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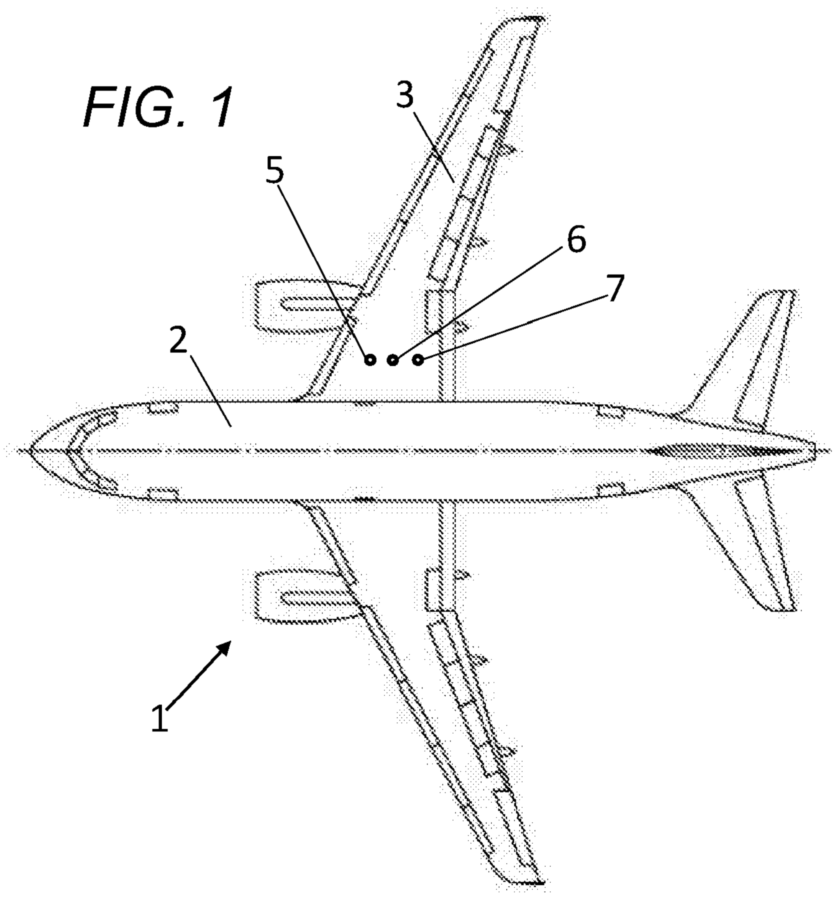


