METHOD AND APPARATUS FOR PRODUCING COMPOSITE STRUCTURES

A composite part is formed by a composite tape application machine that lays up a plurality of tapes on a substrate. The lateral position of the tapes may be adjusted as the tapes are being laid up.
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TECHNICAL FIELD

This disclosure generally relates to automated machines and methods for laying up composite tape.

BACKGROUND

Composite structures such as those used in the automotive, marine, and aerospace industries may be fabricated using automated composite material application machines, commonly referred to as automated fiber placement (AFP) machines. AFP machines may be used in the aircraft industry, for example, to fabricate structural shapes and skin assemblies by laying up relatively narrow strips of composite tape or "tows," collimated into a wider band, on a manufacturing tool. The AFP machine aligns and places a plurality of tape strips, typically six or more, in continuous edge-to-edge contact forming a single conformal band which is placed on and compacted against the tool.

In order to fabricate large complex laminated assemblies, current AFP machines using fiber placement heads may have a relatively high degree of operational flexibility. For example, current placement heads may have the ability to add, drop-off, or cut any or all of the contiguous tape strips independently of all others by providing separate, independently controllable cutters for each tape strip.

While both highly flexible and efficient, current AFP machines may have limitations in terms of their productivity. For example, current AFP machines employ a single head having multiple tape supplies that lay down aligned tape courses edge-to-edge to form a single bandwidth. In those applications where head speed has been optimized, additional increases in productivity, i.e., the amount of tape laid down per unit time, may require the provision of additional tape supplies on the head in order to increase the bandwidth. Adding tape supplies not only result in a larger and more complicated head, but may limit flexibility in some applications due, for example, to difficulties in steering a larger head.

Accordingly, there is a continuing need for improved methods and apparatus that increase the laydown rate of composite tape.
SUMMARY

According to a number of disclosed embodiments, a method is provided of laying tape to form a composite part. The method comprises adjusting the lateral position of at least one tape control module in a plurality of the tape control modules as tape is being laid by the modules. Adjusting the lateral position of the tape control module is performed such that the distance between adjacent tapes is altered, the lateral position being substantially orthogonally oriented to a direction of travel of the plurality of tape control modules. Adjusting the lateral position of the tape control module may be performed automatically according to a preprogrammed set of instructions.

According a number of other embodiments, a method is provided of forming a composite part by laying up a plurality of composite tapes. The lateral position of at least one of the tapes is automatically adjusted and the tapes are aggregated into a bandwidth of tape during lay-up. Automatically adjustment of the lateral position is performed using a programmed control system. The adjusting step may comprise adjusting the lateral position of two adjacent tapes.

According to still other embodiments, a method is provided of applying bands of composite tape over a substrate. The method includes moving a tape application head over the substrate and laying down multiple courses of composite tape on the substrate from positions on the head that are staggered in the direction of travel of the head. The lateral positions of at least certain of the courses are adjusted as the head is moving over the substrate. Adjusting the lateral positions of the courses is performed automatically according to a set of pre-programmed instructions, and by adjusting the lateral positions of tape control modules on the tape application head.

According to other embodiments, a tape layup machine is provided for forming a composite part. The machine comprises a plurality of tape control modules for laying up tape, and means coupled with the modules for adjusting the lateral position of at least certain of the modules. The machine farther comprises a control system and a program used by the control system to adjust the lateral position of the at least certain modules as tape is being laid up by the modules.

According to another embodiment, a tape application machine is provided for laying up composite tape on a substrate. The machine comprises a head movable over the substrate in a direction of travel, and a carrier mounted on the head. A plurality of tape control modules are mounted on the carrier for laying up courses of tape on the substrate. A motor is mounted on the
head, and a drive coupled between the motor and the modules is operable for adjusting the lateral position of at least certain of the modules of the head.

Other features and advantages of the present invention will become apparent to those skilled in the art from a consideration of the following detailed description taken in conjunction with the accompanying drawings.

DESCRIPTION OF THE ILLUSTRATIONS

FIG. 1 is an illustration of an overall block diagram of a system for producing composite laminates.

