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A wind turbine blade comprising an elongate reinforcing structure and a lightning protection system (LPS) component, the reinforcing structure comprising: a plurality of strips of carbon fibre-reinforced plastic (CFRP) arranged to form a stack; and a conductor element woven between the plurality of CFRP strips. The conductor element is connected to the LPS component thereby to connect the plurality of CFRP strips to the LPS component, and to enable electrical conduction through the stack to the LPS component.

Fortsættes...

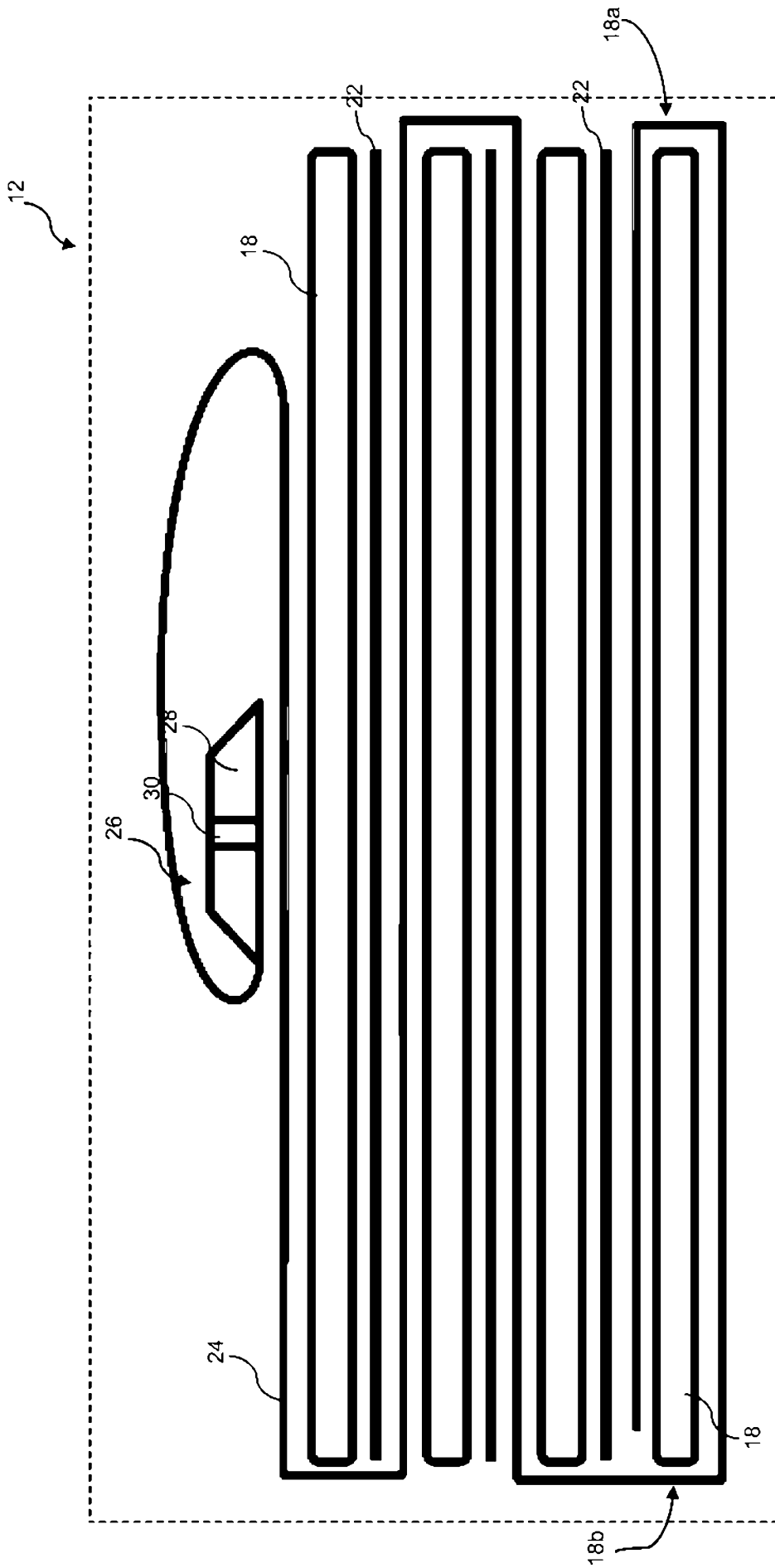


Figure 2

IMPROVEMENTS RELATING TO STRUCTURAL COMPONENTS FOR WIND TURBINE BLADES

TECHNICAL FIELD

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Aspects of the present invention relate to structural components for wind turbine blades, and more particularly to systems and methods for improving connection between structural components of the wind turbine blade and a lightning protection system installed in the wind turbine.

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BACKGROUND

Wind turbine blades are susceptible to being struck by lightning, as wind turbines are typically located in wide open spaces. A lightning strike event, and the accompanying massive build-up and transfer of electric charges that occur as a result, has the potential to cause serious physical damage to the turbine blades, as well as electrical damage to the internal control electronics of the wind turbine. Such damage is clearly undesirable due to the wind turbine downtime involved in making repairs, as well as the cost in time and materials.

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Much effort has therefore been invested in designing wind turbines, and particularly wind turbine blades, such that they are able to handle the electric discharges caused by the lightning strikes.

Various known lightning protection systems (LPS) for wind turbines exist. In one example, the wind turbine blades are equipped with a series of electrically conductive elements that are embedded in an outer surface of the wind turbine blade. These conductive elements are connected (within the blade shell) to a cable, also referred to as a 'down conductor', that extends from the blade tip to its root. With such a system installed, the lightning and the generated electric charges are more likely to attach to these conductive elements than to the relatively less-conductive material that forms the majority of the wind turbine blade outer surface. The electric charges are thereafter transmitted via the down-conductor to the wind turbine main structure, where they are grounded.

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Some turbine blades incorporate a conductive layer of material (for example, a metallic foil component) which is provided over or just below the outer surface of the blade, and helps to increase the area of the blade that can handle or receive lightning strikes safely.

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Good electrical connection between the receptor elements and/or the metallic foil component, and conductive elements that are present within the internal structure of the turbine blade, is important as it helps to prevent build-up of charges in those components, which could result in arcs between components that may damage the blade. However, such good electrical connections can be difficult to achieve due to the number of different components present within the layered structure of the turbine blade. In addition, as some structural components of the turbine blade may comprise a mixture of conductive and non-conductive elements, it is important to ensure that good electrical connection is also achieved within such structural components.

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It is against this background that the embodiments of the invention have been devised.

SUMMARY OF THE INVENTION

According to an aspect of the present invention there is provided a wind turbine blade comprising an elongate reinforcing structure and a lightning protection system (LPS) component. The reinforcing structure comprises a plurality of strips of carbon fibre-reinforced plastic (CFRP) arranged to form a stack; and a conductor element woven or interlaced between the plurality of CFRP strips. The conductor element is connected to the LPS component thereby to connect the plurality of CFRP strips to the LPS component, and to enable electrical conduction through the stack to the LPS component.

Advantageously, the weaving or interlacing of the conductor element between the CFRP strips within the reinforcing structure, such that the conductor element is interleaved between the CFRP layers, ensures equipotential bonding between all of the layers of the reinforcing structure. Ensuring that the conductor element is connected to a component of the wind turbine LPS is a simple and easy mechanism to connect all of the layers to the wind turbine LPS – since all of the layers are equipotentially bonded and are also in contact with the conductor element, all that is

required is for an electrical connection to be made between the conductor element and a component of the LPS.

5 The conductor element may comprise a continuous element winding between the CFRP strips, which configuration advantageously ensures that connecting a small portion of the conductor element to the LPS component will result in the entirety of the conductor element being in electrical connection with the LPS component. In some cases, the conductor element is woven and interleaved between each one of the plurality of CFRP strips. Alternatively, the conductor element may be interleaved only
10 between specific ones of the CFRP strips (for example, between alternate FRP strips).

