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(54) Benævnelse: **System og fremgangsmåde til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf**

(56) Fremdragne publikationer:

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DESCRIPTION

FIELD OF THE INVENTION

[0001] The present invention relates generally to the fabrication of structures from composite materials.

BACKGROUND OF THE INVENTION

[0002] The following publications are believed to represent the current state of the art:

U.S. Patent Nos.: 8,068,659; 7,889,907 and 5,963,660; and

U.S. Published Patent Application Nos.: 2009/0043533; 2007/0173966; 2007/0034313 and 2004/0031567.

[0003] US 2007/0173966 relates to visual fiber placement inspection, and discloses a method and system of inspecting structures formed of composite materials during the fabrication thereof as defined respectively in the pre-amble of appended independent claims 1 and 5.

SUMMARY OF THE INVENTION

[0004] In accordance with the present invention, there is provided a method and system for inspecting structures formed of composite materials during the fabrication thereof as defined respectively in appended independent claim 1 and appended independent claim 5. Embodiments of the invention are defined in the appended claims which depend on appended independent claim 1 or appended independent claim 5. The present invention seeks to provide a system and methodology for inspecting structures formed of composite materials during the fabrication thereof.

[0005] There is thus provided in accordance with one aspect of the present invention a method for inspecting structures formed of composite materials during the fabrication thereof including: imaging multiple individual plies of a structure, whereby the locations and orientations of edge joints between adjacent courses of each ply are recorded; characterized by: providing a three-dimensional image file of the structure; and ascertaining from the three-dimensional image file mutual offsets in the locations of mutually parallel ones of the edge joints of different plies in the multiple individual plies.

[0006] Preferably, the individual plies each extend in an X-Y plane and are stacked in a Z-direction, perpendicular to the X-Y plane of each of the individual plies and the mutual offsets may be ascertained by comparing the location of each of the mutually parallel edge joints in the X-Y plane of each of the individual plies with the corresponding location of an edge joint which is mutually parallel thereto in the X-Y plane of another one of the individual plies.

[0007] In accordance with a preferred embodiment of the present invention the individual plies are non-planar and the mutual offsets may be ascertained by comparing the location of each of the mutually parallel edge joints in each of the individual plies with the corresponding location of an edge joint which most closely corresponds thereto in location and orientation in another one of the individual plies.

[0008] In accordance with a preferred embodiment of the present invention the imaging multiple individual plies of a structure takes place during fabrication of the structure at least between laying down of each of the multiple individual plies.

[0009] There is also thus provided in accordance with another aspect of the present invention a system for inspecting structures formed of composite materials during the fabrication thereof, the system including: an imager operative to image multiple individual plies of a structure, whereby the locations and orientations of edge joints between adjacent courses of each ply are recorded; characterized by: an offset analyzer operative to ascertain mutual offsets in the locations of mutually parallel ones of the edge joints of different plies in the multiple individual plies; and an image file generator operative to provide a three-dimensional image file of the structure to the offset analyzer.

[0010] Preferably, the individual plies each extend in an X-Y plane and are stacked in a Z-direction, perpendicular to the X-Y plane of each of the individual plies and the mutual offsets may be ascertained by comparing the location of each of the mutually parallel edge joints in the X-Y plane of each of the individual plies with the corresponding location of an edge joint which is mutually parallel thereto in the X-Y plane of another one of the individual plies.

[0011] In accordance with a preferred embodiment of the present invention the individual plies are non-planar and the mutual offsets may be ascertained by comparing the location of each of the mutually parallel edge joints in each of the individual plies with the corresponding location of an edge joint which most closely corresponds thereto in location and orientation in another one of the individual plies.

[0012] In accordance with a preferred embodiment of the present invention the imager is operative to image the multiple individual plies during fabrication of the structure at least between laying down of each of the multiple individual plies.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which:

Fig. 1 is a simplified illustration of a system for inspecting structures formed of composite materials during the fabrication thereof, constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 2 is a simplified illustration of a system for inspecting structures formed of composite materials during the fabrication thereof, constructed and operative in accordance with another preferred embodiment of the present invention;

Fig. 3 is a simplified illustration of a system for inspecting structures formed of composite materials during the fabrication thereof, constructed and operative in accordance with a yet another preferred embodiment of the present invention;

Fig. 4 is a simplified illustration of an output from the system of any of Figs. 1 - 3 showing plies in a generally planar orientation; and

Fig. 5 is a simplified illustration of an output from the system of any of Figs. 1 - 3 showing plies in a generally non- planar orientation.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0014] Reference is now made to Fig. 1, which is a simplified illustration of a system for inspecting structures formed of composite materials during the fabrication thereof, constructed and operative in accordance with a preferred embodiment of the present invention.

[0015] In the embodiment of Fig. 1, the system of the present invention is constructed and operative within the context of a Cincinnati Charger Tape Layer (CTL) machine 100, commercially available from Cincinnati Machine LLC of Hebron Kentucky, USA, preferably including a V5 head 102. It is appreciated that the system of the present invention is applicable to any suitable tape layup or fiber placement machine environment.

