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(54) **CIRCULAR WINDING APPARATUS AND METHOD**

(57) Winding apparatuses and methods for manufacturing an article of apparel. The winding apparatus can comprise a first rim and a second rim coupled to and spaced apart from each other and rotatable on a rotation axis. The winding apparatus can comprise a first plurality of projections coupled to and extending from a perimeter of the first rim and a second plurality of projections coupled to and extending from a perimeter of the second rim. A thread guide can be configured to dispense a continuous thread to wind one or more continuous threads around all or a subset of the first and second plurality of projections on the first and second rims.

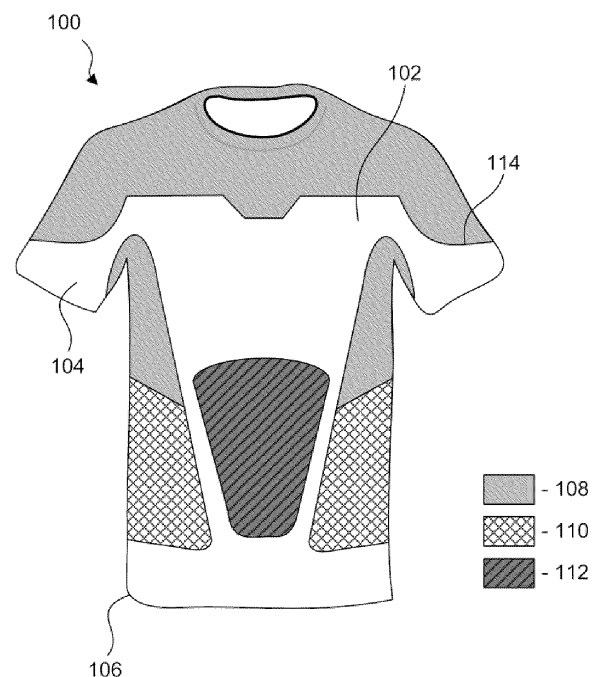


FIG. 1A

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Description

FIELD

[0001] The described embodiments generally relate to apparatuses and methods for making apparel. In particular, described embodiments relate to apparatuses for winding one or more continuous threads around anchor points to create a material for apparel.

BACKGROUND

[0002] Apparel can be manufactured from various materials using a wide range of techniques, including weaving and knitting. Individuals are often concerned with the durability, comfort, and/or performance characteristics for an article of apparel. This is true for apparel worn for athletic and non-athletic activities. Proper apparel should be durable, comfortable, and provide other beneficial characteristics for an individual. Therefore, a continuing need exists for innovations in apparel and methods of making apparel to suit individuals across a range of use cases. Particularly, there is need for methods of making materials for apparel that have customizable characteristics yet can be efficiently manufactured in large quantities and/or sizes.

BRIEF SUMMARY

[0003] A first embodiment (1) of the present application is directed to a winding apparatus for manufacturing an article of apparel, the winding apparatus comprising a first rim; a second rim coupled to and spaced apart from the first rim, the first and second rims rotatable on a rotation axis; a first plurality of projections coupled to and extending from a perimeter of the first rim; a second plurality of projections coupled to and extending from a perimeter of the second rim; a thread guide configured to dispense a continuous thread, the thread guide moveable along a second axis parallel to the rotation axis; a first actuator configured to rotate the first and second rims; and a second actuator configured to move the thread guide along the second axis and between projections of the first and second pluralities of projections.

[0004] In a second embodiment (2), the rotation axis according to the first embodiment (1) is parallel or perpendicular to a gravity vector during operation.

[0005] In a third embodiment (3), the winding apparatus according to any one of embodiments (1) - (2) further comprises a first flexible chain comprising the first plurality of projections, the first flexible chain removably coupled to the first rim; and a second flexible chain comprising the second plurality of projections, the second flexible chain removably coupled to the second rim.

[0006] In a fourth embodiment (4), the first and second flexible chains according to the third embodiment (3) are flexible between a linear state and a circular state to couple the first and second flexible chains to the first

and second rims.

[0007] In a fifth embodiment (5), the first and second rims according to any one of embodiments (1) - (4) are each coupled to a plurality of spokes.

[0008] In a sixth embodiment (6), the first and second rims according to any one of embodiments (1) - (5) are spaced apart by a distance between 5 cm and 3 m.

[0009] In a seventh embodiment (7), each projection of the first and second pluralities of projections according to any one of embodiments (1) - (6) extends at an angle relative to the rotation axis, the angle being from 45 degrees to 180 degrees.

[0010] In an eighth embodiment (8), the angle according to the seventh embodiment (7) is from 95 degrees to 175 degrees.

[0011] In a ninth embodiment (9), the winding apparatus according to any one of embodiments (1) - (8) further comprises a support, the support comprising a first end coupled to the first rim and a second end coupled to the second rim.

[0012] In a tenth embodiment (10), the winding apparatus according to any one of embodiments (1) - (2) and (5) - (9) further comprises a flexible sheet comprising the first plurality of projections and the second plurality of projections, the flexible sheet removably coupled to the first and second rims.

[0013] In an eleventh embodiment (11), the flexible sheet of the fifth embodiment (10) is flexible between a linear state and a circular state to couple the first and second pluralities of projections to the first and second rims.

[0014] A twelfth embodiment (12) of the present application is directed to a method of making an article of apparel, the method comprising rotating a first rim and a second rim coupled together and spaced apart by a support, the first rim coupled to a first plurality of projections that extend from a perimeter of the first rim, and the second rim coupled to a second plurality of projections that extend from a perimeter of the second rim; dispensing a continuous thread via a thread guide; and moving the thread guide along an axis parallel to the support and between projections of the first and second pluralities of projections to wind the continuous thread around a plurality of the first plurality of projections and around a plurality of the second plurality of projections.

[0015] In a thirteenth embodiment (13), the method according to the twelfth embodiment (12) further comprises changing at least one of a rotation rate or a rotation direction of the first and second rims while moving the thread guide.

[0016] In a fourteenth embodiment (14), the method according to any one of embodiments (12) - (13) further comprises rotating at least one of the first rim or the second rim independently from one another after winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections.

[0017] In a fifteenth embodiment (15), a first flexible

chain comprises the first plurality of projections, the first flexible chain removably coupled to the first rim; and a second flexible chain comprises the second plurality of projections, the second flexible chain removably coupled to the second rim; wherein the method according to any one of embodiments (12) - (14) further comprises removing the first and second flexible chains from the first and second rims after winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections.

[0018] In a sixteenth embodiment (16), winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections according to any one of embodiments (12) - (15) forms a thread layer comprising a plurality of thread lines, with each thread line extending between one of the first plurality of projections and one of the second plurality of projections.

[0019] In a seventeenth embodiment (17), the method according to the sixteenth embodiment (16) further comprises bonding thread lines of the plurality of thread lines to one another after removing the first and second flexible chains from the first and second rims.

[0020] In an eighteenth embodiment (18), the method according to any one of embodiments (16) - (17) further comprises cutting the thread layer after removing the first and second flexible chains from the first and second rims.

[0021] In a nineteenth embodiment (19), the method according to any one of embodiments (16) - (18) further comprises winding a second continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections to form a second thread layer comprising a second plurality of thread lines, with each thread line of the second plurality of thread lines extending between one of the first plurality of projections and one of the second plurality of projections.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

[0022]

FIGS. 1A and 1B show an article of apparel according to some embodiments.

FIG. 2 shows an apparatus for producing a wound material according to some embodiments.

FIG. 3 shows components of the apparatus shown in FIG. 2 according to some embodiments.

FIG. 4 shows the apparatus shown in FIG. 2 and a wound continuous thread according to some embodiments.

FIG. 5 shows a wound material manufactured using the apparatus shown in FIG. 2 according to some embodiments.

