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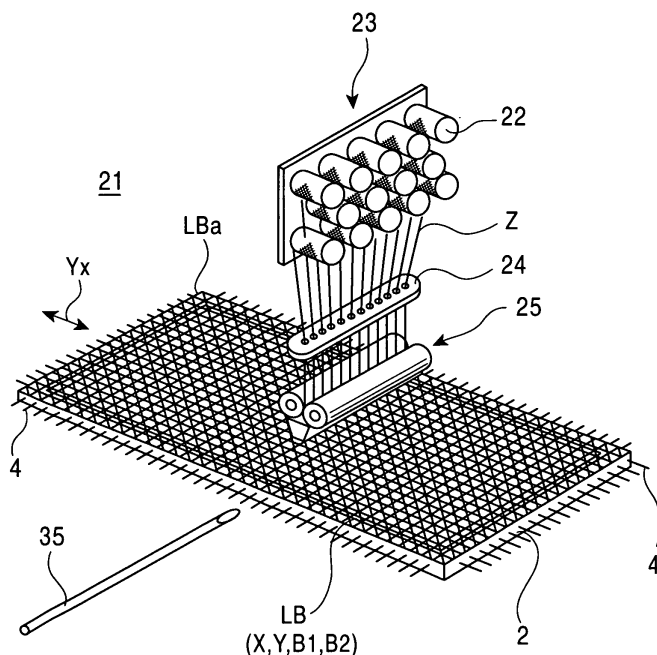
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(54) Three-dimensional woven fabric manufacturing method and apparatus

(57) The present invention provides a multiaxis three-dimensional woven fabric manufacturing method and apparatus which serves to increase the density of a weave in a three dimensional woven fabric product. A three-dimensional woven fabric manufacturing method according to the present invention is characterized by including a step of forming a 4-axis yarn laminate LB of a desired thickness by using warps X, wefts Y, and a set

of bias yarns B1, B2 to laminate a plurality of warp layers, a plurality of weft layers, and a plurality of layers each comprising the set of bias yarn layers, and a vertical yarn stitching step of stitching vertical yarns Z into the 4-axis yarn laminate from one surface of it in its laminating direction, and in that a three-dimensional woven fabric is formed by stitching the vertical yarn to fasten the warps X, wefts Y, and set of bias yarns B1, B2 together (Fig.3).

FIG. 3



Description

Field of the Invention

[0001] The present invention relates to a three-dimensional woven fabric manufacturing method and apparatus for manufacturing a multiaxis three-dimensional woven fiber structure (a multiaxis three-dimensional woven fabric), and in particular, to a three-dimensional woven fabric manufacturing method and apparatus adapted to increase the density of a weave in a three-dimensional woven fabric.

Background of the Invention

[0002] A 5-axis three-dimensional woven fabric W has hitherto been developed and provided which is composed of warps X, wefts Y, a set of bias yarns B1, B2, and vertical yarns Z as shown in Figure 1. A three-dimensional weaving machine that weaves this 5-axis three-dimensional woven fabric W has been described and proposed in, for example, the Unexamined Japanese Patent Application Publication (Tokkai Hei) No. 10-325041. With the three-dimensional weaving machine described in this publication, the warps X and the set of bias yarns B1, B2 are first guided to a cloth fell of the weaving machine. Then, the warps X are used to form a plurality of warp layers. The bias yarns B1, B2 are used to form a set of two bias yarn layers. Each of the bias yarn layers is arranged between the warp layers. The bias yarns in one of the two bias yarn layers of the set are inclined from the warps at a specified angle, while the bias yarns in the other bias yarn layer are inclined in the opposite direction at the same angle. Furthermore, the wefts Y are inlaid between the warp layers and between the bias layer. In the thickness direction of the warp layers and bias yarn layers, the vertical yarns Z are inlaid between the warps of each warp layer and between the bias yarns of each bias yarn layer. Thus, a 5-axis three-dimensional woven fabric is woven so that the vertical yarns connect and integrate the warps, wefts, and bias yarns together.

[0003] In the above 5-axis three-dimensional weaving machine, a vertical yarn inlaying member for inlaying the vertical yarns Z is controlled by means that moves up and down between the warps. Further, a beating operation is performed while threading the vertical yarns between fabric layers. With this conventional 5-axis three-dimensional weaving machine, the vertical yarns are supplied and beaten by the vertical yarn inlaying member, also acting as a yarn guide. Accordingly, a gap is required through which the yarn guide can pass. This disadvantageously limits the dense arrangement of fibers. This in turn limits an increase in the density of a weave as a three-dimensional woven fabric product.

[0004] Thus, it is an object of the present invention to fundamentally correct the concept of the above three-dimensional weaving machine that the vertical yarns Z

are inlaid, to provide a method and apparatus which provides a three-dimensional woven fabric by stitching the vertical yarns Z into a 4-axis yarn laminate composed of the warps X, wefts Y, and set of bias yarns B1, B2.

Summary of the Invention

[0005] Specifically, to accomplish the above object, the present invention provides a three-dimensional woven fabric manufacturing method comprising a step of forming a 4-axis yarn laminate of a desired thickness by using warps, wefts, and a set of bias yarns to laminate a plurality of warp layers, a plurality of weft layers, and a plurality of layers of a set of bias yarns each, and a vertical yarn stitching step of stitching vertical yarns into the 4-axis yarn laminate from one surface of the 4-axis yarn laminate in its laminating direction, and in that a three-dimensional woven fabric is formed by stitching the vertical yarns to fasten the warps, wefts, and set of bias yarns together.

[0006] Furthermore, according to the present invention, the present invention provides a three-dimensional woven fabric manufacturing apparatus comprising 4-axis yarn laminate forming means for forming a 4-axis yarn laminate by operating, in order to form warp layers, weft layers, and layers of a set of bias yarns each on a frame comprising yarn guard switching means around an outer periphery of the frame, to route a plurality of yarns supplied by a yarn supplying source in a direction in which the warp layers are formed, in a direction in which the weft layers are formed, and in a direction in which the layers of a set of bias yarns each are formed, respectively, to distributively direct said plurality of yarns, and vertical yarn stitching means for stitching vertical yarns into the 4-axis yarn laminate from one surface of the 4-axis yarn laminate in its laminating direction to allow the vertical yarns to fasten the warps, wefts, and set of bias yarns together.