FIG. 1

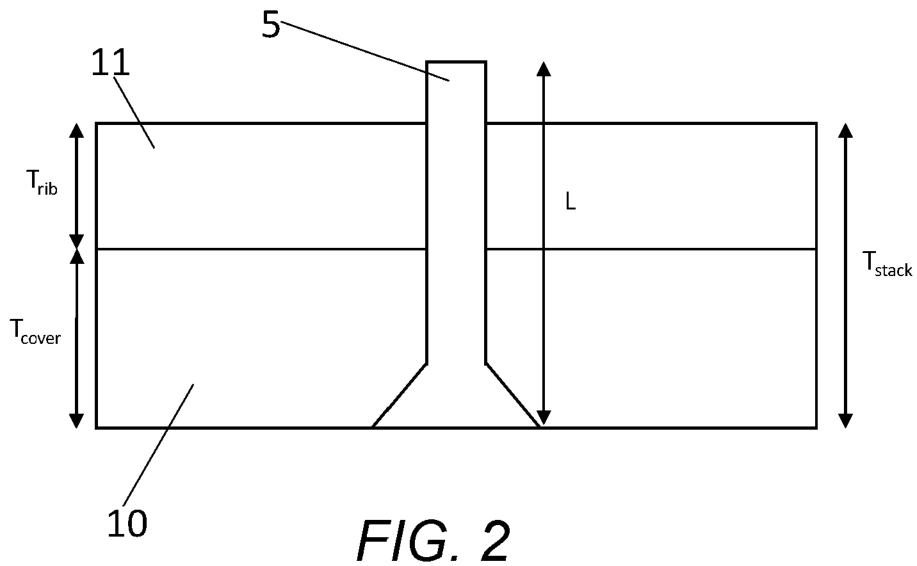


FIG. 2

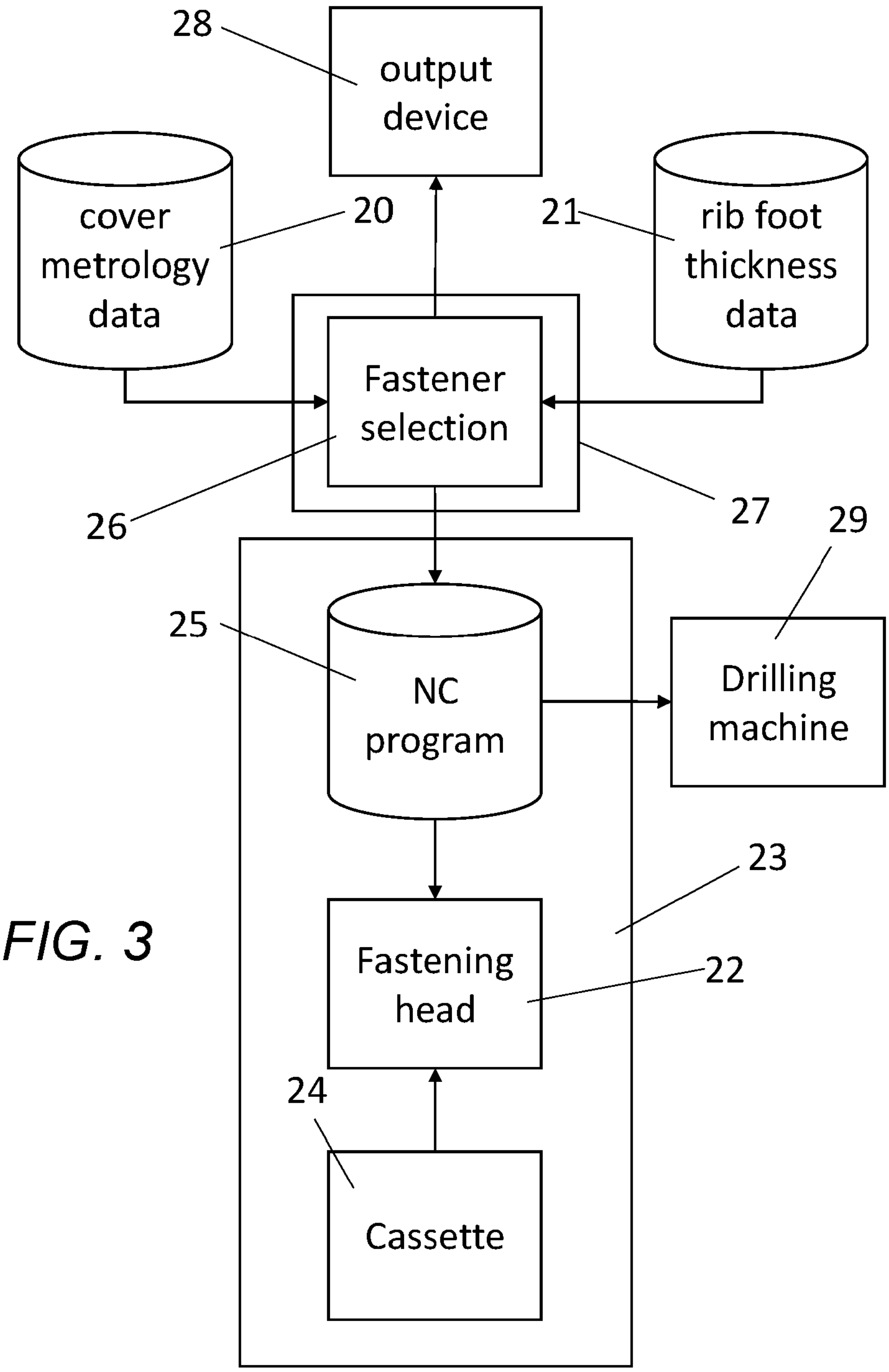

28
output device
cover metrology data
20
21
rib foot thickness data
Fastener selection
26
27
29
25
NC program
Drilling machine
23
Fastening head
22
24
Cassette

