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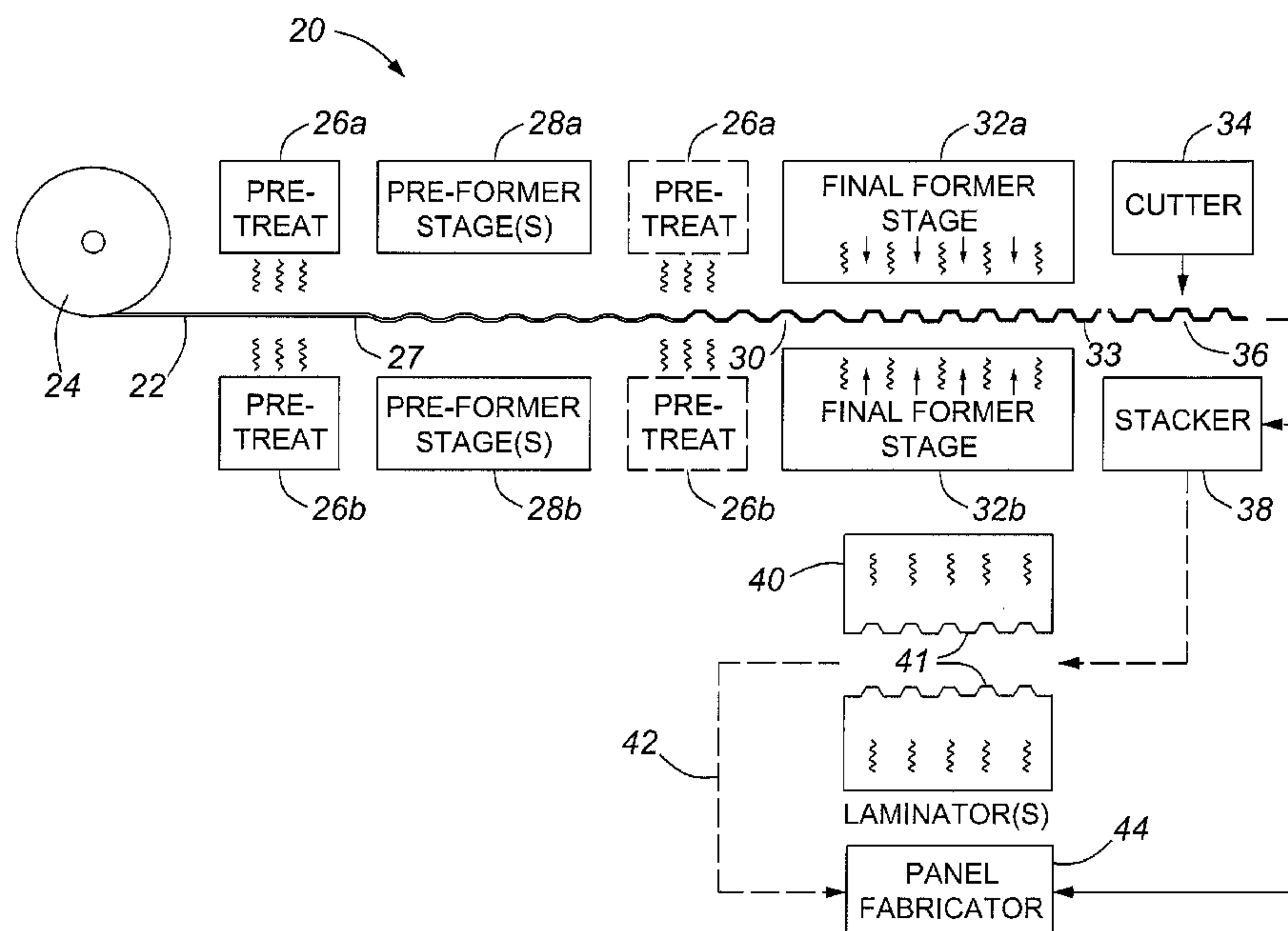
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(54) Title: MULTI-STAGE CORRUGATOR FOR COMPOSITE WOOD PANEL CORES



(57) Abrégé/Abstract:

A multi-stage corrugator for corrugating a thin, flat, pliable cold rolled wood laminae stock to form a half honeycomb corrugated web that includes at least one pre-former stage that bends the stock at spaced intervals to an angle of less than $\pm 60^\circ$, and a final former stage that further bends the stock at each of the spaced intervals to a final angle of about $\pm 60^\circ$. The final former stage includes means for applying heat and pressure to set the web at the final angle.

ABSTRACT

A multi-stage corrugator for corrugating a thin, flat, pliable cold rolled wood laminae stock to form a half honeycomb corrugated web that includes at least one pre-former stage that bends the stock at spaced intervals to an angle of less than $\pm 60^\circ$, and a final former stage that further bends the stock at each of the spaced intervals to a final angle of about $\pm 60^\circ$. The final former stage includes means for applying heat and pressure to set the web at the final angle.

MULTI-STAGE CORRUGATOR FOR COMPOSITE WOOD

PANEL CORES

FIELD OF THE INVENTION

This invention relates in general to corrugation machines and, in particular, to a novel multi-stage corrugator for half honeycomb corrugation of composite wood panel cores.

BACKGROUND OF THE INVENTION

Composite wood panels with corrugated cores are known and various machines have been invented for manufacturing the corrugated cores of those composite wood panels.

There is also a long history of apparatus for creating flat-crested corrugated webs of various materials, particularly metal foils, resin impregnated fabric webs, plastic sheet, and webs made from wood fiber slurries. Each of these materials is readily deformed and tolerant of a certain amount of shear stress when properly prepared for flat-crested corrugation, one form of which is referred to as "double-reverse bend" or "half honeycomb" corrugation.

Applicant's co-pending Canadian patent application number 2,924,288 filed March 21, 2016 describes a novel wood panel composition manufactured from wood laminae bonded together with a cold set adhesive. The wood laminae are discrete, elongated wood laminae cut from solid wood stock and sorted to be within close tolerances of thickness, width and length. The sorted wood laminae are formed into a randomly oriented mat and bonded together with the cold set adhesive to provide a thin composite wood panel that is pliable. The thin composite wood panel can be corrugated in a flat-crested, half honeycomb configuration as taught in applicant's pending patent application. However, it has been determined that the high-speed production required for commercial applications of half honeycomb corrugated wood panel cores cannot be achieved using known single-stage corrugators.

There therefore remains a need for a multi-stage corrugator for half honeycomb corrugation of composite wood panel cores.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a multi-stage corrugator for half honeycomb corrugation of composite wood panel cores.

The invention therefore provides a multi-stage corrugator for corrugating a thin, flat, pliable cold rolled wood laminae stock to form a half honeycomb corrugated web, comprising: at least one pre-former stage that accepts the flat wood laminae stock and outputs a pre-formed web, each of the at least one pre-former stages having a plurality of opposed, intermeshing nodes that respectively transversely bend the stock into the pre-formed web having an intermediate half honeycomb shape with respective bends of less than $\pm 60^\circ$; and a final former stage that accepts the pre-formed web, the final former stage having a plurality of opposed, intermeshing nodes that respectively further bend the preformed stock at each of the spaced intervals into the final half honeycomb shape.

The invention further provides a multi-stage corrugator for corrugating a thin, flat, pliable cold rolled wood laminae stock to form a half honeycomb corrugated web, comprising: a pre-former stage that accepts the flat wood laminae stock and outputs an intermediate half honeycomb stock, the pre-former stage having a plurality of opposed, intermeshing nodes that respectively transversely bend the flat stock at respective angles of less than $\pm 60^\circ$ on spaced intervals to form the intermediate half honeycomb stock; and a final former stage that accepts the intermediate half honeycomb stock, the final former stage having a plurality of opposed, intermeshing nodes that respectively further bend the intermediate half honeycomb stock at each of the spaced intervals into the final half honeycomb shape.

The invention yet further provides a multi-stage corrugator for corrugating a thin, flat, pliable cold rolled wood laminae stock to form a half honeycomb corrugated web, comprising: a first pre-former stage that accepts the flat wood laminae stock and outputs a first intermediate half honeycomb stock, the first pre-former stage having a plurality of opposed, intermeshing nodes that respectively transversely bend the flat stock at respective angles of $\pm 20^\circ$ on spaced intervals

to form the first intermediate half honeycomb stock; a second pre-former stage that accepts the first intermediate half honeycomb stock and outputs a second intermediate half honeycomb stock, the second pre-former stage having a plurality of opposed, intermeshing nodes that respectively further bend the first intermediate half honeycomb stock at each of the spaced intervals to form the second intermediate half honeycomb stock having respective angles of $\pm 40^\circ$; and a final former stage that accepts the second intermediate half honeycomb stock, the final former stage having a plurality of opposed, intermeshing nodes that respectively further bend the second intermediate half honeycomb stock at each of the spaced intervals into the final half honeycomb shape.

BRIEF DESCRIPTION OF THE DRAWINGS

Having thus generally described the nature of the invention, reference will now be made to the accompanying drawings, in which:

FIG. 1 is a block diagram of a multi-stage corrugator in accordance with one embodiment of the invention, and exemplary related equipment for manufacturing composite wood panels with half honeycomb corrugated cores;

FIG. 2 is a schematic side view diagram of an exemplary 3-stage corrugator in accordance with one embodiment of the invention;

FIG. 3 is a detailed schematic end view of the first pre-former stage rollers of the exemplary 3-stage corrugator shown in FIG. 2;

FIG. 4 is a detailed schematic end view of the second pre-former stage rollers of the exemplary 3-stage corrugator shown in FIG. 2;

FIG. 5 is a schematic end view of an alternate embodiment of the pre-former stage rollers of one embodiment of the multi-stage corrugator shown in FIG. 1;

FIG. 6 is a schematic diagram illustrating a method of computing node dimensions and roller diameters for each stage of the exemplary multi-stage corrugator shown in FIG. 1;

FIG. 7 is a schematic side view of one embodiment of a pre-stage or final stage former of the multi-stage corrugator shown in FIG. 1;

FIG. 8 is a schematic side view of a belt and node configuration for one embodiment of the exemplary multi-stage corrugator shown in FIG. 1; and

FIG. 9 is a schematic side view of a chain and node configuration for the exemplary multi-stage corrugator shown in FIG. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention provides a novel multi-stage corrugator for half honeycomb corrugation of composite wood panel cores. The multi-stage corrugator includes at least one pre-former stage and a final former stage that function synchronously to transform a flat pliable web manufactured from wood laminae bonded together with a cold set adhesive into a half honeycomb corrugated wood panel core component at commercial production speeds of at least 20 meters per minute. The invention therefore enables the commercial production of rigid, high strength panels useful for robust packaging and structural panels useful in the furniture and building construction industries.

