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## (54) Title: METHOD FOR MANUFACTURING WIND TURBINE BLADES

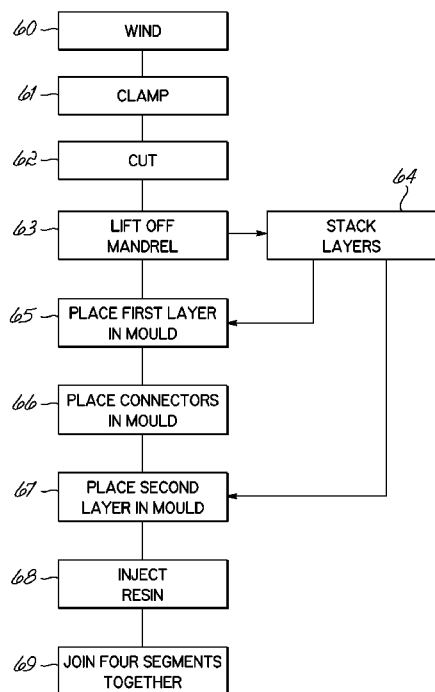


FIG. 15

(57) Abstract: A root section of a wind turbine blade is formed by winding a length of glass fibre around a mandrel 14 to form a glass fibre layer 16 without the application of any thermosetting resin. The glass fibre layer 16 is then clamped between two pairs of elongate upper and lower clamps 18, 19. The layer 16 is then cut between the two pairs of clamps, and separated from the mandrel 14 and lowered on to a supporting hammock 26. The resulting preform 28 is then placed in a mould (not shown) where a thermosetting resin is allowed to infuse the preform 28 so as to form a segment of a root section of a desired shape. Four such segments are joined together to form the root section.



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## METHOD FOR MANUFACTURING WIND TURBINE BLADES

The present invention relates to wind turbines, and in particular to methods of manufacturing the root section of a blade of a wind turbine.

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A typical wind turbine is illustrated in Figure 1. The wind turbine 1 comprises a tower 2, a nacelle 3 at top of the tower 2 and a rotor 4 operatively coupled to a generator 5 within the nacelle 3. The wind turbine 1 converts kinetic energy of the wind into electrical energy. In addition to the generator 5, the nacelle 3 houses the various components required to convert the wind energy into electrical energy and also the various components required to operate and optimize the performance of the wind turbine 1. The tower 2 supports the load presented by the nacelle 3, the rotor 4 and other wind turbine components within the nacelle 3.

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The rotor 4 includes a central hub 6 and three elongate rotor blades 7 which extend radially outward from the central hub 6. The blades 7 are configured to interact with the passing air flow to produce lift that causes the central hub 6 to rotate about its longitudinal axis. Wind exceeding a minimum level will activate the rotor 4 and allow it to rotate in a substantially perpendicular direction to the wind. The rotation movement is converted to electric power by the generator 5 and is usually supplied to the utility grid.

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Each rotor blade 7 comprises a proximal root section 8 and a distal tip end 9 section. The boundary of the root section 8 and the tip end section 9 of each blade 7 is indicated in Figure 1 by a dotted line 10. The root section 8 typically extends over about one fifth of the total length of the blade 7.

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The blades 7 must be able to withstand the large stresses typically encountered in use. In particular, they must be able to bear tensile, compressive and torsion loads and transmit these to the central hub 6. For this reason, the blades 7 must be rugged in construction.

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The root sections of wind turbine blades are of hollow construction and may be constructed from an internal spar formed from wound fibre glass and an external shell, also made from fibre glass. The spar in the root section is approximately circular in cross section. The spar comprises two spar caps and two spar webs. Fibre glass is particularly preferred as the material of construction because of its relatively low cost and

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high tensile strength. To form the spar, fibre glass is wound over the surface of a mandrel, and the fibre glass is impregnated with resin by running the fibre through a resin bath prior to winding. Alternatively, a thermosetting resin may be sprayed on to the fibre glass during winding. Alternatively, the fibre may be pre-impregnated with thermosetting resin. After winding is complete, the resin is cured by heating and under vacuum so as to bind the glass fibres together into the form of a rigid hollow cylinder which is removed from the mandrel by sliding the cylinder longitudinally along the surface of the mandrel.

10 The term "cylinder" as used throughout this specification is intended merely to refer to a generally elongate hollow structure, and is not intended to imply any further geometrical restriction. For example, a "cylinder" as used herein can be of any cross-sectional shape, and the cross-sectional shape of the structure can itself vary along its length.

15 It will be appreciated that, the requirement to slide the cylinder along the surface of the mandrel imposes severe limitations on the profile of the cylinder. Thus, the cylinder must either have a constant cross section along its length or one which monotonically increases (i.e. increases and never decreases) along an axial direction. Even with such limited profiles, considerable force is required to effect removal of the cylinder from the mandrel. Furthermore, it will be appreciated that it is not possible to create a profile in which any part of the cross section is concave, since the fibre must be under tension at all times during the winding operation.

25 The winding surface of the mandrel is shaped so as to match the desired shape of the root section. It follows that each different shape of root section requires a different mandrel.

Since the hollow cylinder is of substantially uniform thickness, the shape of the outer surface will also correspond to the shape of the mandrel. However, since the outer surface is formed by the outermost windings of glass fibre, it will therefore not be perfectly smooth. The inner surface of the outer shell of the root section is attached to the spar using a suitable adhesive. However, the quantity of adhesive must be sufficient not only to fill the void between the hollow cylinder and the outer shell, but also to fill the interstices between the outermost layer of glass fibres of the hollow cylinder.

Current wind turbine generators have blades up to 70 metres in length, with root sections up to 18 metres in length. The manufacture of root sections of such lengths using the above method is both impractical and expensive, since large root sections require correspondingly large mandrels for their manufacture and high-power motors and brakes are required to rotate such mandrels. In addition, the large size of such mandrels means that there is a lot of wasted factory space in the centre of the mandrels and they require high ceilings. Furthermore, to cure the thermosetting resin, it is necessary for the winding operation to take place within a heating chamber, which requires considerable floor space.

In addition, when manufacturing root sections for large turbine blades using this method, it is possible for the inner windings to be cured before the winding operation is complete, which can lead to non-uniformities in the finished root section.

The glass fibres are typically bound together with a thermosetting resin. As described above, this is typically achieved by impregnating the fibre glass in a bath with the resin as it is being wound on the mandrel or by spraying with resin as it is being wound on the mandrel. However, at high winding speeds, there is a tendency for the resin to be deflected away from the surface of the glass fibres, and this therefore limits the speed at which the fibre glass can be wound. Indeed, it has been found that spraying the resin on to the glass fibres during winding reduces the maximum winding speed by a factor of five.

It would be desirable to provide a method of manufacturing blades for wind turbine generators which overcomes or at least mitigates one or more of the above disadvantages.

Thus, in accordance with the present invention there is provided a method of manufacturing a section of a blade for a wind turbine generator, the method comprising:

- (a) winding a length of fibre around a mandrel so as to form a layer of fibrous material;
- (b) cutting the layer of fibrous material along the length of the mandrel;
- (c) removing the fibrous material from the mandrel; and
- (d) moulding the removed fibrous material into a desired shape.

In a preferred embodiment, the step of moulding takes place in a female mould.

The term "fibre" is intended to cover not only a single fibre but also a bundle of fibres, such as a fibre tow, a tape of pre-stitched multi-axial fibres, or a fibre ribbon or fibre sheet.

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The layer of fibrous material removed from the mandrel is known as a "preform". By moulding the preform, the final shape of the blade section is not governed by the surface profile of the mandrel, as with the conventional method described above, but rather by the shape of the mould used in the subsequent moulding step. As a consequence, a single mandrel can be used to manufacture blade sections having a number of different profiles.

The method preferably further comprises applying a binding agent, such as an adhesive to the fibre during winding. Such an arrangement serves to retain the wound fibre in place during and after the winding operation. The adhesive is preferably a thermoplastic adhesive, and is preferably applied by spraying on to the surface of the fibre. Alternatively, or in addition, a powdered epoxy may be sprayed on the fibre during winding to stabilise the fibre.

It is preferred that the fibrous material is cut while supported on the mandrel, since this enables the fibrous material to be removed from the mandrel simply by lifting it from the mandrel surface, as opposed to sliding it along the entire surface of the mandrel, as required by the conventional method described above.

This provides the further advantage that the preform can be formed in an arbitrary desired shape. For example, the central region of the preform, along the winding axis, could be either narrower or wider than the two end regions, neither of which arrangements would be possible with the above conventional method.

In addition, the arbitrary shape of the preform enables the method to be used for manufacturing single segments of a root section, which can then be joined together to form the complete root section. The preforms could also be used for other parts of the blade such as, for example, the aerodynamic shell.

The step of cutting the layer of fibrous material may be performed using a standard industrial process, for example, sawing, using ultrasonic knives or cutters, and/or shearing.

- 5 One advantage of this arrangement is that a large root section can be manufactured by joining together two or more small segments which are moulded from respective preforms formed by winding the fibre on one or more correspondingly small mandrels. With the conventional method, a large root section can only be manufactured using a correspondingly large mandrel.