FIG. 3

FIG. 4

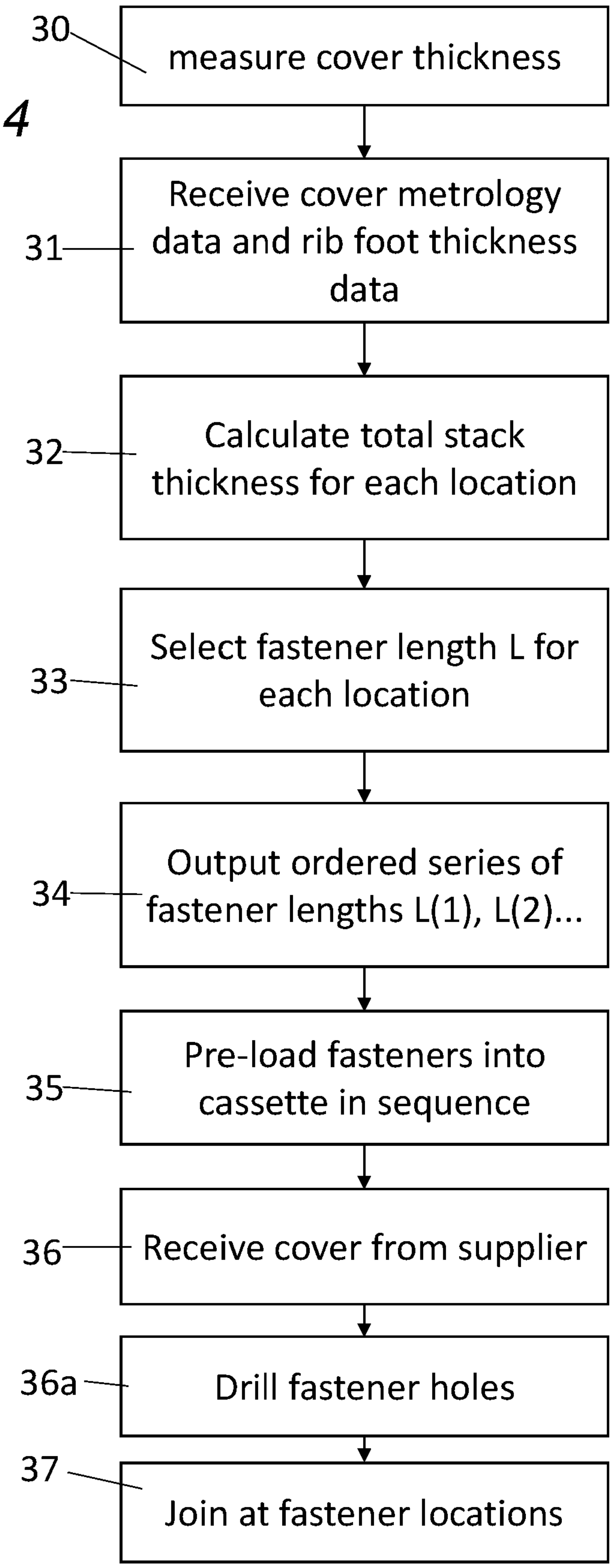

30
measure cover thickness
31
Receive cover metrology data and rib foot thickness data
32
Calculate total stack thickness for each location
33
Select fastener length L for each location
34
Output ordered series of fastener lengths L(1), L(2)...
35
Pre-load fasteners into cassette in sequence
36
Receive cover from supplier
36a
Drill fastener holes
37
Join at fastener locations