The conductor element may comprise at least one of the following: a metallic material, a non-metallic material, a woven fabric, or a non-woven fabric. Specifically, the conductive element may comprise copper, aluminium, stainless steel or carbon.

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For example, the conductor element could take the form of a thin strip of copper braid or mesh, or even a piece or strip of metallic foil, that is interleaved between the CFRP layers of the reinforcing structure. Alternatively, a strip of carbon fibre fabric (either woven or non-woven) could be used as the conductor element. Other possible
20 materials that have been envisioned for use in producing the conductor element include a metallic wool/fabric-like material; a woven/non-woven fabric of conductive fibres; a mixture of conductive and non-conductive fibres; or any useful combination of these materials.

25 Alternatively, the conductor element may comprise a fabric sheet assembly, the fabric sheet assembly comprising one or more non-conductive fabric sheets which define first and second outer surfaces of the fabric sheet assembly; and at least one conductive thread stitch penetrating a depth of the one or more fabric sheets and being exposed at each one of the outer surfaces, thereby to permit electrical
30 conduction between those outer surfaces.

Specifically, the conductive thread stitch is electrically conductive, whilst the fabric sheets are relatively much less electrically-conductive. Various different types of materials may be utilised to form the fabric sheets in the conductive assembly, and
35 these materials may take the form of woven or non-woven fabric.

In this case, the conductive fabric sheet assembly may be provided in the form of a pre-fabricated kit that can be easily woven and incorporated into the layers of the reinforcing structure during its manufacture so as to provide an equipotential bonding
5 between the CFRP layers. This enables electrical charge to be conducted between the CFRP layers through the fabric sheet assembly, and specifically via the electrically conductive thread stitch or stitches. Advantageously, this ensures that there is no build-up of charge in, or a large voltage difference between, any of the layers during a lightning strike and also prevents arcing between components which might damage
10 the blade. The use of discrete stitches also minimises the total amount of conductive material that is required.

In some instances, a portion of the conductor element may extend from the reinforcing structure, which allows easy connection with the wind turbine LPS component.
15 Additionally, this portion of the conductor element may terminate in a connector, which is also electrically conductive, and it is the connector which enables electrical connection with the wind turbine LPS.

In some cases, the connector comprises a block of electrically conductive material, for
20 example, copper or brass, which are both advantageously good electrical conductors. However, other possible materials for the connector and the form that the connector may take have also been envisioned (for example, a threaded screw or a thin plate made of electrically conductive material). In addition, if the conductor element takes the form of a conductive fabric sheet assembly, the connector may simply correspond
25 to a portion of the fabric sheet assembly that extends away from the carbon strip and is connected to or otherwise in contact with a component of the wind turbine LPS.

In some cases, the reinforcing structure is a spar cap. Additionally or alternatively, the LPS component is one of: a down-conductor located within the blade shell, or a
30 metallic foil component located at or near the blade outer surface.

The wind turbine blade may further comprise a structural blade component adjacent to the elongate reinforcing structure, and the extended conductor element portion and/or connector may be arranged to be located at a surface of the structural blade
35 component. For example, if the LPS component in question is a down-conductor, the

extended conductor element portion and/or connector may be located on an internal (or 'in-board') surface of the structural blade component; however, if the LPS component in question is a metallic foil component, the connector and/or extended conductor element portion may instead be located at or near an external (or 'out-board') surface of the structural component.

According to another aspect of the present invention, there is provided a method of assembling a wind turbine blade in a blade mould. The method comprises: laying an elongate reinforcing structure in the blade mould, the reinforcing structure comprising:
 10 a plurality of strips of carbon fibre-reinforced plastic (CFRP) arranged to form a stack; and a conductor element woven or interlaced between the plurality of CFRP strips. The method further comprises electrically connecting the conductor element to an LPS component of the wind turbine blade, thereby to permit electrical conduction between the plurality of CFRP strips and the LPS component.

15 Advantageously, incorporating the conductor element directly into the reinforcing structure prior to blade layup means that the reinforcing structure (with its integrated conductor element) can be simply placed in the appropriate location in the blade mould during blade layup, thereby simplifying the manufacturing process. In some cases, a
 20 portion of the conductor element may extend from the stack in order to connect the conductor element with the LPS component; this advantageously simplifies the subsequent connection process, as that portion of the conductor element will remain exposed for easy access after the blade layup process is completed.

25 The conductor element may terminate in a connector that extends from the spar cap stack, in which case it is the connector that facilitates the electrical connection between the spar cap and the LPS component, and the method will therefore involve electrically connecting the connector to the LPS component

30 In some cases, prior to electrically connecting the conductor element (and where applicable, specifically the connector) to the LPS component, the method may further comprise locating a portion of the conductor element (including the connector, if applicable) at a surface of a structural blade component located adjacent to the reinforcing structure.

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Advantageously, this additional step increases the ease of access for subsequently connecting the conductor element to the LPS after the blade has undergone a final curing process. In particular, any subsequent steps/processes that need to be carried out to attach the conductor element/connector to the LPS component would be easier
 5 to carry out if the accessibility of the conductor element/connector is maintained by placing it at a surface of an adjacent structural blade component. For example, where a connector is utilised and if a drilling process is utilised to attach the connector to the LPS, placing the connector on an adjacent structural component (such as a structural foam core panel) would be advantageous as the depth of drilling would not need to be
 10 monitored as carefully, due to the presence of the core panel below the connector.

The method may further comprise inserting a fastener into the extended conductor element portion and/or connector for attachment to the structural blade component on which it is located. In particular, the fastener may take the form of a bolt or screw
 15 (inserted, for example, after drilling); a cable or other connection means may then be utilised to attach the fastener to the LPS component.

In some instances, electrically connecting the conductor element to the LPS component may comprise at least one of the following: connecting the conductor
 20 element portion and/or connector to a down-conductor in-board of the structural blade components; or connecting or contacting the extended conductor element portion and/or connector with a metallic foil component out-board of the structural blade components. It will therefore be appreciated that depending on which LPS component is intended for connection/contact, the extended conductor element portion (including
 25 the connector if applicable) would most likely need to be located at different surfaces of the adjacent structural component – specifically, at an inner (or in-board) surface for connection to the LPS down-conductor; or at an outer (or ‘outboard’) surface for connection to the metallic foil component.

30 According to an aspect of the present invention, there is provided an elongate reinforcing structure for a wind turbine blade. The reinforcing structure comprises: a plurality of strips of carbon fibre-reinforced plastic (CFRP) arranged to form a stack, and a conductor element woven or interlaced between the plurality of CFRP strips. The conductor element is connected to an LPS component of the wind turbine blade

thereby to connect the plurality of CFRP strips to the LPS component, and hence to enable electrical conduction through the stack to the LPS component.

The above configuration advantageously ensures that the CFRP layers are equipotentially bonded with one another, and that there is also electrical connection between the layers and the wind turbine blade LPS. This will prevent a build-up of charge within the reinforcing structure, and avoid any arcing between the internal conductive components which might damage the blade. This is particularly important in instances where the FRP layers are interleaved with other non-conducting materials.

In some instances, a portion of the conductor element may extend from the stack to facilitate connection with the LPS component; furthermore, the conductor element may also terminate in a connector which extends from the spar cap stack and via which electrical connection with the wind turbine LPS is achieved.

According to another aspect of the present invention, there is provided a method of manufacturing an elongate reinforcing structure for a wind turbine blade. The method comprises: providing a plurality of strips of carbon fibre-reinforced plastic (CFRP); and weaving or interlacing a conductor element between the CFRP strips. The CFRP strips with their integrated woven conductor element are arranged to form a stack, and the conductor element may be arranged for connection with an LPS component of the wind turbine blade, thereby to enable electrical conduction through the stack and to the LPS component. For example, a portion of the conductor element may extend from or beyond the tack to facilitate this connection. In some cases, the conductor element may comprise and terminate in a connector that is arranged to extend from the stack in order to facilitate electrical connection between the reinforcing structure and the LPS component(s).