[0007] Moreover, the present invention provides the three-dimensional woven fabric manufacturing apparatus wherein the yarn guard switching means comprises a large number of yarn guard pins attached to the outer periphery of the frame so as to extend in a lateral direction.

[0008] Moreover, the present invention provides the three-dimensional woven fabric manufacturing apparatus wherein the vertical yarn stitching means comprises a stitching head provided with a plurality of vertical yarn stitching needles and vertical yarn feeding means, and a needle guide plate that guides the plurality of vertical yarn stitching needles, and the apparatus further comprises controlled driving means for driving the vertical stitching means and the needle guide plate in a controlled manner so that when the vertical yarn stitching means lowers, the needle guide plate lowers before the vertical yarn stitching means to press the 4-axis yarn laminate and so that when the vertical yarn stitching means elevates, the needle guide plate leaves said

4-axis yarn laminate after the vertical yarn stitching means.

[0009] Furthermore, the present invention provides the three-dimensional woven fabric manufacturing apparatus wherein the vertical yarn stitching means comprise fastening yarn inlaying means for inlaying a fastening yarn at the other surface of the 4-axis yarn laminate in its laminating direction so that the fastening yarn intertwines with said vertical yarns, every time the vertical yarns are stitched.

[0010] Moreover, the present invention provides the three-dimensional woven fabric manufacturing apparatus wherein the plurality of vertical yarn stitching needles of the vertical yarn stitching means each comprises a through-hole that penetrates the vertical yarn stitching needle in its axial direction so that the vertical yarn Z is inlaid and guided through the through-hole.

Brief Description of the Drawings

[0011]

Figure 1 is a schematic partly exploded perspective view showing an example of a basic configuration of a 5-axis three-dimensional woven fabric W composed of warps X, wefts Y, a set of bias yarns B1, B2, and vertical yarns Z.

Figure 2 shows an embodiment of a specific apparatus for a step of using the warps X, wefts Y, and set of bias yarns B1, B2 to form a 4-axis yarn laminate in a three-dimensional woven fabric manufacturing method according to the present invention, wherein Figure 2A is a schematic perspective view showing an entire configuration of the 4-axis yarn laminate forming means, Figure 2B is a schematic side view showing how the 4-axis yarn laminate forming means sets yarns from a yarn supplying source on yarn guard switching means, and Figures 2C1 to 2C3 are schematic perspective views showing the details of a yarn distribution guide member in the 4-axis yarn laminate forming means.

Figure 3 is a schematic perspective view showing an entire configuration of specific example of an apparatus for a step of stitching the vertical yarns Z into the 4-axis yarn laminate from one surface of it in its laminating direction in the three-dimensional woven fabric manufacturing method according to the present invention.

Figure 4 is a schematic perspective view showing an example of configuration of essential parts of the vertical yarn stitching means.

Figure 5 is a schematic side view showing the relationship between a stitching needle of the vertical yarn stitching means and a rapier for a fastening yarn.

Figure 6 is a schematic perspective view showing a specific example of configuration of a rapier reciprocatory driving mechanism for reciprocation of

the rapier.

Figure 7 is a side sectional view showing a specific embodiment of a clamp portion of the rapier.

Figure 8 is a schematic perspective view showing a specific embodiment of a control mechanism for feeding of the fastening yarn.

Detailed Description of the Preferred Embodiments

[0012] On the basis of the specific embodiment shown in the drawings, description will be given of a method and apparatus for manufacturing a multiaxis three-dimensional woven fabric according to the present invention.

[0013] First, the three-dimensional woven fabric manufacturing method according to the present invention comprises a step of forming a 4-axis laminate LB of a desired thickness by using the warps X, the wefts Y and the set of bias yarns B1, B2 to laminate a plurality of warp layers, a plurality of weft layers, and a plurality of layers of a set of bias yarns B1, B2, and a vertical yarn stitching step of stitching the vertical yarns Z into the 4-axis laminate LB from one surface LBA of it in its laminating direction. A three-dimensional woven fabric W is woven by thus stitching the vertical yarns to fasten the warps X, wefts Y, and set of bias yarns B1, B2 together.

[0014] The above 4-axis laminate LB is formed by 4-axis yarn laminate forming means 1 such as the one shown in Figure 2. First, in the present invention, a frame 2 is provided to form the 4-axis yarn laminate LB. The frame 2 is composed of a shaft member 3 having a rectangular horizontal cross section and is shaped like a rectangle of external size $L1 \times L2$. Yarn guard pins 4 are provided around the outer periphery of the frame 2 at predetermined pitch intervals as yarn guard switching means. In the present invention, the yarn guard pins 4 are utilized to form the following layers on the frame: warp layers each comprising a plurality of yarns extending in the warp direction, weft layers each comprising a plurality of yarns extending in the weft direction, + θ -degree bias yarn layers each comprising a plurality of yarns extending in a + θ -degree bias yarn direction, and - θ -degree bias yarn layers each comprising a plurality of yarns extending in a - θ -degree bias yarn direction.