FIG. 5

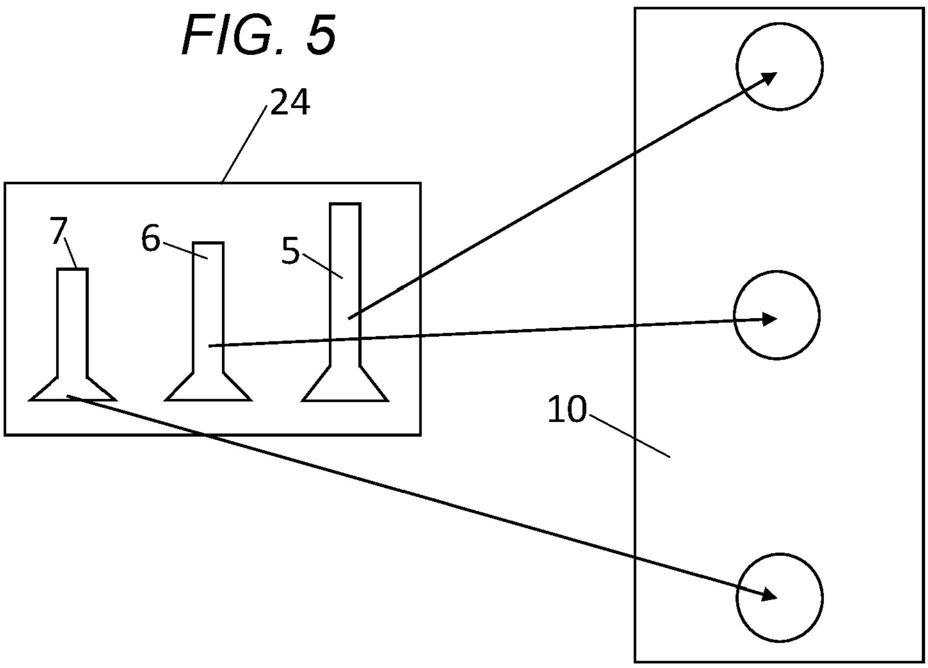


FIG. 6

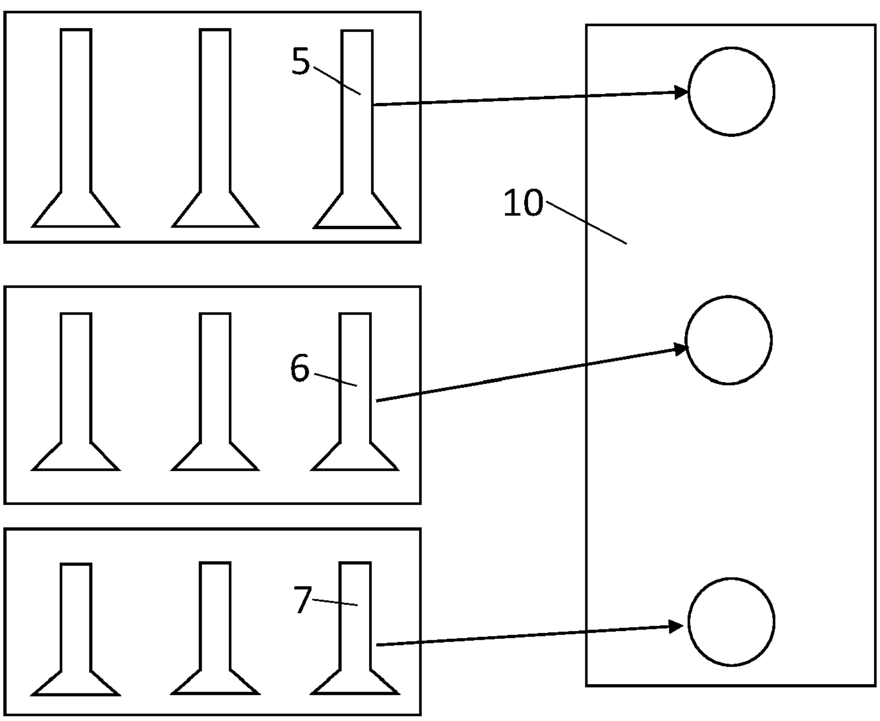


FIG. 7

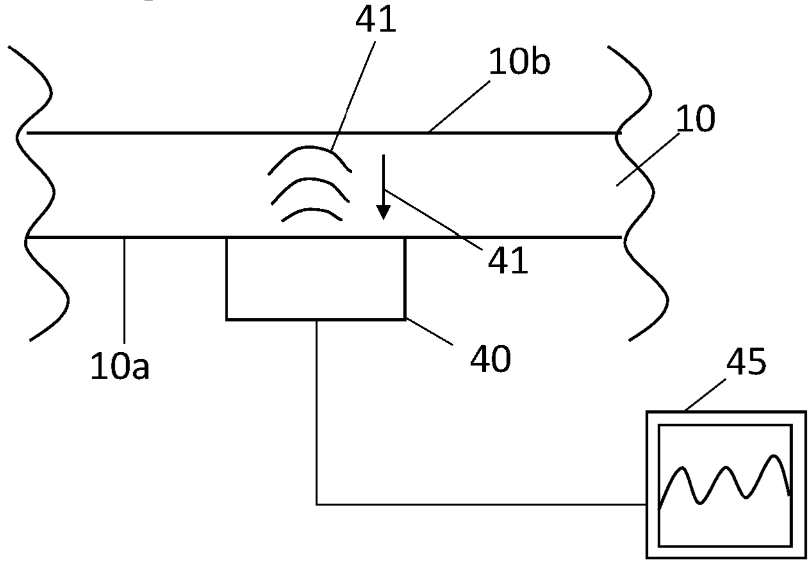
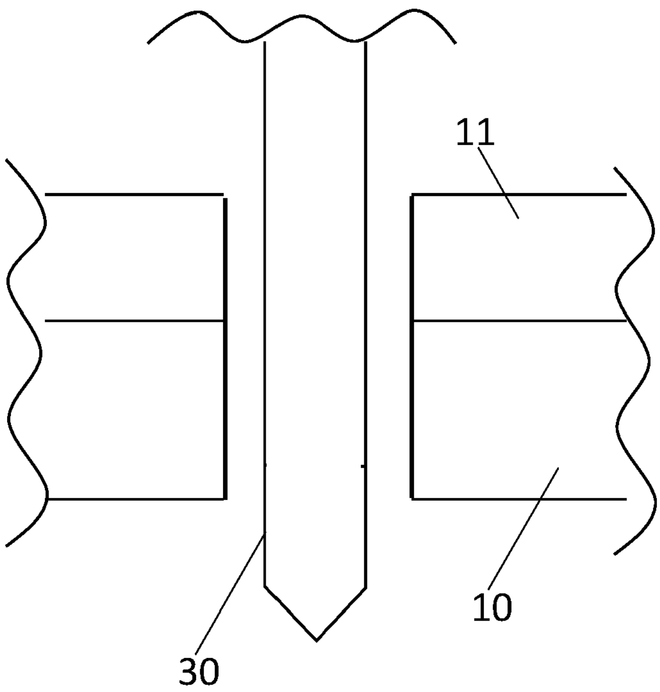


FIG. 8



METHOD OF MANUFACTURING A STRUCTURE

FIELD OF THE INVENTION

[0001] The present invention relates to a method of manufacturing a structure, the structure comprising a laminar composite part and a second part.

BACKGROUND OF THE INVENTION

[0002] Joining a laminar composite part to a second part with an automated fastening machine (such as a robot or a Computer Numerical Control (CNC) machine) requires fasteners of various lengths to be available to the fastening machine.

[0003] The thickness of the laminar composite part can be difficult to predict accurately because manufacturing tolerances for a laminar composite part are quite large. Therefore a large range of fastener lengths must be made available to the fastening machine, which can cause high inventory costs.

SUMMARY OF THE INVENTION

[0004] A first aspect of the invention provides a method of manufacturing a structure, the structure comprising a laminar composite part and a second part; the method comprising: receiving metrology data, the metrology data indicating a thickness of the laminar composite part at a plurality of fastening locations; for each fastening location, calculating a stack thickness based on the metrology data and a thickness of the second part at the fastening location, and selecting a fastener length based on the stack thickness; defining an ordered series of fastener lengths based on the fastener lengths selected; after the ordered series of fastener lengths has been defined, pre-loading fasteners into a fastening machine, the fasteners having fastener lengths arranged in a loading sequence based on the ordered series; and operating the fastening machine to join the parts together with the fasteners at the fastening locations in the loading sequence, wherein at each fastening location the fastening machine passes one of the fasteners through the laminar composite part and the second part.

[0005] The method reduces inventory costs by pre-loading fasteners into a fastening machine, the fasteners having fastener lengths arranged in a loading sequence based on an ordered series.