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A further advantage is that the thickness of each segment can be selected independently, so as to manufacture a root section having a desired circumferential profile. This is particularly advantageous when the method is used to manufacture the internal spar of the root section, made from two spar caps and spar webs, as described  
15 above, since it can be desirable for the spar caps to be of greater thickness than the spar webs. Again, this would not be possible with the conventional method, in which the entire root section is made using a single winding operation and is therefore necessarily of uniform circumferential thickness.

- 20 In this context, the term “circumferential” is not intended to imply that the root section is of circular cross section, but is intended merely to refer to the region of the hollow root section within a plane perpendicular to the elongate direction of the turbine blade.

In this case, the preform is preferably moulded into a shape which is arcuate in cross  
25 section. In this context, the term “arcuate” can mean either a part of a substantially perfect circle, or more generally curved. By selecting an appropriate radius of curvature for each arcuate segment, a desired profile of the root section can be created.

Two or more such segments may be joined together by applying a strong adhesive, such  
30 as epoxy or polyurethane, to the cut edges of the segments and mounting the segments together in an assembly jig. In this way, the continuous windings of a conventional root section are emulated by joining together the ends of the fibres of separate segments.

In order for the segments to be joined together more securely, it is desirable for the  
35 segments to be mounted together on a steel end-plate which can be attached to the hub of the wind turbine. To achieve this, each segment is preferably formed with a respective

connecting means, such as one or more projections, which can engage a corresponding connecting means, such as one or more recesses, in the end-plate. In the preferred embodiment, the root section is made from four quadrants, and each quadrant is provided with 22 connecting projections.

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The connecting means may be formed in the segments by creating a layered structure of two overlying preforms between which is sandwiched the connecting means, and then moulding the layered structure so as to seal the connecting means between the two preforms.

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By joining together two or more segments, the required size of the mandrel is substantially less than that required with the above conventional method. For example, if four segments are joined together in this way to form the root section, the diameter of the mandrel can be reduced by about 75%.

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By moulding the fibrous material after removal from the mandrel, there is no need for the fibre to be pre-impregnated with resin. As a result, the fibre can be wound at a substantially greater speed than can be achieved with the conventional "wet-winding" method.

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Thus, in one embodiment, the layer of fibrous material which is formed on the mandrel is substantially free of resin. In particular, the layer of fibrous material which is formed on the mandrel may be substantially free of thermosetting resin.

25 It is desirable for the layer of fibrous material to be clamped on both sides of the cutting region, prior to cutting, thereby to prevent the cut ends of the fibre from separating.

A preferred way of clamping the fibrous material is to place battens on the surface of the material and to screw the battens through the material to the underlying mandrel.

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The clamping of the layer of fibrous material may then be released prior to moulding, to enable the layers of the resulting preform to conform to the shape of the mould.

35 The step of cutting the layer of fibrous material may advantageously comprise removing a selected portion of the fibrous material. This enables preforms of different sizes to be

formed using one or more mandrels of the same size, thereby reducing the cost of manufacture.

Another preferred method for enabling different sizes of preforms to be formed from a single mandrel is to wind a second length of fibre on to the mandrel so as to form a second layer of fibrous material which overlies the first layer, thereby forming two separate preforms having different surface areas.

In this case, a selected thickness of an intermediate layer of a suitable material is preferably placed on the first layer of fibrous material prior to winding the second fibre, so as to select a desired surface area for the second layer of fibrous material.

The layer of fibrous material is preferably cut at an angle to the surface of the layer, where the angle is selected such that, after the fibrous material has been moulded into the desired shape, the cut edge of the fibrous material is square, i.e. substantially perpendicular to the surface of the fibrous material. This enables two or more moulded layers of fibrous material to be joined together along the cut edges without creating any discontinuity in the surface at the joints. When the outer surface of the mandrel is circular, and the fibrous material comprises a single quadrant section, the preferred angle is substantially  $67^\circ$  to the normal, i.e. to the radial direction of the mandrel. The angle at which the layer of fibrous material is cut on the mandrel should lead to the preform having a  $90^\circ$  angle at the edge of the layer of fibrous material relative to the surface of the mould into which the preform is subsequently laid. Thus, for root sections formed from more than four sections, the angle of the cut will be different.

After the layer of fibrous material is removed from the mandrel, it is preferably formed into a substantially planar configuration prior to moulding. This enables a number of preforms to be conveniently stacked on top of each other in preparation for the moulding stage. It also facilitates transportation of the preforms to a separate moulding location, if desired.

The moulding operation preferably involves the placing of the preforms in a mould and infusing a thermosetting resin into the preform within the mould, which is then cured by heating the resin-impregnated preform under a vacuum. The resin may be an epoxy, vinyl ester or polyester based resin.

The shape of the lower surface of the mould is selected to correspond to the desired outer shape of the blade section. In the preferred arrangement, the desired shape has an arcuate cross section.

- 5 As a result of the moulding operation, the resin fills the interstices within the lower surface of the preform so that the resulting outer surface of the moulded root section is smooth. This provides two advantages. First, when the outer fibre glass shell is attached, less adhesive is required than with the conventional method, in which additional adhesive is required to fill the interstices between the outermost fibre glass
- 10 windings. Secondly, it may be possible with such an arrangement to dispense with the requirement for an outer fibre glass shell, resulting in a simplified and less costly construction of turbine blade.

- When manufacturing root sections of substantial length, e.g. in excess of 10 metres, it is
- 15 desirable to form these by combining two preforms as follows. A first preform is placed in a mould, and a second preform is placed in the mould so as to partially overlap the first preform in the longitudinal direction, and the two preforms are then moulded together into the desired shape. As a result, the length of the moulded section is greater than the length of either of the two preforms.

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It will be appreciated that such a method could alternatively, or in addition, be used to join together two or more preforms in the width-wise direction by co-infusing the two or more preforms together in the mould.

- 25 The use of a mandrel of circular cross section will normally generate some waste material, since the desired shape of the preform would not normally correspond to the surface of such a mandrel. It may therefore be desirable to use a mandrel of non-circular cross section having a surface which corresponds to the desired shape of the preform.

- 30 Depending on the desired shape of the preforms, it may be advantageous to cut two or more preforms from a single fibrous layer. In the case of a mandrel of circular cross section, this could result in less waste material being produced. In the case of a mandrel having an irregular, non-circular shape, the shape of the mandrel may advantageously be made to correspond the to the shape of the mould.

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Thus, in a preferred embodiment, two or more differently shaped preforms are wound simultaneously on to a single mandrel, and the fibrous material is clamped and cut, as described above, along an appropriate number of generally axially extending lines. Thus, with two preforms, the material will be clamped along two pairs of lines, each pair  
5 of lines defining a respective cutting path. When the surface of the mandrel is larger than the combined surface areas of the preforms, there will be some waste material, in which case additional clamps will be required which define additional cutting paths.

In this case, the mandrel with the wound fibrous material is preferably transported by  
10 crane and rotated such that the section of the material which will form the first preform is positioned lowermost, i.e. in the 6 o'clock position. The mandrel is then lowered on to a first support tray.

The surface of the mandrel is then clamped to define cutting lines which will delineate the  
15 preforms and any waste material. The first preform is then cut from the mandrel, and the two clamps which are still attached to the first preform are then removed from the mandrel. The mandrel is then lifted from the first support tray, leaving the cut preform on the support tray. The mandrel is then rotated such that the second preform is now lowermost, and lowered on to a second support tray. The second preform is then cut  
20 from the mandrel, the clamps which are attached to the second preform removed, and the mandrel lifted from the second support tray. The process is then repeated until all preforms have been deposited on respective support trays. Any remaining clamps which are used to attach the waste material to the mandrel are then removed from the mandrel, together with the waste material itself.

25 The fibre used in the method of the present invention is preferably glass fibre, in view of its relatively low cost, but may alternatively be carbon fibre, basalt fibre, or any combination of glass, carbon and basalt fibres.