[0015] The 4-axis yarn laminate forming means 1 includes a machine body 8 provided with a yarn supplying source composed of a plurality of bobbins 5 and a yarn distribution guide member 7 that guides a plurality of yarns (warps X, wefts Y, and shared yarns Cy as bias yarns B1, B2) supplied by the yarn supplying source 6. The 4-axis yarn laminate forming means 1 further includes an X-axis direction reciprocatory driving mechanism 9 on which the frame 2 is mounted and reciprocated in the direction of an arrow Yx. The machine body 8 comprises a machine base 10 and a Y-axis direction reciprocatory driving mechanism 12 for reciprocation along an upper rail 11 of the machine base 10 in the direction of an arrow Yx. A strut member 13 reciprocated

by the Y-axis direction reciprocatory driving mechanism 12 along the upper rail 11 of the machine base 10 in the direction of an arrow Yy is provided with the yarn supplying source 6, composed of the plurality of bobbins 5, and the yarn distribution guide member 7, which guides a plurality of yarns supplied by the yarn supplying source 6. The yarn distribution guide member 7 has a plurality of guide holes 14 formed in a line and through which yarns are inserted and guided.

[0016] The yarn distribution guide member 7 is adapted to move up and down in the direction of an arrow Ya with respect to the strut member 13. The yarn distribution guide member 7 is further adapted to be freely rotationally moved along the direction of an arrow Yb and fixed so that the row of the guide holes 14, arranged in a line, is placed at a 0-degree angular position, shown in Figure 2A, and a 90-degree angular position. It is also adapted to pivot freely along an arrow Yc around a shaft 15 as shown in Figure 2B. The plurality of guide holes 14 are formed by a pipe-like yarn inserting member Pa of appropriate length dimensions as shown in Figures 2C2 and 2C3.

[0017] With the 4-axis yarn laminate forming means 1, to form a warp layer X on the frame 2, the row of the guide holes 14 in the yarn distribution guide member 7 is first fixed at the 90-degree angular position. The X-axis direction reciprocatory driving mechanism 9 is used to move the frame 2 in the direction of the arrow Yx. Once the position of end side 2a or end side 2b of the frame 2 is reached, the yarn distribution guide member 7 is allowed to pivot along the direction of the arrow Yc to catch yarns on the yarn guard pins 4. Then, the Y-axis direction reciprocatory driving mechanism 12 is used to slide the yarn distribution guide member 7 in the direction of the arrow Yy. The X-axis direction reciprocatory driving mechanism 9 is then used to repeat the movement in the direction of the arrow Yx to form a warp layer on the frame 2.

[0018] To form a weft layer Y on the frame 2, the row of the guide holes 14 in the yarn distribution guide member 7 is first fixed at the 0-degree angular position. The Y-axis direction reciprocatory driving mechanism 12 is used to move the yarn distribution guide member 7 in the direction of the arrow Yy. Once the yarn distribution guide member 7 reaches the position of end side 2c or end side 2d of the frame 2, it is allowed to pivot along the direction of the arrow Yc to catch yarns on the yarn guard pins 4. Then, the X-axis direction reciprocatory driving mechanism 9 is used to slide the frame 2 in the direction of the arrow Yx. The Y-axis direction reciprocatory driving mechanism 12 is then used to repeat the movement in the direction of the arrow Yy to form a weft layer Y on the frame 2.

[0019] On the other hand, to form a +45-degree bias yarn layer B1 on the frame 2, the row of the guide holes 14 in the yarn distribution guide member 7 is fixed at the 0-degree angular position. Then, both X-axis direction reciprocatory driving mechanism 9 and Y-axis direction

reciprocatory driving means 12 are operated at the same speed to run yarns over the frame 2 at +45-degree to it. The yarns are then allowed to cross the yarn guard pins 4 at 90-degree. This operation is repeated to form a +45-degree bias yarn layer B1 on the frame 2. To form a -45-degree bias yarn layer B2, the row of the guide holes 14 in the yarn distribution guide member 7 is fixed at the 0-degree angular position. Then, both X-axis direction reciprocatory driving mechanism 9 and Y-axis direction reciprocatory driving means 12 are operated at the same speed to run yarns over the frame 2 at -45-degree to it. The yarns are then allowed to cross the yarn guard pins 4 at 90-degree. This operation is repeated to form a -45-degree bias yarn layer B2 on the frame 2.

[0020] Each of these operations is repeated to form a 4-axis yarn laminate LB of a desired thickness dimension which is composed of the warp layers X, weft layers Y, and ± 45 -degree bias yarn layers B1, B2. After the 4-axis yarn laminate forming means 1 has formed the 4-axis yarn laminate LB on the frame 2, the 4-axis yarn laminate LB is transferred to the succeeding vertical yarn stitching step while being supported by the frame 2.

[0021] An important point of the present invention is that it includes a vertical yarn stitching step of stitching the vertical yarns Z into the 4-axis yarn laminate LB. In the vertical yarn stitching step, the 4-axis yarn laminate LB formed on the frame 2 is fixedly arranged on a driving mechanism (not shown in the drawings) that can move the laminate LB in the direction of the arrow Yx, as shown in Figures 3 and 4. A vertical yarn stitching means 21 for the vertical yarn stitching step stitches the vertical yarns Z into the 4-axis yarn laminate LB from one surface LBa of it in its laminating direction so that the vertical yarns Z can fasten the warps X, wefts Y, and set of bias yarns B1, B2 together. More specifically, the vertical yarn stitching means 21 includes a vertical yarn supplying source 23 composed of a group of a large number bobbins 22, a vertical yarn guide 24, a stitching head 25, a needle guide plate 26, and fastening yarn inlaying means 27.

[0022] The stitching head 25 of the vertical yarn stitching means 21 is provided with a plurality of vertical yarn stitching needles 29 supported by a needle supporting member 28, and vertical yarn feeding means 31 composed of a pair of vertical yarn feeding rollers 30, 30. The present invention comprises driving control means (not shown in the drawings) for driving the stitching head 25 and needle guide plate 26 of the vertical yarn stitching means 21 in a controlled manner such that when the vertical yarn stitching means 21 lowers, the needle guide plate 26 lowers before the stitching head 25 to press the 4-axis laminate LB and such that when the vertical yarn stitching means 21 elevates, the needle guide plate 26 leaves the 4-axis laminate LB after the stitching head 25.

