FIG 5

The invention describes a manufacturing arrangement (1) realised for the manufacture of a rotor blade, comprising a pair of tracks (11A, 11B) arranged along the longitudinal sides of a blade mould (M1, M2); a first gantry assembly (2) realised to span the track pair (11A, 11B) and to carry a first tool arrangement (20, 21) comprising at least a fibre distributor (20) for distributing a fibre material (41) into the blade mould (M1, M2); a second gantry assembly (3) realised to span the track pair (11A, 11B) and to carry a second tool arrangement (30, 31, 301) realised to carry a supply of fibre material (42) and to provide the fibre material (42) to the fibre distributor (20); and a control arrangement (10) realised to effect a coordinated movement of the gantry assemblies (2, 3) along the track pair (11A, 11B) and to coordinate the operation of the second tool arrangement (30, 31) with the operation of the first tool arrangement (20). The invention further describes a fibre mat magazine (30); a manufacturing line (100); a method of manufacturing a rotor blade; and a rotor blade manufactured using such a method.
Description

Rotor blade manufacturing arrangement

The invention describes a manufacturing arrangement for manufacturing a rotor blade; a fibre mat magazine; a manufacturing line; a method of manufacturing a rotor blade; and a wind turbine rotor blade.

A wind turbine rotor blade is usually made of a reinforced fibre material, and is constructed by laying up a suitable fibre arrangement in two mould halves (one for the suction side of the blade and one for the pressure side of the blade). In the known methods, the fibre layup is infused with a resin to bond the fibres and fibre layers and then cured to harden in a vacuum-assisted resin transfer moulding (VARTM) technique. The blade halves are joined, and the outer surface of the blade can be treated as necessary.

The desired aerodynamic shape of a wind turbine rotor blade airfoil, the inclusion of a circular root section for connection to a hub, and the requirements of lightness as well as structural strength all add up to a costly and complex manufacturing process. For example, the process of laying out fibre material manually in the blade mould is very time consuming, leading to a lengthy total production time of a blade. Furthermore, manual layup is difficult and even if great care is taken, faulty positioning of the fibre material cannot be ruled out. Inconsistencies in the fibre layup - for example too thin or too thick fibre layers, over-tensioned or under-tensioned fibre rovings, wrinkles or creases in the fibre material etc. - can lead to structural deformities in the finished rotor blade.

Different regions of a wind turbine rotor blade are subject to different types of loading during operation, and some regions of the blade are subject to greater loading than other regions. A certain minimum material thickness is
therefore necessary in order to avoid cracks developing in the blade. However, an increase in material thickness will result in an increase in the weight of the blade. In conventional manufacturing techniques, the fibre material layup may not properly consider these factors, so that the resulting blade may not exhibit the necessary structural strength, or the blade may be excessively heavy so that handling during transport and installation is made more difficult and time-consuming.

It is therefore an object of the invention to provide a reliable, more economical, and less time-consuming way of manufacturing a structurally robust wind turbine rotor blade.

This object is achieved by the manufacturing arrangement of claim 1; by the fibre mat magazine of claim 9; by the manufacturing line of claim 10; by the method of claim 12 of manufacturing a rotor blade; and by the wind turbine rotor blade of claim 16.

According to the invention, the manufacturing arrangement is realised for the manufacture of a rotor blade, and comprises a pair of tracks arranged along the longitudinal sides of a blade mould; a first gantry assembly realised to span the track pair and to carry a first tool arrangement comprising at least a fibre distributor for distributing a fibre material into the blade mould; a second gantry assembly realised to span the track pair and to carry a second tool arrangement realised to carry a supply of fibre material and to provide the fibre material to the fibre distributor; and a control arrangement realised to effect a coordinated movement of the gantry assemblies along the track pair and to coordinate the operation of the second tool arrangement with the operation of the first tool arrangement.

The tool arrangements are operated to perform functions such as distributing fibre material in the moulds during the layup procedure. In the context of the invention, a "tool
arrangement" can comprise any tool or device that can be used actively or passively to perform or fulfil a function. By controlling the movement of the gantries along the track pair and coordinating the tool arrangements at the same time, the manufacturing arrangement according to the invention allows a favourably efficient and accurate fibre layup to be performed, since fibre material can be supplied to the fibre distributor in a controlled and pre-determined manner and other layup-related functions can be carried out as required.

In the context of the invention, the control arrangement can control the operation and function of any controllable tool or device of the tool arrangements, and can control the rate(s) at which the first and second gantries move along the tracks. The control of the gantries and tool arrangements in this way can be regarded as a type of choreography. A further advantage of the manufacturing arrangement according to the invention is that it significantly shortens the "time in mould" for a blade. This leads to a more cost-effective manufacturing process, since the blade moulds are the most expensive components of rotor blade manufacture. Effectively, fewer moulds are required when a plurality of rotor blades is to be manufactured. Furthermore, the production time of each individual rotor blade is decreased by the efficient and coordinated control of the tool arrangements that are operated.

According to the invention, the fibre mat magazine is realised for use with such a manufacturing arrangement and comprises a holding means for holding a number of fibre mat reels; and a winding unit for winding a length of fibre material to a tool attachment in preparation for providing the fibre material to the fibre distributor.

An advantage of the fibre mat magazine according to the invention is that a supply of fibre matting can be held conveniently during the layup procedure, and fibre matting of a desired length can be easily provided to the fibre distributor during layup. This allows a smooth and
uninterrupted layup procedure, since time-consuming fetching and loading steps can essentially be eliminated. Furthermore, the duration of the fibre layup procedure can be greatly reduced by the efficient cooperation of the fibre mat magazine with the fibre distributor of the manufacturing arrangement.