FIG. 1 is a block diagram of a multi-stage corrugator 20 in accordance with one embodiment of the invention and exemplary related equipment for manufacturing composite wood panels with half honeycomb corrugated cores. The multi-stage corrugator 20 transforms a flat pliable web 22 manufactured from wood laminae bonded together with a cold set adhesive into a half honeycomb corrugated wood panel core component 36. The flat pliable web 22 is typically supplied from a roll 24 of the flat pliable web material manufactured as described in applicant's co-pending Canadian patent application number 2,924,288 filed March 21, 2016. The web 22 is first passed between pre-treaters 26a, 26b, which heat and soften the web 22 to prepare it for corrugation. In one embodiment the pre-treaters 26a, 26b deliver pressurized steam to opposite sides of the web 22 to heat and moisten it. In an alternate embodiment, the pre-treaters 26a, 26b moisten opposite sides of the web 22 by spraying a water mist on each side of it, and apply radiant heat to each side of the moistened web 22 to heat and soften it for corrugation.

The heated and softened web 27 then enters at least one pre-former stage where opposed pre-formers 28a, 28b pre-form the softened web 27 using a

plurality of opposed, intermeshing nodes (see 53a, 53b FIG. 2, or 106a, 106b, FIG. 7, for example) that respectively transversely bend the stock at predetermined spaced intervals into the pre-formed web 30 having an intermediate half honeycomb shape with respective double reverse bends of less than $\pm 60^\circ$. The pre-formers may be opposed nip rollers with intermeshing nodes (see FIG. 2), or opposed belts or chains that support transverse intermeshing nodes, the belts or chains being supported by roller/bearing structures (see FIG. 7) that include opposed nip rollers where the intermeshing nodes bend, or further bend, the web 30 at the predetermined spaced intervals. The pre-formed web 30 may be further moistened and softened by optional treaters 26a, 26b (shown in dashed lines) between, and/or after, the pre-former stages before the pre-formed web enters a final former stage 32a, 32b where opposed, intermeshing nodes (see 66a, 66b, FIG. 2 or 106a, 106b, FIG. 7) connected to opposed belts or chains supported by roller/bearing structures with nip rollers complete the double reverse bends and apply heat and pressure to stabilize the half honeycomb corrugation. The final stage formers 32a, 32b output a half honeycomb corrugated web 33 with double reverse bends of $\pm 60^\circ$. The half honeycomb corrugated web 33 is then cut transversely, and optionally longitudinally, by a web cutter 34 to a desired length and width for composite wood panel cores 36.

In one embodiment of the invention, the composite wood panel cores 36 are then passed to a panel fabricator 44, which fabricates panels by gluing the flat crests of the composite wood panel cores 36 to one or more face sheets (not shown) to produce a panel having a half honeycomb laminated core in a manner well known in the art.

In another embodiment, the composite wood panel cores 36 are conveyed to a core stacker 38, which stacks a predetermined number of the composite wood panel cores 36 before they are conveyed to a laminator 40. The stacker 34 may apply a heat-set adhesive to mating surfaces of the composite wood panel cores 36 to ensure a rigid bond between the laminated composite wood panel cores 36 after lamination. In another embodiment, the cold set adhesive in the composite wood panel cores 36 is a hybrid adhesive having a heat set component described in applicant's co-pending patent application that is activated by heat

and pressure supplied by the laminator 40 to permanently bond the stacked wood panel cores 36.

The laminator 40 is a heat press having heated stationary, intermeshing nodes 41 that compress together two or more of the composite wood panel cores 36 until they are permanently bonded together into laminated panel cores 42. The laminated panel cores 42 are then conveyed to the panel fabricator 44, which fabricates panels by gluing the flat crests of the laminated panel cores 42 to one or more face sheets to produce a fabricated panel having a half honeycomb laminated core using methods well known in the art.

As will be understood by those skilled in the art, the cutter 34, core stacker 38, laminator 40 and panel fabricator 44 are prior art components that may work in concert with the multi-stage corrugator 20, but are not a part of the multi-stage corrugator 20 and are only described by way of example to illustrate one exemplary post-corrugation process for producing panels having a half honeycomb corrugated core.

FIG. 2 is a schematic side view of an exemplary 3-stage corrugator 50 in accordance with one embodiment of the invention. In this embodiment, the flat web 22 is pulled from roll 24 (see FIG. 1) through the pre-treaters 26a, 26b which moisten and heat the flat web 22. The moistened, heated web 27 is pulled by a nip 51 between opposed, counter-rotating 1st stage pre-former nip rollers 52a, 52b. A plurality of equally spaced-apart nodes 53a extend longitudinally of the outer periphery of the 1st stage pre-former nip roller 52a. A plurality of equally spaced-apart nodes 53b extend longitudinally of the outer periphery of the 1st stage pre-former nip roller 52b. The nodes 53a, 53b intermesh to form the nip 51 that grips the flat web 27. As the flat web 27 passes through the nip 51, the web 27 is transversely bent into a pre-formed web 54 having an intermediate half honeycomb shape with respective reverse bend angles of, for example, $\pm 20^\circ$. The pre-formed web 54 passes between flat, parallel guide plates 56a, 56b. The guide plates 56a, 56b dampen vibration of the preformed web 54 and support the pre-formed web 54 to inhibit "spring back" from the 1st stage pre-formed corrugation. Spring back from high speed bending is a natural tendency of the resilient wood laminae of the pre-formed web 54. In one embodiment, the guide plates 56a, 56b

are equipped with steam or water mist nozzles (not shown) to apply further moisture and/or heat to the web to keep the web 54 moist and soft after it passes through the nip 51.

The preformed web 54 is then pulled by a nip 57 between opposed, counter-rotating 2nd stage pre-former nip rollers 58a, 58b. A plurality of equally spaced-apart nodes 59a extend longitudinally of the outer periphery of the 2nd stage pre-former nip roller 58a. A plurality of equally spaced-apart nodes 59b extend longitudinally of the outer periphery of the 2nd stage pre-former nip roller 58b. The nodes 59a, 59b intermesh to form the nip 57 that grips and transversely further bends the 1st stage pre-formed web 54 into a pre-formed web 60 having an intermediate half honeycomb shape with respective reverse bend angles of, for example, $\pm 40^\circ$. The pre-formed web 60 passes between flat, parallel guide plates 62a, 62b. The guide plates 62a, 62b dampen vibration of the preformed web 60 and support the pre-formed web 60 to inhibit spring back from the 2nd stage pre-formed corrugation. In one embodiment, the guide plates 62a, 62b are equipped with steam or water mist nozzles (not shown) to apply further moisture and/or moist heat to the web 54, to keep the web 54 moist and soft after it passes through the nip 57.

The 2nd stage preformed web 60 is then pulled by a nip 63 between opposed, counter-rotating final stage nip rollers 65a, 65b that drive belts or chains 66a, 66b of a final stage former 64. A plurality of equally spaced-apart nodes 67a are connected in a transverse orientation to an outer periphery of the final former stage belt(s) or chains 66a. A plurality of equally spaced-apart nodes 67b are connected in a transverse orientation to an outer periphery of the final former stage belt(s) or chains 66b. The nodes 67a, 67b intermesh to form the nip 63 that further bends the 2nd stage preformed web 60 into a corrugated web having a half honeycomb shape with respective reverse bend angles of $\pm 60^\circ$. In order to enhance a permanence of the half honeycomb shape of the corrugated web, the final stage former is provided with at least one pressure source 68 that forces the counter rotating belts 66a, 66b together and enhances pressure on the double reverse $\pm 60^\circ$ bends. The final stage former is further provided with at least one

heat source 70. The heat source 70 drives moisture out of the moistened web to set the cold set adhesive and lock the laminae of the corrugated half honeycomb web in a position into which they have been marginally shifted during the 3-stage corrugation process. In one embodiment, the final stage former has an unheated section 79 beyond the heated section 70. The unheated section 79 allows the corrugated web to cool half honeycomb corrugated web to further set the cold set adhesive. A long unheated section, 10 meters for example, facilitates faster corrugation speeds.

In order to function properly, the 1st, 2nd, and 3rd stage formers must be correctly dimensioned, spaced apart and rotated at the same rate. In one embodiment the 1st, 2nd, and 3rd stage formers are driven in unison by a single chain drive 72 that runs in an oil bath 74. In one embodiment, the chain drive 72 is driven by an electric motor 76 having a drive sprocket 78 that engages the chain drive 72. In one embodiment only the bottom formers of each of the 1st, 2nd, and 3rd stage formers are driven, while the opposite side of the 1st, 2nd, and 3rd stage formers are forced to follow the driven formers in a manner well understood in the art. The nip 51 of the 1st stage pre-formers 52a, 52b is spaced from the nip 57 of the 2nd stage pre-formers 58a, 58b by a predetermined distance D1. The nip 57 of the 2nd stage pre-formers 58a, 58b is spaced from the nip 63 of the 3rd stage former by a predetermined distance D2. One method of computing the diameters and spacing of the 1st, 2nd, and 3rd stage former nip rollers is explained in detail below with reference to FIG. 6. Further details about one exemplary embodiment of a belt(s) or chain former suitable for any one or more of the pre-former or final stages of the multi-stage formers 20, 50 will be described in more detail below with reference to FIGS. 7-9.