[0016] In accordance with a preferred arrangement, multiple illuminators 104, preferably Nerlite® Machine Vision Lighting illuminators, such as dark field illuminators, DOAL® (Diffuse On-Axis Light) illuminators, or dome illuminators, commercially available from Microscan Systems, Inc., 700 SW 39th St., Renton, WA 98057, are mounted on head 102. Preferably multiple cameras 106, such as In-Sight Micro Series vision system cameras, commercially available from Cognex Corporation, One Vision Drive, Natick, MA 01760, are also mounted on head 102 to view multiple adjacent courses 108 of laid up tapes of a composite structure 110 in real time or near real time, thereby imaging multiple individual plies 112 of the composite structure, whereby the locations and orientations of edge joints 114 between adjacent courses 108 of each ply are preferably recorded. Edge joints 114 may be butt joints, at which edges of adjacent courses 108 touch each other, gap joints, at which edges of adjacent courses 108 are separated from each other by a separation S, or overlap joints at which edges of adjacent courses 108 overlap each other.

[0017] Outputs of cameras 106 are supplied to one or more computers 120 which provide a three-dimensional image file of the composite structure. This three-dimensional image file enables ascertaining mutual offsets in the locations of mutually parallel ones of edge joints 114 in multiple individual plies 112. One or more display 122 shows a desired view of the composite structure, enabling an operator to view in real time or near real time the locations and orientations of edge joints 114 between adjacent courses 108 of each ply as the courses 108 are laid on the composite structure.

[0018] In the example illustrated in Fig. 1, all of the courses 108 in three illustrated plies 112 are mutually parallel and gap joints 130 are defined between adjacent parallel courses 108 in each ply 112. Typically in the aircraft industry there exist requirements as to the extent of separation between adjacent courses 108. In the illustrated example the requirements for gap joints 130 are that the adjacent parallel courses 108 be separated by a distance of between 0 and 2.54 mm. Overlaps of adjacent courses and separations between adjacent courses of more than 2.54 mm are considered to be defects and are detected by the system and methodology of the present invention.

[0019] Another important characteristic in the construction of composite structures is the offset between gap joints 130 of parallel plies 112, even when those plies are not adjacent each other in the composite structure. In the illustrated example, the offset between gap joints 130 of parallel plies 112 must be at least 12.7 mm. Offsets between gap joints 130 of parallel plies 112 less than 12.7 mm are considered to be defects and are detected by the system and methodology of the present invention.

[0020] In the context of the illustrated example, three plies 112, each including five adjacent courses 108, are shown. The separation between adjacent courses 108 at each gap joint 130 is designated as S and the offset between gap joints 130 of parallel plies 112 is designated as O. It is appreciated that the offset between gap joints 130 is normally equivalent to the offset between edge joints between adjacent courses.

[0021] In accordance with a preferred arragement, the computer 120 automatically provides an output indication when at least one mutual offset of the edge joints is less than a predetermined minimum offset.

[0022] Reference is now made to Fig. 2, which is a simplified illustration of a system for inspecting structures formed of composite materials during the fabrication thereof, constructed and operative in accordance with another preferred embodiment of the present invention.

[0023] In the embodiment of Fig. 2, the system of the present invention is constructed and operative within the context of a Cincinnati Charger Tape Layer (CTL) machine 200, commercially available from Cincinnati Machine LLC of Hebron Kentucky, USA, preferably including a V5 head 202. It is appreciated that the system of the present invention is applicable to any suitable tape layup or fiber placement machine environment.

[0024] In accordance with a preferredarrangement, multiple illuminators 204, preferably Nerlite® Machine Vision Lighting illuminators, such as dark field illuminators, DOAL® (Diffuse On-Axis Light) illuminators, or dome illuminators, commercially available from Microscan Systems, Inc., 700 SW 39th St., Renton, WA 98057, are mounted on the CTL machine 200. Preferably multiple cameras 206, such as In-Sight Micro Series vision system cameras, commercially available from Cognex Corporation, One Vision Drive, Natick, MA 01760, are mounted above the CTL machine 200, preferably on a ceiling, to view multiple adjacent courses 208 of laid up tapes of a composite structure 210 in real time or near real time, thereby imaging multiple individual plies 212 of the composite structure, whereby the locations and orientations of edge joints 214 between adjacent courses 208 of each ply are preferably recorded.

[0025] Outputs of cameras 206 are supplied to one or more computers 220 which provide a three-dimensional image file of the composite structure. It is appreciated that whereas in the embodiment of Fig. 1, at any one time only a relatively small region of the composite structure 210 is viewed, in the embodiment of Fig. 2, nearly the entire composite structure 210 is viewed.

[0026] This three-dimensional image file enables ascertaining mutual offsets in the locations of mutually parallel ones of edge joints 214 in multiple individual plies 212. One or more display 222 shows a desired view of the composite structure, enabling an operator to view in real time or near real time the locations and orientations of edge joints 214 between adjacent courses 208 of each ply as the courses 208 are laid on the composite structure.

[0027] In the example illustrated in Fig. 2, all of the courses 208 in three illustrated plies 212 are mutually parallel and gap joints 230 are defined between adjacent parallel courses 208 in each ply 212. Typically in the aircraft industry there exist requirements as to the extent of separation between adjacent courses 208. In the illustrated example the requirements for gap joints 230 are that the adjacent parallel courses 208 be separated by a distance of between 0 and 2.54 mm. Overlaps of adjacent courses and separations between adjacent courses of more than 2.54 mm are considered to be defects and are detected by the system and methodology of the present invention.