FIG. 6 shows the wound material shown in FIG. 5 and a consolidation sheet according to some embodiments.

FIG. 7 shows the wound material shown in FIG. 5 and

a consolidation frame according to some embodiments.

FIG. 8 shows a schematic block diagram of a winding assembly according to some embodiments.

FIG. 9A shows a schematic block diagram of the winding assembly shown in FIG. 8 according to some embodiments.

FIG. 9B shows a schematic block diagram of the winding assembly shown in FIG. 8 according to some embodiments.

FIG. 10 is an exemplary flowchart for methods according to some embodiments.

FIG. 11 shows a schematic block diagram of an exemplary computer system with which embodiments can be implemented.

FIG. 12 shows an apparatus for producing a wound material according to some embodiments.

DETAILED DESCRIPTION

[0023] The present invention(s) will now be described in detail with reference to embodiments thereof as illustrated in the accompanying drawings. References to "some embodiments", "one embodiment", "an embodiment", "an exemplary embodiment", etc., indicate that the embodiment described can comprise a particular feature, structure, or characteristic, but every embodiment may not necessarily comprise the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0024] As used herein, unless specified otherwise, references to "first," "second," "third," "fourth," etc. are not intended to denote order, or that an earlier-numbered feature is required for a later-numbered feature. Also, unless specified otherwise, the use of "first," "second," "third," "fourth," etc. does not necessarily mean that the "first," "second," "third," "fourth," etc. features have different properties or values.

[0025] As used herein, "thread" means a material having a length that is substantially larger than its width. A "thread" can be a filament, a fiber, a yarn, a cable, a cord, a fiber tow, a tape, a ribbon, a monofilament, a braid, a string, a plied thread, and other forms of materials which can be spooled and laid down in a thread pattern as described herein.

[0026] An article of apparel has many purposes. Among other things, apparel can provide a unique aesthetic look, provide warming or cooling characteristics, provide support for portions of an individual's body, and provide other performance characteristics, such as air permeability, moisture wicking properties, compression properties. Each of these purposes, alone or in combina-

tion, provides for comfortable apparel suitable for use in a variety of scenarios (for example, exercise and every day activities). The features of an article of apparel (for example, the materials and components used to make apparel, and the way these materials/components are made) can be altered to produce desired characteristics, for example, durability, stiffness, weight, tackiness, texture, haptics, tackiness, and/or air permeability.

[0027] Automated or partially automated production of an article of apparel can involve many different techniques. In some techniques, computer numeric control (CNC) can be used to automate the control and movement of components of an apparatus used to produce a material for the article of apparel. CNC can require programming computer software to execute desired movements of the components of the apparatus, such as movements required to wind a continuous thread around anchor points to create a thread layer or thread pattern, as described herein. In the embodiments described herein, simultaneous and/or successive movements of rim(s) coupled to the anchor points and a thread guide that directs the continuous thread can be used to reduce the amount of movement required during production, leading to reduced manufacturing times and reduced programming complexity.

[0028] As used herein, "anchor point" means a location to which a thread or group of thread lines is fixedly attached. A thread or thread line can be wrapped, wound, bonded, or otherwise attached at an anchor point. In some embodiments, an anchor point can be a location on an article of apparel. For example, an anchor point can be a hole or opening left behind by a structure (for example, pin, projection, or nub) used to wind continuous thread(s) of a thread layer and/or thread pattern. In some embodiments, a thread layer or thread pattern for an article of apparel may not comprise any anchor point locations because all the anchor point locations present during winding of the thread layer or thread pattern have been removed (for example, cut off). An anchor point can be a structure (for example, pin, projection, or nub) used to wind continuous thread(s) of a thread layer and/or thread pattern. And the anchor point structure may or may not form a portion of a thread layer or thread pattern for an article of apparel.

[0029] A continuous thread wrapped or wound around an anchor point need not be wrapped or wound completely (i.e., 360 degrees) around the anchor point. A continuous thread wrapped or wound around an anchor point can be wrapped or wound around only a portion of the anchor point. For example, a continuous thread wrapped or wound around an anchor point can be wrapped or wound around 25% (90 degrees) of an anchor point's perimeter, 50% (180 degrees) of an anchor point's perimeter, or 75% (270 degrees) of an anchor point's perimeter, or 100% (360 degrees) of an anchor point's perimeter. In some embodiments, a continuous thread can be wrapped or wound around an anchor point's perimeter more than once before being threaded to the next anchor

point. For example, a continuous thread can be wrapped or wound around an anchor point's perimeter one and a half times (540 degrees) or twice (720 degrees) before being threaded to the next anchor point.

[0030] The articles of apparel described herein can be made by, or can comprise a layer made by, winding one or more continuous threads around anchor points to create a desired thread layer or thread pattern. Winding the continuous thread(s) around the anchor points comprises wrapping a continuous thread around a first anchor point, extending that continuous thread to a second anchor point, wrapping that continuous thread around the second anchor point, and so on. The number and position of the anchor points can be utilized to control characteristics of the thread layer or thread pattern, and therefore characteristics of the apparel. Also, the number of times a continuous thread is wound from anchor point to anchor point can be utilized to control characteristics of the thread layer or thread pattern, and therefore characteristics of the apparel.

[0031] Continuous thread(s) of a thread layer or thread pattern can be bonded within the thread layer or thread pattern. The bonding of continuous thread(s) of a thread layer or thread pattern can consolidate the layer or pattern and fix thread lines within the layer or pattern. In some embodiments, bonding continuous thread(s) of a thread layer or thread pattern can be utilized to control characteristics of the layer or pattern. In some embodiments, a continuous thread can be bonded to itself within a thread layer or thread pattern. In some embodiments, a continuous thread can be bonded to itself at points of overlap between different thread lines of the continuous thread (i.e., at thread line intersection points). In some embodiments, different continuous threads of a thread layer or pattern can be bonded together. In some embodiments, different continuous threads can be bonded to each other at points of overlap between the different continuous threads (i.e., at intersection points between the different continuous threads). The bonding of continuous thread(s) can fix the continuous thread(s) in tension because the thread(s) can be wound around anchor points in tension.

[0032] In some embodiments, a plurality of different continuous threads can be wound around anchor points to form a plurality of thread layers for a thread pattern. In some embodiments, different continuous threads can be wound in the same configuration (i.e., around the same anchor points and along the same paths). In some embodiments, different continuous threads can be wound in different configurations (i.e., around one or more different anchor points and/or along different paths between one or more anchor points). In some embodiments, different continuous threads can define different wound layers for an article of apparel, or portion thereof. In such embodiments, the different layers can provide different characteristics to a thread pattern, and therefore provide different characteristics on the article of apparel. Both thread layers, which can comprise a single continuous wound

thread, and thread patterns, which can comprise multiple thread layers, are discussed herein. For clarity, the term "wound material" is used herein to refer to either a thread layer or a thread pattern comprising multiple thread layers.

[0033] Continuous thread(s) can be wound around anchor points (for example, projections as discussed herein) in various configurations to provide varying degrees of characteristics for an article of apparel. The number of anchor points, the position of the anchor points, the way continuous threads are wound around the anchor points, and/or of the material of threads wound around the anchor points can be utilized to produce apparel having desired characteristics, such as strength, stiffness, air permeability, comfort, abrasion resistance, fit, texture, haptics, tackiness, and durability. Characteristics of an article of apparel can be varied by changing the arrangement of anchor points and/or the way continuous thread(s) are wound around the anchor points. Characteristics can also be varied by altering the material of continuous thread(s).

[0034] In some embodiments, different thread layers or thread patterns can provide a first degree of a characteristic in one region of an article of apparel and a second degree of that characteristic in a second region of the article of apparel. In some embodiments, different thread layers or thread patterns can provide targeted characteristics to different regions of an article of apparel. In some embodiments, different thread layers or thread patterns can comprise thread lines oriented in different directions to provide targeted characteristics to different regions of an article of apparel.