[0023] In the present invention, a more important point is the configuration of the plurality of vertical yarn stitching needles 29 of the vertical yarn stitching means

21. The vertical yarn stitching needles 29 each comprise a through-hole 32 that penetrates the vertical yarn stitching needle 29 in its axial direction and a needle tip 33 at its leading end. The vertical yarn Z is inserted through the through-hole 32.

[0024] The vertical yarn stitching means 21 comprises fastening yarn inlaying means 27 for inlaying a fastening yarn 34 at the other surface LBb of the 4-axis yarn laminate in its laminating direction so that the fastening yarn 34 intertwines with the vertical yarns Z, every time the vertical yarns Z are stitched. The fastening yarn inlaying means 27 is adapted to be inserted, by a rapier 35, into loop portions Za of the vertical yarns Z at the other surface LBb side of the 4-axis yarn laminate LB in its laminating direction. At the other surface LBb side of the 4-axis yarn laminate LB in its laminating direction, a plurality of rapier guide plates 37 are arranged in parallel with one another and are held at predetermined intervals by spacer plates 36. A rapier guide groove 38 is formed in each of the rapier guide plates 37.

[0025] The rapier 35 is adapted to be reciprocated freely in the direction of arrow Yd by a rapier driving mechanism 39 such as the one shown in Figure 6. According to this example, the rapier 35 comprise a yarn locking groove 40 formed on its leading end side and in which the fastening yarn 34 is locked, and also comprises flat surfaces 41, 41 extending in its axial direction. The rapier driving mechanism 39 is composed of a rapier driving source 42, a pair of rapier feeding rollers 43, 43, and plural pairs of rapier guide rollers 44, 44.

[0026] Figure 7 shows a specific example of a clamp portion 45 of the rapier 35. According to this example, with the fastening yarn 34 locked in the yarn locking groove 40, formed on its leading end side, the rapier 35 comprises a cylindrical clasper 46 that blocks the opening of the yarn locking groove 40 and a brake portion 47 that governs the clasper 46.

[0027] Furthermore, in the present invention, feeding of the fastening yarn 34 is controlled by yarn feeding control means 48, shown in Figure 8. The fastening yarn feeding control means 48 includes a driving source 50 that positively rotationally drives a fastening yarn bobbin 49, sensor means 51 that detects the amount of fastening yarn 34 positively delivered, a guide 52, and clamp cutter means 53. According to this arrangement, the fastening yarn 34 is locked in the yarn locking groove 40 of the rapier 35 by inclining the clamp cutter means 53 in the direction of arrow Ye while the fastening yarn 34 is clamped by the clamp cutter means 53. The fastening yarn 34 is driven by the driving source 50 and positively delivered as shown by the alternate long and two short dashes line in the figure. A detection signal from the sensor means 51 drives the rapier driving mechanism 39 to drive the rapier 35 in the direction of arrow Yd. The fastening yarn 34 is thus run and inlaid into the loop portions Za of the vertical yarns Z. The fastening yarn 34 can be cut every insertion stroke by the clamp cutter means 53.

[0028] With the three-dimensional woven fabric man-

ufacturing method and apparatus according to the present invention configured as described above, the warps X, the wefts Y, and the set of bias yarns B1, B2 are used to form a 4-axis yarn laminate LB composed of warp layers, weft layers, and bias yarn layers each composed of the set of bias yarns. Then, the vertical yarns are stitched into the 4-axis yarn laminate LB. This configuration eliminates the need for a vertical yarn inlaying mechanism also acting as a yarn guide for the vertical yarns Z as well as the need for a beating step. Accordingly, no gap needs to be formed through which the yarn guide pass. Consequently, the present invention contributes to allowing fibers to be densely arranged and thus increasing the density of a weave as a three-dimensional woven fabric product. Therefore, the present invention is very effective in these points.

[0029] Furthermore, with the three-dimensional woven fabric manufacturing method and apparatus according to the present invention, the vertical yarns Z are stitched into the 4-axis yarn laminate LB composed of the warps X, wefts Y, and set of bias yarns B1, B2. The present invention is thus effective in that the vertical yarns Z may be composed of carbon yarns, ceramic yarns, or many other types of yarns.

[0030] Moreover, according to the present invention, the laterally extending yarn guard pins are provided around the outer periphery of the frame of the 4-axis yarn laminate forming means for forming the 4-axis laminate LB. Consequently, opened wide yarns can be used to manufacture a three-dimensional woven fabric with higher performance. The present invention is also very effective in this point.

Claims

1. A three-dimensional woven fabric manufacturing method **characterized by** comprising a step of forming a 4-axis yarn laminate of a desired thickness by using warps, wefts, and a set of bias yarns to laminate a plurality of warp layers, a plurality of weft layers, and a plurality of layers of a set of bias yarns each, and a vertical yarn stitching step of stitching vertical yarns Z into said 4-axis yarn laminate from one surface of said 4-axis yarn laminate in its laminating direction, and in that a three-dimensional woven fabric is formed by stitching the vertical yarns to fasten said warps, wefts, and set of bias yarns together.
2. A three-dimensional woven fabric manufacturing apparatus **characterized by** comprising 4-axis yarn laminate forming means for forming a 4-axis yarn laminate by operating in forming warp layers, weft layers, and layers of a set of bias yarns each on a frame comprising yarn guard switching means around an outer periphery of the frame, to route a plurality of yarns supplied by a yarn supplying

source in a direction in which the warp layers are formed, in a direction in which the weft layers are formed, and in a direction in which the layers of a set of bias yarns each are formed, respectively, to distributively direct said plurality of yarns, and vertical yarn stitching means for stitching vertical yarns into said 4-axis yarn laminate from one surface of said 4-axis yarn laminate in its laminating direction to allow said vertical yarns to fasten said warps, wefts, and set of bias yarns together.