FIG. 3 is a detailed schematic end view of one embodiment of the 1st stage pre-former nip rollers 52a, 52b of the exemplary 3-stage corrugator 50 shown in FIG. 2. As described above with reference to FIG. 2, the outer periphery of the respective 1st stage nip rollers 52a, 52b are provided with spaced-apart transverse nodes 53a, 53b. The nodes 53a, 53b may be machined on the outer surface of each of the 1st stage nip rollers 52a, 52b, or manufactured separately and affixed to the respective outer surfaces 55a, 55b of each of the respective 1st

stage nip rollers 52a, 52b using fasteners or adhesives known in the art. Each node 53a, 53b has a top surface of a predetermined width (N_{TW}), as will be explained in more detail with reference to FIG. 6. The respective nodes 53a, 53b of each of the respective 1st stage rollers are separated from each other by a predetermined distance N_{TI} , which equals N_{TW} plus twice the thickness (T) of the web 27. Each side of the respective nodes 53a, 53b have a length N_{HY} , which is identical for the side surfaces of the nodes of each of the pre-former and final former stages, as will also be explained below in more detail with reference to FIG. 6. The top surfaces N_{TW} join the side surfaces N_{HY} of the respective nodes 53a, 53b at a predetermined angle ($\pm\theta_1$). In one embodiment, that angle is $\pm 20^\circ$. It must be understood that the angle ($\pm\theta_1$) for the 1st stage former is a matter of design choice, but $\pm\theta_1$ must be less than $\pm\theta_2$ described below with reference to FIG. 4 if the multi-stage former is a 3-stage former as shown in FIG. 2.

FIG. 4 is a detailed schematic end view of the 2nd pre-former stage nip rollers 58a, 58b of the exemplary 3-stage corrugator 50 shown in FIG. 2. As described above with reference to FIG. 2, the outer periphery of the respective 2nd stage nip rollers 58a, 58b are provided with spaced-apart transverse nodes 59a, 59b. The nodes 59a, 59b may be machined on the outer surface of each of the 2nd stage nip rollers 58a, 58b, or manufactured separately and affixed to the respective outer surfaces 61a, 61b of each of the respective 2nd stage nip rollers 58a, 58b using fasteners or adhesives well known in the art. Each node 58a, 58b has a top surface of the predetermined width (N_{TW}). The respective nodes 59a, 59b of each of the respective 2nd stage nip rollers 58a, 58b are separated from each other by the predetermined distance N_{TI} . Each side of the respective nodes 59a, 59b have the length N_{HY} , as described above. The top surfaces N_{TW} join the side surfaces N_{HY} of the respective nodes 59a, 59b at a predetermined angle ($\pm\theta_2$). In one embodiment, $\pm\theta_2$ is $\pm 40^\circ$. It must be understood that the angle ($\pm\theta_2$) for the 2nd stage former is a matter of design choice, but the angle is normally greater than the angle of the 1st stage pre-former nodes and less than the angle ($\pm 60^\circ$) of the final stage former nodes, if the multi-stage corrugator is the 3-stage corrugator 50 shown in FIG. 2.

FIG. 5 is a schematic end view of an alternate embodiment of the pre-former stage rollers of the exemplary embodiment of the 3-stage corrugator shown in FIG. 2. As described above with reference to FIGs. 2-4, some spring back of the pre-former double reverse bends is normal due to the resilience of the wood laminae in the composite wood web. In order to reduce spring back respective pre-former nip rollers 80a, 80b are machined to provide an inwardly curved radius 84a, 84b on a top surface of each node 82a, 82b of the respective pre-former rollers 80a, 80b. A complimentary protrusion 86a, 86b having the same radius is provided between each node 82a, 82b. The inwardly curved radii interact with the outwardly curved radii in a nip 81 between the pre-former nip rollers 80a, 80b to accentuate pressure at the first and second stage pre-former bends to reduce spring back, which has utility when thicker, and consequently stiffer, webs 27 are corrugated. This modification may be used in any one or more of the pre-former stages of the multi-stage corrugators 20, 50 in accordance with the invention. The node dimensions N_{TW} , N_{TI} and N_{HY} are all as described above below reference to FIG. 6.

FIG. 6 is a schematic diagram illustrating a method of computing node dimensions and nip roller diameters for each stage of the exemplary 3-stage corrugator shown in FIG. 2. The first step is to select a corrugation height (C_H) for the half honeycomb corrugation (not shown), and a node top width (N_{TW}) for the respective nodes of each stage of the multi-stage corrugator 50. As explained above, all nodes of each stage of the multi-stage corrugator have the same node top width (N_{TW}). A node height (N_H) of the half honeycomb corrugation is computed by subtracting web thickness (T) from corrugation height (C_H). Corrugation height (C_H) and node top width (N_{TW}) are dependent on the design requirements of a panel for which a panel core is being corrugated. N_{TW} is frequently about the same as the corrugation height (C_H) of the half honeycomb corrugation, but that is a matter of design choice. The corrugation height (C_H) of the half honeycomb corrugation is dependent on a desired finished thickness of a panel with the half honeycomb corrugated core. For one example of a panel with a single-ply half honeycomb core, if a finished panel thickness is to be 2.54 cm (1") and each face ply of the panel is 6.35 mm thick, the corrugation height

C_H of the half honeycomb corrugated core is $25.4 \text{ mm} - (2 * 6.35 \text{ mm}) = 12.7 \text{ mm}$ or 1.27 cm (0.5"). In this example, the node top width (N_{TW}) may be the same (1.27 cm) as corrugation height (C_H), and node height (N_H) = $12.7 \text{ mm} - T$ (0.5 mm, for example) = $12.2 \text{ mm} = 1.22 \text{ cm}$.

After node height (N_H) and node top (N_{TW}) width have been determined, a length of the node side (N_{HY}) can be computed. As explained above, the length of the node side (N_{HY}) must be the same for each of the nodes of each stage of the multi-stage corrugator 50. The length of the node side is computed for the half honeycomb corrugation using the trigonometric function of right triangles, namely:

$$\sin \theta = N_H / N_{HY} \quad \text{eq. 1}$$

Therefore:

$$N_{HY} * \sin \theta = N_H$$

And

$$N_{HY} = N_H / \sin \theta$$

So, for the 60 degree bend of the half honeycomb corrugation, the length of the node side is:

$$\begin{aligned} N_{HY} &= 1.22 / \sin 60^\circ \\ N_{HY} &= 1.22 / 0.866 \\ N_{HY} &= 1.409 \text{ cm} \end{aligned}$$

Once the length of the node side (N_{HY}) is known, the respective lengths of the opposite sides (N_{OSx} , N_{OSy} and N_{OSz}) can be computed, i.e. the respective distances (x, y, z) from a line perpendicular to the node top 90 at a bend 92 on one side of the node top 90, to a bend 94 at a bottom of the node side (N_{HY}) using the trigonometric function for right triangles to find the length of the node opposite side (N_{OS}):

$$\cos \theta = N_{OS} / N_{HY} \quad \text{eq. 2}$$

Therefore:

$$\cos \theta = N_{OS} / 1.409$$

And

$$N_{OS} = \cos \theta * 1.409$$

And for N_{OSx} , y and z

$$N_{OSx} = \cos \theta * 1.409 = 0.5 * 1.409 = 0.7045 \text{ cm};$$

$$N_{OSy} = \cos \theta * 1.409 = 0.766 * 1.409 = 1.0793 \text{ cm};$$

and

$$N_{OSz} = \cos \theta * 1.409 = 0.940 * 1.409 = 1.3244 \text{ cm}$$

After the respective distances N_{OSx} , N_{OSy} and N_{OSz} have been computed, the diameter (D) of each roller for each stage of the multi-stage corrugator 50 can be computed using the formula:

$$D = \frac{(2 N_{TW} + 2 N_{OS} + 2T) N_c}{\pi} \quad \text{eq.3}$$

Where: D = roller diameter at the bottom of the nodes, T = thickness of the web 24 (0.5 mm in this example) and N_c = selected node count (in this example a node count N_c of 12 is selected for the roller in pre-former stages 1 and 2). It should be noted that node count (N_c) is a matter of design choice. N_c is dependent on a diameter of the rollers in the multi-stage corrugator that will provide a required rigidity of the respective rollers, which is dictated in part by a width of the web 27, a thickness of the web 27, a design of the bearing structures (not shown) used to support the respective rollers, roller material and construction, etc., as will be understood by those skilled in the art. In this example, the diameter of the first stage pre-former rollers is:

$$D_{52a,52b} = \frac{(2 * 1.27) + (2 * 1.324) + (2 * 0.05) * 12}{\pi}$$

$$D_{52a,52b} = \frac{63.456}{\pi}$$

$$D_{52a,52b} = 20.199 \text{ cm} = 7.95'';$$

A diameter of the second stage pre-former rollers is:

$$D_{58a,58b} = \frac{(2 * 1.27) + (2 * 1.079) + (2 * 0.05) * 12}{\pi}$$

$$D_{58a,58b} = \frac{57.576}{\pi}$$

$$D_{58a,58b} = 18.327 \text{ cm} = 7.35''; \text{ and a diameter of the final stage intake rollers is:}$$

$$D_{65a,65b} = \frac{(2 * 1.27) + (2 * 0.733) + (2 * 0.05) * 12}{\pi}$$

$$D_{65a,65b} = \frac{49.272}{\pi}$$

$$D_{65a,65b} = 15.684 \text{ cm} = 6.17''.$$

These calculations are repeated for any given node height (N_H), node top width (N_{TW}) and selected number of nodes (N_C) per roller.