According to the invention, the manufacturing line is realised for the manufacture of wind turbine rotor blades, and comprises a first manufacturing arrangement according to the invention for manufacturing an upper blade half, wherein the track pair is arranged along the longitudinal sides of an upper blade mould; and a second manufacturing arrangement according to the invention for manufacturing a lower blade half, wherein the track pair is arranged along the longitudinal sides of a lower blade mould; and wherein the control arrangements of the first and second manufacturing arrangements are realised to coordinate the operation of the tool arrangements such that the blade halves are manufactured essentially simultaneously.

Here also, the manufacturing line according to the invention can achieve a significant cost reduction in the manufacture of multiple rotor blades. Both blade halves of a single rotor blade can be prepared essentially at the same time, and the gantry assemblies and tools of both manufacturing arrangements can be optimally utilised. For example, a gantry assembly with tool arrangement can be put to use essentially continuously without any significant idle time. As soon as one upper blade half and one lower blade half have been prepared, the gantry assemblies and tool arrangements can be used to commence preparation of a further rotor blade.

According to the invention, the method of manufacturing a rotor blade comprises the steps of

(A) arranging a pair of tracks along the longitudinal sides of a blade mould;
(B) arranging a first gantry assembly to span the track pair and placing a first tool arrangement on the first gantry, which first tool arrangement comprises at least a fibre distributor for distributing a fibre material into the blade mould;

(C) arranging a second gantry assembly to span the track pair and placing a second tool arrangement on the second gantry which second tool arrangement is realised to carry a supply of fibre material and to provide the fibre material to the fibre distributor; and

(D) operating a control arrangement to effect a coordinated movement of the gantry assemblies along the track pair and to coordinate the operation of the second tool arrangement with the operation of the first tool arrangement.

An advantage of the method according to the invention is that it is possible to produce the halves of the blade in the moulds essentially simultaneously, so that the blade halves correspond in terms of quality.

According to the invention, the wind turbine rotor blade is manufactured using such a method. An advantage of the rotor blade according to the invention is that the fibre layup can be completed in a controlled and efficient manner by the coordinated operation of the tool arrangements. The result is a high-quality and even distribution of fibre material, which is obtained in a significantly shorter time compared to conventional manufacturing techniques. Another advantage is that the second tool arrangement can always provide a specific quality of fibre material to the fibre distributor, so that material thickness can be adjusted according to the region of the blade in which the fibre material is being laid. In this way, the method according to the invention makes it possible to obtain a blade with superior structural qualities even though its manufacturing time may be significantly shorter than a blade made using a prior art manufacturing technique.
Particularly advantageous embodiments and features of the invention are given by the dependent claims, as revealed in the following description. Features of different claim categories may be combined as appropriate to give further embodiments not described herein.

The manufacturing arrangement and method according to the invention are particularly suited to a "dry layup" process in which fibre (usually glass fibre, carbon fibre or similar) is distributed or laid in the mould in an initial stage. Resin is infused into the fibre material only after the two blade mould halves have been joined. The rotor blade is therefore essentially manufactured in one piece, since the resin infusion and curing stages are performed on the joined blade halves. This process can be referred to as "mould-assisted resin transfer moulding" (VARTM). Of course, the manufacturing arrangement and method according to the invention could also be used in a "wet layup" process, in which fibre material such as fibre matting is already infused with resin before laying up; or to manufacture blade halves for which resin infusion and curing are performed separately before joining the cured blade halves together. However, in the following but without restricting the invention in any way, it may be assumed that the fibre distribution is performed as a "dry layup" process.

A pair of tracks can be arranged alongside a blade mould in any suitable manner. Preferably, the manufacturing arrangement comprises a track supporting structure for supporting the tracks of the track pair such that height of the tracks exceeds the height of the blade mould by a certain clearance. In this way, the gantries and tool arrangements can travel over the blade mould at a safe distance. The gantries and tools are moved relative to the blade mould, which preferably remains stationary throughout the fibre layup process.
Preferably, the control arrangement comprises a drive unit arranged in a gantry for moving the gantry along the track pair and/or an actuating unit for actuating a tool arrangement. For example, each gantry can be equipped with a motor to move the gantry along the track pair. To allow a smooth motion, a gantry can have an arrangement of wheels or rollers on each outer end, arranged to move along the tracks.

To actuate a tool arrangement, the tool itself may have any number of actuating means such as a stepper motor which can be controlled by the control arrangement. For example, the control arrangement can be realised to run a computer algorithm which issues control commands to such actuating means. One or more algorithms can be realised as a computer program product for carrying out the relevant steps of the method according to the invention when the computer program product is loaded into a memory of a programmable device such as a programmable logic controller (PLC) of the control arrangement. Preferably, the control arrangement is operated to move the gantry assemblies from one end of the blade mould to the other, while at the same time controlling the tool arrangements to perform appropriate fibre distribution steps, depending on the position of at least the first gantry and fibre distributor relative to the blade mould.

Preferably, each tool arrangement is realised to at least partially traverse its gantry. For example, the fibre distributor can be realised to move over the width of the first gantry, so that the fibre distributor can reach all parts of the inner surface of the mould.

The fibre distributor is preferably realised to automatically distribute or layup fibre material into the blade mould. To this end, in a preferred embodiment of the invention, the fibre distributor is realised as a robotic tool that can be controlled to perform appropriate functions. The robotic tool may comprise one, two or more arms. Preferably, the fibre distributor is realised as a robot arm which has several degrees of freedom, and which can interface to various tool
attachments used for distributing different kinds of fibre material. Such a robot arm on its own and/or connected to a tool attachment may be referred to as the "fibre distributor" in the following.