The method may further comprise the steps of securing the stack of the plurality of CFRP strips and the woven, interleaved conducting element; and infusing the stack with resin in order to unify the components of the stack. This advantageously provides a reinforcing structure for use in blade layup with a pre-integrated conductor element, thereby simplifying the subsequent blade manufacture process. Alternatively, it would be possible to construct the reinforcing structure, and to integrate the conductor element, *in situ* in the blade mould during blade manufacture.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual
5 features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any
10 other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example
15 only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a vertical cross-section of a wind turbine blade in which an embodiment of the present invention may be implemented;

20 **Figure 2** shows an enlarged view of a portion of the layered structure of a wind turbine spar cap, incorporating a conductor element according to an aspect of the present invention;

Figure 3 shows schematically the steps involved in a method of producing the
25 layered spar cap structure that is shown in Figure 2;

Figure 4 shows schematically the steps involved in a method of installing the spar cap of Figure 3 at the relevant portion of the wind turbine blade according to an embodiment of the present invention; and
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Figure 5 shows schematically the steps involved in connecting the spar cap to the wind turbine lightning protection system according to an embodiment of the present invention.

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DETAILED DESCRIPTION

In order to place the invention in context, it is important first to understand the integral components of a wind turbine blade, and the method that is used to manufacture the
 5 blade.

A modern utility-scale wind turbine blade is typically formed from a two-part hollow shell. The blade is stiffened to prevent it from bending excessively and, usually, each shell incorporates one or more relatively stiff strips or 'spars' that run along the length
 10 of the blade. To provide the blade with the necessary strength to withstand the forces acting on it during operation, the opposing spars are interconnected by a construction called a shear web. There are two main approaches to achieving this design, and one of these approaches is shown in Figure 1.

Figure 1 shows a vertical cross-section of the spanwise length of a wind turbine blade 2 (i.e. the width of the blade), in which the blade 2 has a hollow shell structure comprising an upper half shell 4 and a lower half shell 6 that are united to form the complete shell having an aerofoil cross section. Each half shell is a composite structure comprising inner and outer laminate layers or 'skins' 8, 10 of material, for
 20 example fibre reinforced plastic (FRP).

The upper and lower half shells 4,6 each includes a strengthening structure comprising two spar caps 12, each of which runs along the spanwise length of the blade 2. The spar caps 12 may also be known by other terminology in the art such as 'spars',
 25 'beams' or 'girders'. The number of spar caps 12 within a blade may vary, and they may be located at intervals along the chordwise length of the blade. It is preferable for the spar caps 12 to be extremely stiff and lightweight and for this reason they may be fabricated from carbon fibre reinforced plastic (CFRP) material. Carbon fibre is not essential, however, but it is generally preferred due to its very high strength to weight
 30 ratio. In this blade 2, the spar caps 12 are embedded in the laminated FRP layers and so form an integral part of the shells 4, 6. Such a blade design is sometimes referred to as a 'structural shell'. Certain regions of the blade incorporate lightweight cores 14 such as structural foam or balsa wood that are sandwiched between the outer and inner skins 8, 10 and located in between the spar caps 12. Such a sandwich panel

construction improves bending stiffness and reduces the risk of buckling in these regions. Similar blade structures are also known having a single spar cap.

Referring more specifically to the spar caps 12, each of these has a substantially rectangular cross section and is made up of a stack of pre-fabricated elongate reinforcing planks or strips 18. The strips 18 are pultruded members of carbon-fibre reinforced plastic, and are substantially flat and of rectangular cross section. The number of strips 18 in the stack depends upon the thickness of the strips 18 and the required thickness of the shells 4,6, but typically the strips 18 each have a thickness of a few millimetres and there may be between two and twelve strips in the stack. The strips 18 have a high tensile strength, and thus have a high load bearing capacity.

Manufacture of the blade using a resin-infusion process, will now be described, by way of example, in which components of the blade are laid up in a blade mould and subsequently infused with resin. Firstly one or more layers of dry glass-fibre fabric are arranged in the mould to form the outer skin of the blade. Then, panels of structural foam (or alternatively other materials such as balsa wood) are arranged on top of the glass-fibre layer to form the sandwich panel cores 14 referred to in Figure 1. The foam panels 14 are spaced apart relative to one another to define a pair of channels in between them for receiving respective spar caps. To assemble the spar caps 12, a plurality of pultruded strips of CFRP, as described above with reference to Figure 1, are stacked in the respective channels. It is also possible to lay pre-assembled stacks into the channels.

Once the spar caps 12 are in place, additional dry glass-fibre fabric layers are arranged on top of the foam panels 14 and the spar caps 12. This forms the inner skin 8 of the blade. Next, vacuum bagging materials and film is placed over the mould to cover the layup. Sealing tape is used to seal the vacuum bagging film to a flange of the mould and a vacuum pump is used to withdraw air from the interior volume between the mould and the vacuum bagging film. Once a suitable partial vacuum has been established, resin is introduced to the sealed volume at one or more insertion points. The resin infuses between the various laminate layers and fills any gaps in the laminate layup. Once sufficient resin has been supplied to the mould, the mould is heated whilst the vacuum is maintained to cure the resin and bond the various layers

together to form the half shell of the blade. The other half shell is made according to an identical process.

It is worth mentioning here that the resin-infusion process described above is one example of a blade fabrication process. Another example is a so-called 'pre-preg' process where the glass fibre components of the blade have been pre-impregnated with resin. In such a case a complete resin infusion process is not necessary as the assembled layers of the blade can simply be heated which triggers the curing process of the resin in the glass-fibre fabric.

In either fabrication process, once both shells are cured and the vacuum bagging consumables removed (if applicable), the shells 4, 6 are ready to be joined. Adhesive is applied to the leading and trailing edges of the shells 4, 6, as well as at the locations where strengthening web structures 16 will be arranged. The web structures 16 are then loaded and more adhesive is applied to their upper surfaces. The shells 4, 6 are then brought together to form the completed blade 2. Subsequent finishing processes can be started once the adhesive is cured.

Other examples of rotor blades having spar caps integral with the shell are described in EP1520983, WO2006/082479 and UK Patent Application GB2497578.

The inset panel to Figure 1 shows an enlarged view of one of the spar caps 12 in a finished wind turbine blade 2, where the spar cap 12 is located in a channel between a pair of foam panels or cores 14. The inner 8 and outer skins 10 are also shown above and below the foam panel cores 14 and spar cap 12 for context.

As previously mentioned, it is important to install a lightning protection system (LPS) within the wind turbine blade, so as to allow the blades to handle the electric discharges caused by the lightning strikes. Two main approaches for an LPS design were described in the background section, namely the provision of conductive elements that are embedded in an outer surface of the wind turbine blade, and the inclusion of a metallic foil component which may take the form of a metallic mesh, net, or an expanded metal foil is provided over or just below the outer surface of the blade. Examples of an LPS are described in WO 2015/055215. In practice, the LPS design may involve a combination of these two design elements. In the context of the blade

manufacture method described previously, the conductive element and the metallic foil component may be incorporated into the blade shell during the initial part of the blade layup process in which one or more glass-fibre fabric layers are layered in the mould to form the blade outer skin 10. Connections to a down conductor (not shown) within the blade shell may be made subsequently at some point during blade layup, after the blade layup or once the blade has been assembled.

As the outer blade skin 10 generally comprises multiple layers of material, the metallic foil component will usually be separated from the spar caps 12 and foam panels 14 by one or more non-conductive layers of material. This is because it is desirable to locate the conductive elements and metallic foil component on the outer surface of the blade, or as close to the blade outer surface as possible, so as to ensure that the lightning strike charge can be conducted by these components without causing significant stress to the FRP blade layers. This configuration is illustrated in the Figure 1 inset panel, in which a metallic foil component 20 is located between two layers 10a, 10b of glass-fibre fabric (or other material) forming the outer skin 10 of the blade. For example, the metallic foil component 20 may be located between a layer of glass-fibre fabric and an outer gel-coat layer of the blade.

