the blade 20, may be bonded together to complete the construction of the blade 20. Although the spar 26 is not shown in the molding sequence shown in Figs. 4 and 6-10, those of ordinary skill in the art will recognize how to incorporate such a spar 26 into the blade construction using molding apparatus 50. The position of the second mold half 54 from that shown in Fig. 8 to that shown in Fig. 10 represents the second phase of the rotation where the distance between the second mold half 54 and the ceiling 176 increases. As described, the pivot axis 88 may be moved upwardly during this phase.

[0057] Fig. 11 illustrates a portion of the molding apparatus 50 from a perspective view. As will be appreciated, the molding apparatus 50 may be relatively long in the longitudinal direction (i.e., the direction of axis 90 of blade 20). Accordingly, the molding apparatus 50 may include one or more turner assemblies 78 for rotating the second mold half 54 relative to the first mold half 52 between the opened and closed positions. As noted above, each of the turner assemblies 78 may include a pivot mechanism 80, a track 110 for guiding the movement of the pivot mechanism 80, and an actuator 124 for moving the pivot mechanism 80 along the track 110. Those of ordinary skill in the art will recognize the number and location of the turner assemblies 78 along, for example, side walls 92, 120 to provide for proper operation of the molding apparatus 50. It should be recognized that the turner assemblies 78 may be operatively coupled to a single controller, such as controller 96, so as to synchronize the operation of all of the turner assemblies 78 and effectuate controlled movement of the second mold half 54 from the opened position to the closed position.

[0058] In summary, blade sizes are growing to such an extent that the molding apparatus used to manufacture the blades may not fit within the existing manufacturing facilities. In this regard, existing manufacturing methods call for rotatable mold halves having a fixed pivot axis. To accommodate the growing size of wind turbine blades, molds have also increased in size, to the point where there is some concern that the rotating mold will contact the ceiling during its movement to the closed position. Aspects of the present invention as fully disclosed herein address this and other problems of conventional systems. More particularly, the molding apparatus disclosed herein includes a pivot axis that is translatable along a translation axis. In this way, as the mold half is rotated, the pivot axis may be moved so as to provide sufficient space for the mold to rotate without contacting the ceiling of the manufacturing facility. This will, in turn, allow the existing manufacturing techniques (e.g., rotating mold halves) to continue being used in existing manufacturing facilities with minimal, cost-effective modifications to the molding apparatus.

[0059] While the invention has been illustrated by a description of various embodiments, and while these embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. For example, in the method described above, the first and second shell halves were nearly completely formed in the first and second shell halves (e.g., but for being fully cured) prior to rotation of the mold halves to the closed position. The invention is not so limited however. In this regard, rotation of the mold halves toward the closed position can occur at other times of the formation process. By way of example, the layers of fabric (and optionally other components) may be place in the mold halves when in the opened position, but the application of vacuum pressure and/or curing may be performed after the mold haves have been moved to the closed position. Thus, the particular order of the steps may be varied and should not be limited to any particular order used to describe the exemplary embodiments.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- DE202010001462U1 **[0006]**

Patentkrav

1. Fremgangsmåde til at fremstille en vindmøllevinge (20) med en første skalhalvdel (32) og en anden skalhalvdel (34) under anvendelse af et støbeformsapparat (50) med en første støbeformshalvdel (52) og en anden støbeformshalvdel (54), fremgangsmåden omfattende:

mindst delvist at forme den første skalhalvdel (32) i den første støbeformshalvdel (52),

mindst delvist at forme den anden skalhalvdel (34) i den anden støbeformshalvdel (54),

at bevæge den første og anden støbeformshalvdel (52, 54) i forhold til hinanden fra en åbnet position, hvor respektive støbeflader af den første og anden støbeformshalvdel er afdækkede, til en lukket position, hvor støbefladerne af den første og anden støbeformshalvdel vender mod hinanden, bevægelsestrinnet yderligere omfattende:

at rotere den første og anden støbeformshalvdel (52, 54) i forhold til hinanden omkring en drejeakse (88),

at translatere drejeaksen (88) i en første retning af translation under bevægelse af støbeformshalvdelene mellem den åbnede og lukkede position; og

at translatere drejeaksen (88)i en anden retning af translation forskellig fra den første retning under bevægelse af støbeformshalvdelene mellem den åbnede og lukkede position; og

at koble den første skalhalvdel (32) og den anden skalhalvdel (34) for at danne vindmøllevingen (20), **kendetegnet ved at** mindst en af den første eller anden støbeformshalvdel (52, 54) er båret på en bæreflade (56) og drejeaksen (88) er placeret ved en højde i forhold til bærefladen (56), hvor at translatere drejeaksen (88) i den første retning omfatter at mindske højden af drejeaksen (88) i forhold til bærefladen (56) og at translatere drejeaksen (88) i den anden retning omfatter at øge højden af drejeaksen (88) i forhold til bærefladen (56).