[0028] Another important characteristic in the construction of composite structures is the offset between gap joints 230 of parallel plies 212, even when those plies are not adjacent each other in the composite structure. In the illustrated example, the offset between gap joints 230 of parallel plies 212 must be at least 12.7 mm. Offsets between gap joints 230 of parallel plies 212 less than 12.7 mm are considered to be defects and are detected by the system and methodology of the present invention.

[0029] In the context of the illustrated example, three plies 212, each including five adjacent courses 208, are shown. The separation between adjacent courses 208 at each gap joint 230 is designated as S and the offset between gap joints of parallel plies is designated as O. It is appreciated that the offset between gap joints is normally equivalent to the offset between edge joints between adjacent courses.

[0030] In accordance with a preferred arrangement, the computer 220 automatically provides an output indication when at least one mutual offset of the edge joints is less than a predetermined minimum offset.

[0031] Reference is now made to Fig. 3, which is a simplified illustration of a system for inspecting structures formed of composite materials during the fabrication thereof, constructed and operative in accordance with yet another preferred embodiment of the present invention.

[0032] In the embodiment of Fig. 3, the system of the present invention is shown alongside a Cincinnati Charger Tape Layer (CTL) machine 300, commercially available from Cincinnati Machine LLC of Hebron Kentucky, USA, preferably including a V5 head 302. In this embodiment, the operation of the system of the present invention is generally independent of the operation of the CTL machine 300 other than to the extent that the gantry 303 of the CTL machine must be out of the way and stationary during the imaging operation of the system of the present invention. It is appreciated that the system of the present invention is useful with any suitable tape layup or fiber placement machine environment.

[0033] In accordance with a preferred arrangement, multiple illuminators 304, preferably Nerlite® Machine Vision Lighting illuminators, such as dark field illuminators, DOAL® (Diffuse On-Axis Light) illuminators, or dome illuminators, commercially available from Microscan Systems, Inc., 700 SW 39th St., Renton, WA 98057, are mounted on a special purpose gantry 305. Preferably multiple cameras 306, such as In-Sight Micro Series vision system cameras, commercially available from Cognex Corporation, One Vision Drive, Natick, MA 01760, are also mounted on gantry 305 to view multiple adjacent courses 308 of laid up tapes of a composite structure 310 in real time or near real time, preferably after each ply 312 is laid down, thereby imaging multiple individual plies 312 of the composite structure, whereby the locations and orientations of edge joints 314 between adjacent courses 308 of each ply are preferably recorded.

[0034] Outputs of cameras 306 are supplied to one or more computers 320 which provide a three-dimensional image file of the composite structure. This three-dimensional image file enables ascertaining mutual offsets in the locations of mutually parallel ones of edge joints 314 in multiple individual plies 312. One or more display 322 shows a desired view of the composite structure, enabling an operator to view in real time or near real time the locations and orientations of edge joints 314 between adjacent courses 308 of each ply as the courses 308 are laid on the composite structure.

[0035] In the example illustrated in Fig. 3, all of the courses 308 in three illustrated plies 312 are mutually parallel and gap joints 330 are defined between adjacent parallel courses 308 in each ply 312. Typically in the aircraft industry there exist requirements as to the extent of separation between adjacent courses 308. In the illustrated example the requirements for gap joints 330 are that the adjacent parallel courses 308 be separated by a distance of between 0 and 2.54 mm. Overlaps of adjacent courses and separations between adjacent courses of more than 2.54 mm are considered to be defects and are detected by the system and methodology of the present invention.

[0036] Another important characteristic in the construction of composite structures is the offset between gap joints 330 of parallel plies 312, even when those plies are not adjacent each other in the composite structure. In the illustrated example, the offset between gap joints 330 of parallel plies 312 must be at least 12.7 mm. Offsets between gap joints 330 of parallel plies 312 less than 12.7 mm are considered to be defects and are detected by the system and methodology of the present invention.

[0037] In the context of the illustrated example, three plies 312, each including five adjacent courses 308, are shown. The separation between adjacent courses 308 at each gap joint 330 is designated as S and the offset between gap joints of parallel plies is designated as O. It is appreciated that the offset between gap joints is normally equivalent to the offset between edge joints between adjacent courses.

[0038] In accordance with a preferred arrangement, the computer 320 automatically provides an output indication when at least one mutual offset of the edge joints is less than a predetermined minimum offset.

[0039] Reference is now made to Fig. 4, which is a simplified illustration of an output from the system of any of Figs. 1 - 3 showing plies in a generally planar orientation. In the example shown in Fig. 4, the courses that make up plies 1, 3, 5 and 8 are mutually parallel; the courses that make up plies 2 and 7 are mutually parallel, but are angled relative to the courses that make up plies 1, 3, 5 and 8, and the courses that make up plies 4 and 6 are each not parallel to courses in any of the other plies in the illustrated composite article.

[0040] Fig. 4 illustrates, at A, a cross-sectional cut taken from a three dimensional map automatically produced by the system of the present invention which clearly shows and emphasizes both the separation, designated S, between adjacent courses 408 at each gap joint 430 in mutually parallel plies 1, 3, 5 and 8, and the offset, designated O, between gap joints 430 of mutually parallel plies 1, 3, 5 and 8.