Fibre material can be, for example, fibre rovings or fibre mats. Fibre rovings may be pre-formed by combining several strands of filament or fibre to give a roving or tow of a desired thickness and/or width and/or strength, and are generally laid from one end of the mould to the other (for example from root end to tip end) to provide an uninterrupted material layer for the rotor blade. Fibre rovings are generally wound on bobbins or reels until they are required. In the context of the invention, the expression "fibre material of the first type" is to be understood to comprise fibre rovings, and can comprise glass fibre, carbon fibre, or any other suitable fibre, for example a fibre with a linear mass density (Tex) of about 9600 g per 1000 m. In contrast, fibre mats can be woven, non-woven or "knitted" mats of fibre material with a certain thickness and width. These are used to provide structural stability to the blade. A length of fibre matting is generally wrapped on a drum or a reel until it is required. In the context of the invention, the expression "fibre material of the second type" is to be understood to comprise fibre matting.

A rotor blade for a multi-megawatt turbine may have a length of 70 m or more, so that considerable amounts of fibre material are needed to line the mould halves. Therefore, a supply of fibre rovings and/or fibre mats is required. In one approach, the material supply could be monitored so that, when a fibre roving reel is seen to be running low, a replacement reel can be brought and provided to the fibre distributor. However, in a preferred embodiment of the invention, the first tool arrangement comprises a first magazine for storing a sufficient supply of fibre rovings. The term "sufficient supply" may be understood to mean, for example, a supply of fibre rovings that is sufficient for the
layup of at least one blade mould half. The fibre rovings can be wound on bobbins, as described above, and several such bobbins can be arranged in the first magazine such that the fibre distributor can automatically fetch a new bobbin and connect to it when the previous bobbin runs empty, so that the distribution of fibre rovings can be performed essentially without interruption or idle time.

The fibre distributor is preferably realised to comprise a robot arm that is able to interface with various tool attachments, as described above. For example, a first tool attachment can be dedicated to the distribution of fibre rovings in the mould. Such a tool attachment may be referred to as a "fibre roving tool attachment" in the following.

Preferably, the fibre roving tool attachment of the fibre distributor comprises a fibre in-feed means for feeding in fibre rovings from a rovings supply. For example, a plurality of narrow tubes mounted to the fibre roving tool attachment can be arranged in a cluster, and a roving bundle or tow can be drawn from a bobbin and passed through a tube into the fibre roving tool attachment. A second tool attachment can be dedicated to the distribution of fibre mats in the mould, and such a tool attachment may be referred to as a "fibre mat tool attachment" in the following.

A bundle of fibre rovings is generally treated or primed with some kind of sizing to protect the fibres from damage and to facilitate handling of the rovings. The sizing also acts as a primer which helps the resin bond to the fibres, thereby also improving the structural strength of the finished blade. However, since the sizing effectively stiffens the roving bundle, it makes it difficult to lay the roving into the curved mould. Therefore, in a further preferred embodiment of the invention, the first tool arrangement comprises a breakup unit or "de-sizer" realised to break up the sizing on a bundle of fibre rovings prior to laying them in the blade mould. For example, the breakup unit can comprise a narrow bent tube through which the bundle of rovings is pulled
before being laid in the mould. The act of pulling the rovings through such a bent tube can be sufficient to break up the sizing. To ensure complete breakup of the sizing to obtain more flexible rovings, the rovings can be pulled through two such bent tubes. The act of breaking up the sizing does not physically remove the sizing from the rovings. Instead, the hard sizing is "shredded" or "flaked" and remains as shreds within the roving fibres. This ensures that the resin will still be able to bond well to the roving fibres. One or more breakup units can be arranged on the fibre distributor, for example as part of a fibre roving tool attachment, on a robot arm holding the tool attachment, on a magazine that provides a supply of fibre roving bobbins, etc. In either case, a roving from a bobbin can be pulled through a narrow tube of the breakup unit. The breakup unit can comprise any number of tubes, for example an array of tubes, so that the sizing can be broken up on a corresponding number of rovings before being fed out by the fibre roving tool attachment.

Several layers of rovings are generally required in order to obtain the desired material thickness for the rotor blade. However, if rovings are simply laid loosely into the mould, creases or folds may result. Any interruption in the lengthwise direction of a roving means a reduction in its strength. As a result, wrinkles or creases in the rovings can detract from the structural strength of the finished blade and can facilitate fatigue damage. Therefore, in a particularly preferred embodiment of the invention, the fibre distributor is realised to lay or guide a cover sheet onto fibre rovings that it has laid into the mould. In this way, the rovings are essentially immediately subject to pressure, so that they are effectively pressed into the mould. A first layer of rovings can therefore be pressed directly onto the mould surface. Later distributed roving layers can then be effectively pressed onto previously laid roving layers. For each roving layer, the cover sheet ensures that the rovings remain flat and smooth, so that the likelihood of wrinkles or
creases developing is essentially ruled out. Since the function of the cover sheet is to apply a weight to the rovings, it may be referred to as a "weighting sheet" or "weighting mat". Of course, the first tool arrangement can also be used to lay the cover sheet directly onto the mould surface in an initial step. To this end, a dedicated tool or tool attachment could be used. Alternatively, the fibre distributor with the fibre rovings tool attachment could be used, but without being fed with any fibre rovings.

While any suitably heavy material may be used as a cover sheet, the cover sheet preferably comprises a material with negligible elasticity in a longitudinal direction, for example with a Young's modulus in the range of 1 - 5 GPa. For example, the cover sheet or weighting mat can be made of a suitable rubber or synthetic material, preferably with favourable antistatic properties. Preferably, the cover sheet has a material thickness in the range of 2.0 mm to 25.0 mm, more preferably in the range of 5.0 mm to 15.0 mm. Such a material can effectively not be stretched in the lengthwise direction. Since the cover sheet cannot be stretched lengthwise, there is no risk of the rovings being lengthwise compressed or wrinkled by the cover sheet. The cover sheet effectively applies a dead weight onto the rovings, so that these are favourably held in place.