2. Fremgangsmåden ifølge krav 1, hvor rotationen af den første og anden støbeformshalvdel (52, 54) fra den åbnede position til en mellemliggende position definerer en første fase af rotation af den første og anden støbeformshalvdel, og rotation af den første og anden støbeformshalvdel (52, 54) fra den mellemliggende position til den lukkede position definerer en anden fase af rotation, trinnet at translatere drejeaksen (88) i den første retning sker under den første fase og trinnet at translatere drejeaksen (88) i den anden retning sker under den anden fase.

3. Fremgangsmåden ifølge krav 2, hvor den første og anden støbeformshalvdel (52, 54) roterer igennem en vinkel θ på cirka 180° fra den åbnede position til den lukkede position og den mellemliggende position er cirka midtvejs igennem den fulde rotation af støbeformshalvdelene.

4. Fremgangsmåden ifølge et hvilket som helst af kravene 1-3, hvor at translatere drejeaksen (88) i den første retning omfatter at translatere drejeaksen (88) vertikalt nedad og at translatere drejeaksen (88) i den anden retning omfatter at translatere drejeaksen (88) vertikalt opad.

5. Fremgangsmåden ifølge et hvilket som helst af kravene 1-4, hvor rotations- og translationstrinnene sker samtidigt for mindst en del af den relative bevægelse af den første og anden støbeformshalvdel (52, 54).

6. Fremgangsmåden ifølge et hvilket som helst af kravene 1-4, hvor rotationstrinnet sker uden translation og translationstrinnene sker uden rotation.

7. Fremgangsmåden ifølge et hvilket som helst af kravene 1-6, hvor rotation af den første og anden støbeformshalvdel (52, 54) sker omkring en enkelt drejeakse.

8. Fremgangsmåden ifølge et hvilket som helst af kravene 1-7, hvor støbeformsapparatet (50) inkluderer en rotationsdrivmaskine (94) og en translationsdrivmaskine, hvor trinnet at rotere den første og anden støbeformshalvdel (52, 54) i forhold til hinanden omkring drejeaksen (88) yderligere omfatter at aktivere rotationsdrivmaskinen, og trinnet at translatere drejeaksen (88) i den første og anden retning omfatter at aktivere translationsdrivmaskinen.

9. Fremgangsmåden ifølge krav 8, hvor støbeformsapparatet (50) yderligere inkluderer en kontroller (96) koblet til rotationsdrivmaskinen (94) og translationsdrivmaskinen, hvor trinnene at rotere den første og anden støbeformshalvdel (52, 54) og at translatere drejeaksen (88) i den første og anden retning styres af kontrolleren (96) og implementeres i en automatiseret rækkefølge.

10. Støbeformsapparat (50) til fremstilling af en vindmøllevinge (20) med en første skalhalvdel (32) og en anden skalhalvdel (34) omfattende:

en første støbeformshalvdel (52) til at forme den første skalhalvdel (32) af vindmøllevingen;

en anden støbeformshalvdel (54) til at forme den anden skalhalvdel (34) af vindmøllevingen; og

en drejeranordning (78) koblet til mindst en af den første og anden støbeformshalvdel (52, 54) og konfigureret til at bevæge den første og anden støbeformshalvdel i forhold til hinanden mellem en åbnet position og en lukket position, den første og anden skalhalvdel (32, 34) konfigureret til at blive mindst delvist dannet i den første og anden støbeformshalvdel (52, 54) når i den åbnede position, og den første og anden skalhalvdel (32, 34) konfigureret til at blive koblet til hinanden for at forme vindmøllevingen (20) når i den lukkede position,

hvor drejeranordningen (78) inkluderer en drejemekanisme (80) koblet til mindst en af den første og anden støbeformshalvdel (52, 54) og definerer en drejeakse (88), hvor drejemekanismen (80) tilvejebringer roterende bevægelse af den første og anden støbeformshalvdel (52, 54) i forhold til hinanden omkring drejeaksen (88), og

hvor drejeranordningen (78) yderligere inkluderer et spor (110) koblet til drejemekanismen (80) og definerer en translationsakse (112), hvor sporet (110) tilvejebringer translaterende bevægelse af drejeaksen (88) i en retning generelt parallel med translationsaksen (112)

hvor sporet (110) yderligere omfatter et første øre (114), et andet øre (116) anbragt med mellemrum fra det første øre (114), og en bevægelsesstang (118) som strækker sig mellem det første og andet øre (114, 116).