[0006] Preferably the method further comprises, before the step of operating the fastening machine, forming fastener holes through the laminar composite part and the second part at the fastening locations, wherein the fasteners are passed through the fastener holes by the fastening machine. The metrology data may be measured by passing a measurement probe through the fastener holes, but this is not preferred because it will delay the operation of the fastening machine. Thus more preferably the metrology data indicates a thickness of the laminar composite part at the fastening locations before the formation of the fastener holes.

[0007] The metrology data may be received before the formation of the fastener holes or after the formation of the fastener holes.

[0008] Each fastener hole may be formed by a single drilling pass through the laminar composite part and the second part.

[0009] The metrology data may be generated by measuring the laminar composite part at the plurality of fastening locations.

[0010] Preferably the laminar composite part is measured at the plurality of fastening locations before the formation of the fastener holes.

[0011] The laminar composite part may be measured at the plurality of fastening locations by transmitting ultrasonic waves into the laminar composite part and monitoring reflections of the ultrasonic waves from a surface of the laminar composite part.

[0012] The metrology data may be received from a supplier, and the laminar composite part received from the supplier after the metrology data has been received from the supplier.

[0013] Preferably the second part is metallic, although it may also be a laminar composite part.

[0014] Optionally the structure is an aircraft wing box, and the laminar composite part is a cover of the aircraft wing box.

[0015] The fastening machine may comprise a fastening head and a cassette, wherein the fasteners are pre-loaded into the cassette, and the fastening head receives the fasteners from the cassette and passes them through the laminar composite part and the second part.

[0016] After all of the fasteners in the loading sequence have been inserted, then at least one of the fasteners may be removed and replaced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

[0018] Figure 1 shows an aircraft;

[0019] Figure 2 shows a cover/rib foot joint;

[0020] Figure 3 is schematic view of a wing-box manufacturing system;

[0021] Figure 4 shows a sequence of steps for joining the cover to the rib foot;

[0022] Figure 5 shows three fasteners pre-loaded into a cassette in a loading sequence;

[0023] Figure 6 shows a comparative example;

[0024] Figure 7 shows an ultrasonic measurement method; and

[0025] Figure 8 shows a method of manufacturing the fastener holes using a drill bit.

DETAILED DESCRIPTION OF EMBODIMENT(S)

[0026] Figure 1 shows an aircraft 1 with a fuselage 2 and a pair of wings 3. The main component of each wing 3 is a wing-box with an upper cover and a lower cover, the upper cover of each wing-box being visible in Figure 1. The wing-box has internal parts (not shown), such as ribs and spars, which are joined to the covers by fasteners (typically rivets) at respective fastening locations. The ribs have rib feet which are joined to the covers. By way of example, three fasteners 5-7 are indicated in Figure 1.

[0027] Figure 2 is a schematic view showing a cover 10 joined to a rib foot 11 by one of the fasteners 5 at one of the fastening locations. The cover 10 is a laminar composite part, formed from layers of carbon-fibre reinforced epoxy resin, and the rib foot 11 is a metallic part.

[0028] The cover 10 is joined to the rib foot 11 by a fastener 5 with a length L which passes through the stack formed by the two parts 10, 11. The cover 10 has a thickness

T_{cover} at the fastening location, and the rib foot 11 has a thickness T_{rib} at the fastening location. The sum of these thicknesses gives a stack thickness: $T_{stack} = T_{cover} + T_{rib}$. The stack thickness T_{stack} varies between the fastening locations, so the fastener length L must be selected accordingly.

[0029] Figure 3 is a schematic view of a system for manufacturing the wing-box. The cover 10 is manufactured by a supplier, then delivered to a wing-box assembly line where it is joined to the ribs and other internal parts of the wing-box by a fastening head 22 of a fastening machine 23. The fastening machine 23 may comprise a robot, or a Computer Numerical Control (CNC) machine for example. The system also comprises a drilling machine 29.

[0030] The supplier generates digital cover metrology data 20 by measuring the thickness of the cover 10 at the fastening locations. Each item of the cover metrology data 20 indicates a thickness T_{cover} of the cover at a respective one of the fastening locations. The metrology data 20 may be in the form of a database or it may be over a common platform such as Dassault 3DEXPERIENCE (R).