The spar caps 12 are predominantly made of carbon fibre material, which is electrically conductive. There is therefore a risk of electrical charge build-up within the spar caps 12, which could result in arcs between the spar caps 12 and components of the LPS (or other conductive components within the blade shell), which could damage the blade. It will therefore be appreciated that there is a need to ensure good electrical connection through the layered structure of the spar cap 12, as well as between the metallic foil component 20 and/or conductive elements which form part of the LPS, and the spar caps 12.

Figure 2 shows a cross section in the chordwise plane of the wind turbine spar cap incorporating a conductor element according to an embodiment of the present invention.

As previously discussed with reference to Figure 1, the spar cap 12 comprises a plurality of CFRP (carbon-fibre reinforced plastic) strips 18, also sometimes referred to as carbon pultrusion strips, that are arranged in a stack. In the illustrated embodiment,

the spar cap 12 also comprises a plurality of fabric sheets 22 interleaved between the CFRP layers 18 and arranged to promote the infusion of resin so as to improve the bonding between the CFRP layers 18. However, it will be appreciated that whilst such a feature may be advantageous, spar caps may still be manufactured without these additional fabric sheet layers 22.

The spar cap 12 of the illustrated embodiment comprises a conductor element 24 integrated within the CFRP layers 18 so as to enable equipotential bonding between the layers. It also allows the CFRP layers 18 (and therefore the spar cap 12 as a whole) to be connected with the wind turbine LPS. Specifically, the conductor element 24 is integrated into the spar cap 12 by weaving it between the CFRP layers 18 – as shown in Figure 2, the conductor element 24 follows a winding path between the CFRP layers 18 such that the resultant configuration involves the conductor element 24 being interleaved between the CFRP layers 18.

In the illustrated embodiment, a portion of the conductor element 24 extends from the stack 12, and is arranged to be connected to a component of the LPS. This configuration thereby enables the plurality of CFRP layers 18 to be connected to the wind turbine LPS, and to enable electrical conduction through the spar cap 12 to the LPS component. In the illustrated embodiment, the portion of the conductor element 24 extending from the spar cap stack 12 terminates in an electrically conductive connector 26 for connection to a component of the wind turbine LPS (as will be described subsequently with reference to Figure 4).

In the illustrated embodiment, the winding path of the conductor element 24 is arranged such that the conductor element 24 is interleaved between *each* CFRP layer 18. More specifically, each portion of the conductor element 24 is sandwiched between two CFRP layers 18 and extends between long edges 18a and 18b of the CFRP layers 18. In addition, the conductor element 24 wraps around one of the long edges of the adjacent CFRP layer 18, before extending to the next CFRP layer 18 in the stack 12. When the stack 12 is viewed in vertical cross-section (as shown in Figure 2), the conductor element 24 follows a series of S-shapes or zig-zags as it threads and weaves through the layers of the stack 12. Each CFRP layer 18 is therefore in contact with the conductor element 24 along at least one surface. However, the bottom-most CFRP layer 18 in the illustrated stack 12 is in contact with the conductor element 24

along both surfaces extending between its long edges – i.e. the conductor element 24 wraps almost entirely around the bottom-most CFRP layer 18 in the stack 12.

Such a configuration is particularly advantageous in situations (such as that shown in Figure 2) where additional layers of non-conductive fabric material 22 are interleaved between adjacent CFRP layers 18, since the conductor element 24 will be in contact with each of the individual CFRP layers 18, and can thereby ensure good electrical conduction through the entire spar cap stack 12. However, due to the nature of the spar cap manufacturing process, air gaps or pockets can be formed between the CFRP layers 18 when the resin is infused through the stack, which can cause the CFRP layers 18 to be at least partially electrically insulated from one another. It is therefore generally useful for the conductor element 24 to be woven between every single CFRP layer 18 in the stack 12; however it will be appreciated that the conductor element 24 could still serve its purpose even if some of the adjacent CFRP layers 18 are not directly adjacent to a portion of the conductor element 24. In other words, some of the CFRP layers 18 may be ‘missed out’ when the conductor element 24 is woven through the stack 12. For example, the conductor element 24 could be arranged to only contact every other CFRP layer 18, or to contact only specific layers in the stack. In addition, it would also be possible to have the top-most CFRP layer being in contact with the conductor element along both its surfaces, or even none of the CFRP layers having such a configuration.

In some embodiments, the conductor element 24 takes the form of a strip of electrically-conductive material, for example a strip of copper braid or mesh. Alternative embodiments of the conductor element 24 are also envisioned, for example a fabric strip of similar dimensions (either woven or non-woven) comprising carbon fibres. The width of the conductor element 24 may be around 1 cm to 2 cm, and it may have a thickness of between 0.1 and 1 mm.

In the illustrated embodiment, the connector 26 takes the form of a block 28 of electrically-conductive material, for example, copper or brass (although other types of metallic or non-metallic conductive materials may be used instead). A hole 30 is provided in the connector block 28 to facilitate subsequent connection of the connector 26 with the wind turbine LPS.

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It will be appreciated that the spar cap 12 with its integrated conductor element 24 can be pre-manufactured as a kit prior to blade layup so as to simplify the blade layup process, since the pre-prepared spar cap kit can simply be placed in a desired location within the wind turbine blade 2 at an appropriate stage of the blade layup process. In
 5 Figure 2, the connector 26 is shown resting on top of the stack 12. However, due to the flexibility of the conductor element 24, the connector 26 can be pulled away from the stack 12 – the conductor element 24 and the attached connector 26 therefore may extend from the stack to a suitable attachment point in the blade 2.

10 The overall process by which the spar cap 12 is produced, incorporated into the blade structure and connected to the wind turbine LPS is shown in Figures 3, 4 and 5. Specifically, Steps A to C shown in **Figure 3** illustrate a method of manufacture of the spar cap 12 in which the conductor element 24 is woven into the spar cap 12; Steps D and E in **Figure 4** show a method of installing the spar cap 12 into the blade structure;
 15 and Steps F and G in Figure 5 highlight a method of connecting the spar cap 12 to the wind turbine LPS.

Beginning with **Figure 3**, in the illustrated manufacture method, the conductor element 24 is provided in the form of a strip of electrically-conductive material arranged that is
 20 initially arranged in a coil 32 with the connector 26 at its centre; however it will be appreciated that other designs and initial configurations of the conductor element 24 would also be possible provided the desired end result is still achievable.

The method begins with Step A which involves unwinding a portion of the conductor
 25 element 24 from its coil 32 and laying a CFRP strip 18 on top of the unwound portion such that a first length 24a of the conductor element 24 extends beyond the CFRP strip 18 and away from the coil 32. This first length 24a is then folded back over on top of the CFRP strip 18 (towards the coil 32) such that the CFRP strip 18 is in contact with the conductor element 24 at both its main exposed (upper and lower) surfaces.

30 Step B is then carried out and begins with (if applicable) a non-conductive fabric sheet layer 22 being placed on the stack on top of the folded conductor element length 24a, another CFRP layer 18 is then added to the stack. After adding the second CFRP layer 18, the conductor element coil 32 is unwound to free a second length 24b of the
 35 conductor element 24; this second length 24b (together with the rest of the coil 32) is

then folded over the top of the second CFRP layer 18, in the opposite direction to that in which the first length 24a was folded.

Step B is then repeated as many times as necessary to produce a spar cap stack 12
 5 comprising the requisite number of CFRP layers 18, by unwinding consecutive lengths of conductor element 24 from the coil 32 and folding these lengths over the growing stack in opposite directions. It will be appreciated that folding consecutive lengths of conductor element 24 in opposite directions on top of their adjacent CFRP layer 18 results in the conductor element 24 being woven in a winding path through the spar
 10 cap stack 12 (as shown in the vertical cross-sectional plane of the blade 2 of Figure 2), and enables the conductor element 24 to be interleaved between each CFRP layer 18.

As mentioned previously, however, the process may instead involve laying down two or more CFRP layers 18 and then laying over a length of conductor element 24.