11. Støbeformsapparatet ifølge krav 10, hvor drejeranordningen (78) yderligere omfatter en rotationsdrivmaskine (94) til at forårsage roterende bevægelse af den første og anden støbeformshalvdel (52, 54) i forhold til hinanden og en translationsdrivmaskine til at forårsage translaterende bevægelse af drejeaksen (88).

12. Støbeformsapparatet ifølge krav 11, yderligere omfattende en kontroller (96) virksomt koblet til rotationsdrivmaskinen (94) og translationsdrivmaskinen, hvor kontrolleren (96) styrer den roterende bevægelse af den første og anden støbeformshalvdel (52, 54) i forhold til hinanden og den translaterende bevægelse af drejeaksen (88).

13. Støbeformsapparatet ifølge krav 11 eller 12, hvor translationsdrivmaskinen inkluderer en aktuator (124) koblet til drejemekanismen (80) og bevægelig mellem en udstrakt position og en tilbagetrukket position, hvor aktuering af aktuatoren (124) bevæger drejemekanismen (80) langs sporet (110) og i en retning generelt parallel med translationsaksen (112).

14. Støbeformsapparatet ifølge et hvilket som helst af kravene 10-13, hvor drejeranordningen (78) definerer kun en enkelt drejeakse (88).

15. Støbeformsapparatet ifølge et hvilket som helst af kravene 10-14, hvor sporet (110) er koblet til den anden af den første og anden støbeformshalvdel (52, 54).