[0031] Figure 7 shows a preferred method of measuring the thickness of the cover 10. An ultrasonic probe 40 transmits an ultrasonic pulse 41 into a surface 10a of the cover. This pulse 41 is reflected by the opposite surface 10b and the reflection 41 is detected by the same probe, or by other probes (not shown) placed on the surface 10a. The travel time for the ultrasonic pulse 41 and reflection 41 is then used to calculate the distance travelled, and hence the thickness of the cover 10 between the surfaces 10a and 10b, using an oscilloscope 45. The reflected pulse 41 may also be analysed to perform non-destructive testing to detect flaws in the cover 10.

[0032] The ultrasonic probe 40 may be scanned over the full area of the cover 10, to measure its thickness and monitor for defects at all points. Thus the metrology data 20 may indicate the thickness of the cover 10 not only at the fastening locations, but also at other locations. Note that the metrology data 10 indicates a thickness of the laminar composite part at the fastening locations before the formation of fastener holes as described below.

[0033] Returning to Figure 3, rib foot thickness data 21 is also provided which indicates the thickness of the rib foot 11 at the fastening locations. Each item of the rib foot thickness data 21 indicates a thickness T_{rib} of the rib foot 11 at a respective one of the fastening locations before the formation of the fastener holes as described below.

[0034] The cover 10 and the rib foot 11 each have design thicknesses which indicate the expected thickness of the part at the fastening locations. The measured thickness T_{cover} may vary considerably from the design thickness because the cover 10 is a laminar composite part with a thickness which is difficult to control accurately, so the manufacturing tolerances are quite large compared with the metallic rib foot 11. The rib foot thickness data 21 may be a set of design thickness values, rather than metrology data generated by measurement of the rib foot 11. If the rib foot thickness data 21 is generated by measurement, then an ultrasonic measurement process may be used (similar to the process of Figure 7).

[0035] The fastening machine 23 comprises a fastening head 22 and a cassette 24. The fasteners are pre-loaded into the cassette 24, and the fastening head 22 receives the fasteners from the cassette and passes them through the cover 10 and the rib foot 11 at the coordinates of the fastening locations defined in a Numerical Control (NC) program 25.

[0036] Figure 4 shows the sequence of method steps. In step 30 the supplier generates the cover metrology data 20 by measuring the cover thickness. In step 31, the cover metrology data 20 and the rib foot thickness data 21 are received by a fastener selection program 26 running on a computer 27. In step 32 the fastener selection program 26 automatically calculates a total stack thickness for each fastening location based on the cover metrology data 20 and the rib foot thickness data 21. This data fusion step 32 may happen using a script or it may occur automatically on the common platform such as Dassault 3DEXPERIENCE (R).

[0037] In step 33 the fastener selection program 26 selects a fastener length for each fastening location based on the total stack thickness. In step 34 the fastener selection program 26 defines, stores and outputs an ordered series of fastener lengths L(1), L(2) etc. based on the fastener lengths selected in step 33. The ordered series may be defined automatically using a script or it may occur automatically on the common platform such as Dassault 3DEXPERIENCE (R). The ordered series of fastener lengths L(1), L(2) is output to an output device 28, such as a printer or display screen.

[0038] In step 35, the ordered series of fastener lengths L(1), L(2) defined and output in step 34 is printed or displayed by the output device 28 as a list. The list is then viewed by a human operator who pre-loads the fasteners into the cassette 24, the fasteners having fastener lengths arranged in a loading sequence based on the list. In step 36 the cover 10 is received from the supplier.

[0039] In step 36a, fastener holes are formed at the fastening locations by the drilling machined 29 under control of the NC program 25. The drilling machine 29 drills through both the cover 10 and the rib foot 11 in a single drilling pass using a drill 30, as shown in Figure 8.

[0040] In step 37 the fastening head 22 is operated by the NC program 25 to join the cover 10 and rib foot 11 together with the fasteners at the fastening locations in the automated loading sequence.

[0041] Note that the metrology data 10 is received from the supplier in step 31 before the fasteners are pre-loaded in step 35, before the cover 10 is received from the supplier in step 36 and before the fastener holes are formed in step 36a.