[0035] In some embodiments, a thread layer or thread pattern can be bonded to the surface of one or more base layers. In some embodiments, a thread layer or thread pattern can be directly bonded to the surface of one or more base layers. In such embodiments, thread lines of the thread layer or thread pattern can be directly bonded to a surface of the base layer. Direct bonding to one or more base layers can impart unique characteristics on the base layer(s), and therefore the article of apparel. For example, direct bonding of a thread layer or thread pattern can impart desired mechanical or aesthetic properties to all or a portion of the article of apparel. In some embodiments, the direct bonding of a thread layer or thread pattern wound under tension can impart a compressive force on the surface of the base layer(s) once the thread pattern or thread layer is removed from anchor points. The compressive force can impart desired mechanical or aesthetic properties. For example, the compressive force can impart a desired shape to the article of apparel.

[0036] As used herein, two components (for example, a thread and a fabric) described as "bonded to" each other means the first component and second component are bonded to each other, either by direct contact and/or bonding between the two components or via an adhesive or bonding layer. Two components (for example, a thread

and a fabric) described as "directly bonded to" each other means the two components are directly bonded to each other via a material of the first component, a material of the second component, or both. For example, where heat and/or pressure is utilized to directly bond the polymeric material of a thread to a base layer, the thread is directly bonded to the base layer via the polymeric material of thread. In such embodiments, the polymeric material can be thermally fused to the base layer.

[0037] FIG. 1 illustrates an article of apparel 100 according to some embodiments. Article of apparel 100 can comprise one or more base layers 102 and one or more thread layers, for example, thread layers 108, 110, and 112. Thread layers 108, 110, 112 can be any exemplary thread layer described herein, for example, thread layer 410. In some embodiments, a thread layer, for example thread layer 108, can comprise a plurality of thread layers. In such embodiments, the thread layer can be referred to as a thread pattern comprising a plurality of thread layers. In some embodiments, article of apparel 100 may not comprise a base layer 102. In such embodiments, one or more thread layers (e.g., 108, 110, and 112), or one or more thread patterns comprising a plurality of thread layers, can define all of a portion of article of apparel 100.

[0038] Article of apparel 100 can comprise any number of thread layers produced according to the embodiments of FIGS. 2-7. Each thread layer 108, 110, 112 (or a thread pattern) can be defined by one or more threads comprising a plurality of thread lines crossing over each other at points of overlap between two or more of the thread lines. Each thread line (for example, thread line 412) of a thread layer (for example, thread layer 410) extends continuously across the thread layer (or thread pattern). Thread lines extending continuously across the thread layer (or thread pattern) are not woven or knitted threads. Similarly, thread lines extending continuously across the thread layer (or thread pattern) are not embroidered threads stitched to a base layer 102. Rather, the thread lines, and therefore the thread layer(s) are formed by winding thread around anchor points as described herein.

[0039] In some embodiments, thread lines extending continuously across the thread layer (or thread pattern) can extend continuously without forming a knitted structure or a woven structure between opposing ends of the thread lines. In some embodiments, thread lines extending continuously across the thread layer (or thread pattern) can extend continuously without forming a knitted structure or a woven structure along a distance greater than or equal to at least 90% of the length of the thread lines measured between opposing ends of the thread lines. In some embodiments, thread lines extending continuously across the thread layer (or thread pattern) can extend continuously without forming an embroidered structure between opposing ends of the thread lines. In some embodiments, thread lines extending continuously across the thread layer (or thread pattern) can extend

continuously without forming an embroidered structure along a distance greater than or equal to at least 90% of the length of the thread lines measured between opposing ends of the thread lines.

[0040] In some embodiments, thread lines of thread layer(s) 108, 110, 112 can be bonded to a surface 104 of a base layer 102 along at least a portion of a length of the thread line. In some embodiments, thread lines of thread layer(s) 108, 110, 112 can be directly bonded to a surface 104 of a base layer 102 along at least a portion of a length of the thread line. In some embodiments, surface 104 can be an exterior surface of base layer 102 facing away from a wearer's body during use. In some embodiments, surface 104 can be an interior surface of base layer 102 facing towards a wearer's body during use. In some embodiments, article of apparel 100 can comprise one or more thread layers bonded (or directly bonded) to an exterior surface of a base layer 102 and one or more thread layers bonded (or directly bonded) to an interior surface of the base layer 102.

[0041] In some embodiments, thread layers 108, 110, 112 can be bonded to different regions on surface 104 of a base layer 102. In some embodiments, thread layers 108, 110, 112 can define all or a portion of different regions of an article of apparel 100. Article of apparel 100 can comprise any number of thread layers (or thread patterns) bonded to or defining different regions of the article of apparel 100. For example, FIG. 1 illustrates article of apparel 100 comprising a first thread layer 108 bonded to a first region on article of apparel 100, a second thread layer 110 bonded to a second region on article of apparel 100, and a third thread layer 112 bonded to a third region on article of apparel 100. In such embodiments, the thread border 114 of each thread layer can define the respective regions on the article of apparel 100. In some embodiments, thread layers (or thread patterns) can overlap in an overlap region.

[0042] In some embodiments, thread layers 108, 110, 112 (or a thread pattern comprising a thread layer 108, 110, 112) can wrap entirely around all or a portion of the article of apparel 100. For example, a thread layer (or thread pattern) can wrap entirely around all or a portion of article of apparel 100 to provide support for a wearer's joint during use. A thread layer (or thread pattern) can wrap entirely around a pant leg, a sleeve, a waist, a torso portion, an abdomen portion, or a chest portion of article of apparel 100. As shown in FIGS. 2 and 4, the circular shape of the winding apparatus disclosed herein can facilitate creating a thread layer (or thread pattern) that wraps entirely around all or a portion of the article of apparel 100.

[0043] Thread layers (or thread patterns) applied to different regions of an article of apparel 100 can impart desired characteristics to the respective regions. Exemplary characteristics comprise, but are not limited to, strength, support, breathability, comfort (stretchability), aesthetics, abrasion resistance, water resistance, texture, tackiness, and haptics. In some embodiments, the

material of a continuous thread used to wind a thread layer can impart the desired characteristics. For example, a thread layer wound using a hydrophobic thread can impart water resistance to a particular region on an article of apparel. In some embodiments, the tension at which a continuous thread is wound can impart the desired characteristics. For example, a thread wound at high tension can impart a high degree of compression for a particular region on article of apparel.

[0044] In some embodiments, each thread layer 108, 110, 112 (or a thread pattern) can occupy a surface area defined by a thread border 114 (for example, border 414). In some embodiments, each thread layer 108, 110, 112 (or a thread pattern) can occupy a surface area defined by a thread border 114 (for example, border 414) on the surface 104 of a base layer 102. Each thread line within a thread layer (or thread pattern) can extend continuously across the layer and comprise a first end disposed at the thread border and a second end disposed at the thread border. In some embodiments, the first end and the second end of each thread line can be bonded to the surface 104 of the base layer 102. In some embodiments, the first end and the second end of each thread line can be directly bonded to the surface 104 of the base layer 102.

[0045] In some embodiments, a thread layer or thread pattern can be visibly exposed on surface 104 of article of apparel 100. In some embodiments, no lamination layer or supporting textile layer is disposed over a thread layer or thread pattern on the surface 104 of article of apparel 100. In some embodiments, a region on article of apparel 100 comprising a thread layer or thread pattern can be devoid of a lamination layer.