DRAWINGS

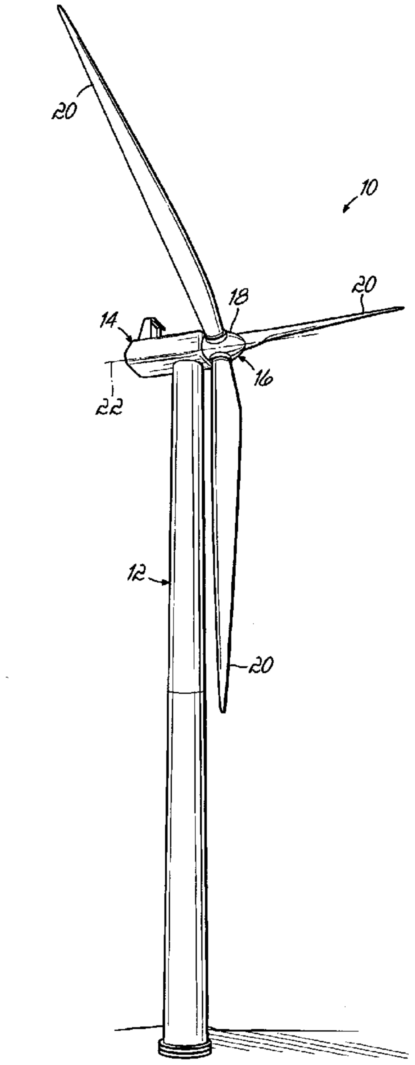


FIG. 1

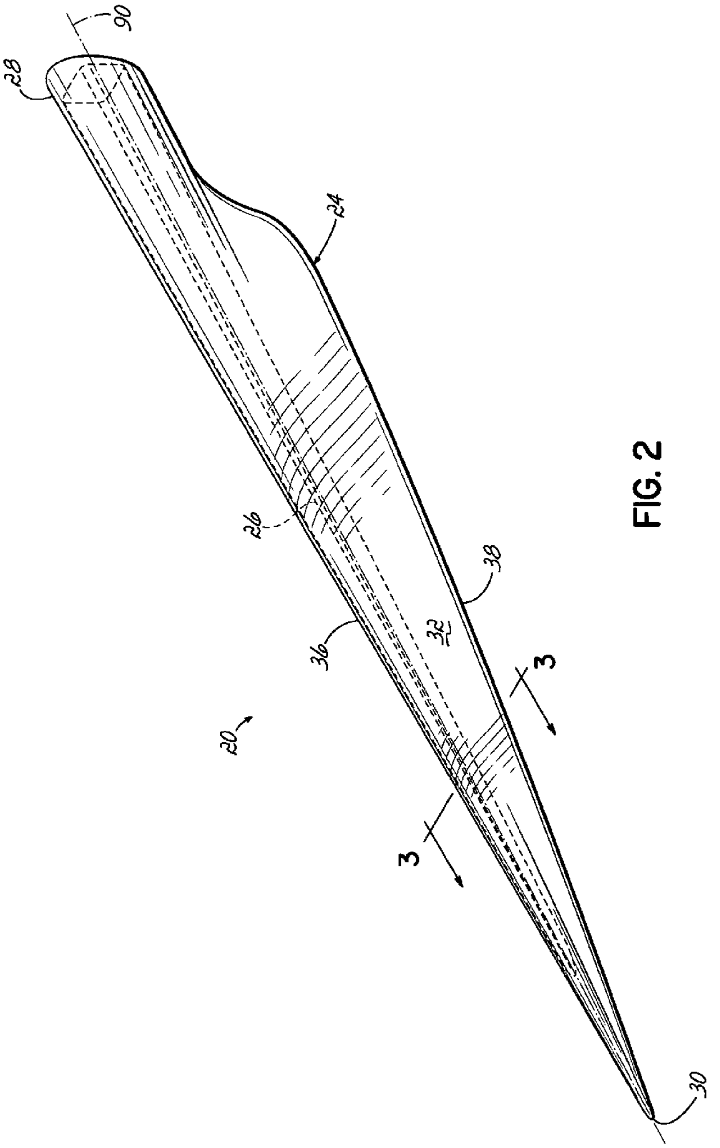


FIG. 2

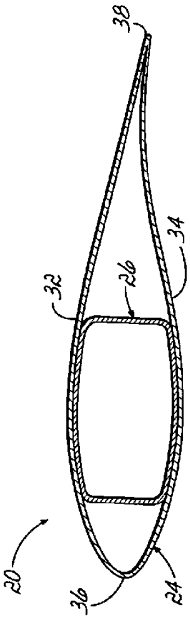
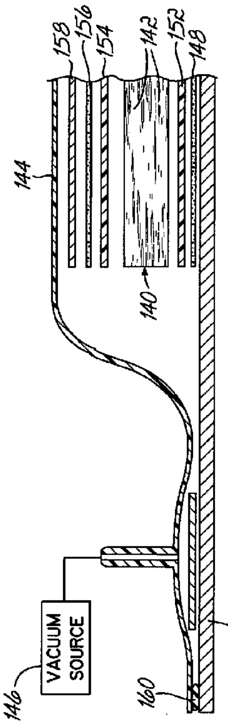

20
36
24
32
26
34
38

FIG. 3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156
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152
148
144
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VACUUM SOURCE
146
160
150