3. A three-dimensional woven fabric manufacturing apparatus according to Claim 2, **characterized in that** said yarn guard switching means comprises a large number of yarn guard pins attached to the outer periphery of the frame so as to extend in a lateral direction.
4. A three-dimensional woven fabric manufacturing apparatus according to Claim 2, **characterized in that** said vertical yarn stitching means comprises a stitching head provided with a plurality of vertical yarn stitching needles and vertical yarn feeding means, and a needle guide plate that guides said plurality of vertical yarn stitching needles, and **in that** the apparatus further comprises controlled driving means for driving said vertical stitching means and said needle guide plate in a controlled manner so that when said vertical yarn stitching means lowers, said needle guide plate lowers before said vertical yarn stitching means to press said 4-axis yarn laminate and so that when said vertical yarn stitching means elevates, said needle guide plate leaves said 4-axis yarn laminate after said vertical yarn stitching means.
5. A three-dimensional woven fabric manufacturing apparatus according to any one of Claims 2 to 4, **characterized in that** said vertical yarn stitching means comprise fastening yarn inlaying means for inlaying a fastening yarn at the other surface of said 4-axis yarn laminate in its laminating direction so that the fastening yarn intertwines with said vertical yarns, every time the vertical yarns are stitched.
6. A three-dimensional woven fabric manufacturing apparatus according to any one of Claims 2 to 5, **characterized in that** the plurality of vertical yarn stitching needles of said vertical yarn stitching means each comprises a through-hole that penetrates the vertical yarn stitching needle in its axial direction so that the vertical yarn is inlaid and guided through said through-hole.