The cover sheet can be laid over the rovings in any suitable manner. For example, a handling tool can follow or track the fibre distributor and lay the cover sheet over the rovings as the first gantry moves along the mould. However, in a preferred embodiment of the invention, the fibre roving tool attachment comprises a guiding means realised to guide the cover sheet through the fibre roving tool attachment, so that the cover sheet can be laid essentially immediately over the rovings (or, in an initial step, directly onto the surface of the mould). In one possible realisation, the cover sheet can be wrapped on a reel or drum of the handling tool mounted on the second gantry. The cover sheet can therefore be dispensed
by the handling tool. In a first step, the outer end of cover sheet can be fed through the fibre roving tool attachment and fixed or secured to one end of the blade mould, for example at the root end. A suitable clamping means can be used to secure the end of the cover sheet. The fibre roving tool attachment is connected to the fibre roving supply by a fibre in-feed means as described above, and can commence to draw fibre rovings from a number of bobbins, break up the sizing, and feed the rovings through a nozzle or nose and into the mould. Here also, a suitable clamping means can be used initially to ensure that the ends of the rovings are fixed to the root end of the mould in some way, before the first gantry starts to travel down the mould. A clamping means can be realised as a tool such as a hydraulic piston, for example as a free-standing device or arranged on the second gantry, which can apply a sufficient downward force to hold the rovings and/or cover sheet in place. A single clamping means can be used to hold both rovings and cover mat in place.

The first and second gantries are moved smoothly along the tracks in the direction of the mould tip end, so that the fibre roving tool attachment lays a strip of rovings in the root-to-tip direction. At the same time, the cover sheet presses on the immediately laid fibre rovings behind the fibre roving tool attachment. In an alternative embodiment, the first gantry and second gantry can be brought to one end of the mould in an initial step, and the cover sheet can be fixed at that end after guiding it through the fibre roving tool attachment. The second gantry can then be moved to the opposite mould end, so that the weighting mat is laid along the full length of the mould. In a subsequent step, the first gantry is moved towards the other end, so that the fibre roving tool attachment can lay a strip of rovings while at the same time lifting the weighting mat in order to feed the rovings into the mould. In this way, the rovings are effectively laid directly under the cover sheet and are not given any opportunity to develop creases or folds. In the embodiments described above, the fibre roving in-feed means
may need to be placed to one side of the fibre roving tool attachment since the fibre distributor must connect to the fibre roving tool attachment from above, and the cover sheet must pass through the body of the fibre roving tool attachment and effectively "blocks" any tip-end face and root-end face of the fibre roving tool attachment. For example, the fibre roving in-feed means can be realised as a cluster of tubes (bent to break up the sizing) protruding from one side face of the fibre roving tool attachment.

In further preferred embodiment of the invention, the cover sheet is realised in two parts, and comprises a first sheet and a second sheet, so that each sheet can be attached at one end to the fibre roving tool attachment. Similarly to the embodiment described above, a fibre roving layup step can be prepared by securing one end of the first sheet to the fibre roving tool attachment, and then unrolling the first sheet from the handling tool on the second gantry as the first gantry is moved towards the tip end of the mould. The outer end of the second cover sheet can also be secured to the fibre roving tool attachment (e.g. on its "tip-end" face), and a reel or drum for rolling up or collecting the second cover sheet can be positioned at the tip end of the mould. The first gantry is then controlled to move towards the tip end, allowing the fibre roving tool attachment to feed out rovings into the mould. At the same time, the first cover sheet is un-wound by the handling tool, while the second cover sheet is re-wound onto the second reel in response to the movement of the first gantry assembly along the track pair. In an alternative embodiment, the fibre distributor itself may be realised to pay out the first cover sheet and roll up or collect the second cover sheet. To this end, for example the fibre roving tool attachment may be realised to support a complete reel of cover sheet on its tip-side face and on its root-side face. In these embodiments, the cover sheet reels can be actuated by the control arrangement as the fibre distributor moves along the mould. Even though these embodiments require two cover sheets, they may be preferable
since the fibre roving tool attachment does not need to raise
of lift the heavy cover sheet in order to feed the rovings
into the mould. Furthermore, these realisations allow a more
flexible approach to designing the fibre roving tool
attachment. For example, a roving in-feed means can be
arranged on either of four vertical faces of an essentially
block-shaped fibre-roving tool attachment.

In a preferred embodiment of the invention, the fibre in-feed
means is arranged on an upper face of the fibre roving tool
attachment. In this way, a "vertical in-feed" is made
possible, and no restrictions are placed on the position or
placement of the fibre roving material supply. For example, a
magazine containing a supply of bobbins for the fibre roving
tool attachment can be placed at any convenient point on the
first gantry. Its placement is not constrained, as might be
the case for a lateral placement of the fibre in-feed means.

A considerably quantity of fibre matting is also required in
the layup of a large rotor blade. Therefore, in a further
preferred embodiment of the invention, the second tool
arrangement comprises a second magazine for storing a
sufficient supply of fibre mats. Here also, the term
"sufficient supply" may be understood to mean, for example, a
supply of fibre mats that is sufficient for the layup of at
least one blade mould half. For example, several reels of
fibre mats can be arranged in the second magazine.

The method according to the invention allows the efficiency
of the fibre distribution process to be optimized. For
example, in a preferred embodiment of the invention, the
second tool arrangement can comprise a feeding tool realised
to provide fibre mats to the first tool arrangement. The
feeding tool can, for example, transfer a length of fibre mat
from a reel to a fibre mat tool attachment. In other words,
the feeding tool can "load" such a fibre mat tool attachment,
and can "park" the tool attachment in readiness for the fibre
distributor, which can "collect" the loaded tool attachment
and proceed to apply the fibre mat to the mould. Preferably, the second magazine is equipped with a feeding tool that can prepare at least one such additional fibre mat tool attachment while the fibre distributor is busy with another fibre mat tool attachment. In this way, the fibre mats can be distributed or laid up without any interruption, since a loaded tool attachment can always be ready and waiting for the fibre distributor.