FIG. 5

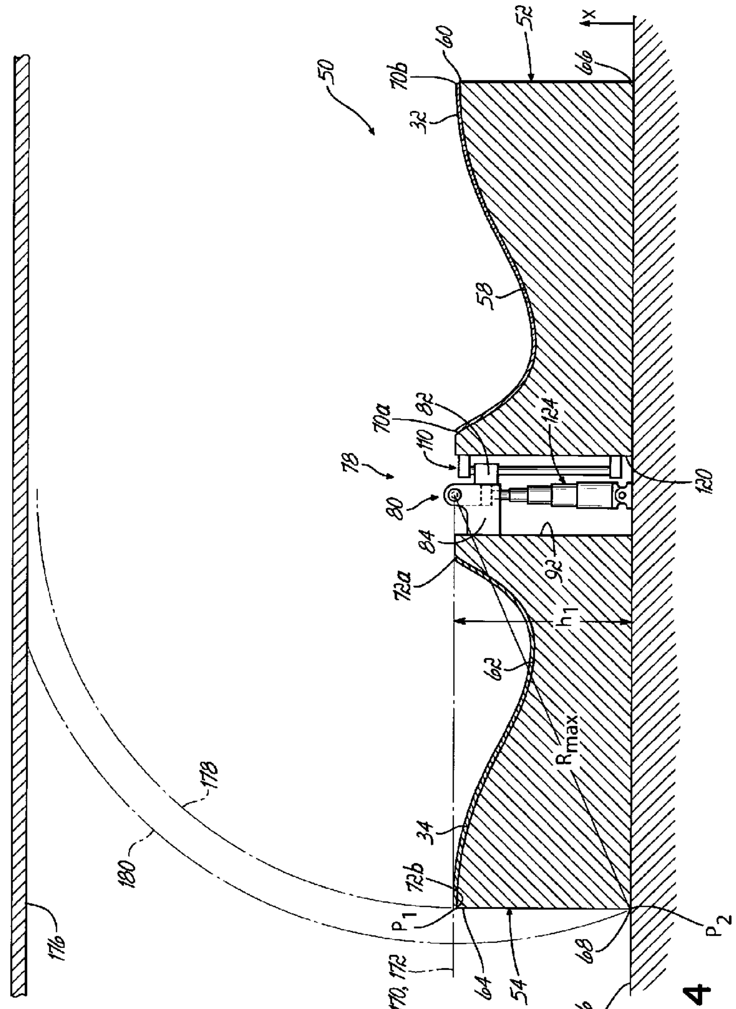
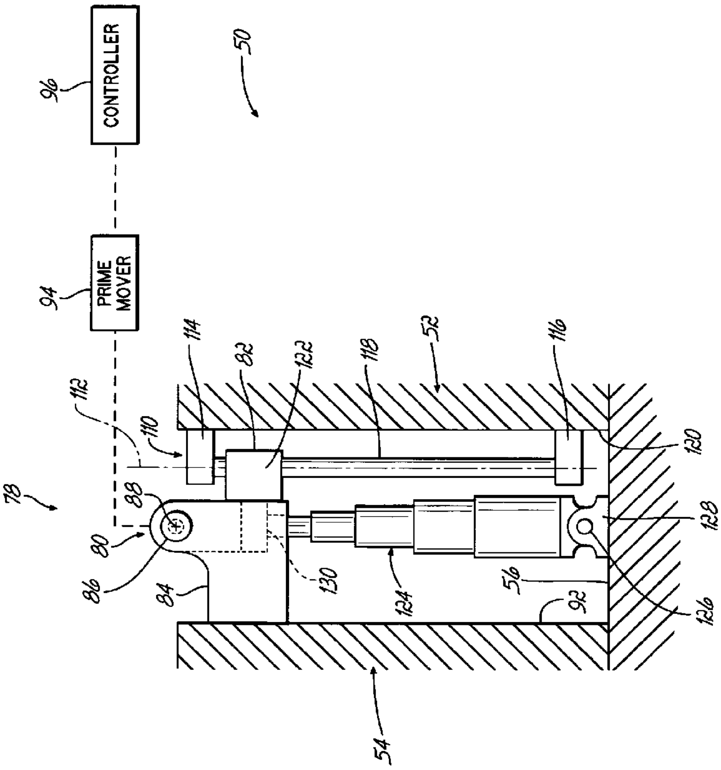

50
52
60
70b
66
x
32
58
70a
82
110
78
124
80
84
130
72a
92
h1
62
Rmax
34
178
180
72b
P1
P2
176
170, 172
64
54
68
56

FIG. 4


CONTROLLER
PRIME MOVER
96
94
50
78
80
86
88
84
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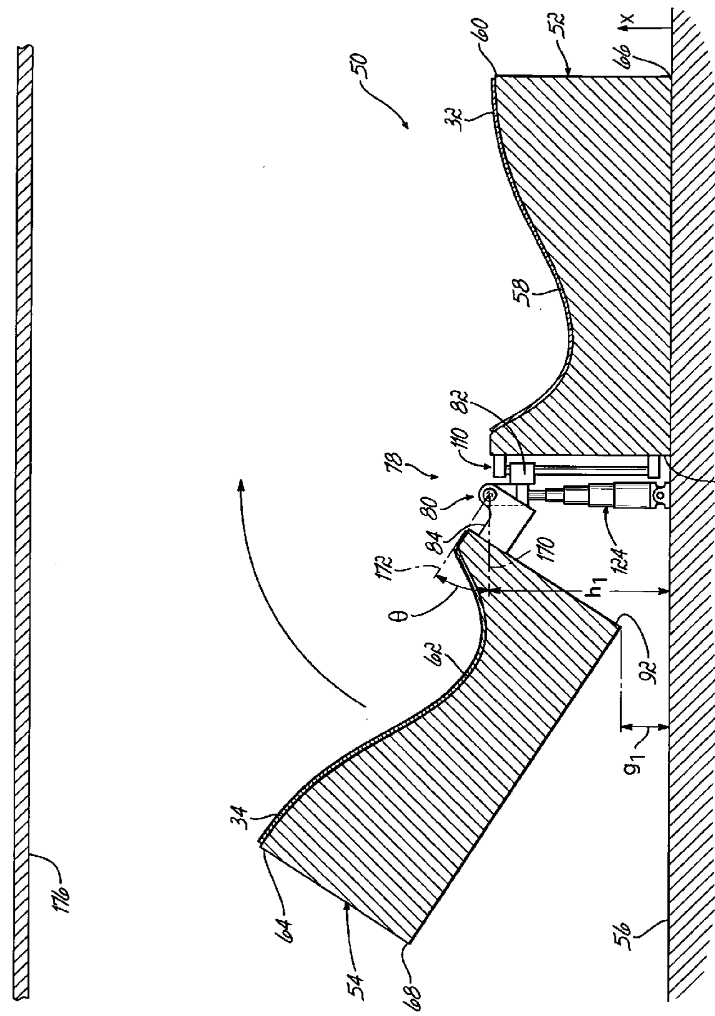
110
114
82
122
118
52
116
120
124
56
92
126
128
54