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FIG. 1

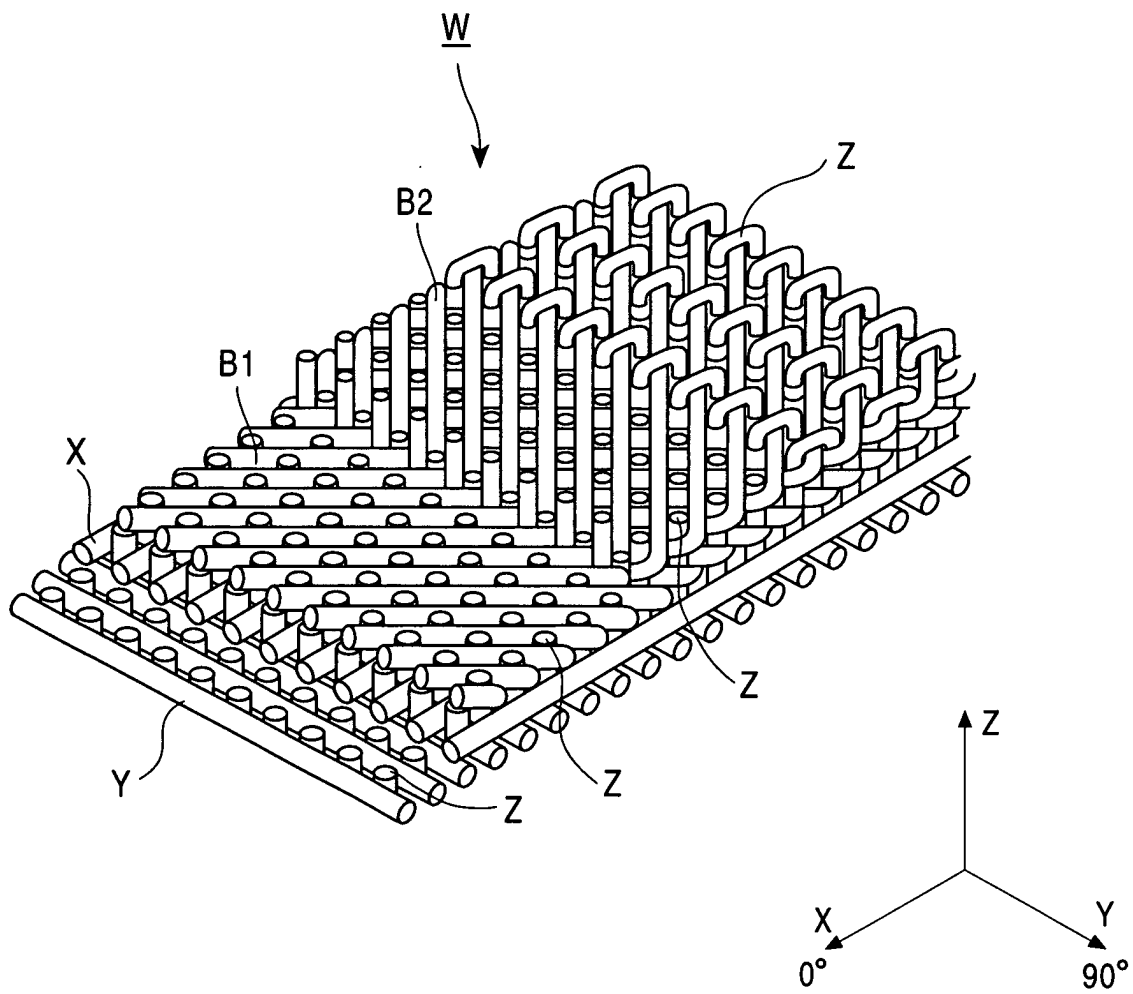


FIG. 2A

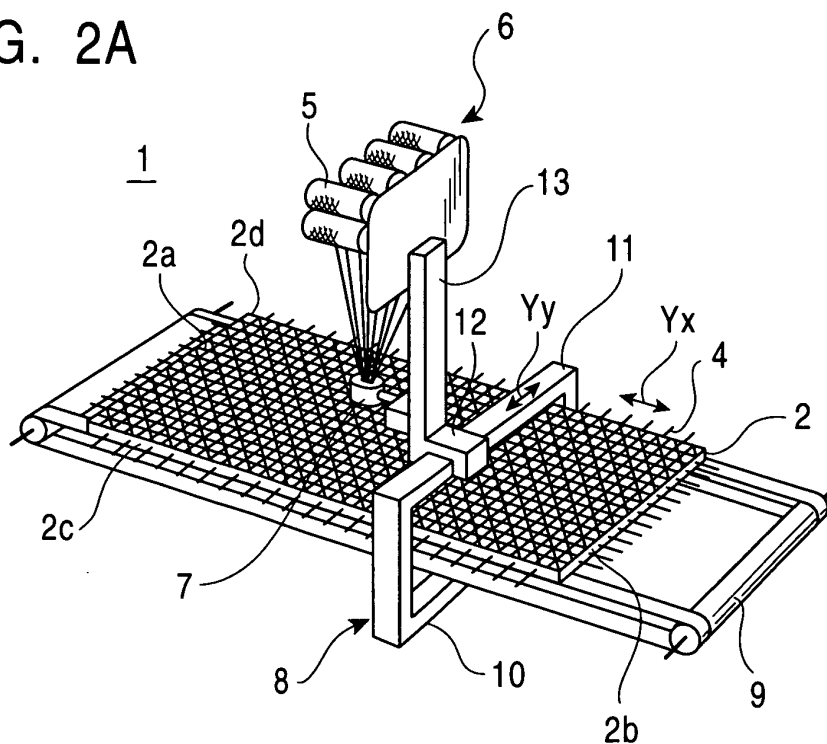


FIG. 2B

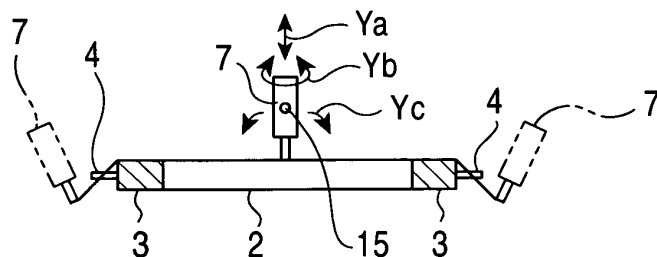