[0046] In some embodiments, the surface area of a first thread layer (or thread pattern) and the surface area of a second thread layer (or thread pattern) can partially overlap on article of apparel 100 in an overlap region. In some embodiments, the surface area of a first thread layer (or thread pattern) and the surface area of a second thread layer (or thread pattern) can partially overlap on the surface 104 of a base layer 102 in an overlap region. In such embodiments, the first thread layer (or thread pattern) and the second thread layer (or thread pattern) can overlap partially on article of apparel 100. In some embodiments, the first thread layer (or thread pattern) and the second a thread layer (or thread pattern) can be bonded to each other at an area of overlap between first thread layer (or thread pattern) and the second a thread layer (or thread pattern). In some embodiments, the first thread layer (or thread pattern) and the second a thread layer (or thread pattern) can be directly bonded to each other at an area of overlap between first thread layer (or thread pattern) and the second a thread layer (or thread pattern).

[0047] In some embodiments, one or more of thread layers 108, 110, 112 (or a thread pattern) can occupy a surface area defined by a thread border that is the same as a perimeter edge 106 of a base layer 102. In such embodiments, the one or more of thread layers 108, 110,

112 (or a thread pattern) can comprise a surface area occupying the entirety of a base layer 102. In some embodiments, one or more of thread layers 108, 110, 112 (or a thread pattern) can occupy a surface area defined by a thread border that is at least partially surrounded by perimeter edge 106 of a base layer 102. In such embodiments, perimeter edge 106 can define a surface area that at least partially comprises the surface area defined by the thread border. In some embodiments, one or more of thread layers 108, 110, 112 (or a thread pattern) can occupy a surface area defined by a thread border that is surrounded by perimeter edge 106 of a base layer 102. In such embodiments, perimeter edge 106 can define a surface area that wholly comprises the surface area defined by the thread border.

[0048] In some embodiments, thread lines of a thread layer (or thread pattern) can apply a compressive force on the surface 104 of the base layer 102, the compressive force being applied along an axis extending from a first end to a second end of the thread line. In such embodiments, the compressive force applied via each thread line can be configured to impart a desired shape on article of apparel.

[0049] In some embodiments, the base layer 102 can comprise a single piece of material. In some embodiments, base layer 102 can comprise a plurality of pieces of material. In such embodiments, base layer 102 can comprise a first piece of material and a second piece of material adjacent to the first piece of material. Pieces of material located adjacent to each other can be disposed in a side-by-side relationship with the perimeter edge of the first piece adjacent to the perimeter edge of the second piece. In some embodiments, the first piece of material and a second piece of material can be joined at a seam. In some embodiments, the first piece of material and a second piece of material may not be joined at a seam such that there is a gap between the adjacent pieces of material. In either case, one or more of the thread lines for a thread layer 108, 110, 112 (or a thread pattern) can extend across and be bonded to both the first piece of material and the second piece of material. In some embodiments, one or more of the thread lines for a thread layer 108, 110, 112 (or a thread pattern) can extend across and be directly bonded to both the first piece of material and the second piece of material.

[0050] As used herein, a "seam" is any attachment region between two portions of a single material piece or two different material pieces. Exemplary attachment regions comprise, but are not limited to, stitched attachment regions, adhesive attachment regions, thermally bonded attachment regions, and interlocking attachments. Exemplary seam structures comprise, but are not limited to, a self-attaching seam, a hem, a butt stitch, a Merrow stitch (tight overlock stitch), a gathered edge, a surge stitch, an overlock stitch, and an interlocking seam construction. In some embodiments, a "seam" can comprise a region where two portions of a single material piece or two different material pieces overlap. For exam-

ple, a seam can be a region where a first piece of material overlaps and is bonded to a second piece of material.

[0051] In some embodiments, base layer 102 can comprise three or more adjacent pieces of material. For example, base layer 102 can comprise three, four, five, six, seven, eight, nine, or ten pieces of material.

[0052] In some embodiments, base layer 102, or a piece of material defining base layer 102, can comprise a fabric material. In some embodiments, the fabric material can be a nonwoven, woven, or knitted fabric material. In some embodiments, base layer 102, or a piece of material defining base layer 102 can comprise a foam material. Exemplary fabric materials for base layer 102 comprise, but are not limited to, thermoplastic polyurethane (TPU), polyester, polyamide, polyethylene (PE), PE foam, polyurethane (PU) foam, nylon, ultra-high molecular weight polyethylene (for example, DYNEEMA® (a type of ultra-high molecular weight polyethylene)), carbon fiber, KEVLAR® (a type of para-aramid), synthetic spider silk, cotton, wool, natural or artificial silk, polyethersulfone (PES), ELASTAN® (a polyether-polyurea copolymer), or a blend of two or more of these materials. In some embodiments, base layer 102, or a piece of material defining base layer 102, can comprise a polymeric sheet or film, for example, a TPU sheet or film. In some embodiments, base layer 102, or a piece of material defining base layer 102, can comprise a mesh material.

[0053] In some embodiments, base layer 102, or a piece of material defining base layer 102, can comprise a first base layer disposed below a thread layer or thread pattern and a second base layer disposed above the thread layer or thread pattern. In such embodiments, the thread layer or thread pattern can be sandwiched between the first base layer and the second base layer. Also in such embodiments, thread lines of the thread layer or thread pattern can be (i) bonded to a surface 104 of the first base layer along at least a portion of a length of the thread line, (ii) bonded to a surface 104 of the second base layer along at least a portion of a length of the thread line, or (iii) both. In some embodiments, the thread lines can be directly bonded to the surface 104 of the first base layer, directly bonded to a surface 104 of the second base layer, or both.

[0054] While article of apparel 100 is depicted as a shirt in FIG. 1, other types of apparel comprising a thread layer 108, 110, 112 (or a thread pattern) as described herein are contemplated. As used herein, "apparel" can be any item that is worn or adorns an individual, including both clothing and accessories. Clothing can comprise, but is not limited to pants, shorts, leggings, socks, a shoe, a shoe upper, a jacket, a coat, a hat, a sleeve, a sweater, a shirt, a bra, a jersey, a bootie, a glove, an arm sleeve, a knee sleeve, an elbow sleeve, a wrist sleeve, an ankle sleeve. Accessories can comprise, but are not limited to a headband, a waistband, a belt, a wristband, a bracelet, a watch band, a shoulder wrap, a tape, a shin guard, a hat, a tie, a scarf, a purse, a handbag, a wallet, a knapsack, or

a backpack.

[0055] FIG. 2 illustrates a winding apparatus 200 for winding continuous thread(s) according to some embodiments. In some embodiments, winding apparatus 200 can be operated using computer numerical control (CNC), as described herein. Winding apparatus 200 can comprise a first rim 206 coupled to and spaced apart from a second rim 214, with both first and second rims 206, 214 rotatable on a rotation axis A. A first plurality of anchor points 208 can be coupled to and can extend from a perimeter of the first rim 206 and a second plurality of anchor points 216 can be coupled to and can extend from a perimeter of the second rim 214. During operation, one or more continuous threads 234 can be wound around anchor points 208, 216 as described herein.

[0056] In some embodiments, anchor points 208 can extend from a perimeter of first rim 206 in a direction perpendicular to axis A. In some embodiments, anchor points 208 can additionally or alternatively extend from the perimeter of first rim 206 in a direction parallel to axis A (e.g., they can extend diagonally from first rim 206). In some embodiments, anchor points 208 can be structures, for example, pins, projections, or nubs. In some embodiments, anchor points 208 can be directly coupled to first rim 206 (e.g., integrally formed with first rim 206 or directly attached to first rim 206). In some embodiments, anchor points 208 can be indirectly and removably coupled to first rim 206, for example as described below with respect to FIG. 3.