15

It should be noted that in the illustrated embodiment the conductor element weaves between the strips of the stack so that each portion of the conductor between neighbouring strips are substantially aligned in a vertical plane. However, it is envisaged that other arrangements are possible in which the individual portions are not
 20 so aligned. For example, the conductor element 24 may be woven between the individual strips of the stack so that each portion of the conductor element between neighbouring strips extends diagonally between the edges of the strip. In this manner, therefore, the conductor element 24 can be arranged within the stack so as well as weaving between the individual strips of the stack in a vertical direction, it also extends
 25 in a direction along the span-wise length of the stack.

Step C shows the finished spar cap 12: once the final CFRP layer 18 has been incorporated into the stack, the remaining length of the conductor element 24 is folded back over the top, whilst leaving the connector 26 free to extend from the stack. For
 30 ease of storage and transportation, the connector 26 may be folded back on top of the uppermost conductor element 24 layer. Alternatively, a short stub of the conductor element 24 could be left exposed to which a connector could be fixed. For example, a connector could be located on/in an adjacent structural component in the blade (for example, an adjacent foam core panel 14), with a length of conducting material

extending from the connector to the stack to enable connection with the conductor element stub.

5 It will be appreciated that the size of the conductor element 24 and its location within the spar cap stack 12 may be varied as necessary to provide optimal charge conductivity through the stack 12. For example, it is envisioned that thin strips of conductor element 24 could be woven into the spar cap stack 12 at intervals along its spanwise length. Purely by way of illustration, strips of conductor element 24 a few
10 centimetres wide could be woven into the spar cap stack 12 at around 1 metre intervals. The width of the conductor element strips, and spanwise spacing between the strips, could be varied as required in order to enable greater charge conductivity. For example, the spacing intervals between strips of conductor element could be around 5 to 10 m.

15 In some applications, it may be preferable for the thickness of the conductor element to be minimised – i.e. if additional charge conduction is required, it would be advantageous to have a wider conductor element strip rather than a thicker one, in order to avoid creating any lumps or distortions in the spar cap profile due to
20 integration of the conductor element. Furthermore, it may also be preferable for the conductor element 24 to be provided in small sections rather than covering the entire spanwise length of the spar cap stack 12. Although the latter arrangement would be possible in principle and could potentially enhance the electrical conduction through the stack 12, it may not be as useful from a structural standpoint, particularly if the
25 conductor element comprises metallic materials. Typically, metallic materials do not bond particularly well with the resin (epoxy) used to secure the components together, which could adversely affect the overall structural properties of the spar cap, particularly as the stiffness of the metallic material may not be a good match for the rest of the components in the spar cap.

30 Turning now to **Figure 4**, which shows a method of installation of the spar cap 12 (with its integrated conductor element 24), as was previously discussed, Step D highlights that the layers of the outer blade skin 10 are first laid in the blade mould, and the other structural blade components are then placed on top. For example, the foam panel
35 cores 14 may be laid in the mould, defining a channel between them that is sized to

accommodate the spar cap stack 12; the spar cap stack 12 is then laid into the channel. Alternatively, the spar cap stack 12 may be laid in the blade mould first with the foam panel cores 14 placed on either side subsequently. The exact order in which the components are placed in the mould is not critical in this case. However, it should be noted that in circumstances where the spar cap 12 is produced in situ in the blade mould during the layup process, it may be easier to weave the conductor element 24 into the stack if the foam panel cores 14 are only laid in the mould after the conductor element 24 has been integrated into the spar cap stack 12.

10 In Step E, after the spar cap 12 and foam panel cores 14 have been laid in the blade mould, the connector 26 (which was initially provided in a 'folded' configuration, resting on top of the spar cap stack 12), is unfolded and extended out to the side of the spar cap 12, so as to contact one of the adjacent foam panel cores 14. Specifically, the connector 26 is placed on top of one of the adjacent cores 14, and may be held
15 securely in place using an adhesive (for example, hot melt glue). Subsequently, the inner blade skin 8 is laid on top of all the other components to complete the blade layup process.

Figure 5 highlights Steps F and G for connecting the conductor element 24 (and hence the spar cap 12) to the wind turbine LPS according to an embodiment of the present invention. Specifically, the method involves connecting the conductor element 24 to the wind turbine LPS via the connector 26.

These steps are carried out after the blade shell is complete – namely, after all of the components have been placed in the blade mould (as shown in Figure 4), and the resin infusion and curing steps (described previously with reference to Figure 1) have been carried out.

The first part (Step F) of this method involves creating a hole, socket or recess 34 in the connector 26 (for example, via drilling) into which a fastener 36 may be inserted to allow connection with the wind turbine LPS. The process may also involve creating a counterbore in the connector block 28, depending on the type of fastener 36 that is to be used and whether the fastener is required to sit flush with the inner surface of the blade inner skin 8. When creating the recess 34, the presence of the hole 30 that was initially provided in the connector block 28 serves to guide the drill or other tool used

so as to ensure that the resultant recess 34 is created in the desired location. This functionality of the hole 30 will still be provided even if it has been filled with resin during the prior resin infusion and curing process that the blade shell is subjected to. Furthermore, the location of the connector 28 on top of one of the foam panel cores 14 is particularly advantageous when carrying out any drilling, as the foam panel core 14 serves as a backstop – it is not critical to monitor the precise depth of the recess 34 that is being created in this case, as the foam panel core 14 prevents the drill or other tool from accidentally contacting any of the more delicate components within the blade shell (such as the layers of the outer blade skin 10).

10

Once the recess 34 has been prepared, Step G involves inserting a fastener 36 into the recess 34 and connecting the fastener 36 to the wind turbine LPS (for example, to the down-conductor within the wind turbine blade 2) via a connection means 38 such as a cable. In some embodiments, the fastener 36 may take the form of a self-tapping bolt or screw, although it will be appreciated that other types of fasteners could also be used depending on the type of connection that is required. It will also be appreciated that depending on the type of fastener required, it may not be necessary to carry out the process in Step F separately from that of Step G – the insertion of the fastener could simultaneously create the recess 34.

20

Once this step has been completed, the CFRP layers 18 of the spar cap 12 will be in electrical connection with the wind turbine LPS; electrical conduction between the CFRP layers 18, and from the spar cap 12 as a whole to the wind turbine LPS, will therefore be possible.

25

Many modifications may be made to the above examples without departing from the scope of the present invention as defined in the accompanying claims.

For example, it will be appreciated that if the spar cap 12 is intended to be connected to a different component of the wind turbine LPS the location of the connector 26 and Steps D to G of the methods may need to be varied. In particular, if an electrical connection between the spar cap 12 and the metallic foil component 20 is required, the connector 26 would not necessarily need to be located on top of one of the foam panel cores 14 during blade layup, as the metallic foil component 20 is located at or near the blade surface and is therefore out-board of the spar cap 12 and foam panel cores 14.

In this case, the connector block 28 could instead be placed underneath (or even partially within) one of the cores 14 in order to allow a connection to be made between the connector 26 and the metallic foil component 20; it is likely that the spar cap 12 would therefore need to be placed in the blade mould before the foam panel cores 14 in Step D. Subsequently, the detailed processes in Steps F and G may not be necessary for connection with the metallic foil component 20; instead, direct contact between the connector block 26 and the metallic foil component 20 could be achievable. Additionally or alternatively, a drilling operation could be used after blade assembly to make the electrical connection between the metallic foil component 20 and the connector block 28 through any intervening non-conductive layers of material.