[0041] Fig. 4 illustrates, at B, a cross-sectional cut taken from a three dimensional map automatically produced by the system of the present invention which clearly shows and emphasizes both the separation, designated S, between adjacent courses 408 at each gap joint 430 in mutually parallel plies 2 & 7, and the offset, designated O, between gap joints 430 of mutually parallel plies 2 & 7.

[0042] Reference is now made to Fig. 5, which is a simplified illustration of an output from the system of any of Figs. 1 - 3 showing plies in a generally non-planar orientation. In the example shown in Fig. 5, the courses 508 that make up plies 1, 3, 5 and 8 are mutually parallel; the courses that make up plies 2 and 7 are mutually parallel but are angled relative to the courses that make up plies 1, 3, 5 and 8 and the courses that make up plies 4 and 6 are each not parallel to courses in any of the other plies in the illustrated composite article.

[0043] Fig. 5 illustrates, at A, a cross-sectional cut taken from a three dimensional map automatically produced by the system of the present invention which clearly shows and emphasizes both the separation, designated S, between adjacent courses 508 at each gap joint 530 in mutually parallel plies 1, 3, 5 and 8, and the offset, designated O, between gap joints 530 of mutually parallel plies 1, 3, 5 and 8.

[0044] Fig. 5 illustrates, at B, a cross-sectional cut taken from a three dimensional map automatically produced by the system of the present invention which clearly shows and emphasizes both the separation, designated S, between adjacent courses 508 at each gap joint 530 in mutually parallel plies 2 & 7, and the offset, designated O, between gap joints 530 of mutually parallel plies 2 & 7.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US8068659B [0002]
- US7889907B [0002]
- US5963660A [0002]
- US20090043533A [0002]
- US20070173966A [0002] [0003]
- US20070034313A [0002]
- US20040031567A [0002]

System og fremgangsmåde til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf

Patentkrav

1. Fremgangsmåde til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf, hvilken fremgangsmåde omfatter:
afbildning af multiple individuelle lag (1, 2, 3, 4, 5, 6, 7, 8) af en struktur, hvorved lokaliteterne og orienteringerne af kantsamlinger (430; 530) mellem nabostillede baner (408; 508) for hvert lag registreres;
kendetegnet ved:

tilvejebringelse af en tredimensionel billedfil af strukturen; og

bestemmelse ud fra den tredimensionelle billedfil af gensidige forskydninger (O) på lokaliteterne for gensidigt parallelle lag af kantsamlingerne for forskellige lag i de multiple individuelle lag.

2. Fremgangsmåde til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf ifølge krav 1, og hvor:

de individuelle lag (1, 2, 3, 4, 5, 6, 7, 8) hver især strækker sig i et X-Y-plan og er stablet i en Z-retning, vinkelret på X-Y-planet for hvert af de individuelle lag; og

de gensidige forskydninger (O) bestemmes ved sammenligning af lokaliteten for hver af de gensidigt parallelle kantsamlinger (430) i X-Y-planet for hvert af de individuelle lag med den tilsvarende lokalitet for en kantsamling, der er gensidigt parallel dermed i X-Y-planet for et andet af de individuelle lag.

3. Fremgangsmåde til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf ifølge krav 1, og hvor:

de individuelle lag (1, 2, 3, 4, 5, 6, 7, 8) er ikke-plane; og

de gensidige forskydninger (O) bestemmes ved sammenligning af lokaliteten for hver af de gensidigt parallelle kantsamlinger (530) i hvert af de individuelle lag med den tilsvarende lokalitet for en kantsamling, der tættest svarer dertil med hensyn til lokalitet og orientering i et andet af de individuelle lag.

4. Fremgangsmåde til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf ifølge krav 1, og hvor afbildningen af multiple individuelle lag (1, 2, 3, 4, 5, 6, 7, 8) af en struktur finder sted under fremstilling af strukturen mindst mellem nedlægning af hvert af de multiple individuelle lag.

5. System til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf, hvilket system omfatter:
et billeddannelsesapparat (106; 206; 306), der kan danne billeder af multiple individuelle lag (1, 2, 3, 4, 5, 6, 7, 8) af en struktur, hvorved lokaliteterne og orienteringerne for kantsamlinger (430, 530) mellem nabostillede baner af hvert lag registreres;
kendetegnet ved:

en forskydningsanalysator, der kan bestemme gensidige forskydninger i lokaliteterne for gensidigt parallelle lag af kantsamlingerne for forskellige lag i de multiple individuelle lag; og

en billedfilgenerator, der kan levere en tredimensionel billedfil af strukturen til forskydningsanalysatoren.

6. System til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf ifølge krav 5, og hvor:

de individuelle lag (1, 2, 3, 4, 5, 6, 7, 8) hver især strækker sig i et X-Y-plan og er stablet i en Z-retning, vinkelret på X-Y-planet for hvert af de individuelle lag; og de gensidige forskydninger (430) bestemmes ved sammenligning af lokaliteten for hver af de gensidigt parallelle kantsamlinger i X-Y-planet for hvert af de individuelle lag med den tilsvarende lokalitet for en kantsamling, der er gensidigt parallel dermed i X-Y-planet for et andet af de individuelle lag.