[0057] Similarly, anchor points 216 can extend from a perimeter of second rim 214 in a direction perpendicular to axis A. In some embodiments, anchor points 216 can additionally or alternatively extend from the perimeter of second rim 214 in a direction parallel to axis A (e.g., they can extend diagonally from second rim 214). In some embodiments, anchor points 216 can be structures, for example, pins, projections, or nubs. In some embodiments, anchor points 216 can be directly coupled to second rim 214 (e.g., integrally formed with second rim 214 or directly attached to second rim 214). In some embodiments, anchor points 216 can be indirectly and removably coupled to second rim 214, for example as described below with respect to FIG. 3.

[0058] In some embodiments, winding apparatus 200 can comprise a first wheel 202. In some embodiments, first wheel 202 can comprise spokes 204 and first rim 206. In such embodiments, first wheel 202 can comprise empty spaces between the spokes 204 and first rim 206. In some embodiments, first wheel 202 can be solid (e.g., comprise a solid plane having a rim 206) and may not comprise spokes 204.

[0059] Anchor points 208 can be coupled to and can extend from a perimeter of first wheel 202. For example, anchor points 208 can be coupled to and can extend from first rim 206. In some embodiments, anchor points 208 can extend from the perimeter of first wheel 202 in a direction perpendicular to axis A. In some embodiments, anchor points 208 can additionally or alternatively extend

from the perimeter of first wheel 202 in a direction parallel to axis A (e.g., they can extend diagonally from first rim 206). In some embodiments, anchor points 208 can be structures, for example, pins, projections, or nubs. In some embodiments, anchor points 208 can be directly coupled to first wheel 202 (e.g., integrally formed with first rim 206 or directly attached to first rim 206). In some embodiments, anchor points 208 can be indirectly and removably coupled to first wheel 202, for example as described below with respect to FIG. 3.

[0060] In some embodiments, winding apparatus 200 can also comprise a second wheel 210. Second wheel 210 can be similar or identical to first wheel 202. For example, in some embodiments, second wheel 210 can comprise spokes 212 and second rim 214. In some embodiments, second wheel 210 can be solid (e.g., comprise a solid plane having a rim 214) and may not comprise spokes 212.

[0061] Anchor points 216 can be coupled to and can extend from a perimeter of second wheel 210. For example, anchor points 216 can be coupled to and can extend from second rim 214. In some embodiments, anchor points 216 can extend from the perimeter of second wheel 210 in a direction perpendicular to axis A. In some embodiments, anchor points 216 can additionally or alternatively extend from the perimeter of second wheel 210 in a direction parallel to axis A (e.g., they can extend diagonally from second rim 214). In some embodiments, like anchor points 208, anchor points 216 can be structures, for example, pins, projections, or nubs. In some embodiments, anchor points 216 can be directly coupled to second wheel 210 (e.g., integrally formed with second rim 214 or directly attached to second rim 214). In some embodiments, anchor points 216 can be indirectly and removably coupled to second wheel 210, for example, as described below with respect to FIG. 3.

[0062] Second rim 214 can be coupled to and spaced apart from first rim 206. In some embodiments, first rim 206 and second rim 214 can be coupled to and spaced apart from one another via a support 218. In embodiments comprising first and second wheels 202, 210, second wheel 210 can be coupled to and spaced apart from first wheel 202. In some embodiments, first wheel 202 and second wheel 210 can be coupled to and spaced apart from one another via support 218.

[0063] Support 218 can take any of a variety of forms without departing from the spirit or scope of this disclosure. For example, support 218 can be or comprise an axle, a rod or plurality of rods, a shaft or plurality of shafts, or a drum. In embodiments in which support 218 comprises a drum, the outward facing surface of support 218 can be substantially even with first rim 206 and second rim 214. Further, when support 218 comprises a drum, support 218 can comprise first and second rims 206, 214 integrally formed with the drum.

[0064] In some embodiments, no part of support 218 extends beyond a perimeter of first rim 206 or second rim

214 in a direction perpendicular to axis A. In some embodiments, such as when support 218 comprises a drum, support 218 can extend beyond the perimeters of first rim 206 and second rim 214 in a direction perpendicular to axis A. In such embodiments, support 218 may be configured to provide tension to a continuous thread 234 being wound around an anchor point 208 and an anchor point 216, be configured to shape a resulting thread layer, or both.

[0065] Support 218 can comprise a first end 220 and a second end 222. In embodiments comprising first and second wheels 202, 210, first wheel 202 can be coupled to first end 220 and second wheel 210 can be coupled to second end 222. Any suitable attachment means, for example, screw(s), adhesive, or nuts and bolts, can be used to attach first wheel 202 to first end 220 and second wheel 210 to second end 222.

[0066] First rim 206 and second rim 214 can be spaced apart by a distance "D." In some embodiments, "D" can range from 5 centimeters (cm) to 3 meters (m), including subranges. For example, in some embodiments, "D" can range from 5 cm to 2.5 m, from 5 cm to 2 m, from 10 cm to 2 m, from 10 cm to 1.5 m, from 15 cm to 1.5 m, from 15 cm to 1 m, from 20 cm to 1 m, or from 20 cm to .5 m.

[0067] First rim 206 and second rim 214 can each have a diameter. As used herein, the term "diameter" is used to describe the size of a component, but this term should not be interpreted as requiring the component to have a circular shape. Instead, the component may have a non-circular shape, and in such embodiments, the term "diameter" is intended to refer to the maximum cross-sectional dimension of the shape. For example, the "diameter" of a component having an elliptical cross-sectional shape would be the length of the major axis of the elliptical shape.

[0068] In some embodiments, the diameters of first rim 206 and second rim 214 can range from 5 centimeters (cm) to 3 meters (m), including subranges. For example, in some embodiments, the diameters can range from 5 cm to 2.5 m, from 5 cm to 2 m, from 10 cm to 2 m, from 10 cm to 1.5 m, from 15 cm to 1.5 m, from 15 cm to 1 m, from 20 cm to 1 m, or from 20 cm to 0.5 m. In some embodiments, first rim 206 and second rim 214 can have the same diameter. In some embodiments, first rim 206 and second rim 214 can have different diameters.

[0069] In some embodiments, the diameters of first rim 206 and second rim 214 can be selected to match or exceed an article of apparel diameter. The article of apparel diameter can be, for example, a diameter of a pant leg, a diameter of a sleeve, a diameter of a waist portion, a diameter of a torso portion, a diameter of an abdomen portion, or a diameter of a chest portion of an article of apparel. The diameters of first and second rims 206, 214 and "D" can be such that segments of wound materials of substantial size (e.g., greater than the size of a shoe upper) can be produced using winding apparatus 200. Accordingly, a variety of types of apparel can be made using only one or a few segments of wound ma-

terial produced using winding apparatus 200. In some embodiments, when a wound material produced using winding apparatus 200 is laid flat, the length of the wound material can range from 15 cm to 9 m, including subranges. For example, the length can range from 15 cm to 7.5 m, from 15 cm to 6 m, from 30 cm to 6 m, from 30 cm to 4.5 m, from 45 cm to 4.5 m, from 45 cm to 3 m, from 0.6 m to 3 m, or from 0.6 m to 1.5 m. In some embodiments, when the wound material produced using winding apparatus 200 is laid flat, the width of the wound material can range from 5 cm to 3 m, including subranges. For example, the width can range from 5 cm to 2.5 m, from 5 cm to 2 m, from 10 cm to 2 m, from 10 cm to 1.5 m, from 15 cm to 1.5 m, from 15 cm to 1 m, from 20 cm to 1 m, or from 20 cm to 0.5 m.

[0070] In some embodiments, ratios of the diameters of first rim 206 and second rim 214 to "D" can be such that a thread layer (or thread pattern) that is wound using winding apparatus 200 can be square or rectangular when removed from winding apparatus 200 and flattened.