Additionally or alternatively, it will be appreciated that the conductor element 24 could be replaced with or supplemented by a fabric sheet assembly that is made up of one or more layers of non-conductive fabric material in which are provided one or more stitches of an electrically conductive material. The electrically conductive stitching allows electrical charge to be conducted through the fabric sheet assembly, and would therefore perform a similar function to that of the conductor element 24. In addition, if the layer(s) of non-conductive fabric material correspond to those which form the inner 8 and outer blade skins 10, the portion of the fabric sheet assembly that extends from the spar cap 12 (i.e. that portion which lies above or below the spar cap stack 12 and extends into the blade skin layers 8, 10) could replace those blade skin layers due to the structural support functionality that would be imparted by the layers of fabric material. In this case, the specific form of the connector 26 in the illustrated embodiments would not necessarily be required, as the conductor element 24 could directly contact the metallic foil component 20, or a fastener 36 could be directly attached to a length of the fabric sheet assembly that protrudes from the spar cap 12.

The examples above have been described with the core panels 14 in the form of foam. However, the core panels 14 could also be formed from other material such as balsa.

CLAIMS

1. A wind turbine blade comprising an elongate reinforcing structure and a lightning protection system (LPS) component, the reinforcing structure comprising:
 - 5 a plurality of strips of carbon fibre-reinforced plastic (CFRP) arranged to form a stack; and
 - a conductor element woven between the plurality of CFRP strips; wherein the conductor element is connected to the LPS component thereby to connect the plurality of CFRP strips to the LPS component, and to enable
 - 10 electrical conduction through the stack to the LPS component.
2. The wind turbine blade of claim 1, wherein the conductor element comprises a continuous element winding between the CFRP strips.
- 15 3. The wind turbine blade of claim 1 or claim 2, wherein the conductor element is woven between each one of the plurality of CFRP strips.
4. The wind turbine blade of any preceding claim, wherein the conductor element comprises at least one of the following: a metallic material, a non-metallic material, a
 - 20 woven fabric, or a non-woven fabric.
5. The wind turbine blade of claim 4, wherein the conductor element comprises copper or carbon.
- 25 6. The wind turbine blade of any preceding claim, wherein the conductor element terminates in a connector.
7. The wind turbine blade of claim 6, wherein the connector comprises a block of electrically conductive material.
 - 30
8. The wind turbine blade of claim 7, wherein the electrically conductive material comprises copper or brass.
9. The wind turbine blade of any preceding claim, wherein the conductor element
 - 35 comprises a fabric sheet assembly, the fabric sheet assembly comprising

one or more non-conductive fabric sheets which define first and second outer surfaces of the fabric sheet assembly; and

at least one conductive thread stitch penetrating a depth of the one or more fabric sheets and being exposed at each one of the outer surfaces, thereby to
5 permit electrical conduction between those outer surfaces.

10. The wind turbine blade of any preceding claim, wherein the reinforcing structure is a spar cap.

10 11. The wind turbine blade of any preceding claim, wherein the LPS component is one of: a down-conductor, or a metallic foil component.

12. The wind turbine blade of any preceding claim, further comprising a structural blade component adjacent to the reinforcing structure, and wherein the conductor
15 element is arranged to extend from the stack to a location at a surface of the structural blade component.

13. A method of assembling a wind turbine blade in a blade mould, the method comprising:

20 laying an elongate reinforcing structure in the blade mould, the reinforcing structure comprising:

a plurality of strips of carbon fibre-reinforced plastic (CFRP) arranged to form a stack; and

25 a conductor element woven between the plurality of CFRP strips; and

electrically connecting the conductor element to an LPS component of the wind turbine blade, thereby to permit electrical conduction between the plurality of CFRP strips and the LPS component.

30 14. The method of claim 13, wherein the conductor element comprises a connector, and wherein electrically connecting the conductor element to an LPS component comprises electrically connecting the connector to the LPS component.

15. The method of claim 14, further comprising, prior to electrically connecting the connector to the LPS component, locating the connector at a surface of a structural blade component located adjacent to the reinforcing structure.

5 16. The method of claim 15, further comprising inserting a fastener into the connector to attach the connector to the structural blade component on which it is located.

17. The method of any of claims 13 to 16, wherein electrically connecting the
10 conductor element to the LPS component comprises at least one of the following:

connecting the conductor element to a down-conductor in-board of the structural blade components; or

contacting the conductor element with a metallic foil component out-board of the structural blade components.

15

18. A method of manufacturing an elongate reinforcing structure for a wind turbine blade, the method comprising:

providing a plurality of strips of carbon fibre-reinforced plastic (CFRP);

weaving a conductor element between the CFRP strips

20

wherein the CFRP strips and the woven conductor element are arranged to form a stack, and the conductor element is arranged to be connected to an LPS component of the wind turbine blade, thereby to enable electrical conduction through the stack and to the LPS component.

25 19. The method of claim 18, further comprising:

securing the stack of the plurality of CFRP strips and the woven conducting element; and

infusing the stack with resin in order to unify the components of the stack.