FIG. 2 is an illustration of a perspective view of a pair of tape application heads mounted on an automatically controlled gantry.

FIG. 3 is an illustration of a functional block diagram of a system for producing laminates using a gantry of the type shown in FIG. 2.

FIG. 4 is an illustration of a functional block diagram showing the relationship between a tape control module and other components of the application head.

FIG. 5 is an illustration of a perspective view of a set of tape control modules, including an alternate form of a tape control module for laying down a band of narrow tape strips.

FIG. 6 is an illustration of a plan view of tape courses forming a single band, and showing the offset between the staggered groups of tape control modules.

FIG. 7 is an illustration similar to FIG. 6 but showing the addition of a tape module laying down a band formed from narrow strips of tape.

FIG. 8 is an illustration of a perspective view of a tape application head having staggered tape control modules.

FIG. 9 is an illustration of a plan view showing tape courses laid down by an application head having sixteen tape control modules.

FIG. 10 is an illustration of a front view of three tape control modules which may form part of the tape application head illustrated in FIG. 8.

FIG. 11 is an illustration of a block diagram of a system for adjusting the lateral positions of the tape control modules.

FIG. 12 is an illustration of a flow chart showing the steps of a method of laying up composite tape.
DETAILED DESCRIPTION

Referring particularly to FIGS. 1 and 2 of the drawings, a number of embodiments relate to an apparatus generally indicated by numeral 50 for producing composite components or structures, for example, a laminate structure 57, by applying bands 87 of composite tape 86 over a tool 59 or other substrate. In many embodiments, the composite fabrication apparatus 50 may be configured to produce composite structures, also sometimes referred to herein as a "part" 57, by adjusting tape position in response to a contour (not shown) of a part 57 being fabricated.

The apparatus 50 may include one or more tape application heads 58, each of which includes at least first and second groups of tape control modules 60a, 60b. Each of the application heads 58 is mounted on a manipulator 52 capable of moving the corresponding head 58 along one or more axes in order to guide the direction in which the bands of tape are applied. The manipulator 52 may be mounted on a machine tool system 54 for movement along multiple axes, which may comprise any of various known systems commonly used to displace tools along multiple axes. The manipulators 52, machine tool system 54 and application heads 58 may be controlled by one or more control systems 56 which may comprise, for example and without limitation, NC or CNC controllers.

Referring particularly now to FIG. 2, the apparatus 50 may comprise, for example and without limitation, a gantry system 55 comprising a gantry beam 62 having its opposite ends mounted on elevated rails 68 for linear movement thereon. The gantry beam 62 may include motors 70 provided with geared drives (not shown) for powering the gantry beam 62 along the rails 68. One or more manipulators 52 may be operatively and movably mounted on the gantry beam 62, with each manipulator 52 being provided a tape application head 58. In the example illustrated in FIG. 2, two manipulators 52 and heads 58 are mounted on opposite sides of a single gantry beam 62. The manipulators 52 may be powered by motors (not shown) that drive the manipulator 52 along the gantry beam 62. Various electrical and other lines and cables (not shown) may be enclosed within conduits (not shown) in order to connect the motors, the manipulators 52, and the application heads 58 to the control system 56 of FIG. 1 and/or to other systems (not shown).

Attention is now directed to FIG. 3 which illustrates in block diagram form additional components of the apparatus 50. In many embodiments, the application head 58 may broadly include a material delivery system 58a and a tape alignment and application head 58b. The material delivery system 58a delivers tape or slit tape known as tows to tape alignment and
application head 58b, which applies the slit tape to a substrate, thereby forming a laminate bandwidth 74. As used herein, "composite fiber tape," "fiber tape," "tape," and "tape strips" are intended to include a wide range of tapes and tows of various widths. Composite tape is supplied to the material delivery system 58a from a suitable raw material supply 76. As previously mentioned, the operations of the gantry system 54a and the tape alignment and application head 58b are controlled by the control systems 56 (FIG. 1).