30 Preferred embodiments of the present invention will now be described in detail with reference to the following accompanying drawings, in which the same reference numerals are used to indicate identical or similar elements:

Figure 1 illustrates the main structural components of a wind turbine;

Figure 2 illustrates in cross section the winding of a length of glass fibre around a mandrel, in accordance with a preferred embodiment of the present invention;

Figure 3 is a cross-sectional illustration of a preferred clamping arrangement of  
5 the glass fibre layer;

Figure 4 illustrates preferred arrangements for cutting the glass fibre layer;

Figures 5(a) and 5(b) show the cut glass fibre layer being removed from the  
10 mandrel and lowered on to a supporting hammock in accordance with a preferred embodiment of the present invention;

Figures 6(a) to 6(e) illustrate in cross-sectional views the sequence of processing steps applied to the glass fibre layer, in accordance with an alternative embodiment of  
15 the invention in which the layer is cut in two separate stages;

Figure 7 illustrates an embodiment in which connecting projections are formed between two preforms prior to moulding;

Figure 8 illustrates how four moulded quadrants are attached together in  
20 accordance with a preferred embodiment;

Figure 9 illustrates an embodiment in which two glass fibre layers are formed on a single mandrel;  
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Figure 10 illustrates how a relatively long blade section can be formed from two relatively short preforms;

Figure 11 illustrates diagrammatically the shape of a preform wound on a profiled  
30 mandrel;

Figures 12(a) to 12(d) illustrate the shapes of a number of preferred preforms which can be made with embodiments of the present invention;

Figure 13 illustrates a preferred embodiment in which two preforms are cut from a  
35 single layer of fibrous material;

Figures 14(a) to (i) illustrate a preferred method of forming preforms on a mandrel and transferring the preforms to a mould; and

5           Figure 15 is a flow chart illustrating the method of a preferred embodiment of the present invention.

Referring to Figure 2, glass fibre 11 is supplied from a supply reel 12 in the direction of arrow 13 to the surface of an elongate mandrel 14 as the mandrel 14 is caused to rotate about its axis in the sense indicated by arrow 15. Means (not shown) are provided for causing at the same time the glass fibre 11 to move linearly in an axial direction at a rate such that, for each rotation of the mandrel 14 the glass fibre 11 moves a distance equal to the diameter of the glass fibre 11, so that each winding of glass fibre 11 lies adjacent the previous winding on the surface of the mandrel 14, thereby to maximise the density of the wound glass fibre 11. This is repeated, with the glass fibre 11 reciprocating axially until a cylindrical layer of glass fibre 16 having the desired thickness has been deposited on the surface of the mandrel 14. A typical thickness of the layer 16 is around 50 mm.

In this way, the glass fibre 11 is wound on the surface of the mandrel 14 without applying any thermosetting resin at this stage.

However, a thermoplastic adhesive or powdered epoxy is sprayed on to the surface of the fibre during winding to stabilise the fibre both during and after the winding operation.

25   The mandrel 14 has a length of around 16 metres and has a surface which is profiled so as to form a layer of glass fibre 11 having a desired shape. The winding surface of the mandrel 14 is of substantially circular cross section, with a diameter which varies along its axial length so as to define the desired profile. For example, in one embodiment, the diameter varies from 1 metre at one end to 3 metres at the other end. However, in other 30   embodiments, the mandrel has a non-circular cross section.

The mandrel 14 is formed with a V-shaped groove 17 on either side of which there is provided an elongate recess in which is located a lower clamp 18 which is separable from the mandrel 14.

Referring to Figure 3, after the winding operation is complete, two corresponding elongate upper clamps 19 are caused to bear on the upper surface of the glass fibre layer 16 in the direction of arrow 20, and which, in combination with the lower elongate clamps 18, grip the upper and lower surfaces of the glass fibre layer 16 along two parallel linear regions extending axially along the entire length of the glass fibre layer 16. The V-shaped groove 17 formed in the mandrel 14 enables the entire thickness of the glass fibre layer 16 to be cut along its axial length within the region between the two upper and lower elongate clamps 18, 19. The glass fibre layer 18 may be cut using either a jig-saw provided with a foam-cutting blade or an ultrasonic knife moving along a guide rail.

Figure 4 illustrates the cutting of the fibre glass layer 16. A first cut 21 is made at an angle 22 of  $67^\circ$  to the normal, and a second cut 23 is also made at the same angle on the other side of the normal, resulting in an overall cut angle of  $134^\circ$ .

However, an alternative second cut, shown by a dotted line 23' in Figure 4 may be made, also at  $67^\circ$  to the normal, but spaced laterally from the position of the second cut 23 by a distance of 200 mm. By selecting the position of the second cut in this way, it is possible to form glass fibre layers 16 of different sizes from a single mandrel 14, or from two mandrels of the same size.

Figures 5(a) and 5(b) illustrate how the glass fibre layer 16, after cutting, is removed from the mandrel 14.

As shown in Figure 5(a), the cut edges of the glass fibre layer 16, gripped by clamps 18, 19, are first attached to respective ends of a series of cables 24 extending along the entire length of the mandrel 14, which are mounted on two elongate pulleys 25. A supporting hammock 26 is located below the mandrel 14, and the pulleys 25 are moved apart in the opposing directions indicated by arrows 27 so as to cause the fibre glass layer 16 to lift away from the surface of the mandrel 14 and to come to rest on the underlying hammock 26, as shown in Figure 5(b). After removal from the mandrel 14, the glass fibre layer 16 now constitutes a preform 28 for the root section of a turbine blade. As can be seen from Figure 5(b), the preform 28 is sufficiently flexible to conform to the substantially horizontal surface of the underlying hammock 26.

At this stage, a number of preforms 28 can conveniently be stacked together on top of each other prior to the step of moulding.

Figures 6(a) to 6(e) illustrate an alternative embodiment in which the edges of the glass fibre layer 16 are cut in two separate stages.

Figure 6(a) illustrates the glass fibre layer 16 formed on the mandrel 14 and having a single radial cut 29 extending the full length of the glass fibre layer 16. For the sake of clarity, the two clamps 18, 19 are not shown, although they are present at this stage.

10 This arrangement provides the advantage that a radial cut is easier to make than an angled cut, when the fibre glass layer 16 is supported on the mandrel 14. The resulting preform 28 is removed from the mandrel 14 and placed on a storage tray 30, as shown in Figure 6(b). As shown in the drawing, as the preform 28 is opened out and the clamps 18, 19 temporarily removed, the two edges of the preform 28 are no longer square, i.e.

15 no longer perpendicular to the plane of the preform at the edge region. This results from the outer windings of the fibre glass layer 16 having a greater length than the inner windings. The clamps 18, 19 are then re-applied to prevent the ends of the glass fibre windings within the preform 28 from separating.

20 With the preform 28 on the storage tray 30, the edges are cut at the desired angle in the direction indicated by arrows 31. The angle of the cut is selected such that the moulded preform 28 will have square edges. The preform 28 with the edges clamped and cut are illustrated in Figure 6(c).

25 The clamps 18, 19 are then removed again, as shown in Figure 6(d), and the preform 28 placed in a mould 32 having the desired shape of the finished root section. The mould 32 comprises a lower supporting structure 33, two edge plants 34 and a cover, such as a vacuum bag (not shown), so as to define an airtight chamber. With the preform 28 in position, the mould 32 is evacuated by pumping air out of a linear arrays of nozzles 35 to

30 form a vacuum as shown in Figure 6(e). A thermosetting resin is then introduced into the evacuated mould 32 through a further linear array of nozzles 36, so as to infuse the preform 28 with the resin, which takes about 30 minutes. The mould is then heated at between 80° and 100° for four hours to cure the resin.

35 As an alternative to the method of stabilising the fibre during winding by spraying the fibre with a thermoplastic adhesive or powdered epoxy referred to above, a further fabric-

stabilisation method may be applied to the fibre glass layer 16 before it is removed from the mandrel 14, to ensure that the preform 28 maintains its shape. This may comprise stitching through the fibre glass layer 16 while it is on the mandrel 14. In this case, thin grooves are provided in the surface of the mandrel 14, over which the fibre glass layer 16 bridges, and a stitching machine can stitch together the wound layers formed on the mandrel 14. Alternatively, the fibre glass layer 16 may be removed from the mandrel 14 and then stitched to maintain its shape in a stitching cradle. In another example, a binder resin, a tackifier, or a heat-activated material is provided in the fibre glass layer 16 formed on the mandrel 14 which can be used to ensure that the preform maintains its shape. The binder resin, the tackifier and the heat-activated material are chosen such that they do not interfere with the subsequent infusion process, and preferably have a viscosity such that they do not adversely affect the winding speed of the fibre 11 on to the mandrel 14.

In a preferred embodiment, as illustrated in Figure 7, a number of connecting projections 37 are formed at one end of the root section. This is achieved by placing a first preform 28 in the mould 32, then laying the connecting projections 37 at equally spaced positions along the end of the first preform 28, and subsequently laying a second preform 28' over the first preform 28 so as to sandwich the connecting projections 37. The connecting projections 37 are retained in position by virtue of the thermosetting resin.

The connecting projections 37 provide a means of attachment to the rotor 4 of the wind turbine 1.

Each connecting projection 37 is formed from a suitable metal encased in a cured glass fibre housing.

In a preferred embodiment, as illustrated in Figure 8, the root section is formed from four separate sections, or quadrants 38, each quadrant 38 being moulded separately. This enables a root section to be formed with a cross section of different thicknesses, if desired. In order to join together the four quadrants 38, a layer of adhesive, such as epoxy or polyurethane, is applied to the side edges of the quadrants 38, and the quadrants are then lowered into an assembly jig 39. As can be seen from the Figure 8, the connecting projections 37 form a near-continuous ring which projects from one of the two ends of the assembled root section. An end-plate (not shown) formed with corresponding recesses is then attached to the root section, with the connecting

projections 37 on the root section mating with the recesses in the end-plate. The end-plate is then, in turn, bolted to the central hub 6 of the wind turbine 1 (see Figure 1).

Two further embodiments will now be described with reference to Figure 9 and 10, each of which enables preforms 28 of different sizes to be formed from a single mandrel 14.