As also described above with reference to FIG. 2, the distances ($D1$, $D2$) between the nip points 51-57, 57-63 of the respective stages of the 3-stage corrugator 50 must be precisely computed to ensure that each nip creases the web at the exact same bend points. The following formula can be used to compute $D1$ and $D2$, namely:

$$D1 = (2 N_{TW} + 2N_{OSz} + 2T) N_D \quad \text{and} \quad \text{eq. 4}$$

$$D2 = (2 N_{TW} + 2N_{OSy} + 2T) N_D \quad \text{eq. 5}$$

Where: N_D is a value selected to ensure that the respective stages are spaced far enough apart that the formers do not contact, while providing adequate space between the respective stages of the exemplary 3-stage corrugator 50 to permit the clearing of any potential web jams, yet ensuring that the space between the stages is small enough to inhibit spring back of the web between the respective stages.

Consequently, $D1 = (2 * 1.27 + 2 * 1.324 + 2 * 0.05) N_D$
and

$$D1 = 5.288 \text{ cm} * N_D$$

The diameter of the 1st stage rollers is known to be 20.2 cm, so the radius is 10.1 cm; and, the diameter of the second stage rollers is 18.3 cm, so the radius is 9.15 cm. Consequently, $D1$ must be greater than 10.1 cm + 9.15 cm = 19.25 cm, at which distance the rollers 52a, 52b of the 1st pre-former stage would just touch the rollers 58a, 58b of the second pre-former stage. Consequently, N_D must be greater than 4. By way of example only, $N_D = 10$ is selected. Therefore, $D1 = 5.288 * 10 = 52.88 \text{ cm}$. and $D2 = (2 * 1.27 + 2 * 1.079 + 2 * 0.05) * 10 = 47.98 \text{ cm}$. Equations 4 and 5 can be used to calculate the desired distance between the nip points of any two stages of a multi-stage corrugator 20 in accordance with the invention.

FIG. 7 is a schematic cross-sectional view of another exemplary embodiment of a final stage former 100 for the multi-stage corrugators 20, 50 shown in FIGs. 1 or 2. In this embodiment, a pair of final stage nip rollers 120a, 120b have a diameter computed in accordance with the method described above with reference to FIG. 6. The final stage nip rollers 120a, 120b are idler rollers that support respective counter rotating final stage former belt(s) or chains 104a, 104b. Transversely affixed to the respective final stage former belt(s) or chains 104a, 104b are a plurality of equally spaced apart nodes 106a, 106b, that grip the pre-bent corrugation 108 output by the pre-former(s) (see FIGs. 1 and 2) and further bend and set the pre-bent corrugation 108 to form a finished half honeycomb corrugation 110.

In this embodiment, the respective counter rotating final stage former belt(s) or chains 104a, 104b are driven by respective drive rollers 107a, 107b, which may be friction-coated rollers or toothed rollers, as will be explained below in more detail with reference to FIGs. 8 and 9. The counter rotating final stage belt(s) or chains 107a, 107b are further supported by rear idler rollers 109a, 109b and 111a, 111b. One or more idler rollers 112a, 112b may also be provided to further support the final stage belt(s) or chains 104a, 104b between rollers 107a, 109a and 107b, 109b, to inhibit sag and vibration of the rapidly moving belt(s) or chain(s). The respective drive rollers 107a, 107b the nip rollers 120a, 120b, and the idler rollers 109a, 109b, 111a and 111b are respectively secured and supported by a rigid framework 114a, 114b, the design and construction of which is a matter of design choice within the ability of one skilled in the art.

In one embodiment, the rigid frameworks 114a, 114b respectively support a corrugation compression unit 116a, 116b briefly described above with reference to FIG. 2. In one embodiment, the compression units 116a, 116b are sealed chambers having a width at least as wide as a pre-formed web 108 entering the final stage former 100, and are respectively transversely divided by a partition 115a, 115b into respective first chambers 111a, 111b and respective second chambers 113a, 113b. High pressure heated fluid such as steam or hot oil is piped into the respective first chambers 111a, 111b of the respective compression units 116a, 116b. The high pressure heated fluid heats a flexible top

surface 118a, 118b of the respective compression units 116a, 116b. The high pressure heated fluid also exerts pressure on the respective flexible top surfaces 118a, 118b which bow and force the respective rotating belt(s) or chains 104a, 104b with nodes 106a, 106b together to further compress the corrugated web 110 while it is dried by the conducted heat. That heat and pressure set the cold set adhesive, which locks the laminae in the corrugated web in the respective positions into which they have been marginally shifted and bent during the corrugation process. High pressure cold fluid such as water or cold oil is piped into the respective second chambers 113a, 113b of the respective compression units 116a, 116b. The high pressure cold fluid cools the flexible top surface 118a, 118b of the respective compression units 116a, 116b. The high pressure cold fluid also exerts pressure on the respective flexible top surfaces 118a, 118b which bow and force the respective rotating belt(s) or chains 104a, 104b with nodes 106a, 106b together to further compress the corrugated web 110 while it is cooled and further dried to further set the cold set adhesive. Covering each of the flexible top surfaces 118a, 118b is a low friction, wear-resistant sheet or coating (polytetrafluoroethylene, for example) which provides a low friction, wear resistant surface 120a, 120b that supports the respective belt(s) or chains 104a, 104b and reduces drag and wear during their high-speed rotation. In another embodiment, about a first half of the length of the top surfaces 118a, 118b are heated by respective electric resistance coils and the entire top surfaces 118a, 118b are forced together by mechanical means such as coil springs, leaf springs or the like (not shown). The design and construction of the corrugation compression units 116a, 116b is therefore a matter of design choice. It should be noted that the final stage former 100 may be 10 meters or more in length to permit the corrugated half honeycomb web 110 to be corrugated at speeds of up to 20 meters per minute.

FIG. 8 is a schematic cross-sectional view of a belt and node configuration 150 for one embodiment of the final stage formers 64 (see FIG. 2) or 100 (see FIG. 7). In this configuration one or more para-aramid fiber (such as Kevlar® fiber, for example) belt(s) 152 support the plurality of nodes 154. Each node 154 has a node height (N_H), a node top width (N_{TW}) and node side surface (N_{HY}) having

dimensions computed in accordance with the methods described above with reference to FIG. 6. The para-aramid fiber belt(s) 152 may be a single belt having a width at least as wide as the respective nodes 154 are long. Alternatively, two or more para-aramid fiber belts 152 of identical length support the respective nodes 154. In one embodiment, the nodes 154 are connected to the para-aramid fiber belt(s) by barrel bolts 156 and screws 158 received in countersunk bores 160 drilled in appropriate locations through the respective nodes 154. The para-aramid fiber belt(s) 152 are captured between the nodes 154 and backing plates 162 received in a hollow 164 in a bottom surface of the respective nodes 154. In one embodiment the nodes 154 and the backing plates 162 are respectively constructed from high-density wear resistant plastic, such as a polyoxymethylene or a nylon copolymer, for example. In another embodiment, the nodes 154 and backing plates 162 are constructed of a light weight, wear-resistant metal such as an aluminum or a titanium alloy, for example. With this embodiment, the respective drive rollers 107a, 107b (see FIG. 7) typically have friction-coated surfaces that grip the para-aramid fiber belt(s) 152.

FIG. 9 is a schematic cross-sectional side view of a chain and node configuration 180 for one embodiment of the final stage formers 64 (see FIG. 2) or 100 (see FIG. 7). In this embodiment the chain is an ANSI double pitch conveyor chain 182 (ANSI number C2040, for example). The double pitch conveyor chain 182 has a plurality of pin links 184 that interconnect a plurality of roller links 186 via a plurality of through pins 188 that may be clipped or riveted in a manner well known in the art. In this embodiment, each pin link 184 optionally includes a lateral flange 190p and each roller link 186 includes a lateral flange 190r. Connected to each roller link flange 190r is a node 192. Each node 192 has a node height (N_H), a node top width (N_{TW}) and node side surface (N_{HY}) having dimensions computed in accordance with the method described above with reference to FIG. 6. The nodes 192 are affixed to the flanges 190r using, for example, barrel nuts (not shown) and screws 194 in a manner similar to that described above with reference to FIG. 8. The respective nodes 192 may be made of a wear resistant plastic such as a polyoxymethylene or a nylon copolymer, or a light weight metal alloy such as an aluminum alloy or titanium

alloy, for example. With this embodiment the respective drive rollers 107a, 107b (see FIG. 7) typically have toothed chain cogs that engage the rollers of the double roller chains 182.

The embodiments of the invention described above are exemplary only and intended to illustrate only the principles for the design and construction of the multi-stage corrugator 50 in accordance with the invention. Although the multi-stage corrugator has been described with specific reference to a 3-stage corrugator by way of example, it should be understood that 2-stage or 4-stage corrugators can also be constructed using the methods described above. The exemplary embodiments described are therefore not intended to illustrate the only ways in which the multi-stage corrugator can be constructed without departing from the scope of the invention.

The Embodiments of the Invention in which an Exclusive Property or Privilege Is Claimed are Defined As:

1. A multi-stage corrugator for corrugating a thin, flat, pliable cold rolled wood laminae stock to form a half honeycomb corrugated web, comprising:
 - at least one pre-former stage that accepts the flat wood laminae stock, each of the at least one pre-former stages having a plurality of opposed, intermeshing nodes that respectively transversely bend the stock at spaced intervals to form a pre-formed web having an intermediate half honeycomb shape with respective bends of less than $\pm 60^\circ$ at the respective spaced intervals; and
 - a final former stage that accepts the pre-formed web, the final former stage having a plurality of opposed, intermeshing nodes that respectively further bend the preformed stock at each of the spaced intervals into the half honeycomb corrugated web.
2. A multi-stage corrugator as claimed in claim 1, comprising:
 - a first pre-former stage that accepts the flat wood laminae stock and outputs a first intermediate half honeycomb stock, the first pre-former stage having a plurality of opposed, intermeshing nodes that respectively transversely bend the flat stock at respective first angles on spaced intervals to form the first intermediate half honeycomb stock;
 - a second pre-former stage that accepts the first intermediate half honeycomb stock and outputs a second intermediate half honeycomb stock, the second pre-former stage having a plurality of opposed, intermeshing nodes that respectively further bend the first intermediate half honeycomb stock at each of the spaced intervals to form the second intermediate half honeycomb stock having respective second angles greater than the first angles; and

a final former stage that accepts the second intermediate half honeycomb stock, the final former stage having a plurality of opposed, intermeshing nodes that respectively further bend the second intermediate half honeycomb stock at each of the spaced intervals into the half honeycomb corrugated web.