Additional details are the tape alignment and application head 58b are shown in FIG. 4. Each of the tape alignment and application heads 58b may include a plurality of tape control modules 84 which output a tape course 86 (see FIG. 6) onto a substrate (not shown). As will be described later in more detail, each of the tape control modules 84 may be removably mounted on the tape alignment and application head 58b, allowing quick change out of the modules 84. Each of the modules 84 may be coupled to suitable power, control and sensor connections 94 by any suitable means. Each of the tape control modules 84 may also be connected by a coupling 96 to a rethread drive 88 or independent servo drive which functions to rethread the module 84 with tape supplied by the material delivery system 58a. Examples of tape control modules 84 may be found in U.S. Patent No. 4,699,683 and U.S. Patent Publication No. 2007/0029030A1, the entire contents of both of which are incorporated by reference herein.

Referring now to FIGS. 5, 6, and 7, as will be described later in more detail, in accordance with the disclosed embodiments, the tape control modules 84 are arranged in two alternating groups 84a, 84b that are staggered or offset in the direction of travel 110 of the application head 58 (see FIG. 2). As shown in FIG. 5, the modules 84 in group 84a are substantially aligned along a first axis 121 that extends in a direction 126 transverse to the direction of travel 110, while the modules 84 in group 84b are substantially aligned along a second axis 123 that extends substantially parallel to the first axis 121. As a result of this alignment and the offset relationship between the two groups of modules 84, as best seen in FIG. 6, the centerlines "A" and "B" of the compaction rollers 112a, 112b associated with the corresponding modules 84a, 84b are separated by a distance "d" in the direction of travel 110. The amount of offset or staggering (distance "d") between adjacent tape control modules 84 may be automatically adjusted by the previously discussed control system 56 (FIG. 1) using pre-programmed values.

The groups of modules 84a, 84b may apply courses of tape 86a, 86b in substantially edge-to-edge alignment to form a tape back 8? (FIG. 7) having a bandwidth "W". As a result of
staggering the groups 84a, 84b of tape control modules 84, an advanced number 86a of the tape
courses are laid up spatially advanced from a trailing number 86b of tape courses, and a
bandwidth 87 of the tapes is laid up as an aggregate of the plurality of tape courses 86 at a
trailing edge 119 of the trailing number of tape courses 86.

FIG. 7 illustrates an alternate embodiment wherein one or more tape control modules 84c
(Fig. 5) may be mounted on the tape alignment and application head 58b, aligned with either
module group 84a, 84b. The tape control module 84c applies a bandwidth 114 of tape segments
116 each having a width less than the tape courses 86a, 86b. The narrower, Individual tape
segments 116 allow a higher resolution profile 117 to be achieved on either end of the tape band
87.

Attention is now directed to FIG. 8 which illustrates an alternate form of the tape
application head 58 wherein the distance between theieiiterlines 125 of two or more of the tape
control modules 84, also referred to as "pitch", may be adjusted to control the aggregate
bandwidth and thus aid in "steering" of the tape courses 86 or for other purposes. In the
illustrated embodiment, the application head 58 includes two groups 84a, 84b of tape control
modules 84 that are staggered in the direction of travel 110 of the head 58 and respectively apply
tape courses 86a, 86b, similar to the groups 84a, 84b of tape control modules 84 shown in FIG. 5.
The application head 58 may include a suitable tape module adjustment system 120 connected to
one or more of the tape control modules 84 that may be controlled and operated by the control
system 56 (FIG. 1). As will be discussed below, the tape module adjustment system 120 may
comprise any of various known mechanical and/or electromechanical devices and/or assemblies
that function to laterally displace one or more of the tape control modules 84 in a transverse
direction 126, thereby adjusting the transverse position of one or more of the tape courses 86,
wherein the transverse direction 126 is substantially orthogonal to the direction of travel 110 of
the application head 58. Lateral displacement of one or more of the tape control modules 84
correspondingly alters the lateral position of the tape courses 86a, 86b. In one of several
embodiments, the groups 84a, 84b of tape control modules 84 are automatically laterally
adjustable relative to each other by the adjustment mechanism 120 based on a set of pre-
programmed instructions forming part of the control system 56 (FIG. 1), while in other
embodiments, the tape control modules 84 in either or both of the groups 84a, 84b may be
separately laterally adjustable. The pitch between the tape modules 84 may be automatically
adjusted prior to a bandwidth 87 being laid down, and/or may be dynamically adjusted "on-the-fly" as a bandwidth 87 is being laid down.