[0071] In some embodiments, the ratios can be about $1:\pi$. In some embodiments, the ratios of the diameters to "D" can range from 1:2.5 to 1:3.6, including subranges. For example, in some embodiments, the ratios can range from 1:2.6 to 1:3.5, from 1:2.7 to 1:3.4, from 1:2.8 to 1:3.3, or from 1:2.9 to 1:3.2.

[0072] In some embodiments, the ratios of the diameters to "D" can range from 1:0.4 to 1:3, including subranges. For example, in some embodiments, the ratios can range from 1:0.6 to 1:2.8, from 1:0.8 to 1:2.6, from 1:1 to 1:2.4, from 1:1.2 to 1:2.2, from 1:1.4 to 1:2, or from 1:1.6 to 1:1.8.

[0073] In some embodiments, the number of anchor points 208, 216 coupled to each of first rim 206 and second rim 214 can range from 10 to 500, including subranges. For example, in some embodiments, the number of anchor points can range from 10 to 400, from 10 to 300, from 10 to 200, from 20 to 175, from 20 to 150, from 20 to 125, from 20 to 100, from 25 to 90, from 25 to 80, from 25 to 70, from 25 to 60, or from 25 to 50. In some embodiments, the distance between adjacent anchor points 208 (or adjacent anchor points 216) can range from 0.2 cm to 5 cm, including subranges. For example, the distance can range from 0.2 cm to 4.5 cm, from 0.2 cm to 4 cm, from 0.3 cm to 3.5 cm, from 0.3 cm to 3 cm, from 0.4 cm to 2.5 cm, from 0.4 cm to 2 cm, from 0.5 cm to 1.5 cm, or can be about 1 cm. In some embodiments, anchor points 208, 216 can be uniformly spaced around the circumference of first rim 206/second rim 214. In alternative embodiments, anchor points 208, 216 can be unevenly spaced around the circumference of first rim 206/second rim 214 (e.g., the distance between adjacent anchor points differs). In some embodiments, the number of anchor points 208 can be the same as the number of anchor points 216. In some embodiments, the number of anchor points 208 can be different from the number of anchor points 216.

[0074] As shown in FIG. 2, first rim 206 and second rim 214 can be rotatable on rotation axis A. In some embodiments, axis A can pass through a geometric center point of first rim 206 (or first wheel 202) and a geometric center point of second rim 214 (or second wheel 210). In some embodiments, first rim 206 and second rim 214 can rotate both counterclockwise or clockwise on rotation axis A. In some embodiments, rotation axis A can be substantially parallel to a gravity vector (i.e., a vector that points downward toward the center of the earth) during operation of winding apparatus 200. In some embodiments, rotation axis A can be substantially perpendicular to the gravity vector during operation of winding apparatus 200, for example, as shown in FIG. 12. In some embodiments, rotation axis A can be diagonal with respect to the gravity vector during operation of winding apparatus 200.

[0075] Winding apparatus 200 can further comprise a first actuator 224 configured to rotate first rim 206 and second rim 214 on rotation axis A. In some embodiments, first actuator 224 can comprise a motor. Additionally, in some embodiments, first actuator 224 can comprise one or more of a gear assembly, a belt and sheave, or a cable and pulley. In some embodiments, first actuator 224 can be coupled to support 218 to produce a torque on support 218 around rotation axis A. The torque can rotate first rim 206 and second rim 214. First actuator 224 can be coupled to a control system 232, which can vary the torque magnitude and/or direction to alter the angular velocity of first rim 206 and second rim 214 either while thread guide 226 is stationary or moving, as described herein in more detail.

[0076] In some embodiments, first actuator 224 can comprise a gear assembly between a motor of first actuator 224 and support 218 that can alter a gear ratio to either increase the precision or efficiency of rotations of first and second rims 206, 214. For example, in some embodiments, such a gear assembly can cause a full rotation of a shaft within the motor to produce less than a full rotation of support 218, which can increase precision in attaining a particular predetermined angular position of first and second rims 206, 214. In some embodiments, such a gear assembly can alternatively or additionally cause a full rotation of a shaft within the motor to produce more than a full rotation of support 218.

[0077] In some embodiments, first rim 206 and second rim 214 can be statically coupled such that a torque on support 218 rotates both rims at the same angular velocity. In some embodiments, first rim 206 can be independently coupled to an actuator, such as an actuator 224, and second rim 214 can be independently coupled to a different actuator, such as an actuator 224, such that first rim 206 and second rim 214 can be rotated at different rates and/or in different directions simultaneously. In such embodiments, support 218 can comprise a tube or other hollow structure inside of which two independent axles, each coupled to one of first and second rims 206, 214, can rotate. Each of the axles can be coupled to an actuator, such as an actuator 224. Such embodiments

can provide increased control over winding patterns (defined by the angles thread lines in a wound thread layer extend with respect to first and second rims 206, 214 and other thread lines, as shown for example in FIG. 4).

[0078] As shown in FIG. 2, winding apparatus 200 can comprise one or more thread guides 226 to guide a continuous thread 234 while it is being wound around anchor points 208, 216. In some embodiments, thread guide 226 can comprise a tube, an eyelet, or other aperture through which continuous thread 234 can pass while being directed by thread guide 226. Thread guide 226 can be coupled to a thread guide support 228, which can operate in response to a second actuator 230 to move thread guide 226. Second actuator 230 can produce translation of thread guide support 228. Like first actuator 224, second actuator 230 can be coupled to control system 232, which can provide signals to second actuator 230 to alter the translation velocity of thread guide 226 either while first and second rims 206, 214 are stationary or rotating, as described herein in more detail. In some embodiments, second actuator 230 can be an electromechanical linear actuator (for example, a motor coupled to a belt, chain, cable, or rack), a hydraulic linear actuator, or a pneumatic linear actuator.

[0079] In some embodiments, thread guide 226 may only move along an axis parallel to axis A during winding of continuous thread 234. For example, during winding, thread guide 226 can move along an axis parallel to axis A but not along any axis perpendicular to axis A. In some embodiments, thread guide support 228 can move thread guide 226 along an axis perpendicular to axis A. In such embodiments, movement of thread guide support 228 along an axis perpendicular to axis A may only be needed to set thread guide 226 at an initial position prior to winding. In some embodiments, movement of thread guide support 228 along an axis perpendicular to axis A may occur when thread guide 226 arrives at an anchor point 208, 216 and serves to wrap continuous thread 234 around the anchor point 208, 216.

[0080] In some embodiments, winding of continuous thread 234 around anchor points 208, 216 may only require movement of thread guide 226 along a single axis, for example a single axis parallel to axis A as described herein. Accordingly, winding apparatus 200 can complete a winding operation, for example, produce a thread layer, without moving thread guide 226 along multiple axes (after thread guide 226 has optionally been set to an initial position). In some embodiments, the single axis along which thread guide 226 moves during a winding operation can be parallel to axis A. In some embodiments, the single axis along which thread guide 226 moves during a winding operation may not be parallel to axis A, for example, if the diameter of first rim 206 is different from the diameter of second rim 214.

[0081] To accomplish winding of continuous thread 234 around anchor points 208, 216, second actuator 230 can move thread guide support 228 such that thread guide 226 passes between adjacent anchor points 208

and adjacent anchor points 216.

[0082] As used herein, a first anchor point described as "adjacent" to a second anchor point means that the second anchor point is the first anchor point's first or second closest anchor point neighbor. An anchor point will typically have two "adjacent" anchor point neighbors, typically located on opposing sides of the anchor point. In embodiments comprising equally spaced anchor points, an anchor point's first and second closest anchor point neighbors may be located at the same distance from the anchor point. As an example, anchor points 208a and 208c are adjacent to anchor point 208b in FIG. 2. Anchor points 208a and 208b comprise a pair of adjacent anchor points and anchor points 208b and 208c comprise a pair of adjacent anchor points.