In Figure 9, a first fibre glass layer 16 is formed on a mandrel 14 using the method described above with reference to Figure 2. However, in this case, after the first fibre glass layer 16 has been wound, an intermediate layer 40 of a suitable material is placed over the surface of the first layer 16, and a second fibre glass layer 16' is then wound on the surface of the intermediate layer 40. By selecting the thickness of the intermediate layer 40 accordingly, it is possible to form fibre glass layers 16 of any desired size from a single mandrel 14, or from multiple mandrels of the same size.

Figure 10 illustrates how a blade section 41 in excess of 6 metres in length can be formed from two preforms 28, 28' each having a length less than 6 metres. In this case, a first preform 28 is placed at one end of a mould 32 (not shown) so that it occupies just over one half of the length of the mould 32, and a second preform 28' is then placed at the other end of the mould 32 such that one end of the second preform 28' overlaps one end of the first preform 28 within a central overlapping region 42 extending over a length of between 500 mm and 1000 mm. In the central overlapping region 42 the two preforms 28, 28' have tapered ends, and this can be achieved by using a smaller number of winding rotations toward the end of the layer of glass fibre wound on to the mandrel 14.

Figure 11 illustrates how a non-rectangular preform 28 can be formed by using a mandrel 14 having a suitably profiled surface. In the preferred embodiments of the present invention, in which the fibre glass layer 16 is cut before removal from the mandrel 14, a preform 28 of almost any arbitrary shape can be formed by using a suitably profiled mandrel 14. Examples of such shapes are illustrated in Figures 12(a) to 12(d).

Figure 13 illustrates a preferred embodiment in which two preforms 43, 44 of the fibrous material, together with two small strips of waste material 45, 46, are cut from a single layer of fibrous material wound on a mandrel 14, by cutting the layer along four cutting lines 47, 48, 49, 50.

In an alternative embodiment, the mandrel 14 is shaped so as to correspond substantially exactly to the combined desired shapes of the preforms, thereby avoiding the need to generate any waste material.

- 5 The method steps involved in forming the two preforms 43, 44 on a mandrel 14 and transferring the preforms 43, 44 to the mould 32 will now be described with reference to Figures 14(a) to (i).

As shown in Figure 14(a), a mandrel 14 formed with four axially extending grooves 17  
10 and bearing a layer of fibrous material 16 which will be cut into two preforms 43, 44 and two strips of waste material 45, 46 is attached at both ends to a crane 51. The crane 51 hoists the mandrel 14 above ground level, and the mandrel 14 is then rotated such that the region of the layer of material 16 which will be used to form the first preform 43 is facing downwards, i.e. at the six o'clock position.

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The mandrel 14 is then lowered on to a plywood support tray 52, as shown in Figure 14(b). In an alternative embodiment, the support tray 52 may be moved into position below the mandrel 14 without requiring the crane 51 to lower the mandrel 14 into position.

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Six wooden battens 53 are then screwed into the mandrel 14 so as to clamp the layer of fibrous material 16, as shown in Figure 14(c). The appropriate position of each of the battens 53 is indicated by suitable indicia on the support tray 52. Four of the battens 53 are positioned so as to define the edges of the two preforms 43, 44, and the two  
25 remaining battens 53 are attached along the regions of the fibrous material 16 which will become the two strips of waste material 45, 46. As can be seen from the drawing, each of the four axial grooves 17 formed in the mandrel 14 lies along a region between adjacent pairs of battens 53.

30 As illustrated in Figure 14(d), the layer of fibrous material 16 is cut along two cutting lines 54 using a jigsaw guided by two of the axial grooves 17 (or alternatively an ultrasonic knife guided along a guide rail) so as to define the first preform 43.

As shown in Figure 14(e), the two side edges 55 of the first preform 43 are then stitched,  
35 either manually or with an automatic sewing machine which may be combined with the ultrasonic knife mentioned above.

The two battens 53 which attach the first preform 43 to the mandrel 14 are then removed, as shown in Figure 14(f), and the crane 51 then lifts the mandrel 14 to a raised position as indicated by arrow 56, leaving the first preform 43 supported on the support tray 52, as shown in Figure 14(g). Alternatively, the support tray 52 may be moved away from the mandrel 14, without requiring the crane 51 to lift the mandrel 14.

A lifting frame 57 is attached to the two side edges 55 of the first preform 43 using toggle clamps 58, as shown in Figure 14(h). The lifting frame 57 with the first preform 43 attached is then raised in the direction of arrow 59 from the support tray 52 and subsequently lowered into position in a mould 32, as shown in Figure 14(i).

A vacuum bag is then placed over the preform and air is evacuated while resin is infused into the preform. The mould 32 is then heated so as to cure the preform 43, as described above. The above procedure is then repeated for the second preform 44.

It will be appreciated that the above method could also applied to arrangements in which the two strips of waste material 45, 46 constitute two additional preforms.

The method according to a preferred embodiment of the present invention is illustrated in the flow chart of Figure 15.

A length of glass fibre is first wound on a mandrel at step 60 to form a glass fibre layer. Two parallel linear regions of the layer are then each clamped between respective upper and lower elongate clamps at step 61. The fibre glass layer is then cut along a linear region extending axially between the two pairs of clamps at step 62. The cut fibre glass layer is then removed from the mandrel at step 63 as a preform and stacked together with other preforms at step 64. A first preform is then lifted from the top of the stack and placed in a mould at step 65. Connector projections, described above with reference to Figure 7, are then placed at regular intervals along one edge of the upper surface of the first preform at step 66. A second preform is then lifted from the stack and placed in the mould on top of the first preform and connector projections at step 67. The mould is then sealed and evacuated, and thermosetting resin is introduced into the mould so as to infuse the preform to form a moulded segment at step 68. Four such moulded segments are then joined together to form a complete root section of a turbine blade at step 69.

Although preferred embodiments of the present invention have been described above, it will be apparent to the person skilled in the art that many variations may be made to these without departing from the scope of the present invention, which is defined solely by the claims appended hereto.

**CLAIMS**

1. A method of manufacturing a section of a blade for a wind turbine generator, the method comprising:
  - 5 (a) winding a length of fibre around a mandrel so as to form a layer of fibrous material;
  - (b) cutting the layer of fibrous material along the length of the mandrel;
  - (c) removing the layer of fibrous material from the mandrel; and
  - 10 (d) moulding the removed layer of fibrous material into a desired shape.
2. A method as claimed in claim 1, further comprising applying a binding agent to the fibre during winding.
3. A method as claimed in claim 1 or claim 2, wherein step (c) is performed after  
15 step (b).
4. A method as claimed in any preceding claim, wherein the layer of fibrous material formed on the mandrel is substantially free of resin.
- 20 5. A method as claimed in any preceding claim, wherein the step of cutting comprises making at least two cuts along the length of the mandrel so as to form at least two layers of the fibrous material.
- 25 6. A method as claimed in any preceding claim, further comprising the step of clamping the layer of fibrous material prior to cutting, thereby to prevent the resulting cut ends of the fibre from separating.
7. A method as claimed in claim 6, wherein the clamping of the layer of fibrous material is released prior to moulding.
- 30 8. A method as claimed in any preceding claim, wherein the step of cutting the layer of fibrous material comprises removing a selected portion of the fibrous material.
- 35 9. A method as claimed in any preceding claim, wherein the layer of fibrous material is cut at an angle to the surface of the layer, the angle being selected such that, after the fibrous material has been moulded into the desired shape, the cut edge

of the fibrous material is substantially perpendicular to the surface of the fibrous material.

- 5 10. A method as claimed in any preceding claim, further comprising forming the layer of fibrous material after removal from the mandrel into a substantially planar configuration prior to the step of moulding.
- 10 11. A method as claimed in any preceding claim, wherein the step of moulding the fibrous material comprises placing the fibrous material in a mould and infusing a resin into the fibrous material in the mould.
12. A method as claimed in any preceding claim, wherein the desired shape is arcuate in cross section.
- 15 13. A method as claimed in any preceding claim, further comprising joining together a plurality of such sections to form a generally cylindrical part of a blade.
14. A method as claimed in claim 13, wherein the plurality of sections are of at least two different thicknesses.
- 20 15. A method as claimed in claim 13 or claim 14, wherein the part of the blade is a root section.
- 25 16. A method as claimed in any preceding claim, further comprising, prior to step (b), winding a further length of fibre around the mandrel so as to form a further layer of fibrous material overlying the first-mentioned layer of fibrous material, and cutting the further layer of fibrous material, thereby to form, from a single mandrel, two separate layers of fibrous material having different surface areas.
- 30 17. A method as claimed in claim 16, further comprising placing an intermediate layer of material of selected thickness above the surface of the first-mentioned layer of fibrous material prior to winding the further length of fibre around the mandrel, thereby to control the surface area of the further layer of fibrous material .
- 35 18. A method as claimed in any preceding claim, further comprising repeating steps (a), (b) and (c), and wherein the step of moulding comprises moulding a layered

structure comprising, in sequence, a first of the two resulting layers, a connecting means, and the second of the two resulting layers, the connecting means projecting from between the two layers.