FIG. 4A


50
52
60
32
66
x
58
82
110
78
120
80
124
84
170
172
θ
h1
62
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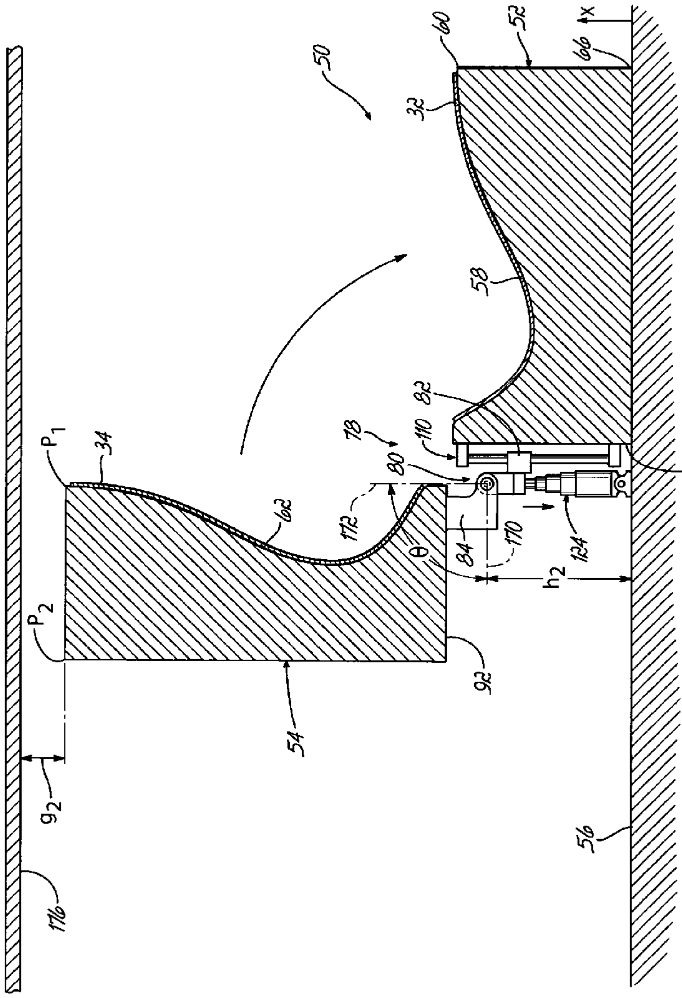
34
176
64
54
68
56

FIG. 6



50
52
60
66
x
32
58
82
110
78
80
120
124
170
172
84
θ
h2
62
34
P1
P2
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g2
176
56