3. The multi-stage corrugator as claimed in claims 1 or 2 further comprising a single drive system that synchronously drives each stage of the multi-stage corrugator.
4. The multi-stage corrugator as claimed in claim 3 wherein the single drive system comprises an electric motor that drives a drive chain connected to the respective stages of the multi-stage corrugator.
5. The multi-stage corrugator as claimed in claim 4 wherein the drive chain runs in an oil bath.
6. The multi-stage corrugator as claimed in any one of claims 1-5 wherein the nodes of the respective pre-former stages comprise opposed rollers having spaced-apart longitudinal nodes that intermesh to provide a nip that bends the stock at the spaced intervals to the intermediate half honeycomb shape.
7. The multi-stage corrugator as claimed in any one of claims 1-5 wherein the nodes of the final former stage comprise opposed belts that support transverse nodes that intermesh to provide a nip that further bends the stock at the spaced intervals to the half honeycomb web.
8. The multi-stage corrugator as claimed in any one of claims 1-5 wherein the nodes of the final former stage comprise opposed chains that support transverse nodes that intermesh to provide a nip that further bends the stock at the spaced intervals to the final half honeycomb shape.

9. The multi-stage corrugator as claimed in claims 7 or 8 wherein the nodes have a node height (N_H) determined by a thickness of a half honeycomb core for a wood panel that is to be manufactured using the half honeycomb web.
10. The multi-stage corrugator as claimed in claim 9 wherein the nodes have a node top width (N_{TW}) that is about equal to the node height (N_H).
11. The multi-stage corrugator as claimed in claim 10 wherein the nodes have a node side length (N_{HY}) that is computed using the trigonometric function, $\sin \theta = N_H / N_{HY}$, wherein: θ = the angle of the bend to be made in the web at the final former stage for which the node is constructed.
12. The multi-stage corrugator as claimed in claim 11 wherein a diameter of a nip roller for each stage of the multi-stage corrugator is computed using the formulas:

$$D = \frac{(2 N_{TW} + 2 N_{OS} + 2T) N_C}{\pi}$$
 wherein: D = the diameter of the nip roller; N_{TW} = the node top width of nodes of the nip roller; N_{OS} = the length of the side opposite the node side (N_{HY}); T = a thickness of a web to be corrugated; and, N_C = a number of nodes on the nip roller; and
 $\cos \theta = N_{OS} / N_{HY}$, wherein: θ = the angle of the bend to be made at the spaced intervals by the respective pre-former and final former stages.
13. The multi-stage corrugator as claimed in any one of claims 1-12 further comprising a web pre-treater that heats and moistens the thin, flat, pliable cold rolled wood laminae stock prior to corrugation.
14. The multi-stage corrugator as claimed in any one of claims 1-12 further comprising a web pre-treater that heats and moistens the thin, flat, pliable cold rolled wood laminae stock between stages of the multi-stage corrugator.

15. The multi-stage corrugator as claimed in any one of claims 1-13 further comprising flat, parallel guide plates that dampen vibration of the preformed web between stages of the multi-stage corrugator and support the pre-formed web to inhibit spring back of the respective transverse bends.
16. The multi-stage corrugator as claimed in any one of claims 1-14 wherein the final stage former includes at least one compression unit that applies pressure to the corrugated web to set the wood laminae of the corrugated web in a shifted and bent condition into which they have been moved during the corrugation process.
17. The multi-stage corrugator as claimed in claim 16 wherein the compression unit is divided transversely into respective first and second chambers.
18. The multi-stage corrugator as claimed in claim 16 wherein the respective first chambers are supplied with pressurized hot fluid to heat the corrugated web and the respective second chambers are supplied with pressurized cold fluid to cool the heated corrugated web.
19. The multi-stage corrugator as claimed in any one of claims 1-16 wherein the final stage former is at least 10 meters long.
20. The multi-stage corrugator as claimed in any one of claims 1-19 wherein in order to reduce spring back of pre-formed bends in the web between the pre-former stages, respective pre-former nip rollers of the at least one of the pre-former stages are machined to provide an inwardly curved radius on a top surface of each the nodes and a complimentary protrusion having the same radius provided between each of the nodes, whereby the top surface of each node meshes with the respective corresponding complimentary protrusions to accentuate pressure in a nip between the nodes at the respective transverse bends to reduce the spring back.