7. System til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf ifølge krav 5, og hvor:

de individuelle lag (1, 2, 3, 4, 5, 6, 7, 8) er ikke-plane; og

de gensidige forskydninger bestemmes ved sammenligning af lokaliteten for hver af de gensidigt parallelle kantsamlinger (530) i hvert af de individuelle lag med den tilsvarende lokalitet for en kantsamling, der tættest svarer dertil med hensyn til lokalitet og orientering i et andet af de individuelle lag.

8. System til inspektion af strukturer dannet af kompositmaterialer under fremstilling deraf ifølge krav 5, og hvor billeddannelsesapparatet (106; 206; 306) kan danne billeder af multiple individuelle lag (1, 2, 3, 4, 5, 6, 7, 8) under fremstilling af strukturen mindst mellem nedlægning af hvert af de multiple individuelle lag.

DRAWINGS

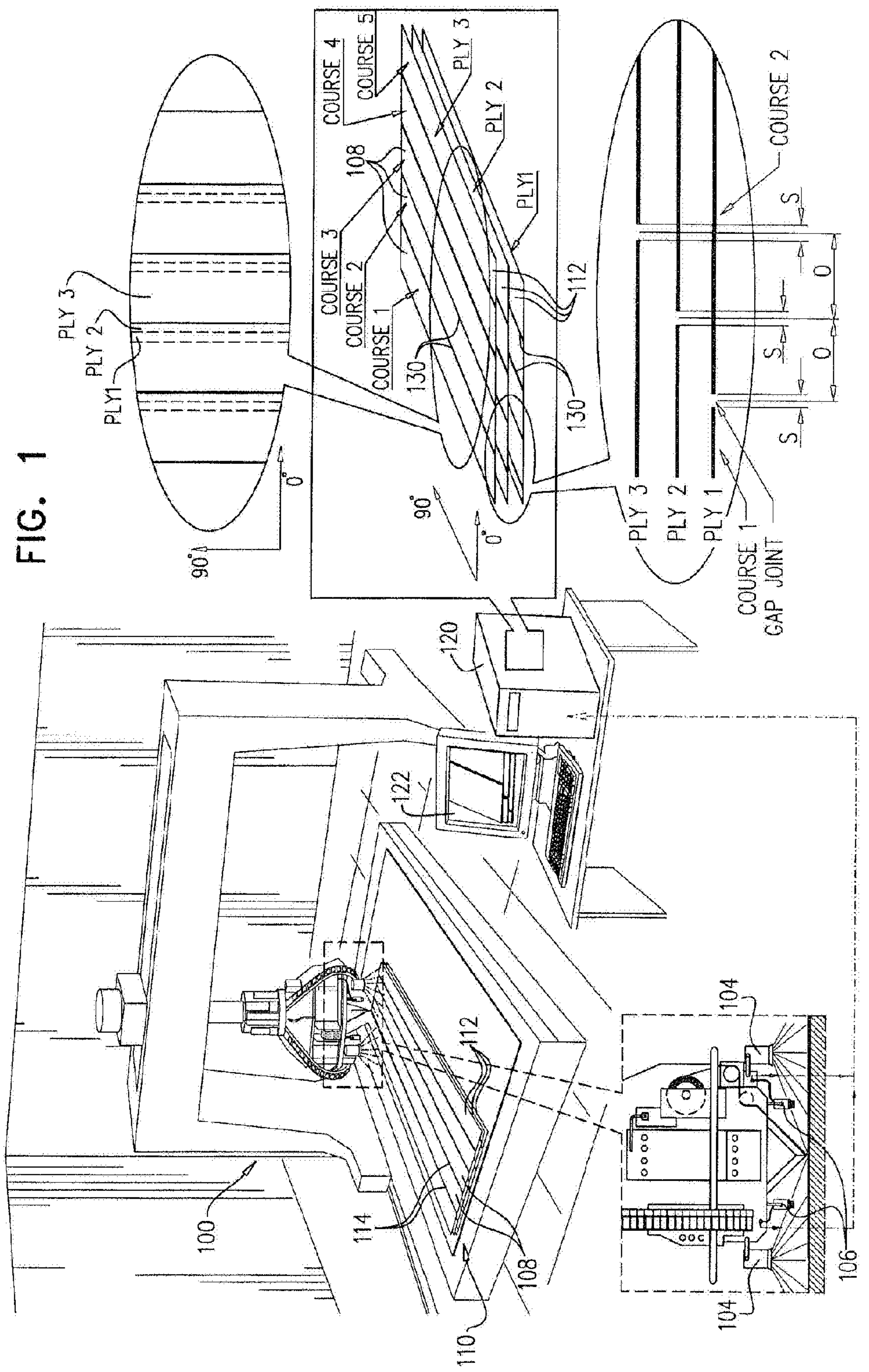
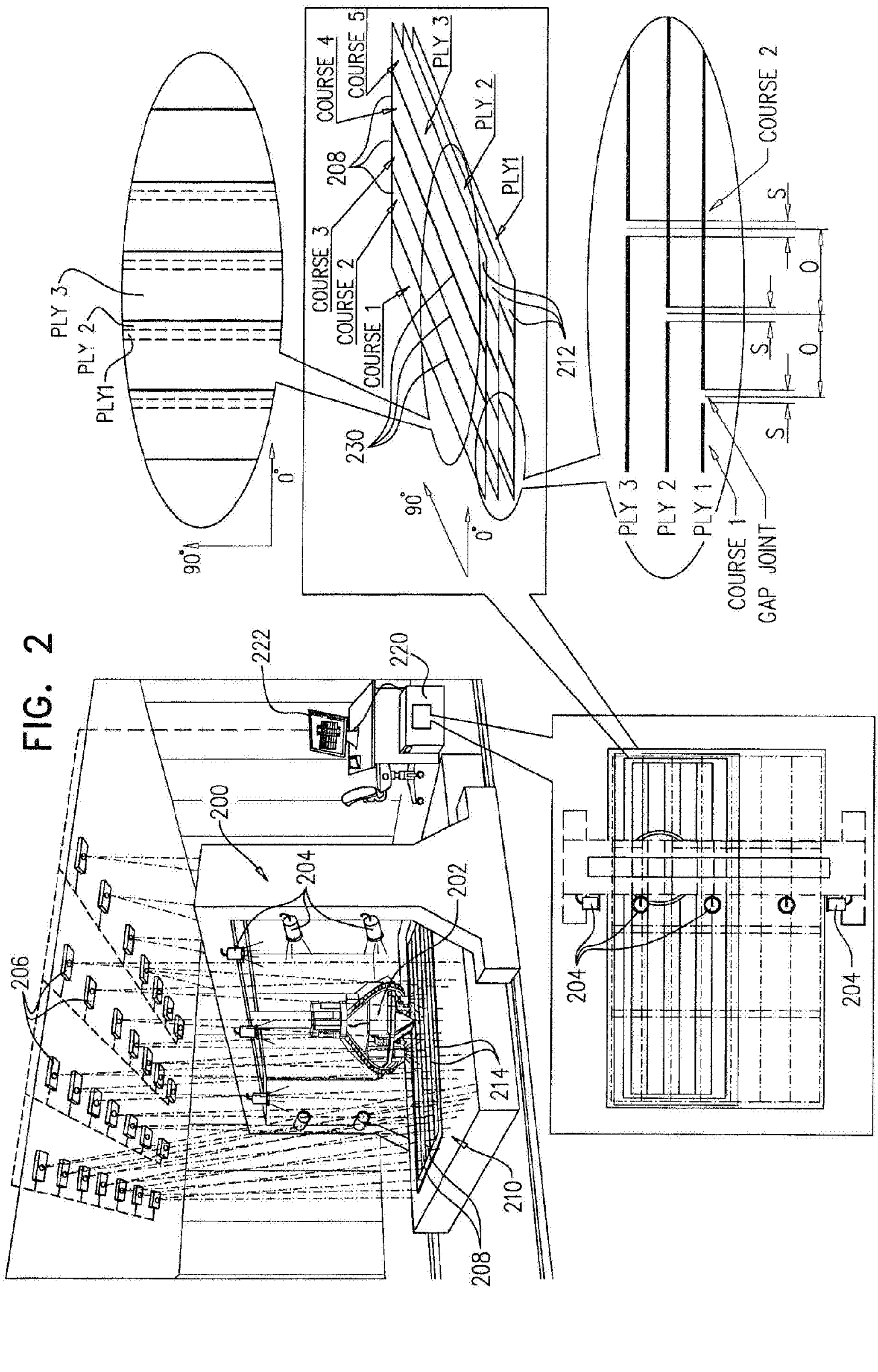