[0083] In some embodiments, multiple continuous threads can pass through thread guide 226 and be wound around an anchor point or anchor points simultaneously. In such embodiments, thread guide 226 can comprise a single tube, eyelet, aperture, or other structure used to guide a continuous thread, and multiple continuous threads can be passed through the tube, eyelet, aperture, or other structure. In some embodiments, thread guide 226 can comprise multiple tubes, eyelets, apertures, or other structures that are configured to move in concert to pass between pairs of adjacent anchor points 208 or 216, and one or more continuous threads can be passed through each of the multiple tubes, eyelets, apertures, or other structures. In some embodiments, passing multiple continuous threads through thread guide 226 and winding them simultaneously around anchor points 208 or 216 can increase the efficiency of winding apparatus 200.

[0084] Second actuator 230 can move thread guide support 228 such that thread guide 226 moves along an axis parallel to axis A while first rim 206 and second rim 214 are rotating under the influence of first actuator 224. In some embodiments, without any movement perpendicular to axis A, thread guide 226 can pass between a first pair of adjacent anchor points (for example, anchor points 208b and 208c), reverse direction, and pass between a second pair of adjacent anchor points (for example, anchor points 208a and 208b) while first rim 206 is rotating. Accordingly, thread guide 226 can loop continuous thread 234 around anchor point 208b.

[0085] After looping continuous thread 234 around an anchor point 208 (for example, anchor point 208b), thread guide support 228 can move thread guide 226 toward second rim 214 and loop continuous thread 234 around an anchor point 216 coupled to second rim 214 in the same manner as the anchor point 208 coupled to first rim 206.

[0086] While FIG. 2 shows a single thread guide 226 and support 228, in some embodiments, winding apparatus 200 can comprise multiple thread guides 226 and supports 228. For example, in some embodiments, winding apparatus 200 can comprise two, three, or four thread guides 226, each coupled to a support 228. In such

embodiments, the multiple thread guides 226 can be arranged at different locations adjacent first rim 206 and second rim 214, for example, on opposite sides of support 218. In some embodiments, the multiple thread guides 226 can be actuated independently of one another, controlled by separate second actuators 230 and either the same control system 232 or separate control systems. In some embodiments, the multiple thread guides 226 can be actuated jointly (i.e., a movement pattern of one thread guide 226 corresponds to a movement pattern of another thread guide 226), controlled by the same control system 232 and the same second actuator 230 or separate actuators.

[0087] In some embodiments, each of anchor points 208, 216 can extend at an angle measured relative to rotation axis A. For example, an axis B defining a lengthwise axis of an anchor point 208 (for example, a projection) can extend at an angle θ measured relative to an axis C that runs parallel to axis A, as shown in FIG. 2. For any anchor point 208, 216, θ can be measured relative to the portion of rotation axis A (or parallel axis C) that lies between first rim 206 and second rim 214. In some embodiments, θ can range from 90 degrees ($^{\circ}$) to 180 $^{\circ}$, including subranges. For example, θ can range from 90 $^{\circ}$ to 175 $^{\circ}$, 95 $^{\circ}$ to 175 $^{\circ}$, from 100 $^{\circ}$ to 175 $^{\circ}$, from 105 $^{\circ}$ to 175 $^{\circ}$, from 110 $^{\circ}$ to 175 $^{\circ}$, from 115 $^{\circ}$ to 175 $^{\circ}$, from 120 $^{\circ}$ to 175 $^{\circ}$, from 125 $^{\circ}$ to 175 $^{\circ}$, from 130 $^{\circ}$ to 175 $^{\circ}$, from 100 $^{\circ}$ to 170 $^{\circ}$, from 115 $^{\circ}$ to 160 $^{\circ}$, or from 125 $^{\circ}$ to 145 $^{\circ}$.

[0088] When θ is less than 180 $^{\circ}$, no movement of thread guide 226 along multiple axes may be required to wind a continuous thread 234 around an anchor point 208, 216. This is because the continuous thread 234 can catch on the anchor point 208, 216 when thread guide 226 passes close to a rim 206, 214, between adjacent anchor points 208, 216, reverses direction, and passes between other adjacent anchor points 208, 216 while first rim 206 and second rim 214 are rotating. In some embodiments, for example, when θ is 180 $^{\circ}$ or greater, thread guide support 228 can provide additional degrees of freedom for thread guide 226's movement such that thread guide 226 can still pass between the adjacent anchor points 208, 216, for example, by moving along a first axis from an anchor point 216 to an anchor point 208 and along a second axis to pass between adjacent anchor points 208.

[0089] In some embodiments, θ ranges from greater than 90 $^{\circ}$ to less than 180 $^{\circ}$. In some embodiments, θ ranges from 95 $^{\circ}$ to 175 $^{\circ}$. In some embodiments, θ can be selected such that a continuous thread 234 is not likely to slip off an anchor point 208, 216 after being wound. Additionally, θ can be selected such that an anchor point 208, 216 projects from a rim 206, 214 in a direction perpendicular to axis A a sufficient amount for thread guide 226 to pass-while moving only along an axis parallel to axis A-through a region between the rim 206, 214 and an arc parallel to the rim 206, 214 that touches an extreme tip of the anchor point 208, 216. In some embodiments, an even larger value for θ , for example, from

120° to 175°, can be preferable to prevent a continuous thread 234 that is being wound around an anchor point 208, 216 from forcing off other portions of the continuous thread 234 (or another continuous thread) that have been wound around the same anchor point 208, 216.

[0090] As shown in FIG. 2, winding apparatus 200 can also comprise a control system 232 for controlling first actuator 224 and second actuator 230. In some embodiments, a plurality of winding apparatuses 200 in a winding assembly can comprise the same control system 232, as shown in FIG. 9A. In some embodiments, a plurality of winding apparatuses 200 in a winding assembly can each comprise a separate control system 232, as shown in FIG. 9B.

[0091] Control system 232 can comprise a computer system such as computer system 1100 shown in FIG. 11, though control system 232 need not comprise all components shown in FIG. 11. Control system 232 can comprise a programmable memory (for example, main memory 1108 and/or second memory 1110). The programmable memory can store computer programs that can direct the rotation of first rim 206 and second rim 214 and the movement of thread guide 226. For example, the programmable memory can store computer programs that instruct first actuator 224 and second actuator 230 to operate at certain conditions. In the case of first actuator 224, the conditions can comprise rate of rotation and direction of rotation. In the case of second actuator 230, the conditions can comprise rate of translation and direction of translation. Control system 232 can set and alter the following conditions, alone or in combination with any other condition, to effect a desired winding pattern (defined by the angles thread lines in a wound thread layer extend with respect to first and second rims 206, 214 and other thread lines, as shown in FIG. 4): i) rate of rotation of first and second rims 206, 214; ii) direction of rotation of first and second rims 206, 214; iii) rate of translation of thread guide 226; and iv) direction of translation of thread guide 226.

[0092] In some embodiments, these conditions can be set by a programmer of control system 232 specifying angular and linear positions (and/or angular and translation velocities) of first and second rims 206, 214 and thread guide 226, respectively, at various times or in various chronological orders. In some embodiments, the programmer can specify these angular and linear positions (and/or angular and translation velocities) in one or more files. In some embodiments, the one or more files can comprise a file describing the positions of anchor points 208, 216 in three dimensions (3D). In such embodiments, each of anchor points 208, 216 can be associated with a unique identifier (e.g., a number or alphanumeric code) that is specified in the file. In some embodiments, the one or more files can be JSON files, but the one or more files are not limited to a particular format. In some embodiments, one or more processors in the control system (for example, processor 1104) can interpret the contents of the one or more files into CNC G-code

commands that control first and second actuators 224, 230 to move first and second rims 206, 214 and thread guide 226. In some embodiments, the contents of the one or more files can also comprise instructions to change a continuous thread to another continuous thread, for example, to transition between winding a first thread layer and winding a second thread layer.