Different sections or regions of a wind turbine rotor blade have different requirements regarding structural strength and flexibility. While it is important to ensure a certain minimum material thickness, it is also important to consider the different loading effects that act on the various blade regions during operation of the wind turbine. The method and manufacturing arrangement according to the invention allow these aspects to be taken into account in a very efficient manner during the fibre material layup stage. To this end, in a preferred embodiment of the invention, the second tool arrangement is realised to select a specific type of fibre mat and/or to cut a specific length of a fibre mat.

In a preferred embodiment of the invention, the second tool arrangement comprises a lifting tool for lifting a fibre matting reel from the fibre material supply to the winding unit. This could be achieved in any suitable way. However, in a preferred embodiment of the invention, the second gantry comprises a robust framework in which the fibre mat supply can be stored, for example in a sloping array so that each reel of fibre matting is accessible from above. Preferably, the lifting tool comprises a carriage realised to traverse the magazine framework in a side-to-side manner, and a gripping arrangement (for example a pair of hooks) to lift a fibre mat reel into the winding unit. To this end, in a preferred embodiment of the invention, the lifting tool preferably comprises an actuator for actuating the carriage and/or for actuating the gripping arrangement in order to select a fibre matting reel for loading into the winding
unit. These actuators can be controlled by the control arrangement.

The control arrangement is preferably operated to issue the respective commands to the actuators of the first and second gantries and the first and second tool arrangements. For example, reels of fibre mats with different material thicknesses can be loaded onto the second magazine, and the second tool arrangement can be controlled to select a specific fibre mat reel, to lift that reel to the winding unit, and to unwind a certain length of fibre mat from that reel and to load that fibre mat length into the fibre mat tool attachment. The fibre distributor is then controlled by the control arrangement to collect that loaded tool attachment and to apply the fibre mat length to a specific region in the blade mould. For example, the control arrangement can specify the desired type and length of fibre mat, as well as the orientation of that fibre mat (side-to-side; root-to-tip) according to the position of the first gantry along the blade mould. As indicated above, the control arrangement can control the gantries and the tool arrangements according to their positions relative to the blade mould. A finite-element analysis of a rotor blade model can have been performed previously to determine the minimum material strengths at specific regions of the rotor blade and to determine the minimum loading that needs to be withstood by specific blade regions. Using this information, the control arrangement can determine an optimum fibre material distribution for the entire blade, and can then control the tool arrangements accordingly. The optimal fibre material distribution for a blade type, and the corresponding "choreography" of tool and gantry control steps required to obtain that fibre material distribution, can be defined in a suitable control algorithm or programme. By running that programme to carry out the defined steps, it is possible to obtain a plurality of essentially identical rotor blades, each of which has essentially the same quality.
In this way, a very precisely tailored fibre material layup can be achieved. This will later ensure a structurally sound rotor blade which is not heavier than necessary, but which has a favourably long lifetime.

The manufacturing line according to the invention is not limited to use with just one pair of blade halves. In a further embodiment of the invention, the track pairs of each manufacturing arrangement are preferably arranged to accommodate a plurality of blade moulds arranged sequentially between the tracks. For example, a first row of upper blade half moulds can be arranged root-to-tip between the tracks of the first manufacturing arrangement, while a second row of lower blade half moulds can be arranged root-to-tip between the tracks of the second manufacturing arrangement. When the fibre layup for a first pair of blade halves is complete, the gantries and tool arrangements can simply progress along the tracks to commence layup in the next pair of blade mould halves. In the meantime, the root end of the first blade can be prepared, for example by placing a root bushing ring into the finished lower mould half; turning the finished upper mould half and lowering it onto the lower mould half; sealing the mould halves; and performing an infusion and curing process such as the VARTM process.

Other objects and features of the present invention will become apparent from the following detailed descriptions considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for the purposes of illustration and not as a definition of the limits of the invention.

Fig. 1 is a schematic representation of an embodiment of a manufacturing line according to the invention;

Fig. 2 is a schematic representation of an embodiment of a manufacturing arrangement according to the invention at an initial stage;
Fig. 3 is a schematic representation of the manufacturing arrangement of Fig. 2 at a subsequent stage;
Fig. 4 is detailed schematic representation of an embodiment of a first gantry for a manufacturing arrangement according to the invention;
Fig. 5 is detailed schematic representation of an embodiment of a fibre mat magazine for a manufacturing arrangement according to the invention;
Fig. 6 shows a schematic cross-section through a first embodiment of a tool attachment of the manufacturing arrangement according to the invention;
Fig. 7 shows a schematic cross-section through a second embodiment of a tool attachment of the manufacturing arrangement according to the invention.

In the diagrams, like numbers refer to like objects throughout. Objects in the diagrams are not necessarily drawn to scale.

Fig. 1 is a schematic representation of an embodiment of a manufacturing line 100 according to the invention. This exemplary embodiment of the manufacturing line 100 consists of two manufacturing arrangements 1, each of which is dedicated to the construction of a specific type of blade half. For example, one manufacturing arrangement 1 is used to make the upper halves, and comprises a pair of tracks 11A, 11B arranged alongside a row of upper blade half moulds M1. The other manufacturing arrangement 1 is used to make the lower halves, and also comprises a pair of tracks 11A, 11B, in this case the tracks 11A, 11B are arranged alongside a row of lower blade half moulds M2.