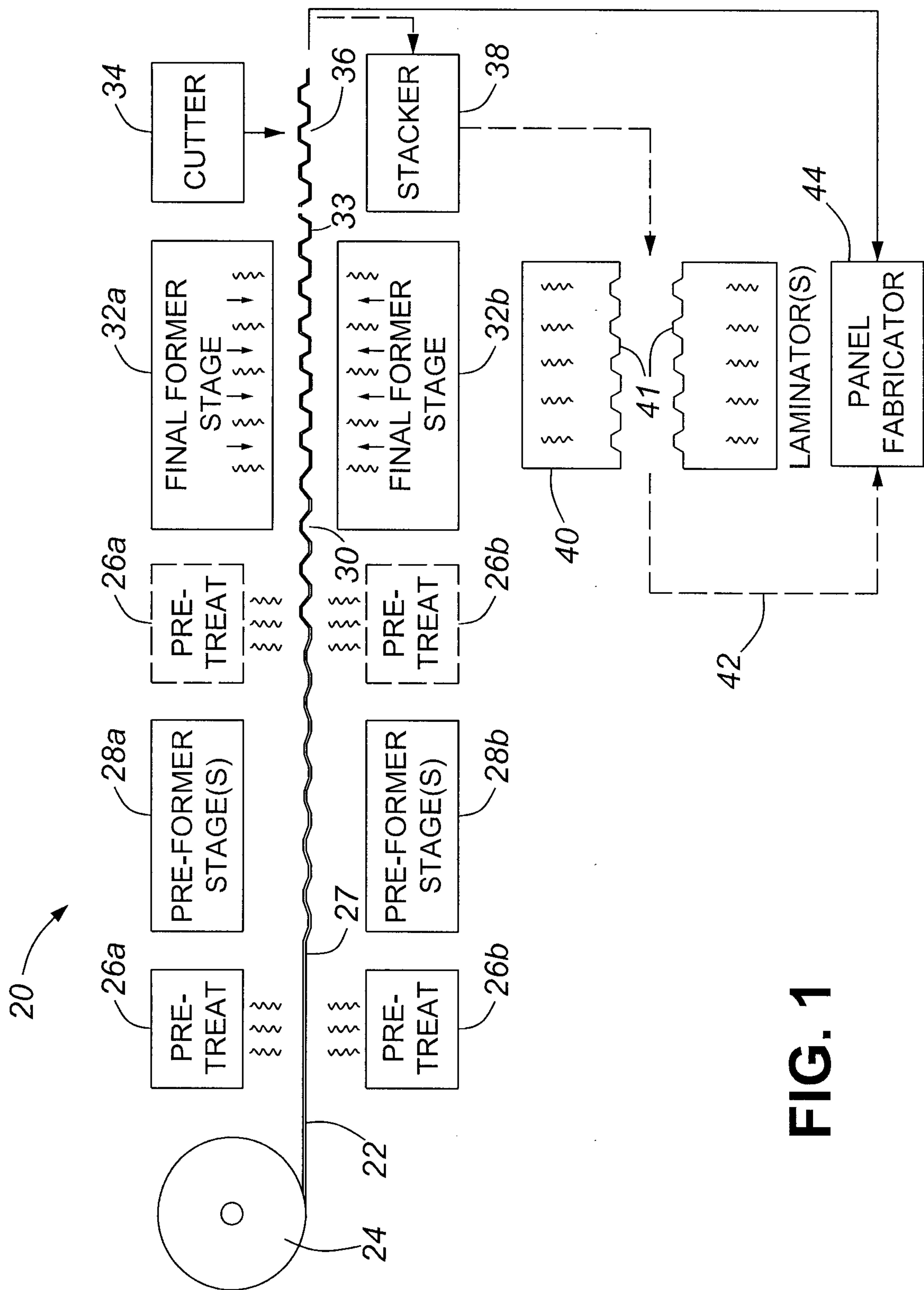


FIG. 1

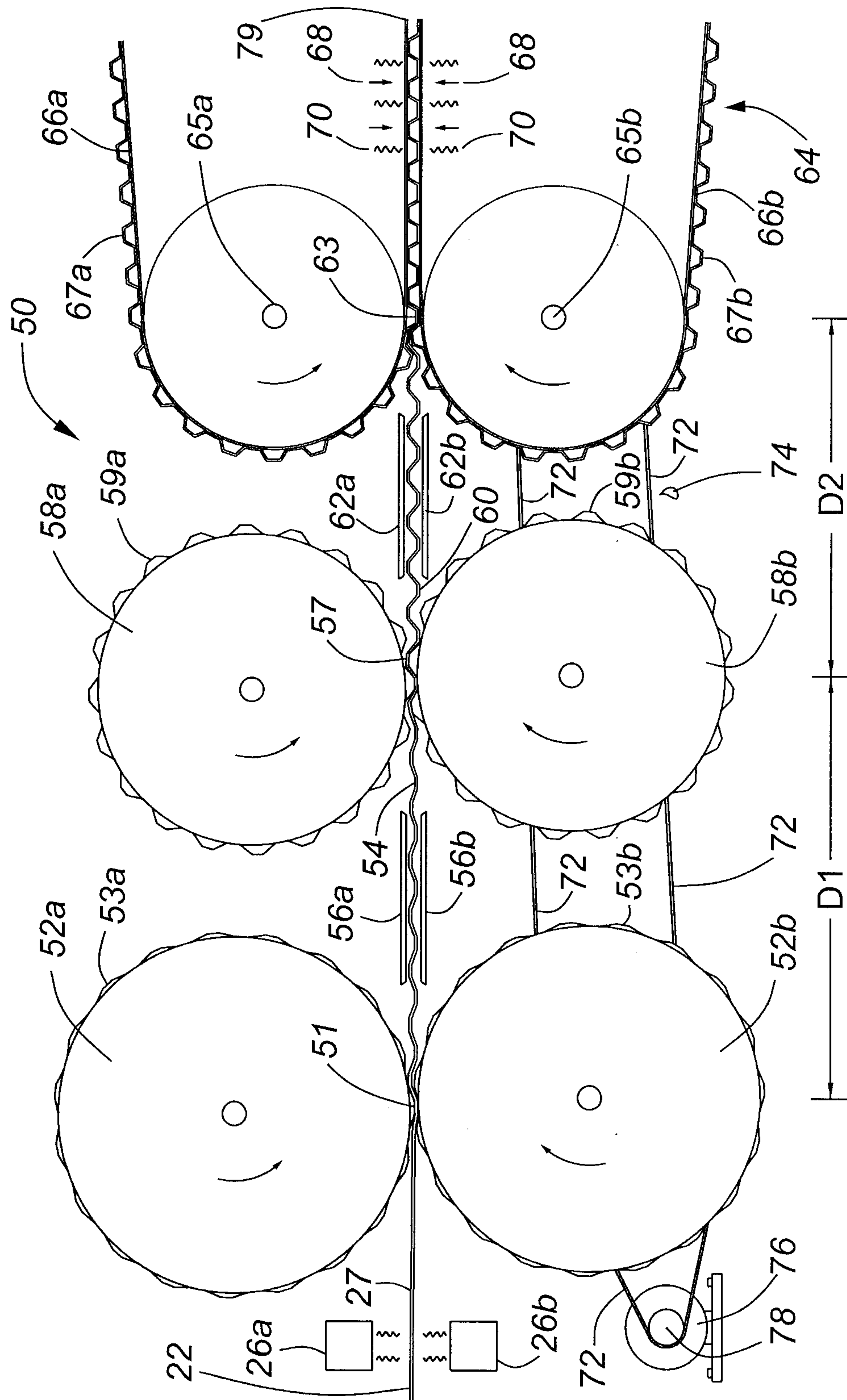


FIG. 2

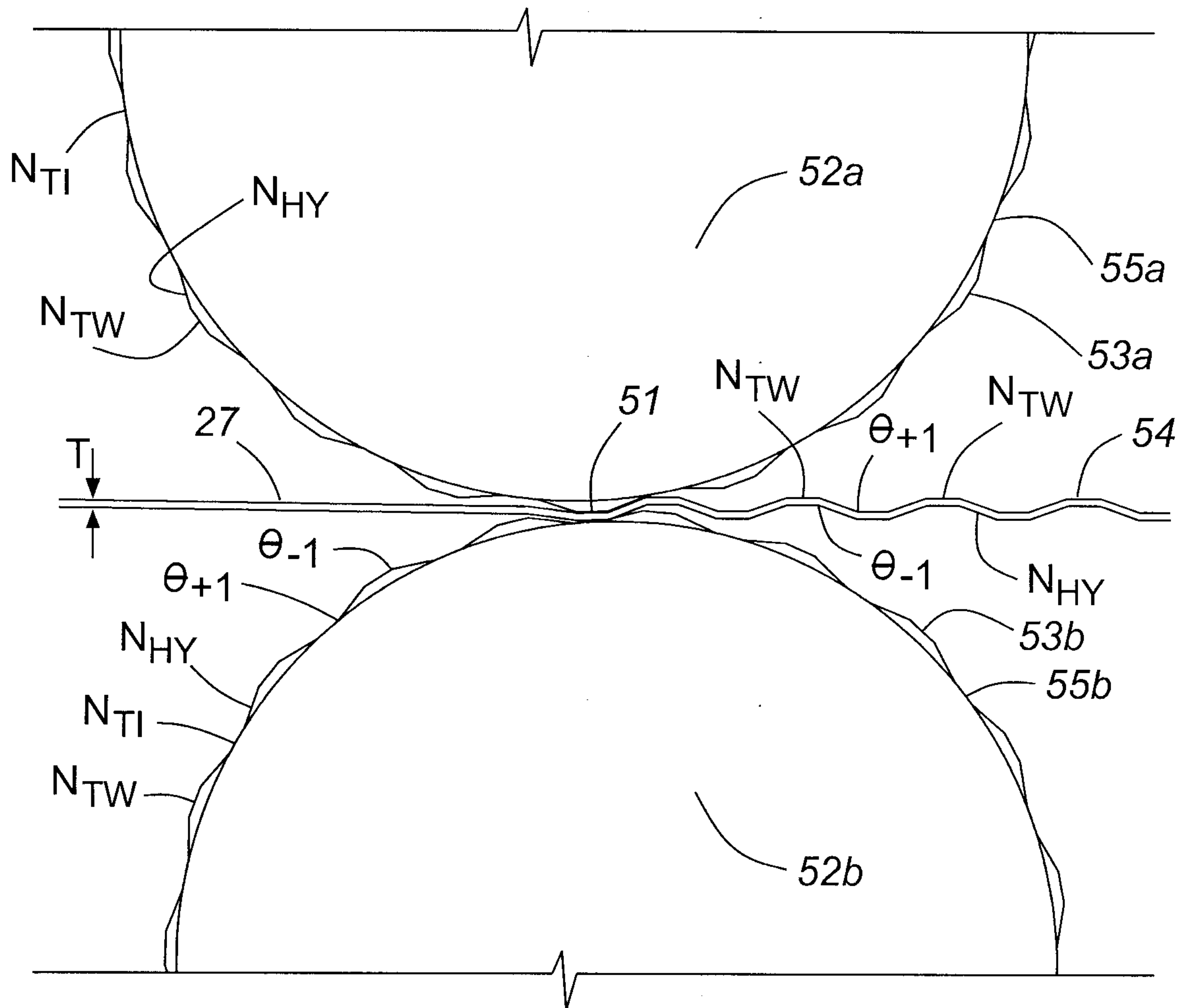