As discussed above, the automated adjustability of the lateral position of the tape control modules 84 allows relatively precise control over the lateral positions of the corresponding tape courses 86a, 86b in each band 87. For example as shown in FIG. 9, automated adjustment of the pitch between the tape modules 84 may be carried out in order to adjust the distance between the centerliiiics 127 of adjacent tape courses 86a, 86b such that the edges of the tape courses 86a 86b are essentially contiguous. Automated control of the lateral positions of adjacent tape courses 86a, 86b through dynamic adjustment of the pitch between the tape modules 84 may improve the ability to "steer" the band 87, particularly over surfaces having complex contours. Thus, the lateral or transverse positions of the tape control modules 84 may be adjusted to adapt to a contour of a part 57 being laid up, or for a variety of other purposes. The compression force applied by the tape control modules 84 through the compaction rollers 112 may be preset, while in other embodiments the pressure may adjusted based on one or more contours of the substrate where tape courses 86 are being laid down.

FIG. 10 illustrates the directions in which the tape control modules 84 may be automatically and independently adjusted. A tape control module 84b forming part of a first group 84b is axially offset or staggered relative to two tape control modules 84a forming part of a second group 84a. The modules 84a are laterally adjustable in either direction (X, -X) along a first common X axis 122 while the module 84b is laterally displaceable in either direction (XX, -XX) along an XX axis 124 that is offset from the X axis 122 in the direction of travel 110 of the tape application head 58 (FIG. 8). As mentioned above, the tape control modules 84 may be laterally adjusted, dynamically, on-the-fly as the tape courses 86 are being applied in order to aid in steering the applied tape band 87 (FIG. 5) and/or to cover complex substrate shapes and/or contours.

Attention is now directed to FIG. 11 which illustrates further details of a system used to automatically adjust the lateral positions of the tape control modules 84. In the illustrated example, two staggered groups 84a, 84b of tape control modules 84 are shown, however, in other embodiments, automated lateral adjustment of the pitch between tape modules 84 may be advantageously employed where only a single group of tape control modules 84 is used.

Each group 84a, 84b of tape control modules 84 is mounted on the head 58 (FIGS. 1 and 2) for lateral adjustment on a corresponding carrier 128a, 128b. Each of the carriers 128a, 128b...
may comprise, without limitation, any of a variety of known types of mechanical supports, trays, tracks, rails or similar devices that mount and support the tape control modules for lateral movement on the head 58, substantially transverse to the direction of travel 110 (FIG. 5) of the head 58. Each of the tape module adjustment systems 120a, 120b is mounted on the head 58 and comprises a motor 130a, 130b coupled with a corresponding mechanical drive 132a, 132b. Each of the motors 132a, 132b may be, without limitation, pneumatic, hydraulic or electric, such as a stepper or servo motor (not shown). Each of the mechanical drives 132a, 132b may comprise, without limitation, a screw drive, a gear drive, a linkage assembly or any of various other known mechanical drive mechanisms. The motors 130a, 130b may be controlled and operated by the control system 56 or other programmed controller (not shown).

The control system 56, or other controller, controls and adjusts the lateral position of the tape control modules 84 based on a set of programmed instructions forming part of a control program 134. These programmed instructions may be based in part on the geometry and/or ply make-up of the composite structure 57 (FIG. 1) being fabricated. Each of the mechanical drives 132a, 132b is coupled with the tape control modules 84 in the corresponding group 84a, 84b. Each of the adjustment systems 120a, 120b may adjust the lateral position of one or more of the tape control modules 84 in the group 84a, 84b, either individually, or as a group. As mentioned above, the lateral positions of one or more of the tape control modules 84 may be adjusted dynamically as a bandwidth 87 of the tape courses 86 is being laid down.