FIG. 1

FIG. 2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COURSE 4
COURSE 5
208
PLY1
PLY 2
PLY 3
212
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GAP JOINT
204
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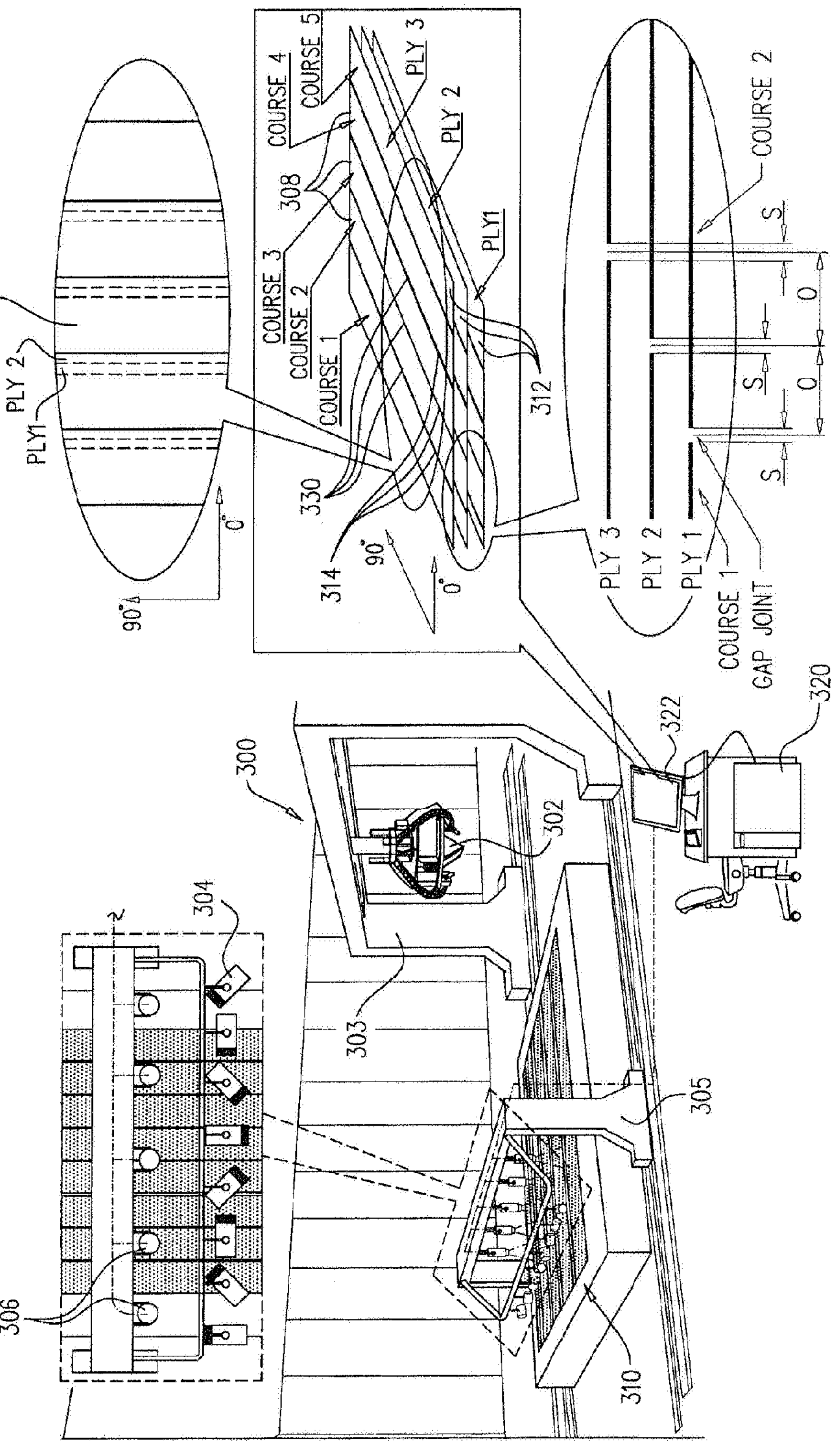
FIG. 3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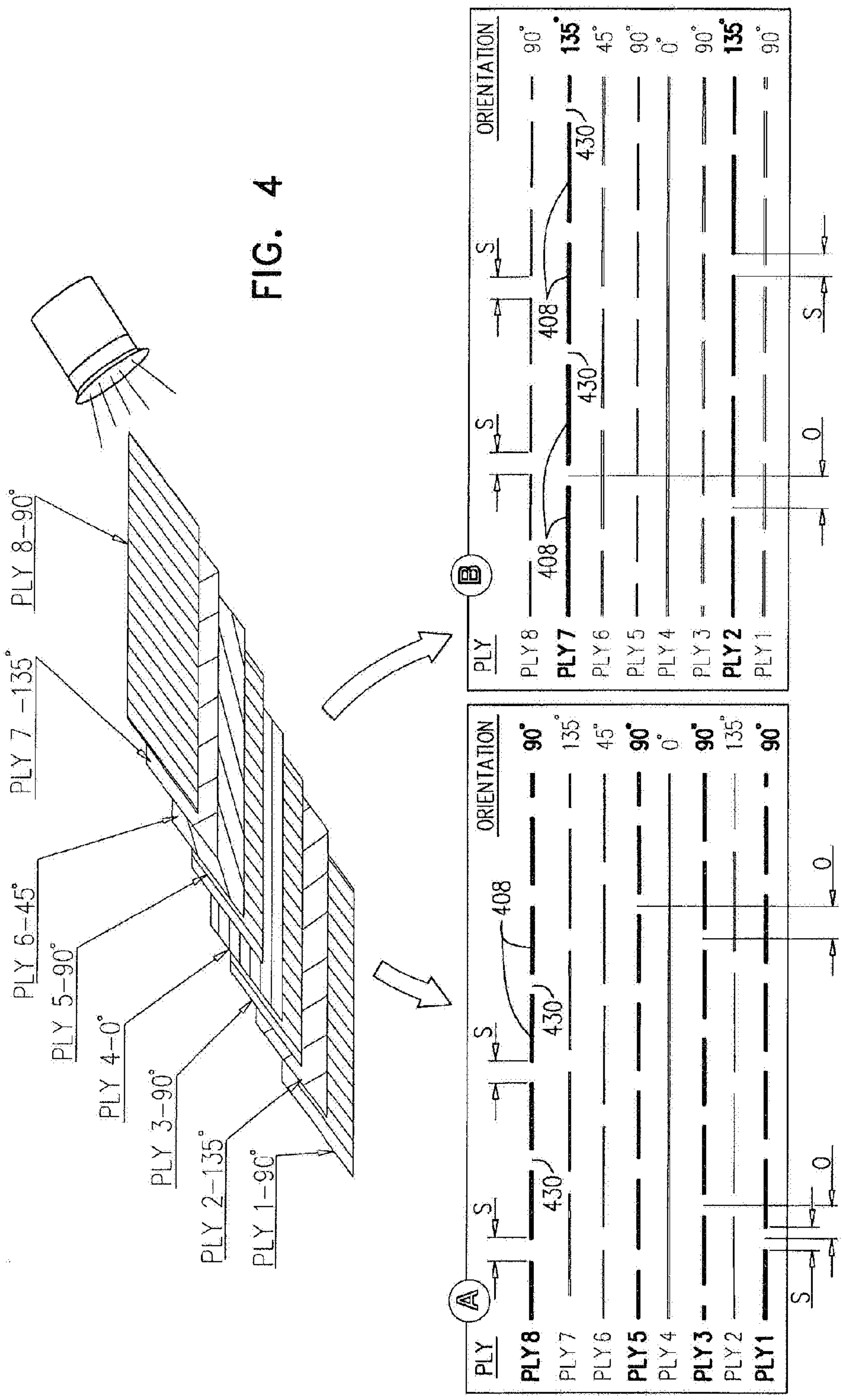
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PLY 7
PLY 6