FIG. 3

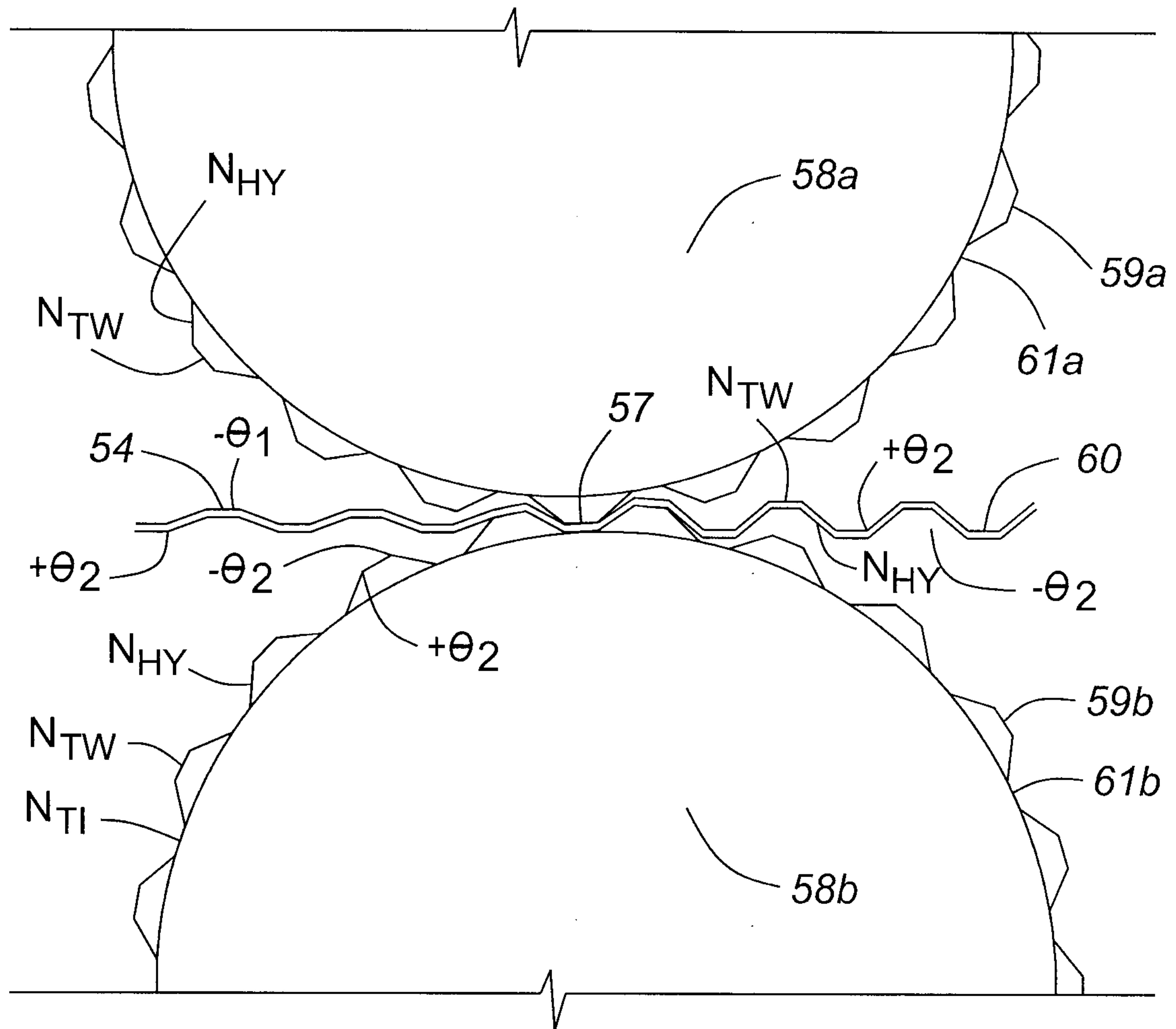


FIG. 4

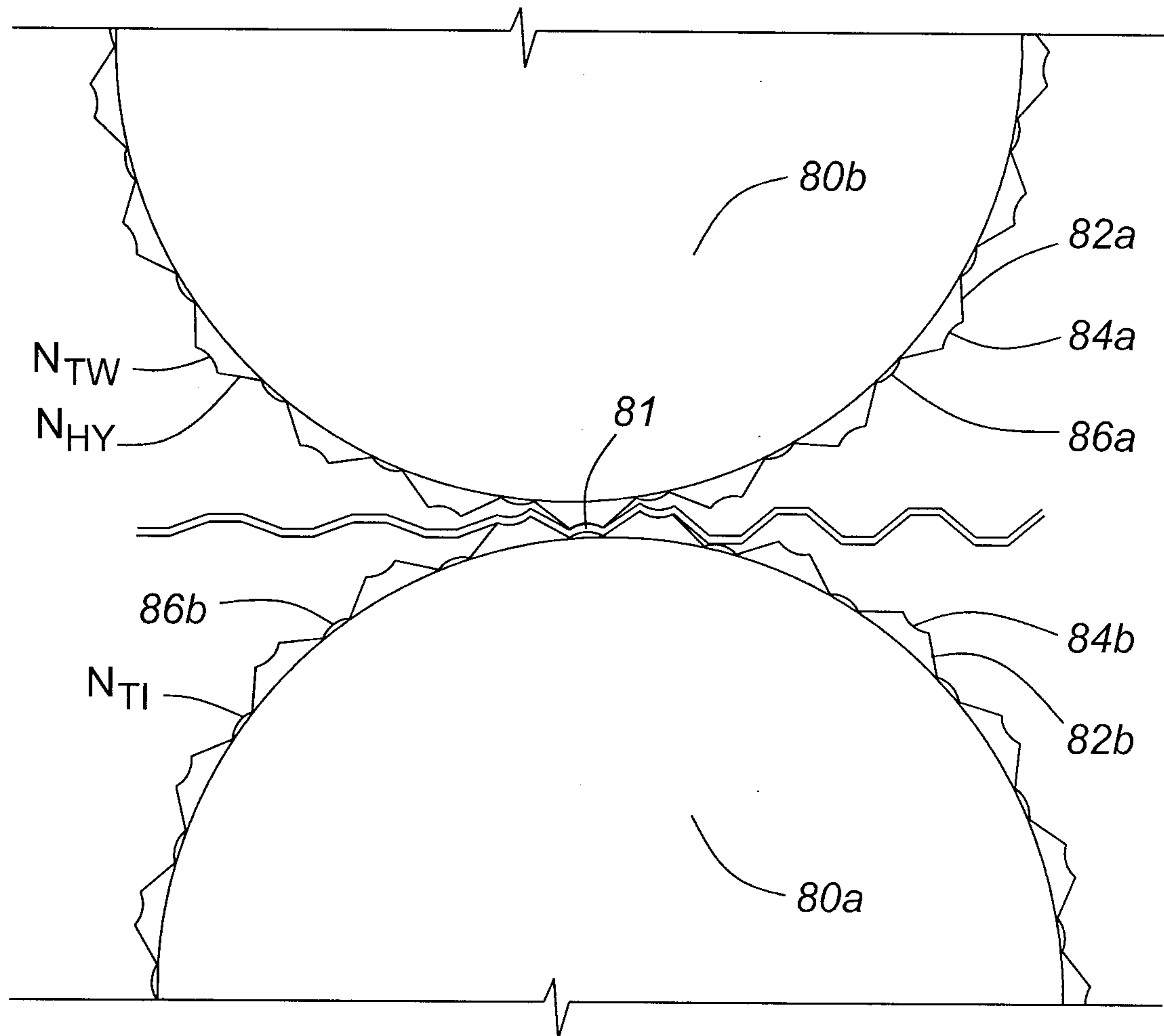
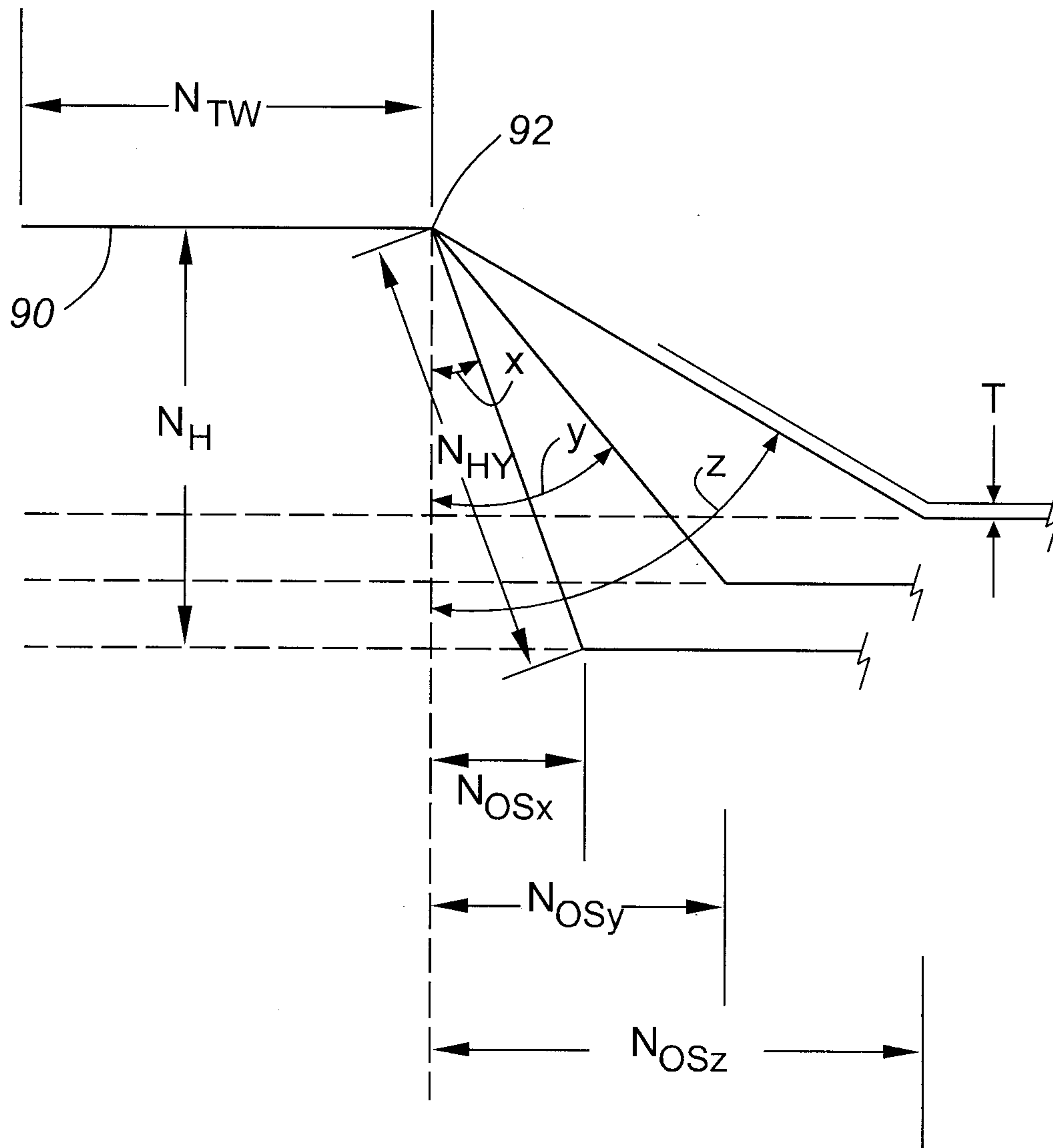