[0042] In this example the ordered series of fastener lengths L(1), L(2) is output to an output device 28, such as a printer or display screen, and the cassette is loaded manually by a human operator. In an alternative example this process may be fully automated, the ordered series of fastener lengths L(1), L(2) being output directly to a cassette loading device which loads the cassette 24 as required.

[0043] Figure 5 shows how the method applies to the three fasteners 5-7 indicated in Figure 1. In this case the three fasteners 5-7 are shown with different lengths (large, medium and small respectively). The fasteners are loaded into the cassette 24 in the loading sequence shown in Figure 5, then the fastening head 22 joins the cover 10 and rib foot 11 together with the fasteners in the loading sequence indicated (fastener 5, followed by fastener 6, followed by fastener 7).

[0044] If one or more of the fasteners malfunctions during insertion, then after all of the fasteners in the loading sequence have been inserted, the (or each) malfunctioning fastener is drilled out and replaced.

[0045] Figure 6 shows a comparative example. In this case the three fasteners 5-7 are picked by the fastening head on the fly from respective cassettes, each carrying three small, medium or large fasteners. Comparing Figure 5 and Figure 6, it can be seen that the method of Figure 5 results in lower inventory costs since only three fasteners are required, rather than nine.

[0046] Note that in the example described above, only a single cassette 24 is referred to. In the event that the cassette 24 cannot carry all of the fasteners required, then multiple cassettes could be pre-loaded (each with a respective sub-set of the ordered series of fastener lengths) and when a cassette is empty it is removed and replaced by the next cassette.

[0047] Where the word 'or' appears this is to be construed to mean 'and/or' such that items referred to are not necessarily mutually exclusive and may be used in any appropriate combination.

[0048] Although the invention has been described above with reference to one or more preferred embodiments, it will be appreciated that various changes or modifications may be made without departing from the scope of the invention as defined in the appended claims.

CLAIMS

1. A method of manufacturing a structure, the structure comprising a laminar composite part and a second part; the method comprising:

   a. forming fastener holes through the laminar composite part and the second part at the fastening locations;

   b. receiving metrology data, the metrology data indicating a thickness of the laminar composite part at a plurality of fastening locations before the formation of the fastener holes in step a.;

   c. for each fastening location, calculating a stack thickness based on the metrology data and a thickness of the second part at the fastening location, and selecting a fastener length based on the stack thickness;

   d. defining an ordered series of fastener lengths based on the fastener lengths selected in step c.;

   e. after step d., pre-loading fasteners into a fastening machine, the fasteners having fastener lengths arranged in a loading sequence based on the ordered series defined in step d.; and

   f. operating the fastening machine to join the parts together with the fasteners at the fastening locations in the loading sequence, wherein at each fastening location the fastening machine passes one of the fasteners through the laminar composite part and the second part through the fastener holes formed in step a.

2. A method according to claim 1, wherein the metrology data is received in step b. before the formation of the fastener holes.

3. A method according to claim 1 or 2, wherein each fastener hole is formed by a single drilling pass through the laminar composite part and the second part.

4. A method according to any preceding claim, further comprising generating the metrology data by measuring the laminar composite part at the plurality of fastening locations.

5. A method according to claim 4, wherein the laminar composite part is measured at the plurality of fastening locations before the formation of the fastener holes.

6. A method according to claim 4 or 5, wherein the laminar composite part is measured at the plurality of fastening locations by transmitting ultrasonic waves into the laminar composite part and monitoring reflections of the ultrasonic waves from a surface of the laminar composite part.

7. A method according to any preceding claim, wherein the metrology data is received from a supplier in step b., and the laminar composite part is received from the supplier after the metrology data has been received from the supplier.

8. A method according to any preceding claim, wherein the second part is metallic.

9. A method according to any preceding claim, wherein the structure is an aircraft wing box, and the laminar composite part is a cover of the aircraft wing box.

10. A method according to any preceding claim, wherein the fastening machine comprises a fastening head and a cassette, the fasteners are pre-loaded into the cassette, and the fastening head receives the fasteners from the cassette and passes them through the laminar composite part and the second part.

11. A method according to any preceding claim, wherein after all of the fasteners in the loading sequence have been inserted, at least one of the fasteners is removed and replaced.