- 5    19.    A method as claimed in any preceding claim, further comprising repeating steps (a), (b) and (c), and wherein the step of moulding comprises moulding the two resulting layers in a partially overlapped configuration so as to form a desired shape having a surface which is greater in extent than that of either of the two layers alone.

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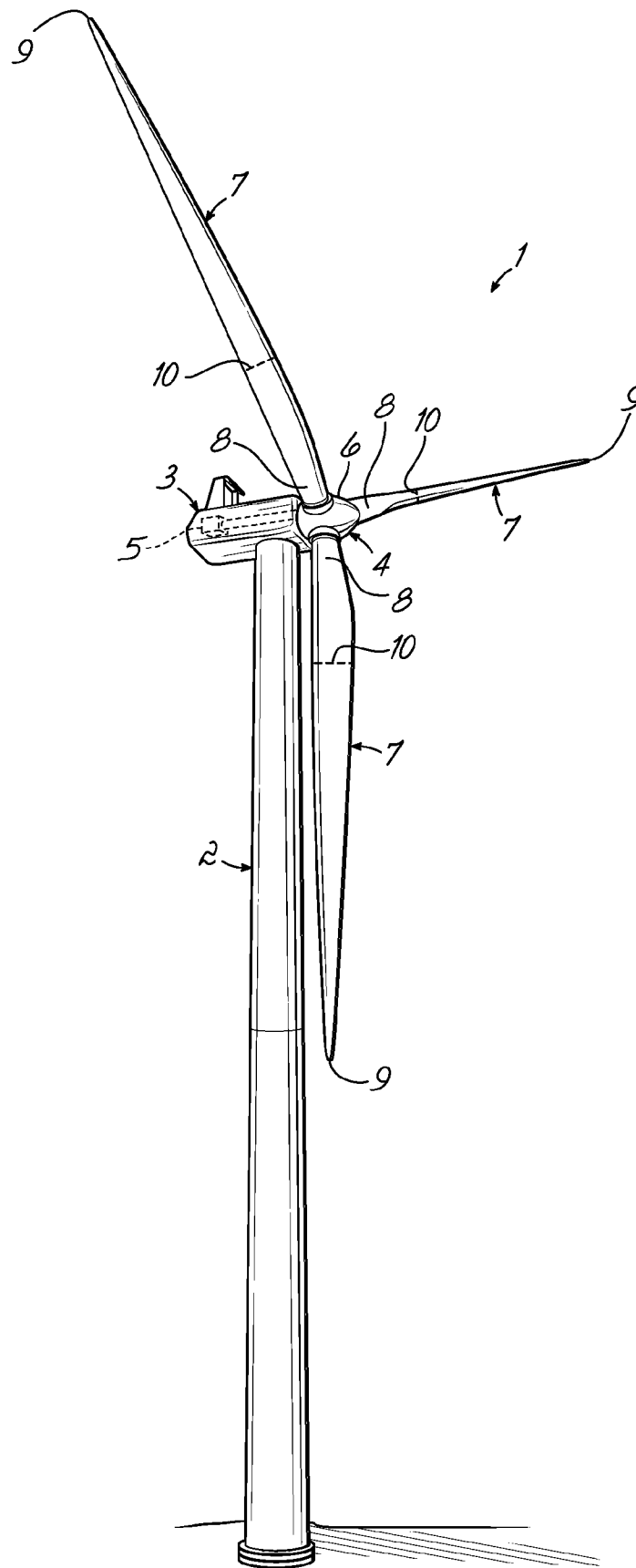


FIG. 1

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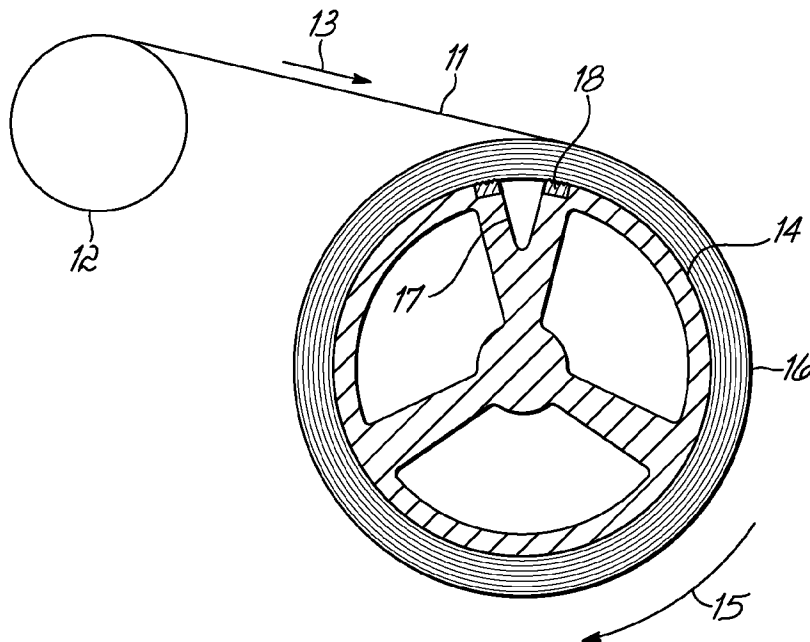


FIG. 2

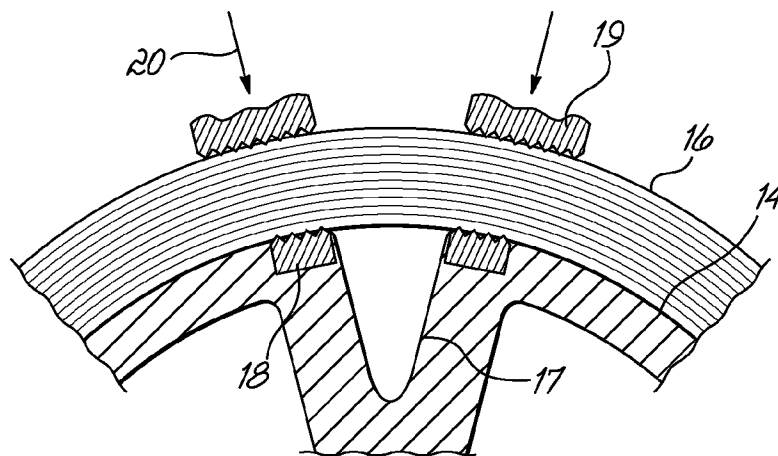


FIG. 3

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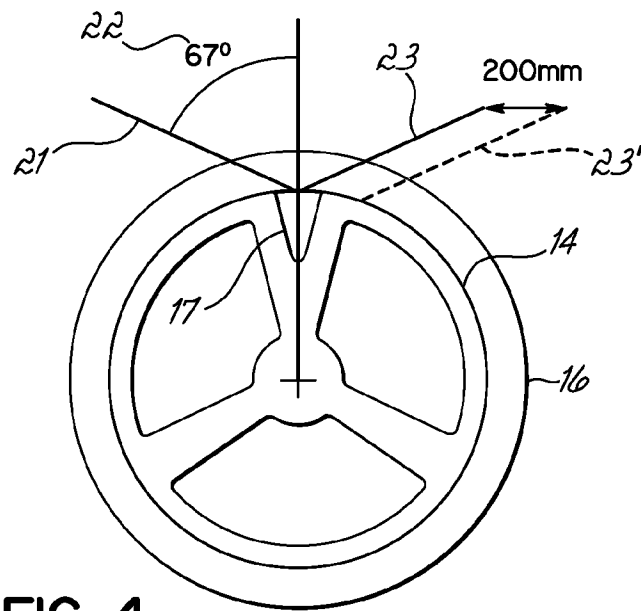
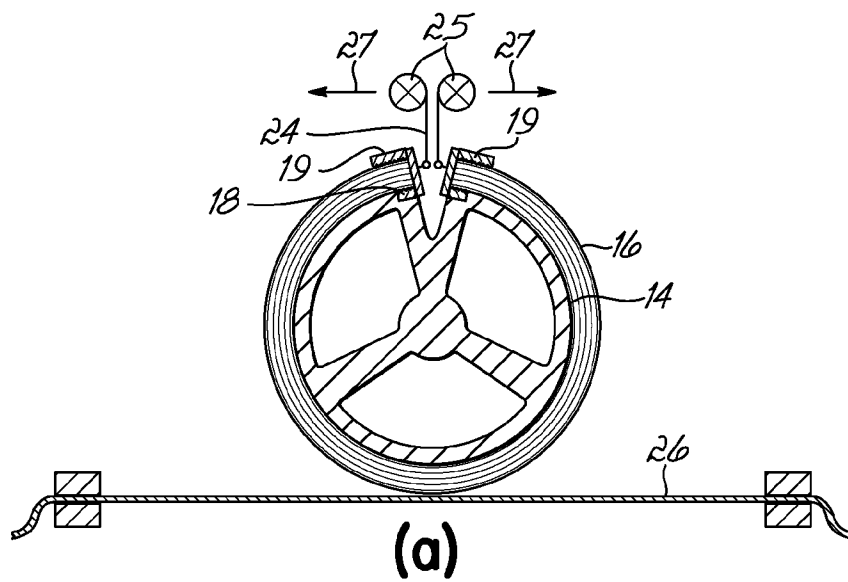
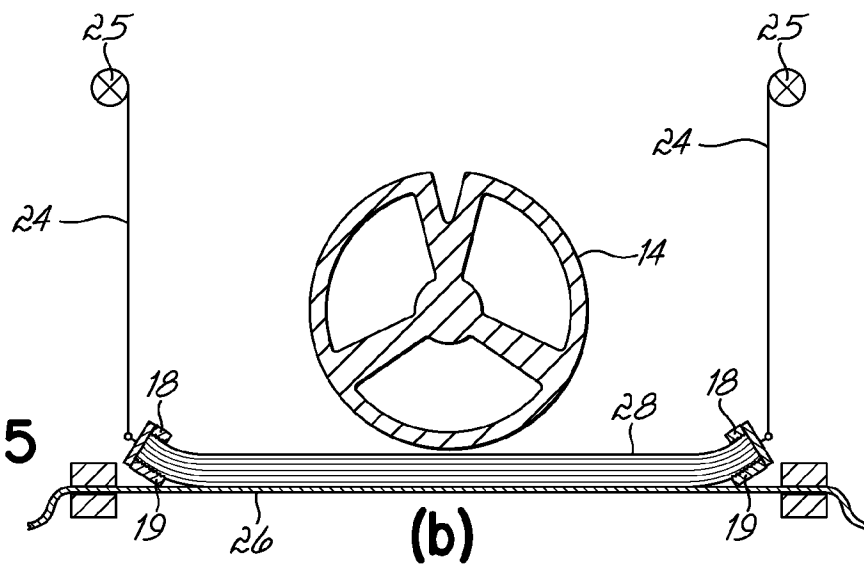