FIG. 5

**FIG. 6**

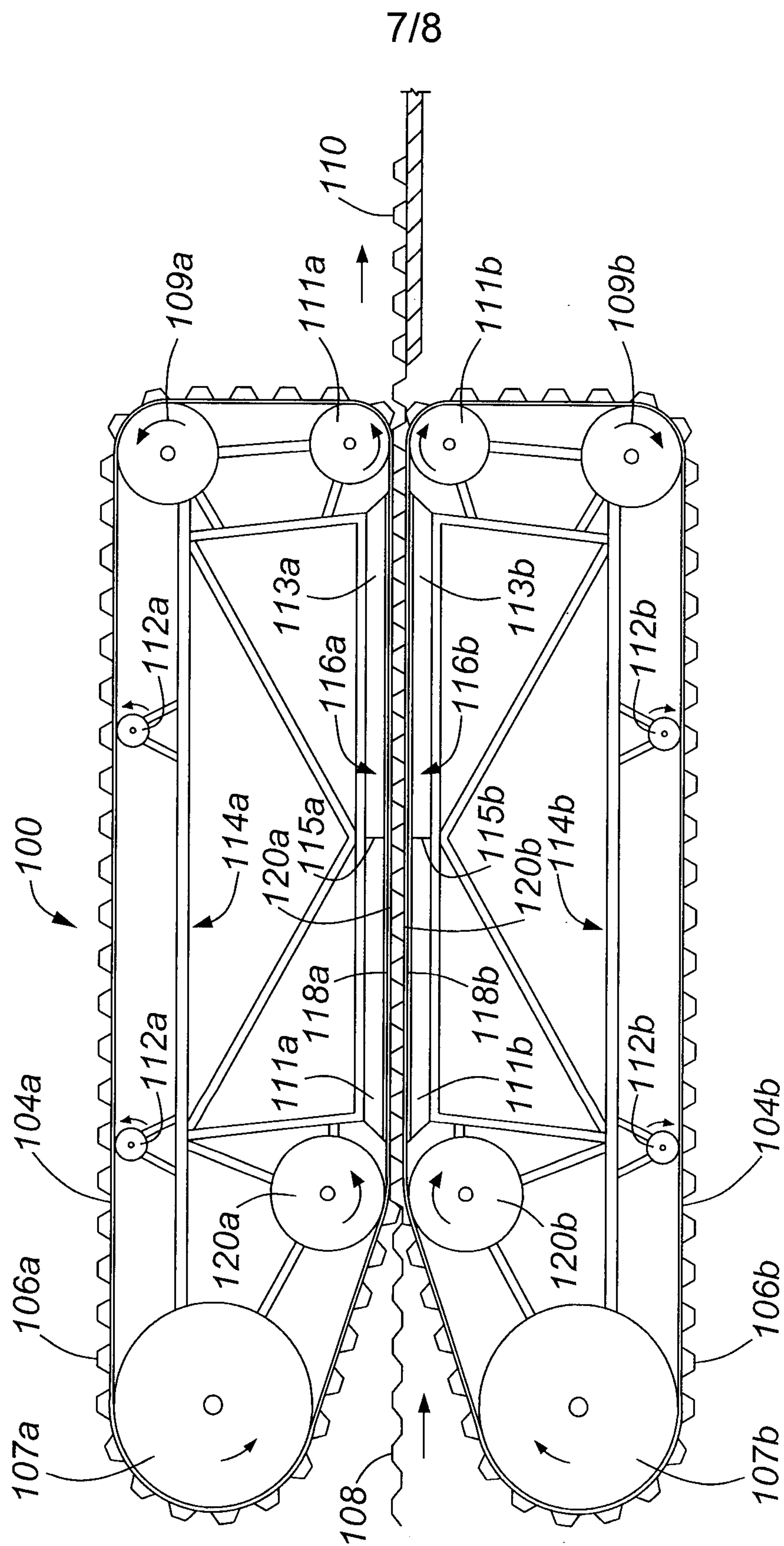


FIG. 7

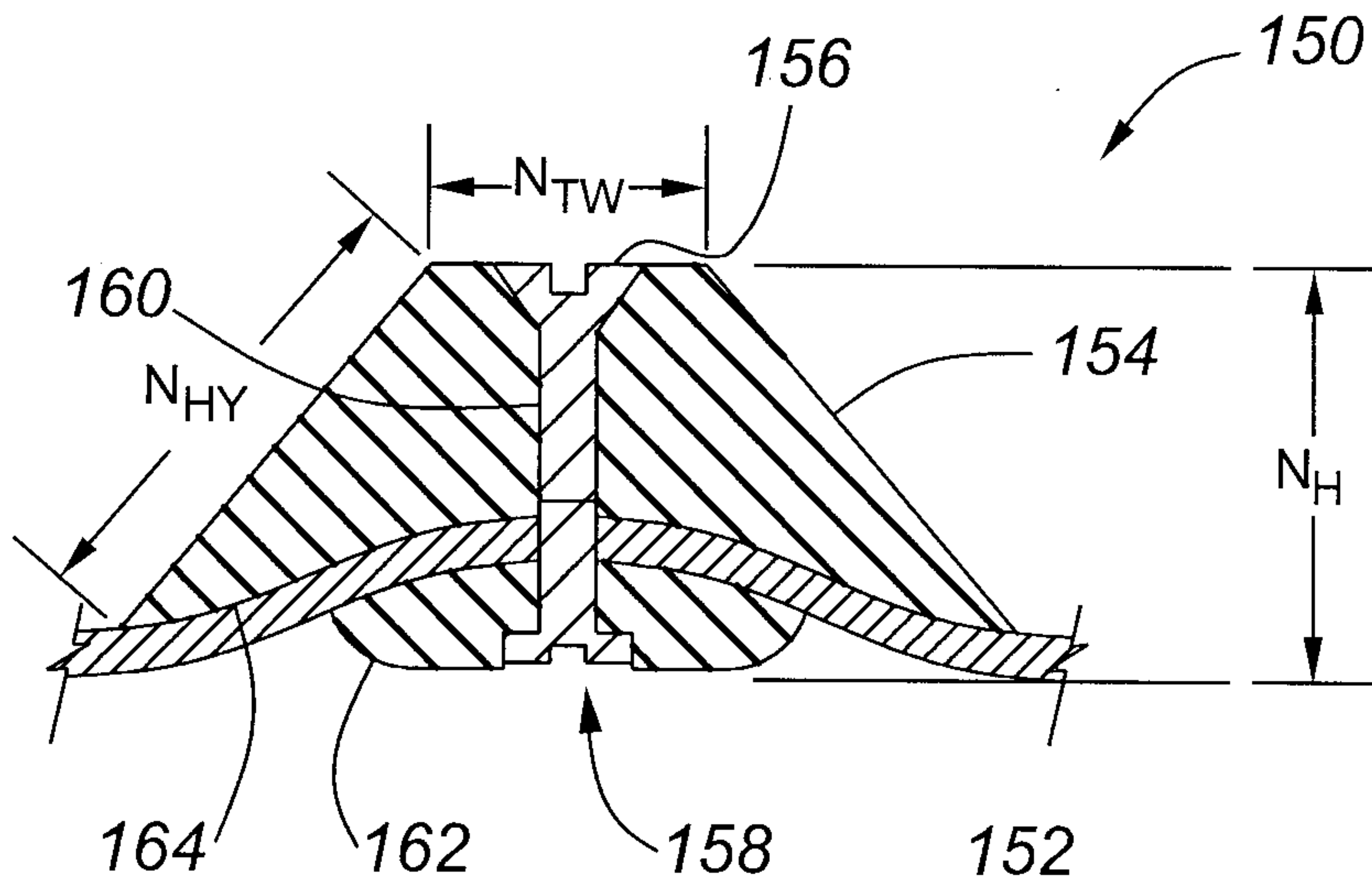


FIG. 8

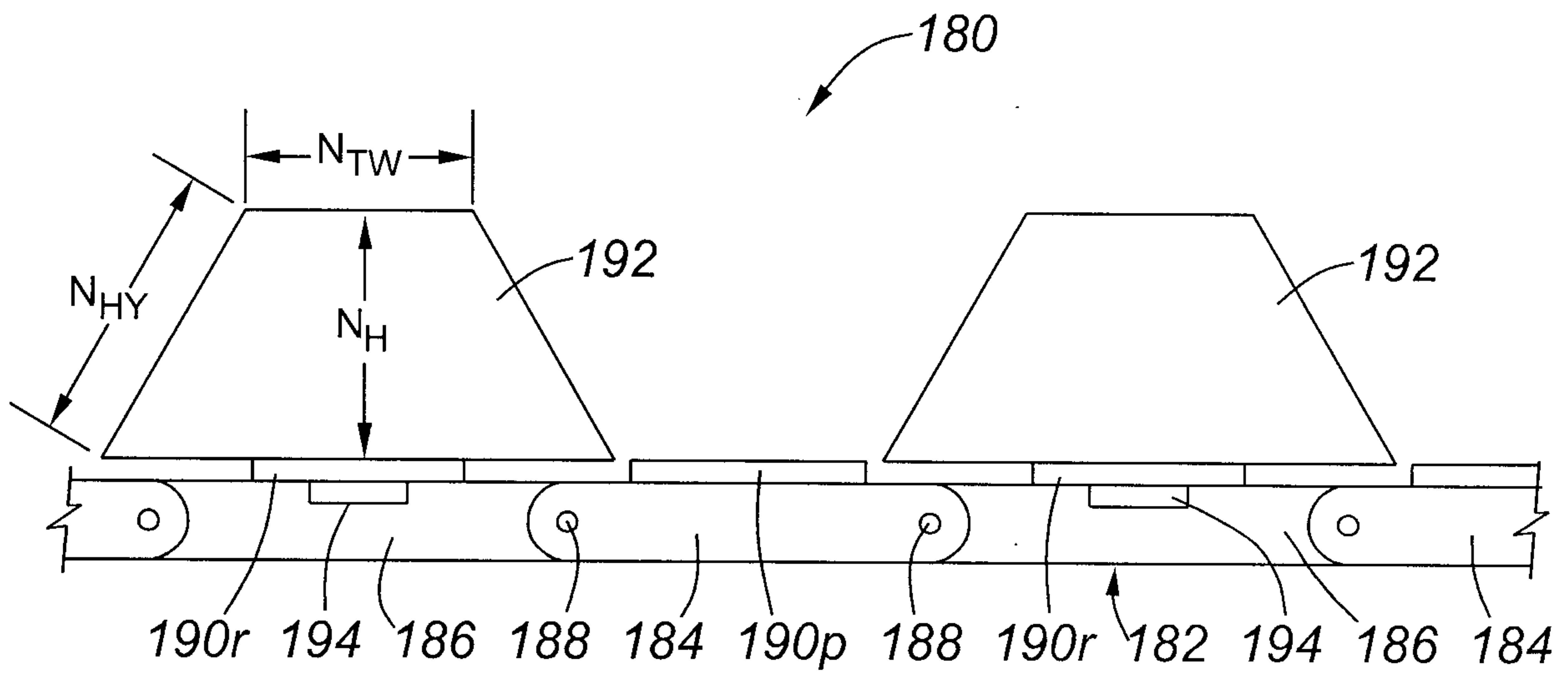


FIG. 9