FIG. 2C1

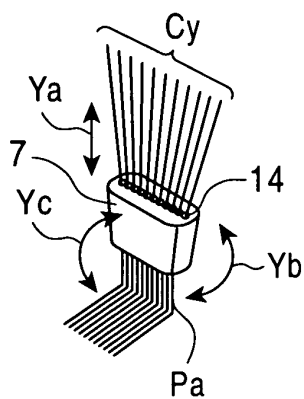


FIG. 2C2

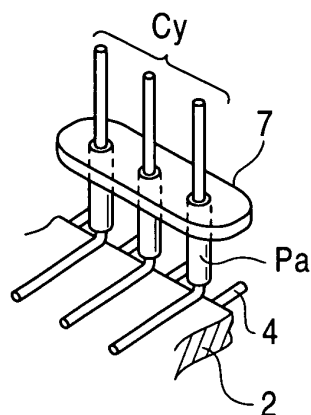


FIG. 2C3

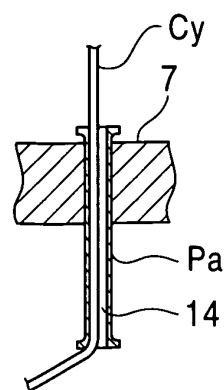


FIG. 3

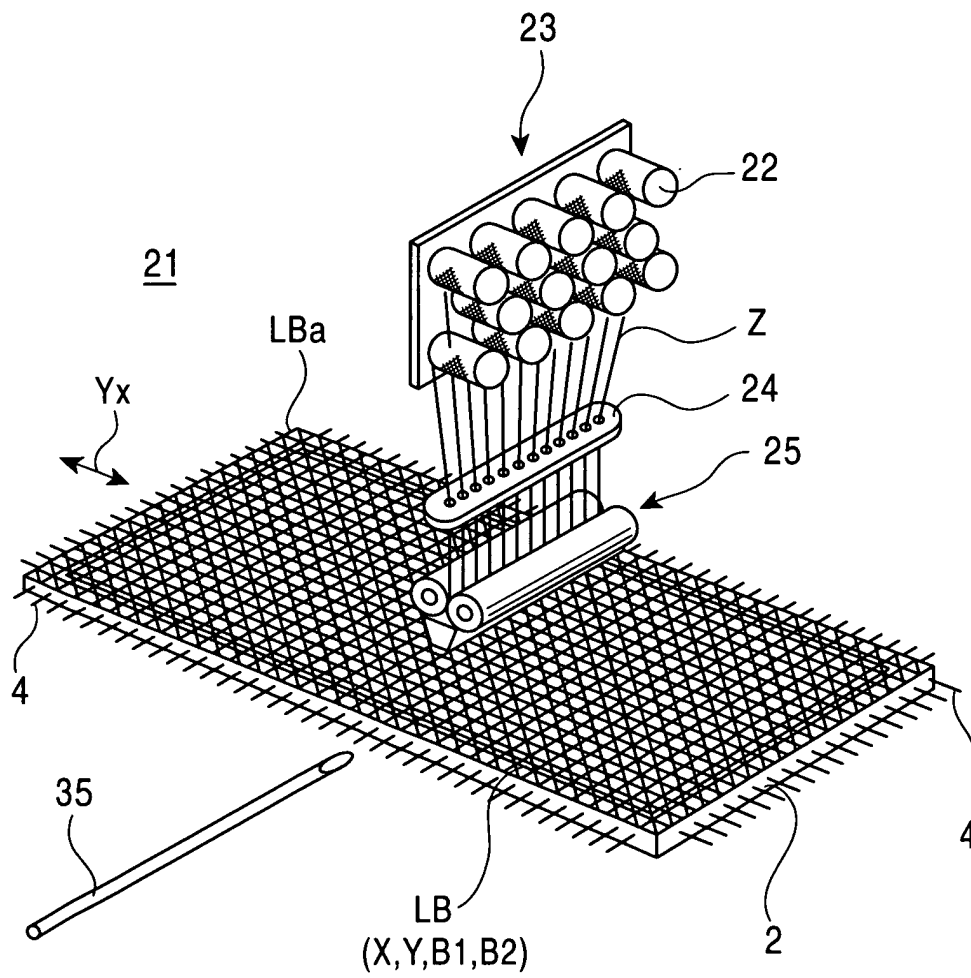