FIG. 4



(a)



(b)

FIG. 5

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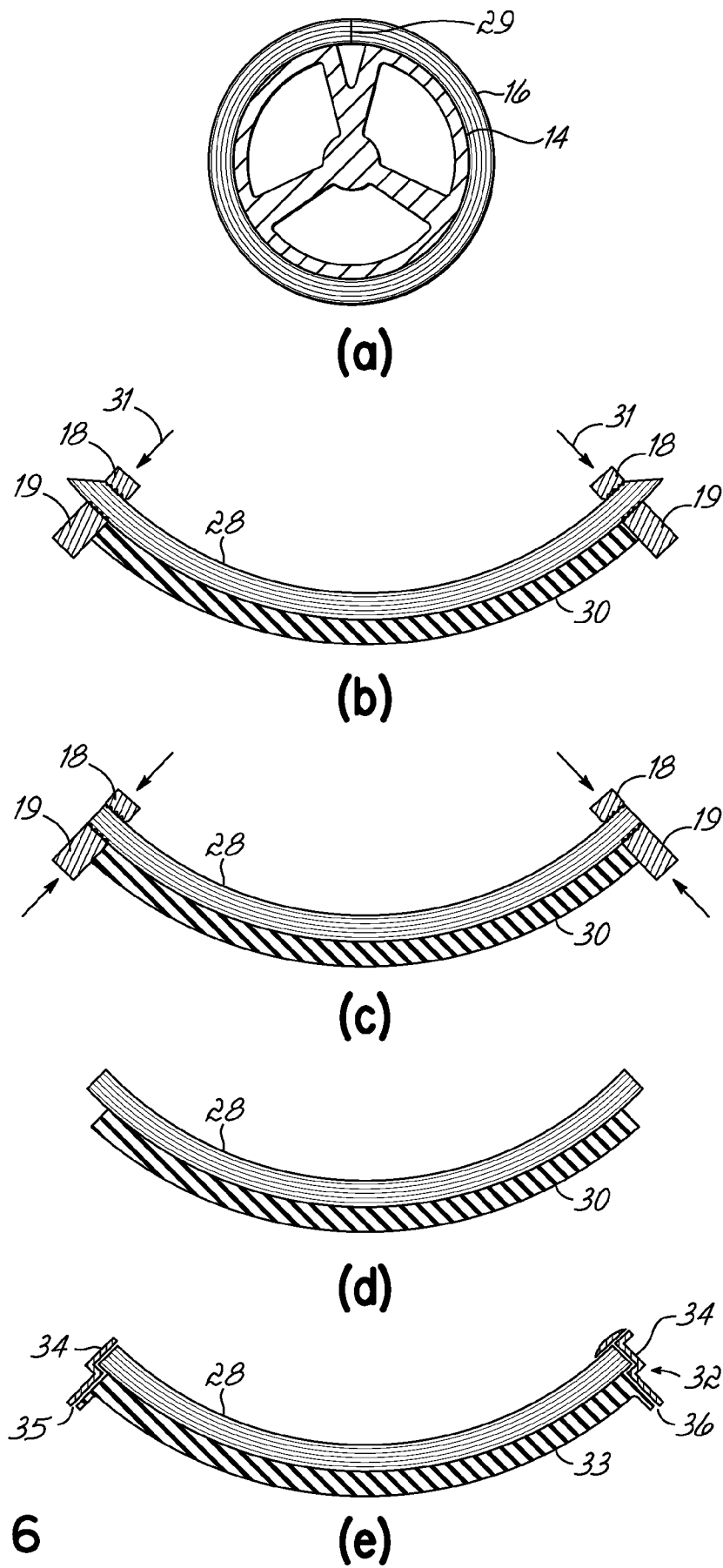


FIG. 6

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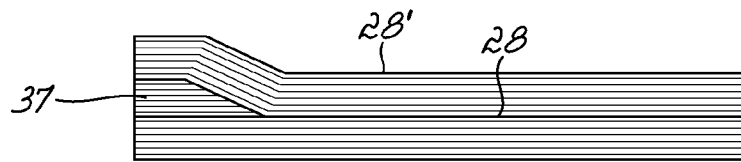


FIG. 7

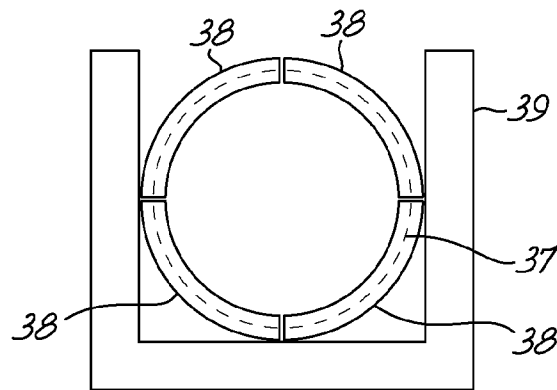


FIG. 8

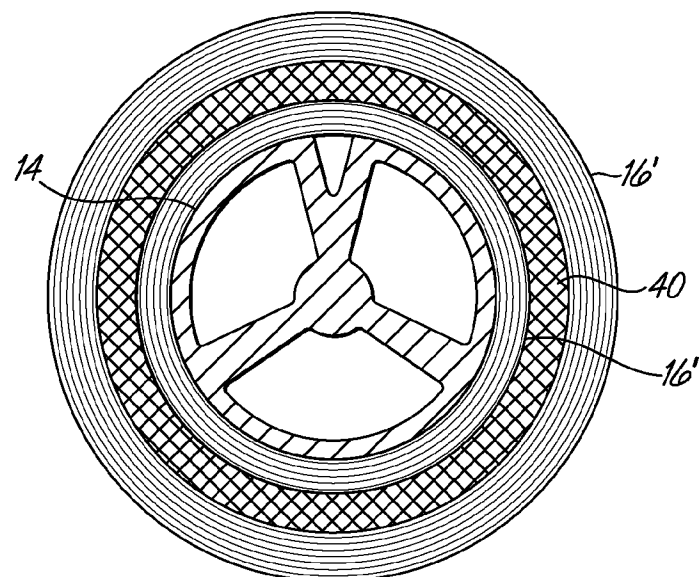


FIG. 9

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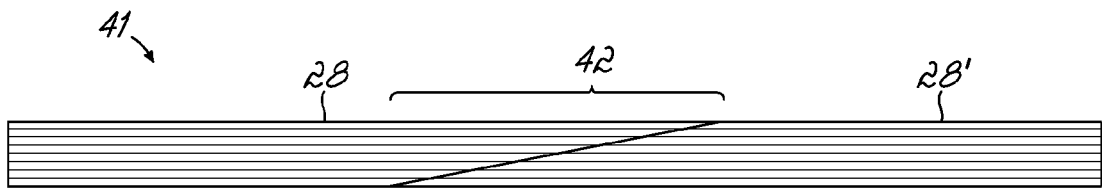