30

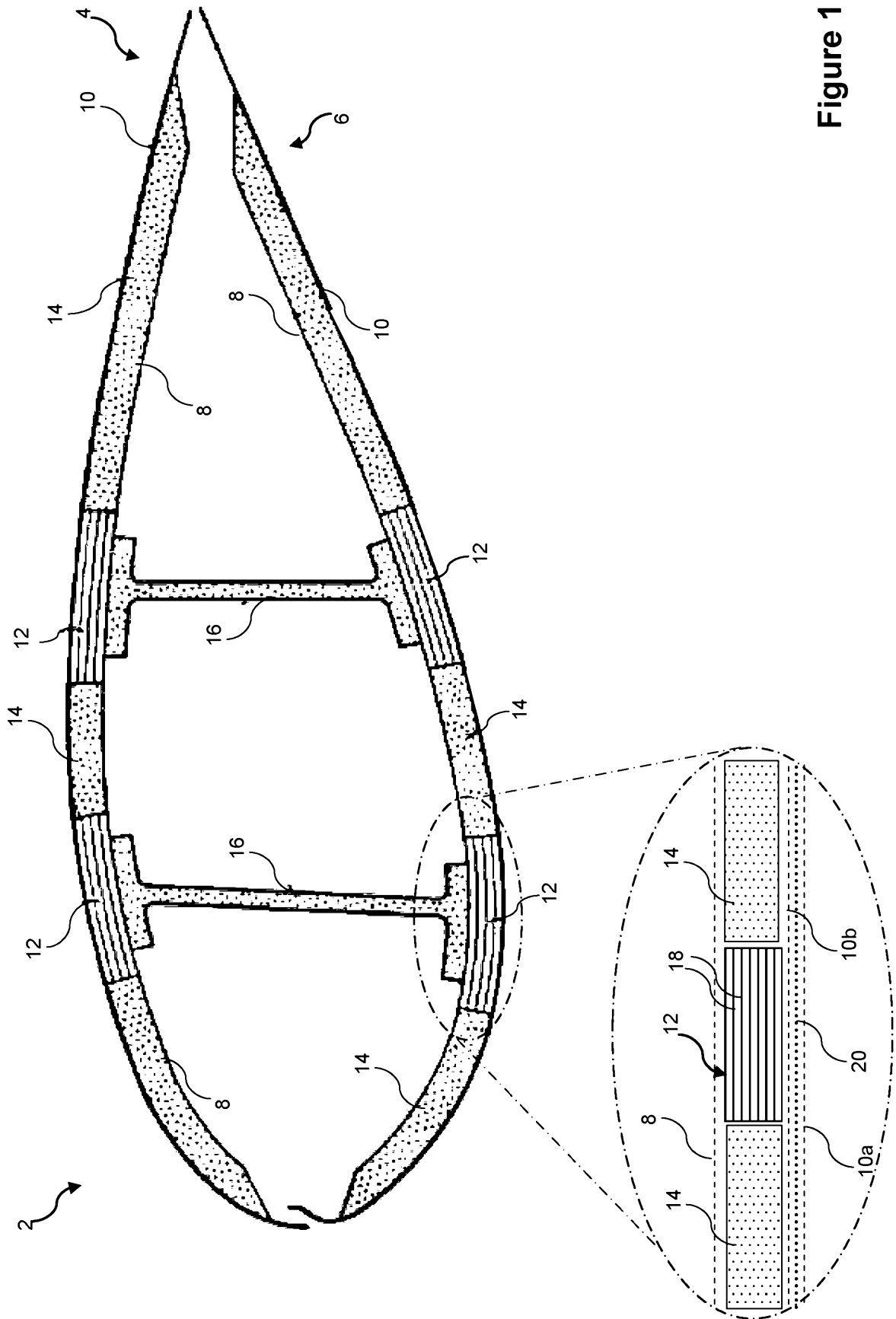


Figure 1

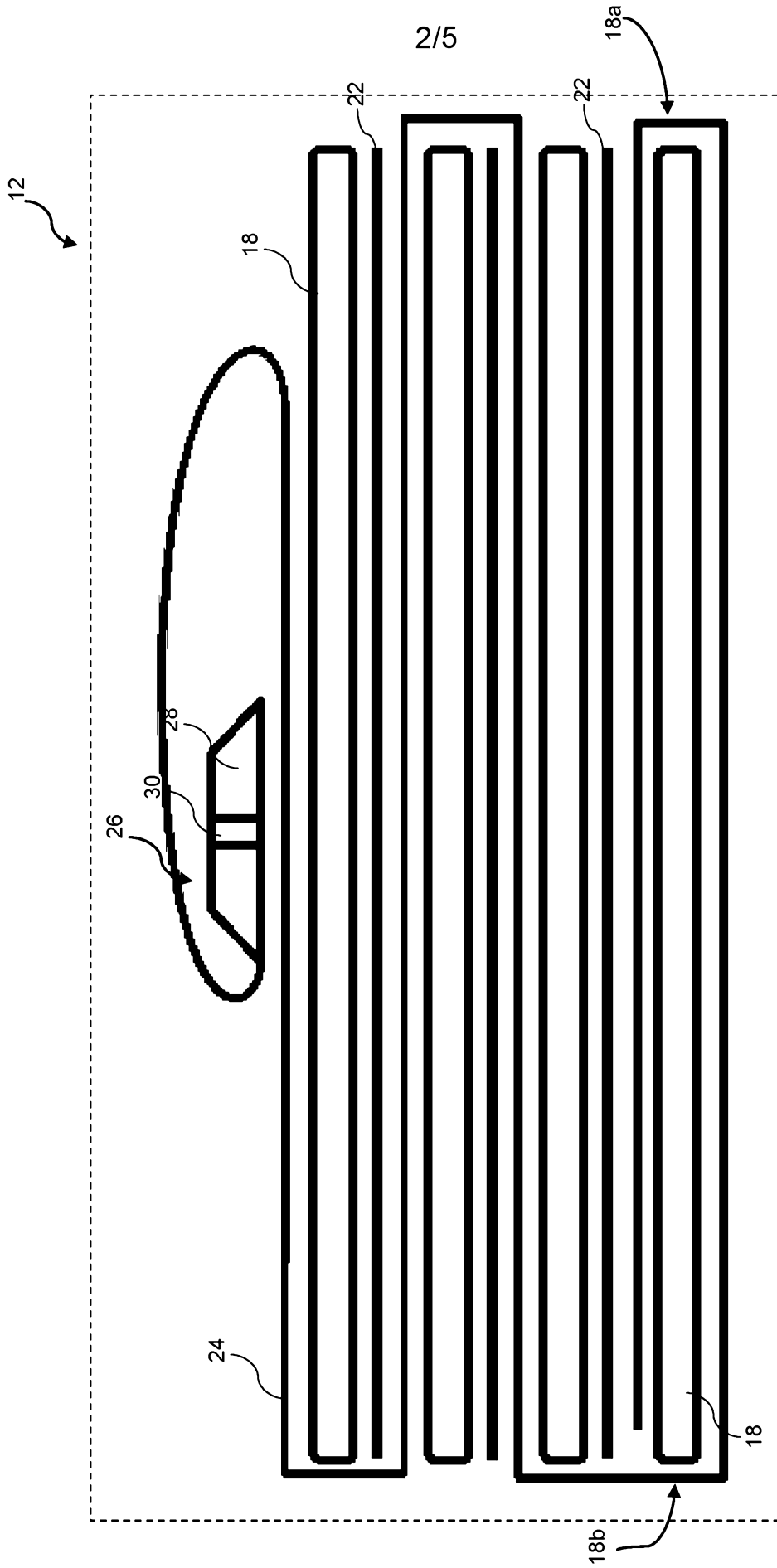


Figure 2

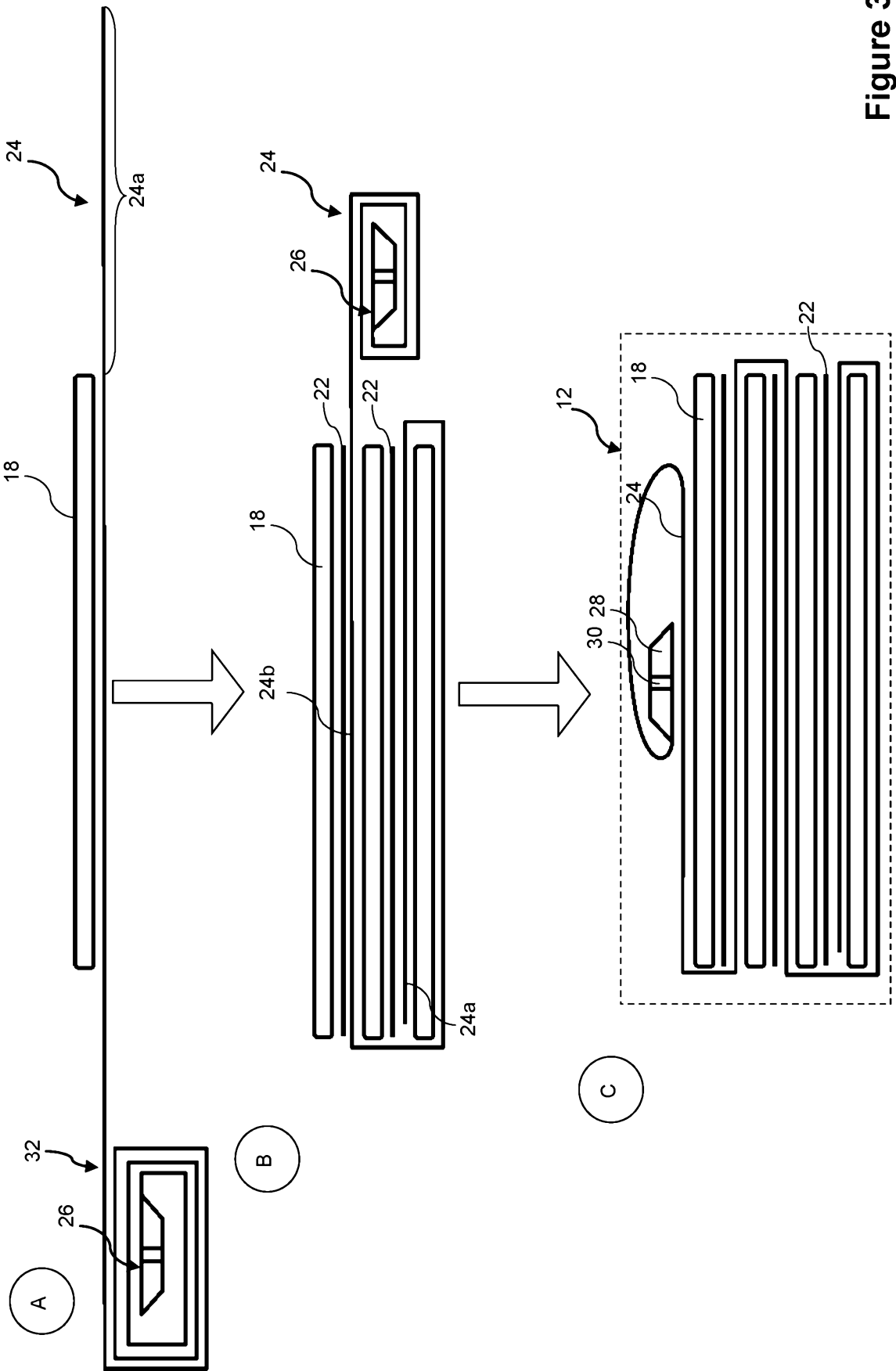