PLY 5
PLY 4
PLY 3
PLY 2
PLY 1
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135°
45°
90°
0°
90°
135°
90°
S
O
408
430
B
PLY
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PLY 7
PLY 6
PLY 5
PLY 4
PLY 3
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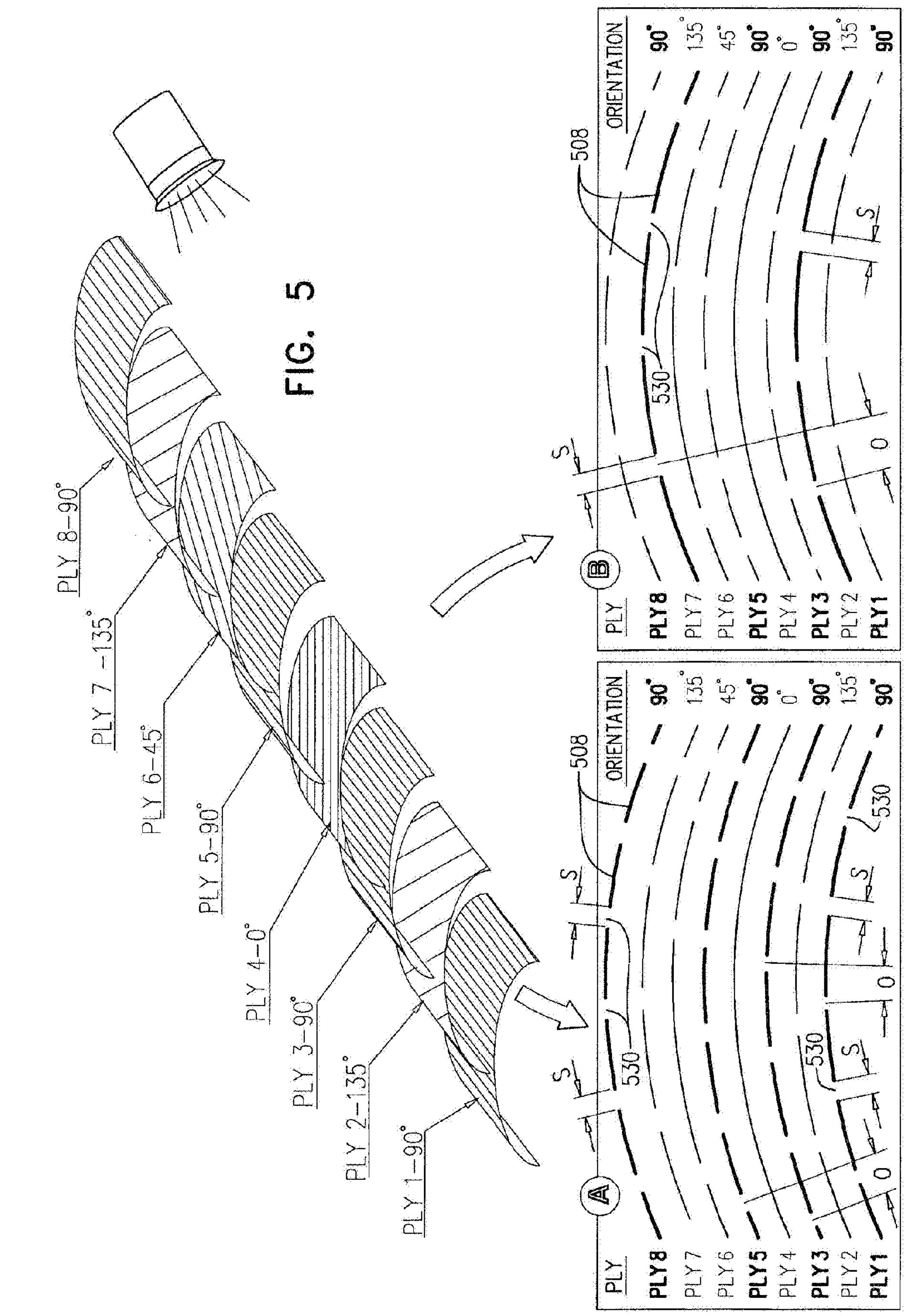
FIG. 4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PLY 4
PLY 3
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FIG. 5