FIG. 10

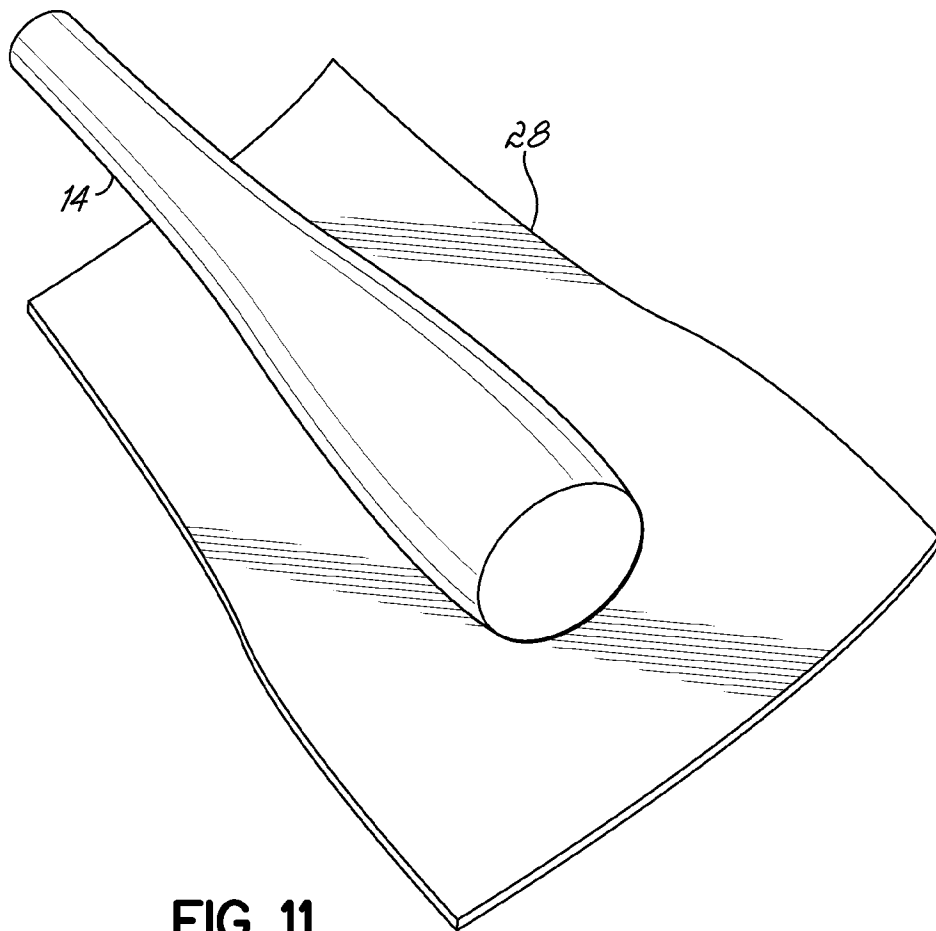
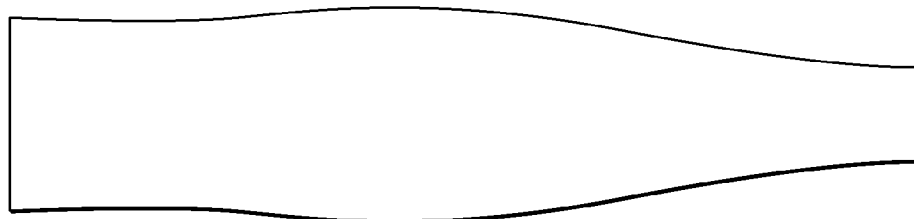
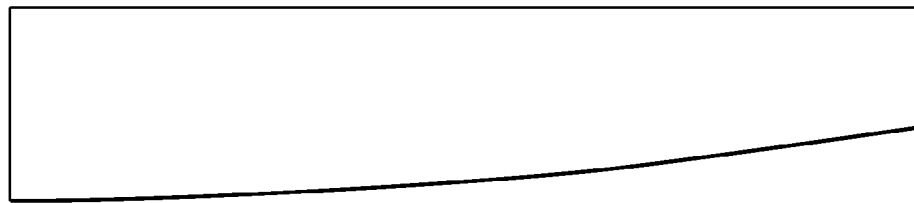


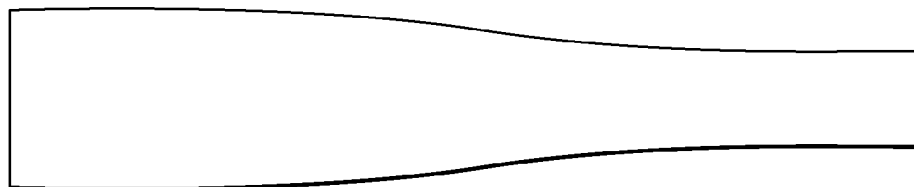
FIG. 11



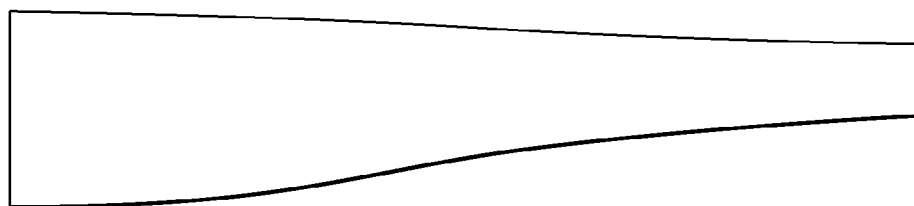
(a)



(b)



(c)



(d)