Figure 3

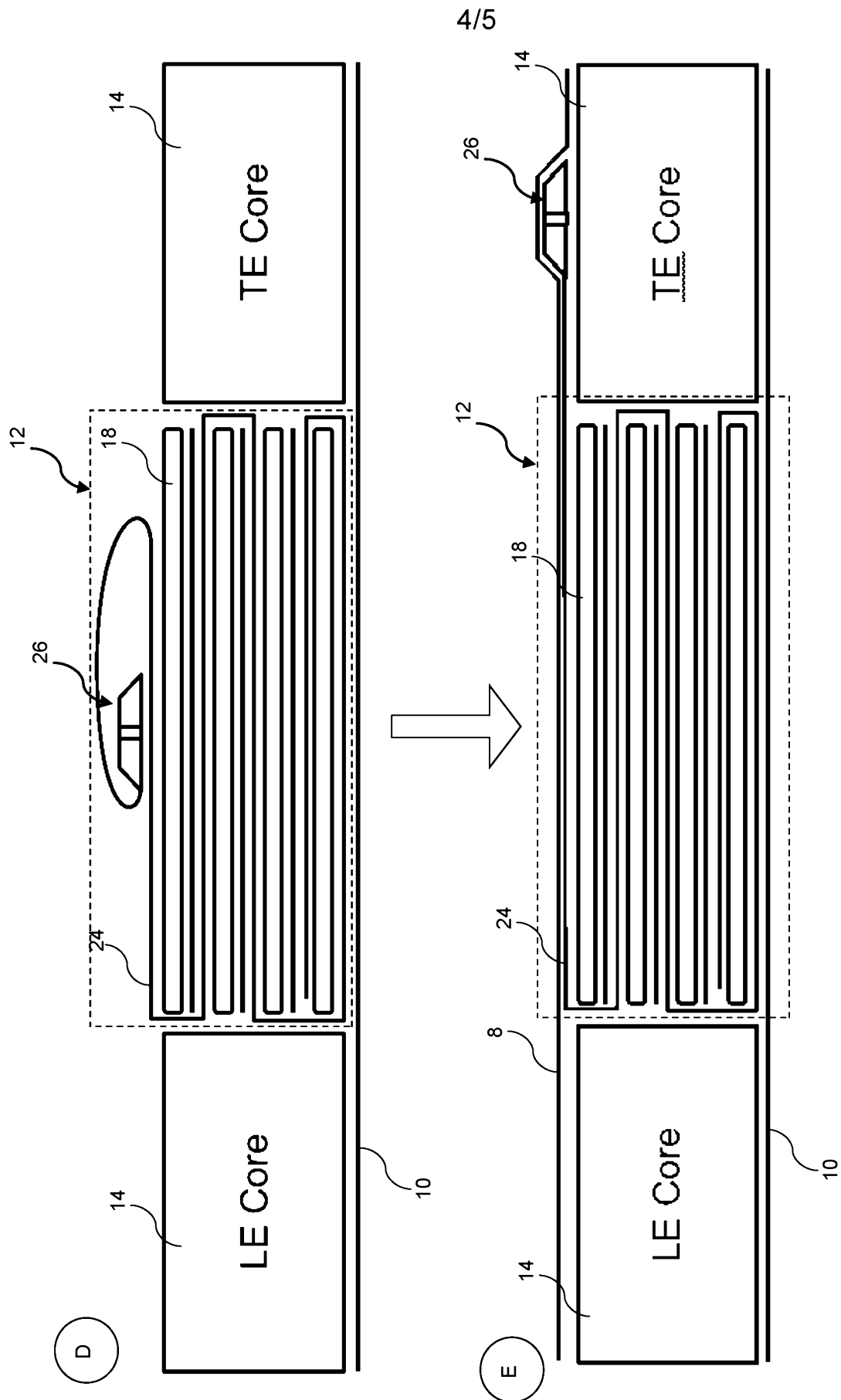


Figure 4

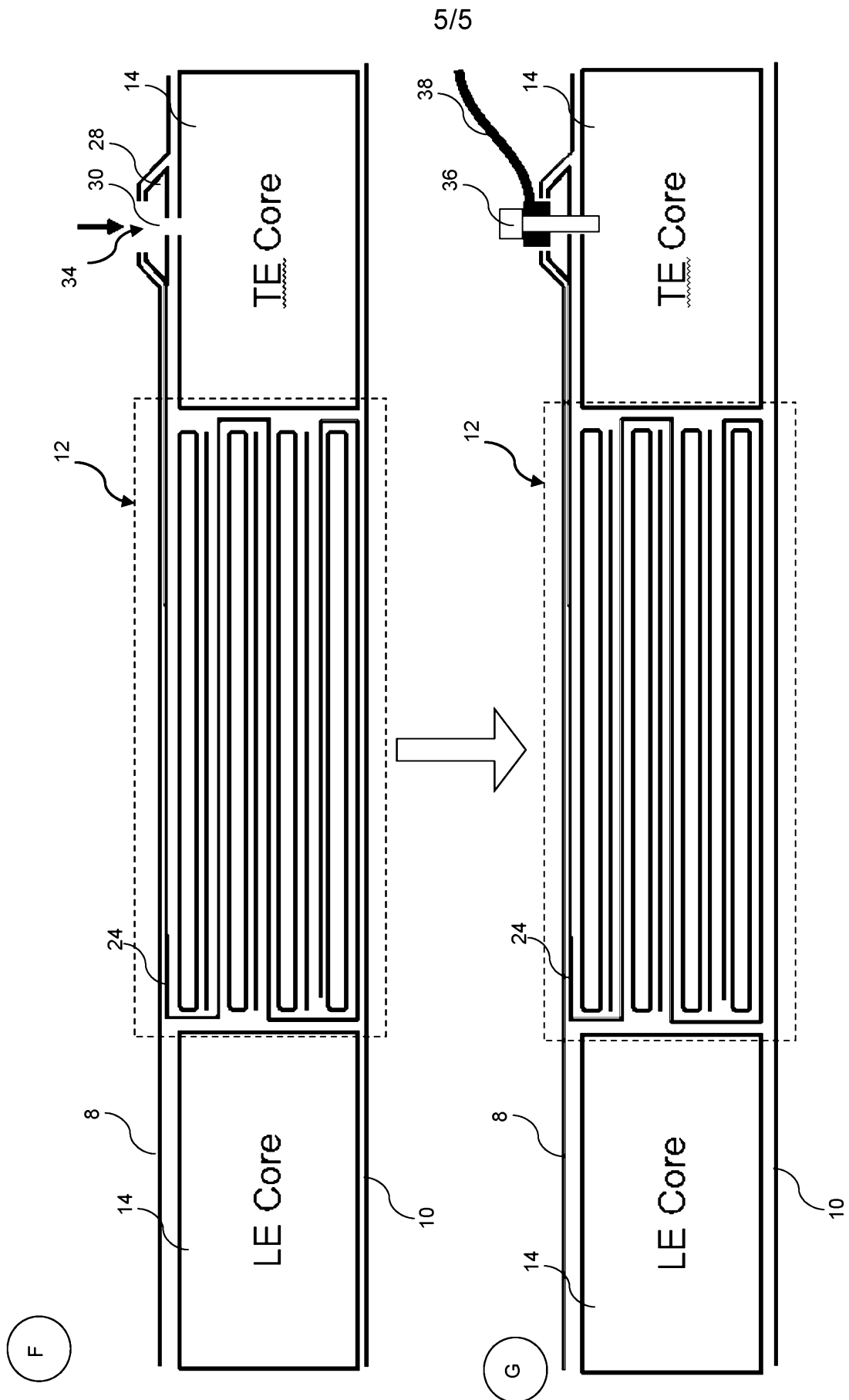


Figure 5