FIG. 7

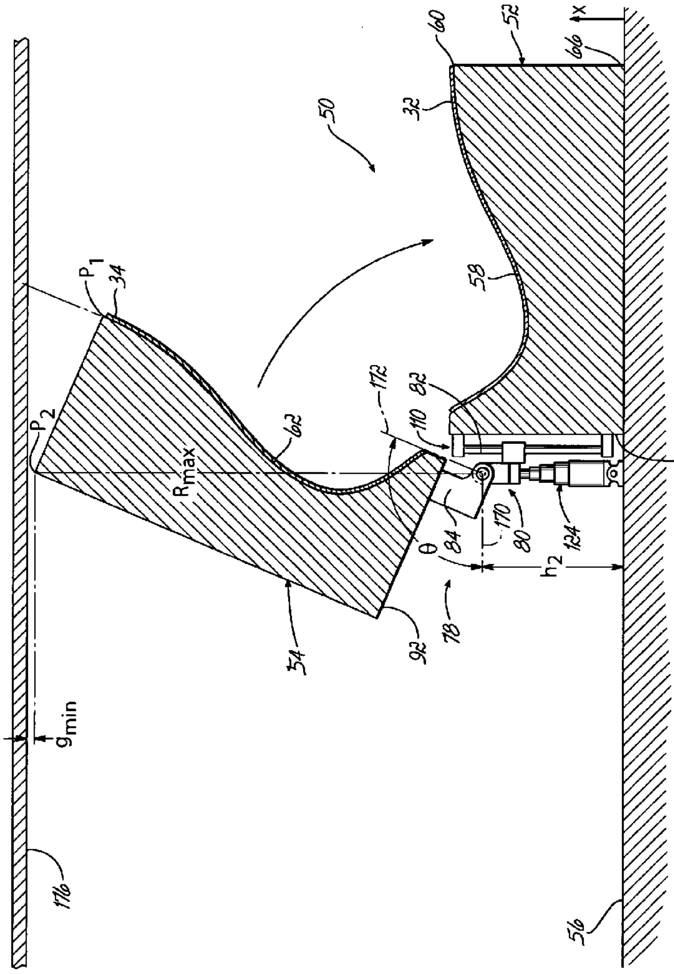
50
52
60
66
x
32
58
34
P_1
P_2
62
R_{max}
172
110
82
120
54
92
78
84
θ
170
80
124
h_2
g_{min}
116
56

FIG. 8

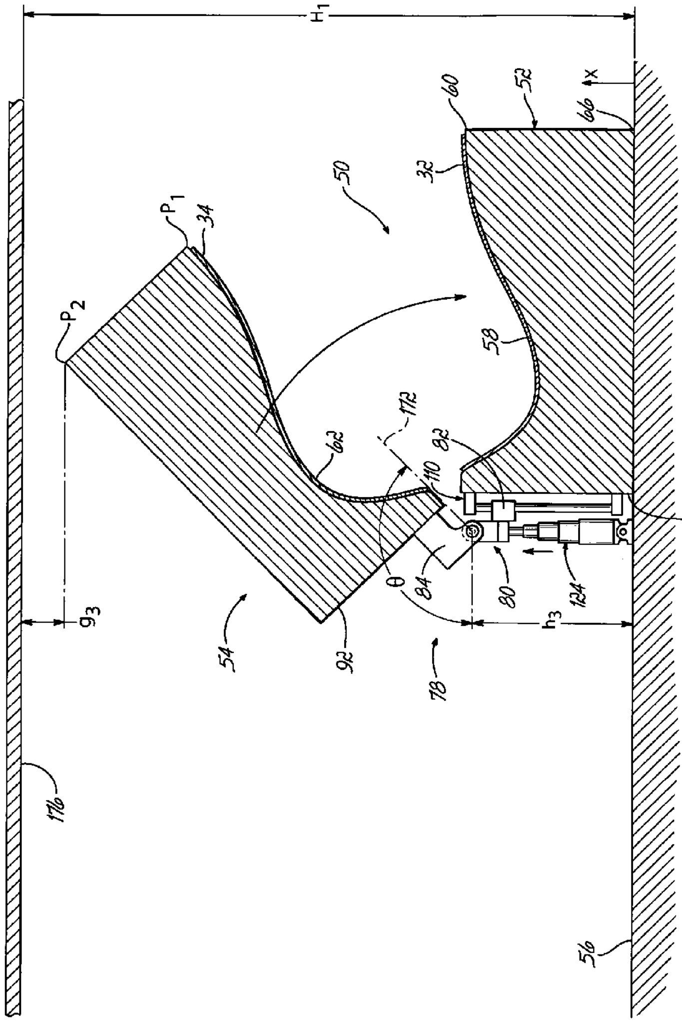
H1
x
60
52
66
50
32
P1
34
P2
58
172
62
82
110
120
θ
84
80
124
g3
h3
54
92
78
176
56