FIG. 12

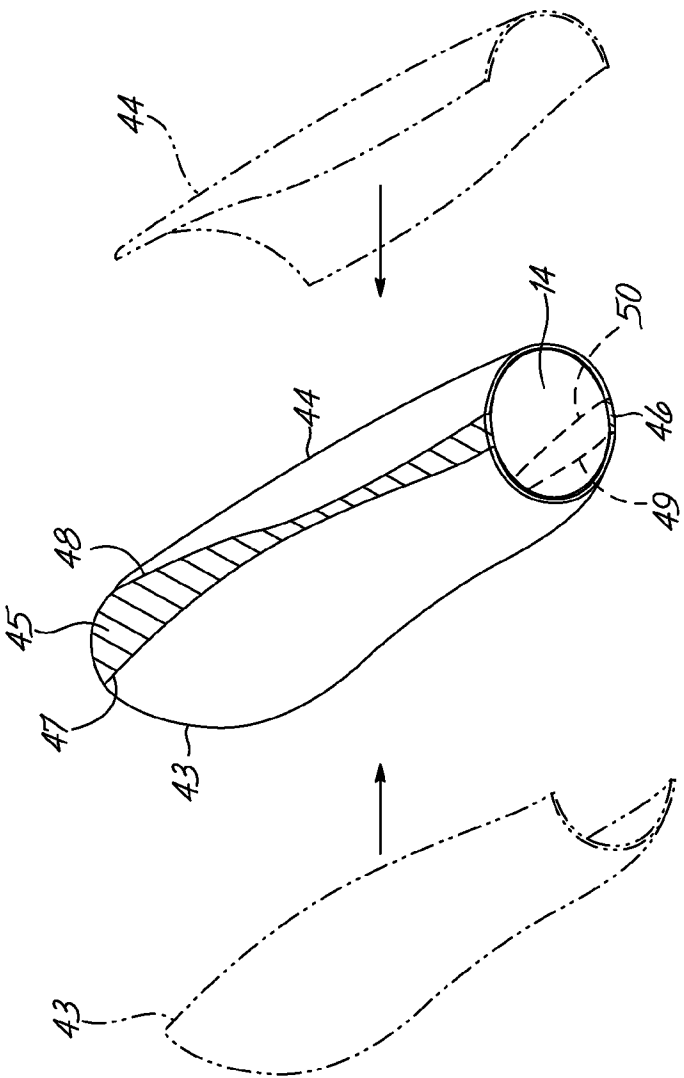


FIG. 13

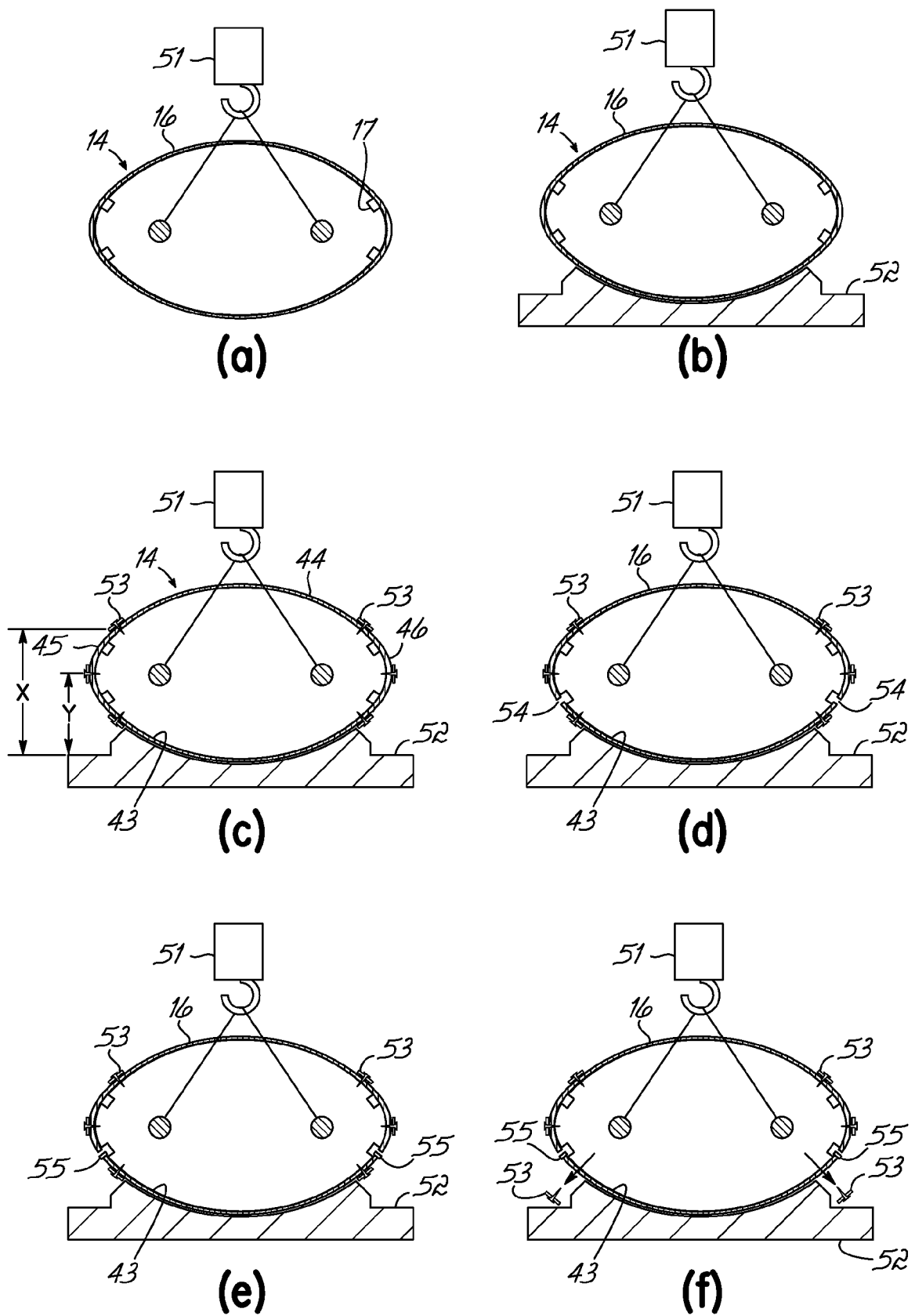


FIG. 14

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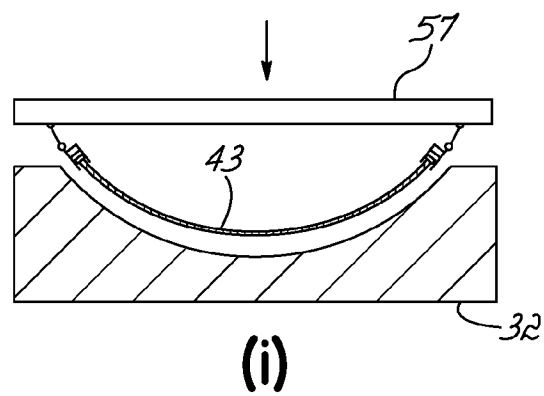
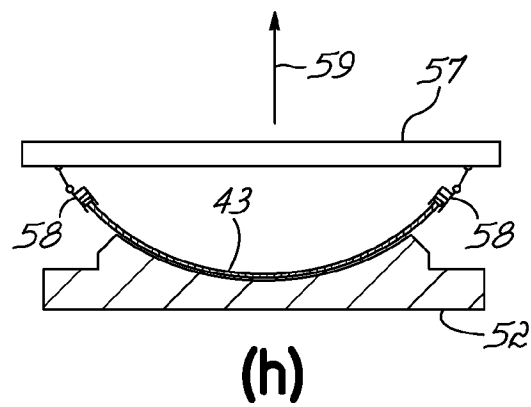
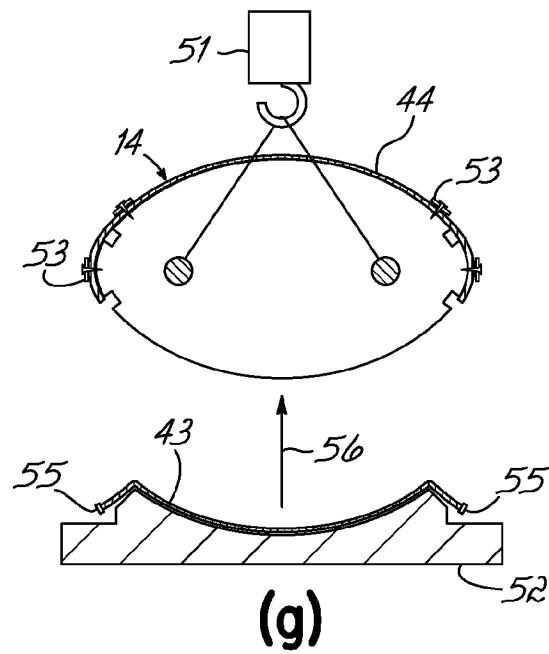


FIG. 14

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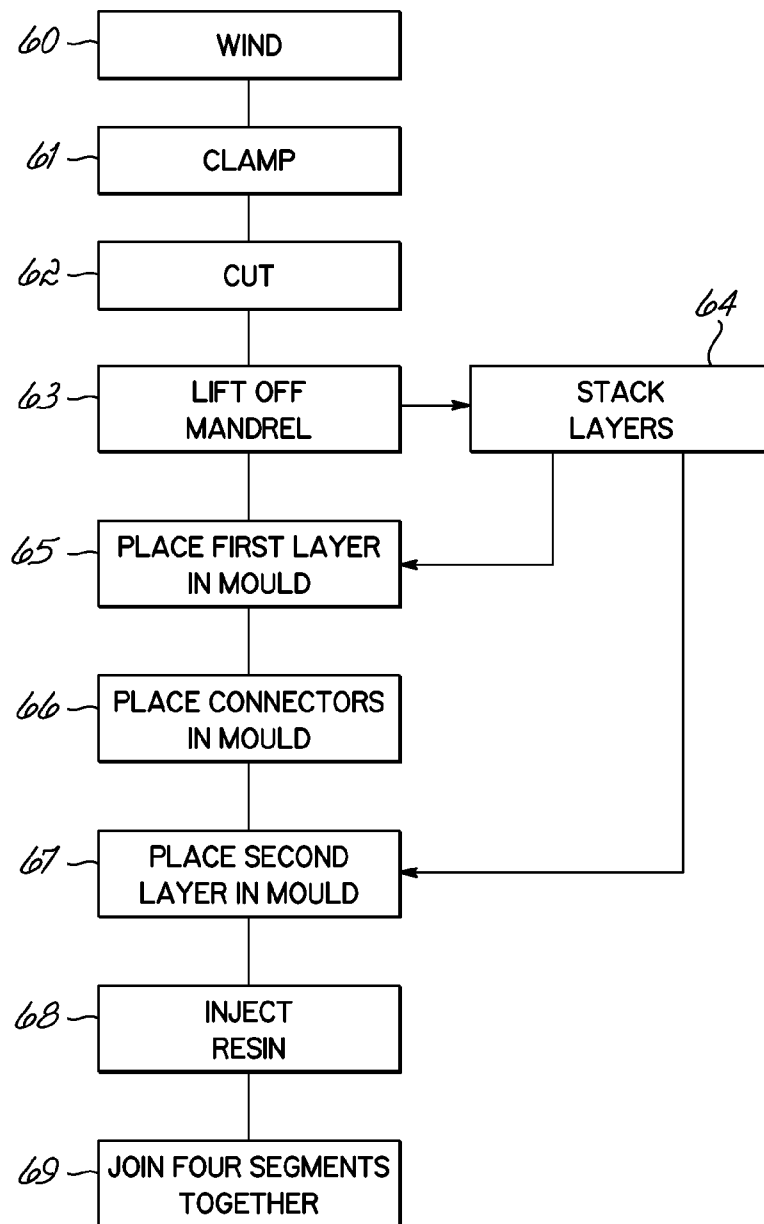


FIG. 15

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2011/051836

A. CLASSIFICATION OF SUBJECT MATTER  
INV. B29C70/34 B29C70/54 B29D99/00 B29C69/00  
ADD.

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
B29C B29D

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

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

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category*   | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                     | Relevant to claim No.                           |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
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| Y<br>A      | US 5 204 033 A (PEARCE ROBERT G [US] ET<br>AL) 20 April 1993 (1993-04-20)<br>column 4, line 65 - column 5, line 7<br>column 5, line 67 - column 6, line 11;<br>figures 3-5<br>column 6, line 55 - line 65<br>column 7, line 40 - line 59; figures 9,10<br>-----<br>-/- | 4,16<br><br>1-3,<br>5-15,<br>17-19              |



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

10 February 2012

Date of mailing of the international search report

21/02/2012

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Authorized officer

Pierre, Nathalie

## INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2011/051836

| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                     |                       |
|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                  | Relevant to claim No. |
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2011/051836

| Patent document<br>cited in search report |    | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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