Each manufacturing arrangement 1 has a first gantry 2 and a second gantry 3, arranged so that the gantries 2, 3 span the tracks 11A, 11B and can move along the tracks 11A, 11B. A control unit 10 controls the travel of each gantry 2, 3 along the track pair 11A, 11B, and issues control signals 102, 103 to move the gantries 2, 3 separately or together, at the same
rate (synchronously) or at different rates, as required. The diagram shows separate control units 10 for each manufacturing arrangement 1, but it should be understood that the gantries 2, 3 of each manufacturing arrangement 1 could be controlled by a common controller.

Various tool arrangements (not shown in this diagram) are mounted on the gantries 2, 3. The tool arrangements and the gantries 2, 3 are operated to perform fibre layup steps in a coordinated manner so that fibre mats and fibre rovings are laid between the root end M₀ and tip end M₁ of each mould half M₁, M₂. During the layup procedure, the control unit 10 can regard the first gantry 2 of a manufacturing arrangement 1 as a "master gantry", and can control the operation of the second gantry 3 ("slave gantry") and the second tool arrangement according to the requirements of the first tool arrangement and the position of the first gantry 2 relative to the mould. For example, the control unit 10 can track the layup rate of the fibre distributor, and can take the necessary steps to ensure that a tool attachment is loaded and ready for the fibre distributor, and can move the second gantry into place so that the robot arm of the fibre distributor can unload an "empty" tool attachment and collect a new, loaded tool attachment. The type and/or quantity and/or direction of fibre material being laid can be determined by the control arrangement 10 according to the position D₂ of the first gantry 2 along the mould M₁, M₂. Both manufacturing arrangements 1 can be operated at the same time. In this way, an upper blade half and a lower blade half can be simultaneously prepared. Once the dry layup is completed for a pair of mould halves M₁, M₂, the gantries 2, 3 are moved on to the next pair of mould halves M₁, M₂, while the first mould pair can be joined in preparation for a VARTM resin infusion and curing procedure. This manufacturing line 100 and method according to the invention significantly reduce the blade-in-mould time and can therefore lower the overall manufacturing costs of wind turbine rotor blades.
Fig. 2 is a schematic representation of an embodiment of a manufacturing arrangement according to the invention at an initial stage in the fibre layup process. The diagram shows a section of a blade mould M1, M2, and the gantries 2, 3 positioned above the mould M1, M2. The gantries 2, 3 are equipped with rollers 221 and drive means (not shown) to allow smooth travel along the tracks 11A, 11B in either direction, as indicated by the arrow. The tracks 11A, 11B are arranged along a suitable arrangement of supporting legs 110.

The first gantry 2 carries a fibre distributor 20, realised as a robot arm 200 with several degrees of freedom. The robot arm 200 can operate various tool attachments. The diagram shows a fibre mat tool attachment 23 being used to apply a length of fibre mat 42 to the inside of the mould M1, M2. The fibre mat 42 of a desired fibre mat type has already been cut to the desired length by a winding unit arranged in a magazine 30 of the second gantry 3, as will be explained with the aid of Fig. 5. The diagram also shows a further tool 31 realised to hold a cover sheet 5 which has been wrapped about a reel or drum. The cover sheet 5 will be used to weigh down fibre rovings as these are being laid, as will be explained with the aid of Fig. 3.

Fig. 3 is a schematic representation of the manufacturing arrangement of Fig. 2 during another stage. The diagram shows the robot arm 200 of the fibre distributor 20 connected to a fibre roving attachment tool 22. This tool attachment 22 draws in fibre roving 41 from a bobbin (not shown). The roving 41 or tow 41 is pulled through a curved tube 224 to break up and remove any sizing. Inside the tool attachment 22, an arrangement of rollers (not shown) feeds the roving 41 onto the surface of the mould M1, M2. To ensure that the roving 41 is pressed against the surface of the mould M1, M2, the tool attachment 22 is realised to apply the rovings 41 underneath a cover sheet 5, which acts to weigh down the rovings 41 as they are applied. In this embodiment, the cover sheet 5, which already extends over a length of the blade
surface (for example from root end to tip end), is fed through the tool attachment 22 which can raise the cover sheet 5 so that rovings 41 can be applied to the mould M1, M2. As the first gantry with this tool attachment 22 moves along the tracks, it lifts the cover sheet 5 and simultaneously applies fibre roving 41 to the blade mould M1, M2. In this way, the rovings 41 are optimally pressed onto the blade surface M1, M2. Additionally, if desired, an underpressure can be applied to the mould M1, M2 by extracting air from between the mould surface and the rovings 41.

Fig. 4 is schematic representation of an embodiment of a first gantry 2 for a manufacturing arrangement according to the invention. In this embodiment, the gantry 2 has rollers 221 on each outer end so that the gantry 2 can roll along the tracks 11A, 11B. The diagram shows a fibre distributor 20 with a robot arm 200 and a connector 203 for connecting to various tool attachments as described above. In this embodiment, a first magazine 21 has been lifted onto the first gantry 2. To this end, the first gantry 2 can be equipped with a support, and a forklift device can be used to lift the first magazine 21 into place onto the support. The first magazine 21 carries a supply of bobbins with fibre roving 41. The robot 20 can access this supply of fibre roving 41 to ensure that the fibre roving tool attachment 22 can be used efficiently. The operation of the fibre distribution robot 20 is controlled by signals 102 issued by the control arrangement (not shown).