FIG. 9

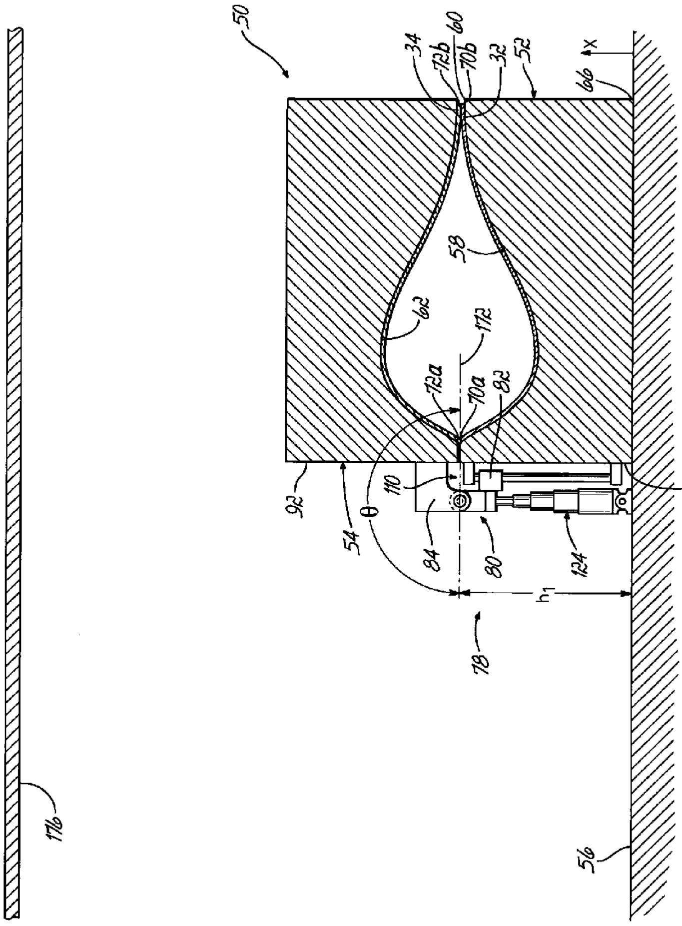
50
34
72b
60
70b
32
52
66
x
62
58
172
72a
70a
82
110
θ
92
54
84
80
124
120
h1
78
176
56

FIG. 10

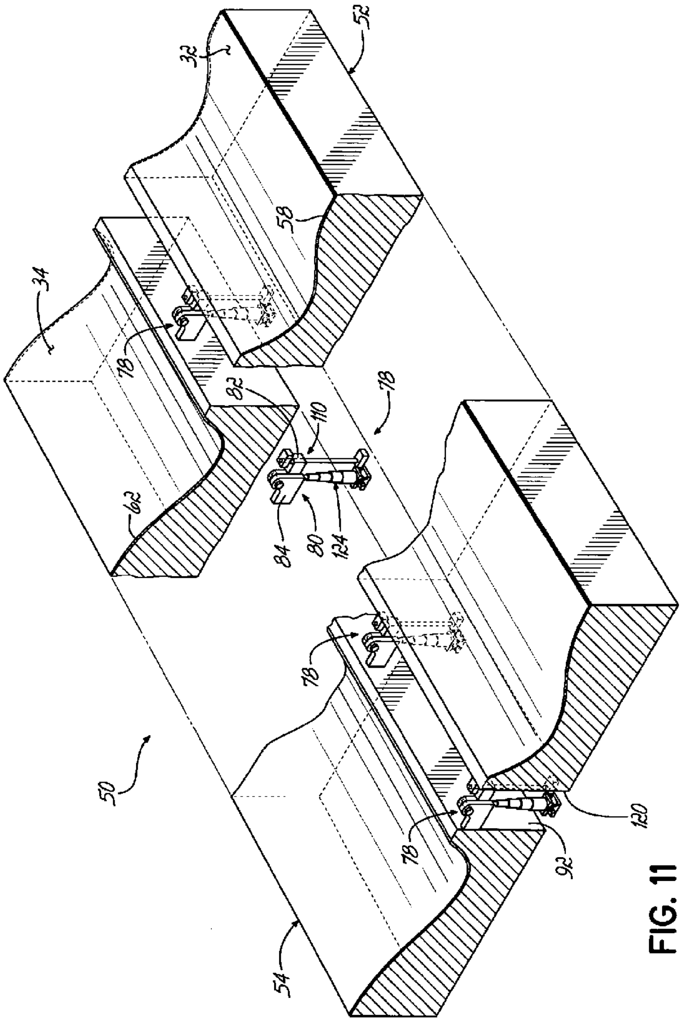

FIG. 11