FIG. 4

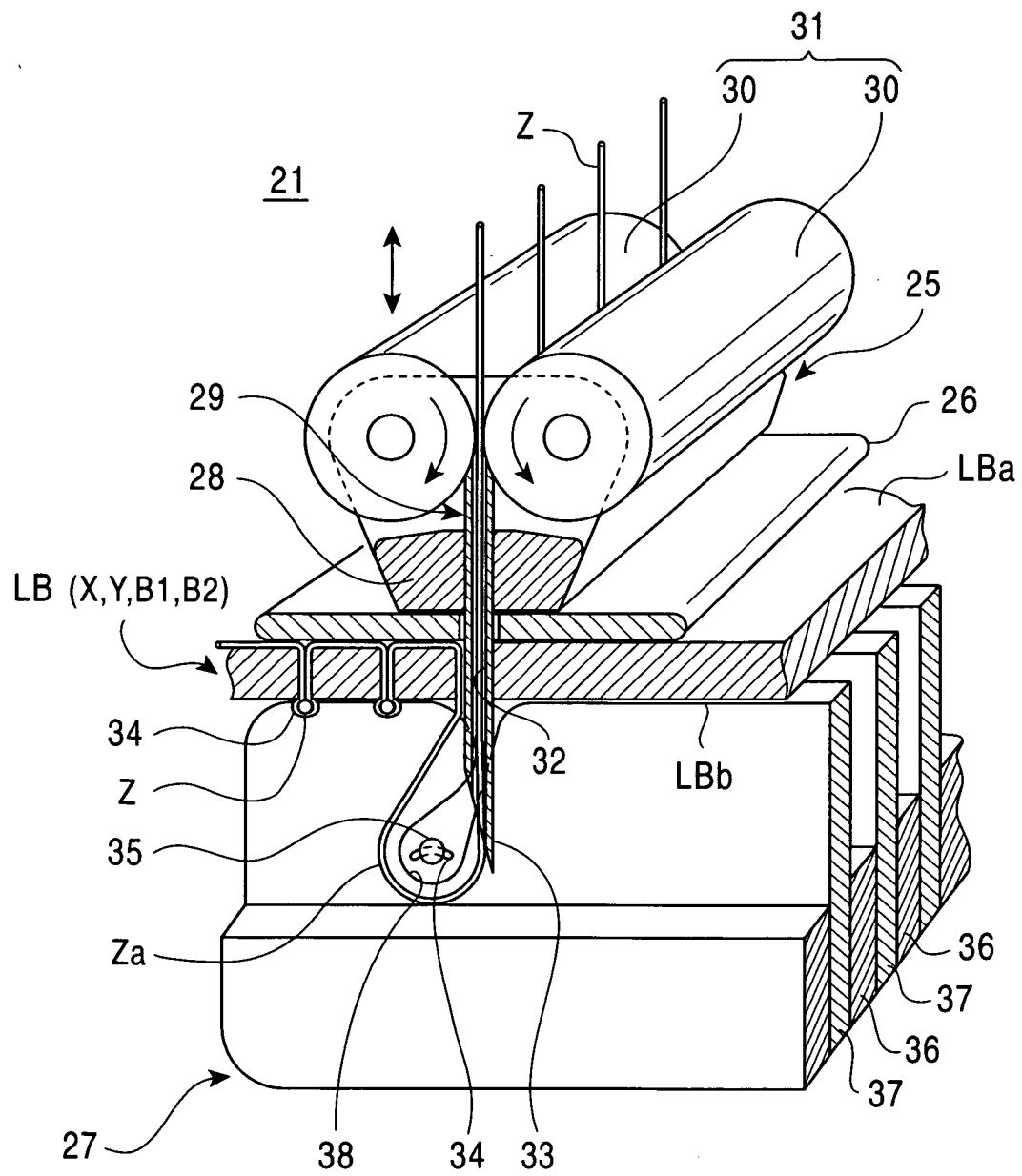


FIG. 5

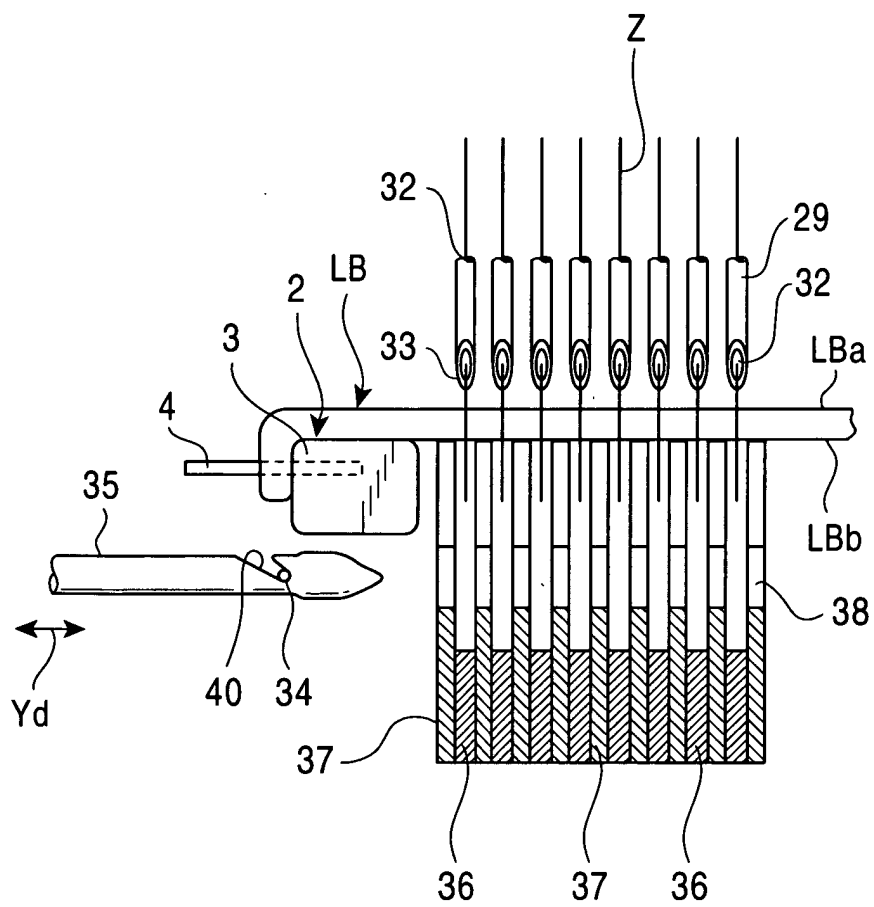


FIG. 6

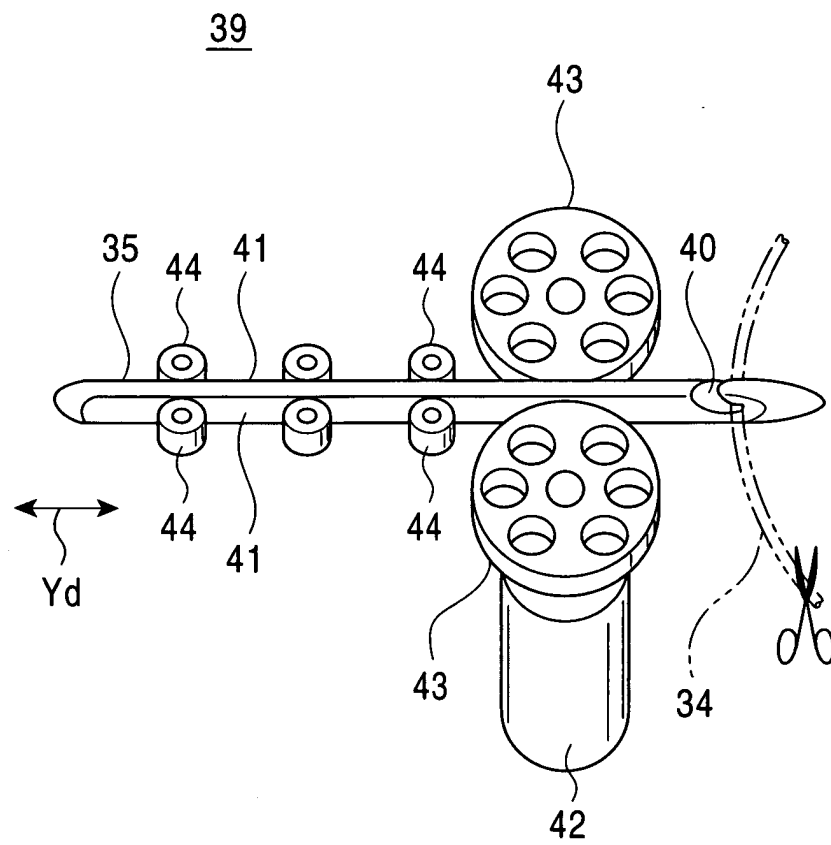


FIG. 7

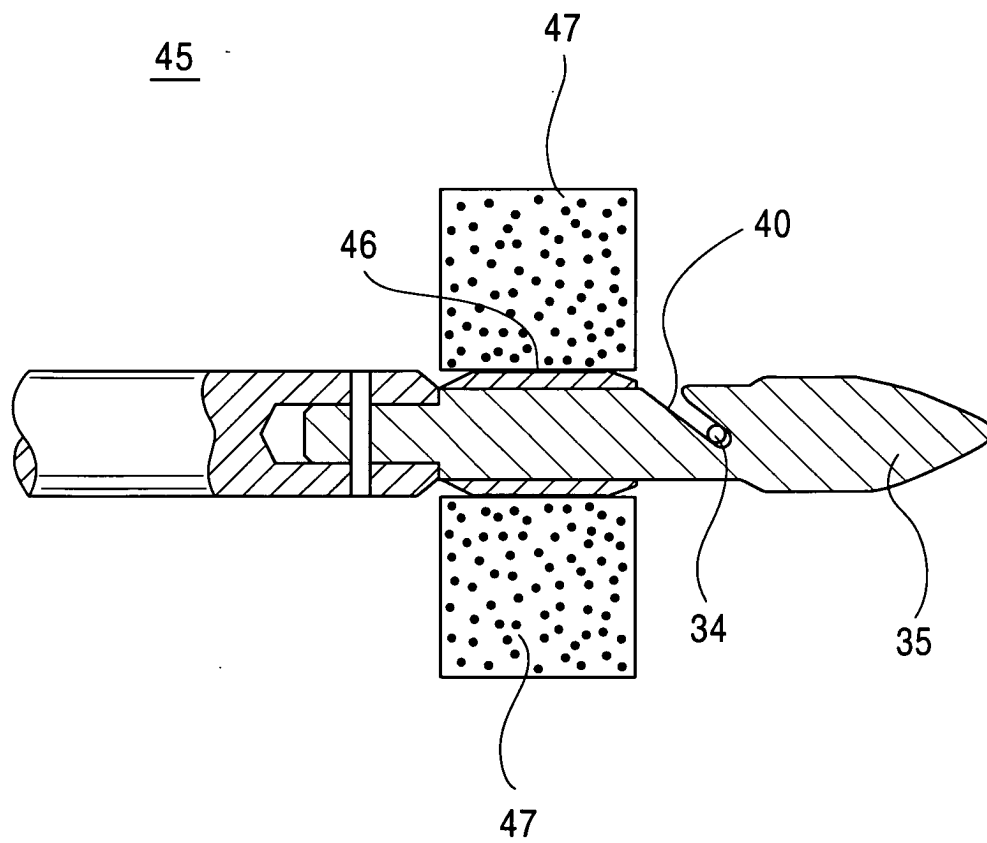


FIG. 8