Fig. 5 is detailed schematic representation of an embodiment of a second magazine 30 for a manufacturing arrangement according to the invention, arranged on the second gantry 3, which is realised to span the tracks 11A, 11B of the manufacturing arrangement. The second magazine 30 comprises a rack 304 for holding a supply of fibre matting wrapped on reels or drums 420, and a carriage 302 which can traverse the second magazine 30 in a side-to-side fashion so that a
gripper 303 - for example a pair of hooks - can access each of the fibre mat reels 420. The second magazine 30 is also equipped with an actuator - e.g. a drive unit and a roller/track arrangement (not shown) - for effecting a movement of the carriage 302 and a gripping action of the gripper 303. In this way, the control arrangement (not shown) can control the second tool arrangement to load the winding unit 301 with a certain type of fibre matting, and can instruct the winding unit 301 to transfer a specific length of the fibre matting to a fibre mat tool attachment 23. The second magazine 30 is realised to place the loaded tool attachment 23 in readiness for the fibre distributor, which can connect to the tool attachment 23 by means of a robot connector interface 202, and can lift it off the second magazine 30. The operation of the second magazine 30 with its winding/cutting unit 301, carriage 302, gripper 303 and actuator is controlled by signals 103 issued by the control arrangement (not shown).

The diagram also shows a cover sheet 5 wrapped on a drum and supported by a dispenser 31 or handling tool 31 which can dispense the cover sheet 5 or re-wind the cover sheet 5 as required during a fibre roving distribution step. In this embodiment, the second magazine 30 is shown to share the second gantry 3 with the cover sheet dispenser 31. In an alternative arrangement, the second magazine 30 could extend across the second gantry 3, so that the rack 304 could store a greater supply of fibre mat reels 420. In a further alternative, the second magazine 30 could accommodate two winding units 301, so that several tool attachments 23 could be primed with certain specific lengths of fibre matting in readiness for use by the fibre distributor.

The second magazine 30 can also be used to store a fibre roving tool attachment, i.e. to hold such a tool attachment in readiness for the robot arm. The second gantry 3 can also be realised to hold a supply of fibre roving bobbins, and may
also be realised to feed the fibre roving to a fibre roving tool attachment during a roving distribution procedure.

In a further development of the functionality of the second gantry, a piston or roller arrangement (not shown) can be used to apply pressure to a layer of fibre material laid by the fibre distribution tool, or to a cover sheet covering a layer of fibre material.

Fig. 6 shows a simplified cross-section through a fibre roving tool attachment 22 during a roving laying step. A cover sheet 5 has been laid over the length of the mould M1, M2 between root end and tip end. The robot arm 200 of the fibre distribution tool 20 is connected to the fibre roving tool attachment 22 by means of an interface 202, which can be a standard connector known from automated assembly lines, containing control signal interface and power supply lines for any drive unit in the fibre roving tool attachment 22. In this realisation, the fibre roving tool attachment 22 is constructed to allow the cover sheet 5 to pass through the fibre roving tool attachment 22 over an arrangement of rollers 221. In this way, the fibre roving tool attachment 22 can lift the cover sheet 5 away from the mould M1, M2 in the region below the fibre roving tool attachment 22. Fibre rovings 41 are fed to the fibre roving tool attachment 22 from a supply of bobbins as described above. The sizing is broken up by drawing the rovings 41 through an arrangement of bent tubes 224 of a fibre feed-in means 224, which is arranged at one side face of the fibre roving tool attachment 22. The rovings 41 arriving through the feed-in means 224 can then be combined into a strip with a certain desired width. A drive unit 222 is mounted inside the fibre roving tool attachment 22 and can move from side to side (i.e. into or out of the plane of the drawing) and can feed the strip of rovings 41 out onto the mould M1, M2. The drive unit 222 is arranged so that the rovings are laid directly onto the mould M1, M2 underneath the heavy cover sheet 5, whose weight \( F_g \) presses the rovings 41 effectively onto the mould M1, M2. The
cover sheet 5 can be a synthetic rubber mat with a thickness of about 10.0 mm. At the same time, the drive unit 222 can apply a desired tension $F_T$ to the rovings 41 as they are being fed out. The combination of the weight $F_0$ of the cover sheet 5 and the tension $F_T$ applied by the fibre roving tool attachment 22 ensures that the roving 41 will not wrinkle as it is laid in the mould. Although this diagram shows an arrangement of five rollers 221, an embodiment with only two rollers placed in the lower region of the tool attachment is also conceivable.

Fig. 7 shows a simplified cross-section through another embodiment of a fibre roving tool attachment 22 during a roving laying step. In this embodiment, one cover sheet 5A has been laid over the length of the mould M1, M2 between root end and tip end, and secured at one end to the tool attachment 22, in this case to the "tip-end face" of the tool attachment 22. The other end of this cover sheet 5A can be re-wound onto a reel or drum mounted as the tool attachment 22 moves towards the tip end of the mould M1, M2. One end of a second cover sheet 5B is secured to the "root-end face" of the tool attachment 22 and can be unrolled from a reel when the tool attachment 22 moves towards the tip end in the direction shown. Here also, the robot arm 200 is connected to the fibre roving tool attachment 22 by means of a standard interface 202. In this embodiment, the fibre roving tool attachment 22 does not need to actually lift the cover sheet away from the mould M1, M2, so that its realisation is less complex. This embodiment allows a fibre in-feed 224 to be mounted on top of the fibre roving tool attachment 22. Here also, a drive unit 222 as described above is mounted inside the fibre roving tool attachment 22 and can feed the strip of rovings 41 out onto the mould M1, M2. The drive unit 222 is arranged so that the rovings are laid directly onto the mould M1, M2 underneath the second cover sheet 5B, whose weight $F_G$ presses the rovings 41 effectively onto the mould M1, M2. At the same time, the drive unit 222 can apply a desired tension $F_T$ to the rovings 41 as they are being fed out. The first
cover sheet 5A ensures that previously laid layers of rovings 41 are continually weighed down.

Although the present invention has been disclosed in the form of preferred embodiments and variations thereon, it will be understood that numerous additional modifications and variations could be made thereto without departing from the scope of the invention.