FIG. 12 shows the steps of a method of laying up composite tape using the technique previously described. At 136, courses of tape 86 are laid up using the tape control modules 84 mentioned above. At 138, the lateral position of at least one of the modules 84 is adjusted as the tape courses are being laid, thereby adjusting the lateral position of at least one of the tape courses 86.

Embodiments of the disclosure may find use in a variety of potential applications, particularly in the transportation industry, including for example, aerospace, marine and automotive applications. Those skilled in the art will understand that the preceding embodiments of the present invention provide the foundation for numerous alternatives and modifications thereto. These other modifications are also within the scope of the present invention.

Accordingly, the present invention is not limited to that precisely as shown and described in the present invention.
CLAIMS

What is claimed is:

L. A method of laying composite tape (86) to form a composite part (57), comprising adjusting the lateral position of at least one tape control module (84) in a plurality of the tape control modules (84a, 84b) as tape (86) is being laid by the modules (84a, 84b).

2. The method of claim 1 wherein the adjusting step includes adjusting the lateral position of the tape control module (84) such that the distance between the centerlines (127) of adjacent tapes (86) is altered, the lateral position being substantially transverse (126) to a direction of travel (110) of the plurality of tape control modules (84a, 84b).

3. The method of claim 1 wherein adjusting the position of the at least one tape control module (84) is performed automatically according to a set of programmed instructions (134).

4. The method of claim 1 further comprising adjusting a stagger of adjacent tape control modules (84).

5. The method of claim 1 further comprising adjusting the position of first and second staggered groups (84a, 84b) of tape control modules (84) relative to each other in a direction (126) substantially transverse to a direction of travel (110) of the tape control modules (84).

6. The method of claim 1 farther comprising aggregating the tapes (86) laid by the plurality of tape control modules (86a, 86b) into a bandwidth (87).

7. The method of claim 1 further comprising laying up the tapes (86) such that an advanced number (86a) of the tapes (86) are laid up spatially advanced (d) in a direction of travel (110) from a trailing number (86b) of tapes (86).

8. A tape layup machine (50) for forming a composite part (57), comprising:

   a plurality of tape control modules (84) for laying up tape (86); means (120a, 120b) coupled with the modules (84) for adjusting the lateral position of at least certain of the modules (84);

   a control system (56); and,

   a program (134) used by the control system (56) to adjust the lateral position of the at least certain modules (84) as tape (86) is being laid up by the modules (84).
9. The machine (50) of claim 8, wherein the tape control modules (84) include first and second groups (84a, 84b) thereof staggered relative to each other in a direction of travel (110) of the modules (84).

10. The machine (50) of claim 8 wherein the tape control modules (84) in the first and second staggered groups (84a, 84b) thereof are alternately arranged in a direction (126) substantially transverse to the direction of travel (110) of the modules (84).

11. The machine (50) of claim 8, wherein the adjusting means (120a, 120b) includes:
   a motor (130a, 130b), and
   a drive (132a, 132b) coupling the motor (130a, 130b) with the at least certain modules (84), and
   a programmed control system (56) for controlling the operation of the motor (130a, 130b).

12. The machine (50) of claim 8, wherein the tape control modules (84) are arranged in first and second groups (84a, 94b) that are staggered relative to each other in the direction of travel (110) of the modules (84).

13. The machine (50) of claim 12, wherein the tape control modules (84) in the first and second groups (84a, 84b) thereof are alternately arranged in a direction (126) substantially transverse to the direction of travel (110) of the modules (84).

14. The machine (50) of claim 11, further comprising a program (134) used by the control system (56) for adjusting the lateral position of the at least certain modules (84).

15. The machine (50) of claim 8, further comprising a carrier (128a, 128b) having the modules (84) mounted thereon for lateral adjustment in a direction (126) substantially transverse to the direction of travel (110) of the modules (84).
FIG. 11

LAYUP TAPES

ADJUST LATERAL POSITION OF AT LEAST ONE TAPE CONTROL MODULE AS TAPE IS BEING LAID

FIG. 12