For the sake of clarity, it is to be understood that the use of "a" or "an" throughout this application does not exclude a plurality, and "comprising" does not exclude other steps or elements. The mention of a "unit" or a "module" does not preclude the use of more than one unit or module.
Claims

1. A manufacturing arrangement (1) realised for the manufacture of a rotor blade, comprising
- a pair of tracks (11A, 11B) arranged along the longitudinal sides of a blade mould (M1; M2);
- a first gantry assembly (2) realised to span the track pair (11A, 11B) and to carry a first tool arrangement (20, 21) comprising at least a fibre distributor (20) for distributing a fibre material (41) into the blade mould (M1, M2);
- a second gantry assembly (3) realised to span the track pair (11A, 11B) and to carry a second tool arrangement (30, 31, 301) realised to carry a supply of fibre material (42) and to provide the fibre material (42) to the fibre distributor (20); and
- a control arrangement (10) realised to effect a coordinated movement of the gantry assemblies (2, 3) along the track pair (11A, 11B) and to coordinate the operation of the second tool arrangement (30, 31) with the operation of the first tool arrangement (20).

2. A manufacturing arrangement according to claim 1, wherein the second tool arrangement (30, 31) comprises a magazine (30) realised to carry a fibre material supply (42), which fibre material supply (42) comprises a plurality of fibre matting reels (420).

3. A manufacturing arrangement according to claim 1 or claim 2, wherein the second tool arrangement (30, 31) comprises a winding unit (301) realised to wind fibre material (42) in preparation for loading to the fibre distributor (20).

4. A manufacturing arrangement according to any of the preceding claims, wherein the second tool arrangement (30, 31) comprises a lifting tool (302, 303) for lifting a fibre matting reel (420) from the fibre material supply (42) to the winding unit (31).
5. A manufacturing arrangement according to claim 4, wherein the lifting tool (302, 303) comprises a carriage (302) realised to traverse the second gantry magazine (30).

6. A manufacturing arrangement according to claim 4 or claim 5, wherein the lifting tool (302, 303) comprises an actuator for actuating the carriage (302) and/or for actuating a gripping means (303) for lifting a fibre matting reel (420) to the winding unit (301).

7. A manufacturing arrangement according to any of the preceding claims, wherein the fibre distributor (20) is realised to distribute fibre material (41, 42) into the blade mould (M1, M2).

8. A manufacturing arrangement according to any of the preceding claims, wherein the control arrangement (10) comprises a drive unit arranged on a gantry (2, 3) for moving the gantry (2, 3) along the track pair (11A, 11B) and/or an actuating unit (201) for actuating a tool arrangement (20, 30, 31).

9. A fibre mat magazine (30) realised for use with a manufacturing arrangement (1) according to any of claims 1 to 8, which fibre mat magazine (30) comprises
   - a holding means (305) for holding a number of fibre mat reels (420); and
   - a winding unit (301) for winding a length of fibre material (42) from a fibre mat reel (420) to a tool attachment (23) for the fibre distributor (20).

10. A manufacturing line (100) realised for the manufacture of wind turbine rotor blades, which manufacturing line (100) comprises
    - a first manufacturing arrangement (1) according to any of claims 1 to 8 for manufacturing an upper blade half,
wherein the track pair (11A, 11B) is arranged along the longitudinal sides of an upper blade mould (M1); and

a second manufacturing arrangement (1) according to any of claims 1 to 8 for manufacturing a lower blade half,

wherein the track pair (11A, 11B) is arranged along the longitudinal sides of a lower blade mould (M2);

wherein the control arrangements (10) of the first and second manufacturing arrangements (1) are realised to coordinate the operation of the tool arrangements (20, 21, 30, 31) such that the blade halves are manufactured essentially simultaneously.

11. A manufacturing line according to claim 10, wherein the track pairs (11A, 11B) of each manufacturing arrangement (1) are arranged to accommodate a plurality of blade moulds (M1, M2) arranged sequentially between the tracks (11A, 11B).

12. A method of manufacturing a rotor blade, which method comprises the steps of

(A) arranging a pair of tracks (11A, 11B) along the longitudinal sides of a blade mould (M1, M2);

(B) arranging a first gantry assembly (2) to span the track pair (11A, 11B) and placing a first tool arrangement (20, 21) on the first gantry (2), which first tool assembly (20, 21) comprises at least a fibre distributor (20) for distributing a fibre material (41) into the blade mould (M1, M2);

(C) arranging a second gantry assembly (3) to span the track pair (11A, 11B) and placing a second tool arrangement (30, 31, 32) on the second gantry (3), which second tool arrangement (30, 31, 32) is realised to carry a supply of fibre material (42) and to provide the fibre material (42) to the fibre distributor (20);

(D) operating a control arrangement (10) to effect a coordinated movement of the gantry assemblies (2, 3) along the track pair (11A, 11B) and to coordinate the operation of the second tool arrangement (30, 31, 32) with the operation of the first tool arrangement (20, 21).
13. A method according to claim 12, wherein the control arrangement (10) is operated to control a winding unit (301) to wind a specific length of fibre material (42) to a tool attachment (23) for the fibre distributor (20).

14. A method according to claim 13, wherein the control arrangement (10) is operated to control a lifting tool (32) to lift a specific fibre matting reel (420) from a fibre material supply (42) to the winding unit (31).

15. A method according to any of claims 13 to 14, wherein the control arrangement (10) is operated to control the gantry assemblies (2, 3) and/or the tool arrangements (20, 21, 30, 31, 32) on the basis of a position (D2) of a gantry assembly (2) relative to the rotor blade mould (M1, M2).

16. A wind turbine rotor blade manufactured using the method according to any of claims 13 to 15.
**INTERNATIONAL SEARCH REPORT**

International application No

PCT/EP2014/001453

A. CLASSIFICATION OF SUBJECT MATTER

INV. B29C70/38

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

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<tr>
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<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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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**

20 October 2014

**Date of mailing of the international search report**

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Van Wallene, Allard
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