[0093] The programmable memory may be preprogrammed with a series of instructions for effecting a single or a variety of winding patterns during the production of a thread layer. The control system can change the winding pattern during winding of the thread layer or thread pattern. The winding pattern(s) may be selected to influence a variety of characteristics of a resulting wound material (for example, a thread layer or thread pattern), for example, durability, stiffness, weight, tackiness, texture, haptics, and/or air permeability.

[0094] Confining movement of thread guide 226 along a single axis during a winding operation in some embodiments, as described herein, can reduce the complexity of both thread guide support 228 and the computer programs required to operate winding apparatus 200. For example, in some embodiments, only values for the angular velocity of first and second rims 206, 214 (which is a vector defining both rate and direction of rotation) and the translation velocity of thread guide 226 (which is a vector defining both rate and direction of translation) must be preprogrammed for various times or in various chronological orders throughout a winding operation. In some embodiments, only values for the angular position of first and second rims 206, 214 (as determined, for example, by an extent of rotation of first and second rims 206, 214 relative to a reference position) and the translation position of thread guide 226 (as determined by the thread guide's position along its axis of translation) must be preprogrammed for various times or in various chronological orders throughout a winding operation. In some embodiments, the programming of angular/translation velocities/positions may be done by a programmer specifying the order in which continuous thread 234 should be wound around anchor points 208, 216, for example, using the unique identifiers associated with anchor points 208, 216.

[0095] In some embodiments, one or more of these conditions can remain constant while a subset of these conditions are periodically changed. For example, to produce a relatively simple winding pattern (for example, first winding pattern 404 shown in FIG. 4), the rate of rotation of first and second rims 206, 214 and the direction of rotation of first and second rims 206, 214 can remain constant, while the rate of translation of thread guide 226 can be changed to periodically reverse the translation direction of thread guide 226. In some embodiments, the direction of translation of thread guide 226 can be reversed at regular time intervals. In some embodiments, the direction of translation of thread guide 226 can be reversed at irregular time intervals. In some embodiments, thread guide 226 can pause for any time

interval between reversals of translation direction.

[0096] In some embodiments, when changing rotation direction or pausing rotation of first and second rims 206, 214, the angular velocity of first and second rims 206, 214 can be varied smoothly. That is, first and second rims 206, 214 can gradually accelerate as it moves toward a midpoint of a movement (i.e., a motion segment between direction reversal points or stopping points) and gradually decelerate after it moves past the midpoint. Likewise, in some embodiments, when changing translation direction or pausing translation of thread guide 226, the velocity of thread guide 226 can be varied smoothly. That is, thread guide 226 can gradually accelerate as it moves toward a midpoint of a movement (i.e., a motion segment between direction reversal points or stopping points) and gradually decelerate after it moves past the midpoint. In some embodiments, varying the angular velocity of first and second rims 206, 214 and/or the translation velocity of thread guide 226 smoothly can minimize mechanical strain and deterioration of the components of first actuator 224 and second actuator 230.

[0097] In some embodiments, for example, in a "simultaneous mode," thread guide 226 can pass between pairs of adjacent anchor points 208, 216 while first and second rims 206, 214 are rotating. For example, first and second rims 206, 214 can rotate continuously in a particular rotation direction while thread guide 226 passes between one or more pairs of adjacent anchor points 208, 216. In the simultaneous mode, first and second rims 206, 214 may change rotation direction, but may not pause apart from executing changes in rotation direction.

[0098] In some embodiments, for example, in a "consecutive" or "partially consecutive" mode, thread guide 226 can pass between a pair of adjacent anchor points 208, 216 while first and second rims 206, 214 are stationary. For example, thread guide 226 can pass between a pair of adjacent anchor points 208, 216 while first and second rims 206, 214 are stationary, first and second rims 206, 214 can rotate a predefined amount and stop, and thread guide 226 can pass between another pair of adjacent anchor points 208, 216 while first and second rims 206, 214 are again stationary.

[0099] In some embodiments, for example, in the "consecutive mode," the movement of first and second rims 206, 214 and thread guide 226 can be consecutive. For example, thread guide 226 can pass between a pair of adjacent anchor points 208, 216 to a point above the plane of first rim 206 or below the plane of second rim 214 while first and second rims 206, 214 are stationary, and stop; first and second rims 206, 214 can rotate a predefined amount and stop; and thread guide 226 can pass between another pair of adjacent anchor points 208, 216 to a point in between the planes of first and second rims 206, 214 while first and second rims 206, 214 are stationary, and stop. Thread guide 226 can then remain at the point in between the planes of first and second rims 206, 214 while first and second rims 206, 214 rotate a predefined amount and stop, and thread guide 226 can

pass between another pair of adjacent anchor points 208, 216 to a point above the plane of first rim 206 or below the plane of second rim 214 while first and second rims 206, 214 are stationary, and stop. Similar consecutive movements can be repeated to create a thread layer.

[0100] In some embodiments, for example, in the "partially consecutive mode," movement of first and second rims 206, 214 and thread guide 226 can be partially simultaneous and partially consecutive. For example, thread guide 226 can pass between a pair of adjacent anchor points 208, 216 to a point above the plane of first rim 206 or below the plane of second rim 214 while first and second rims 206, 214 are stationary; first and second rims 206, 214 can rotate a predefined amount and stop; and thread guide 226 can pass between another pair of adjacent anchor points 208, 216 to a point in between the planes of first and second rims 206, 214 while first and second rims 206, 214 are again stationary. Rather than remaining at the point between the planes of first and second rims 206, 214 while first and second rims 206, 214 rotate, however, thread guide 226 can move across at least a portion of the distance between first rim 206 and second rim 214 while first and second rims 206, 214 rotate a predetermined amount and stop; and thread guide 226 can pass between another pair of adjacent anchor points 208, 216 to a point above the plane of first rim 206 or below the plane of second rim 214 while first and second rims 206, 214 are stationary. Similar partially consecutive and partially simultaneous movements can be repeated to create a thread layer.

[0101] In some embodiments, winding a thread layer can comprise winding the thread layer in the simultaneous mode. In some embodiments, winding a thread layer can comprise winding the thread layer in the consecutive mode. In some embodiments, winding a thread layer can comprise winding the thread layer in the partially consecutive mode. In some embodiments, winding a thread layer can comprise winding the thread layer in two or more of the simultaneous mode, the consecutive mode, and the partially consecutive mode.

[0102] Winding apparatus 200 (or a winding assembly such as that shown in FIG. 8) can comprise one or more thread spools for threading and winding thread lines of one or more thread layers around anchor points 208, 216. In some embodiments, winding apparatus 200 (or a winding assembly) can comprise a plurality of thread spools for threading and winding a plurality of different threads. Thread spools can be operatively coupled to one or more thread guides 226 such that thread guide 226 guides a continuous thread unwound from a thread spool during winding around anchor points 208, 216 as described herein.

[0103] In some embodiments, winding apparatus 200 can comprise one or more thread tensioners configured to apply a desired tension to continuous thread 234 as it is wound around anchor points 208, 216. In some embodiments, control system 232 can control the one or more tensioners to wind continuous thread 234 at desired

tensions. In some embodiments, thread spools and thread tensioners can be the same as or similar to those described in U.S. Patent No. 11,602,196 B2, which is hereby incorporated by reference in its entirety.

[0104] In some embodiments, winding apparatus 200 can wind a plurality of threads from a plurality of thread spools simultaneously when winding a thread layer. In some embodiments, winding apparatus 200 can be used to simultaneously wind overlaying thread lines from a plurality of thread spools.

[0105] In some embodiments, winding apparatus 200 can comprise two or more thread guides 226, thread guide supports 228, and/or second actuators 230 for winding a plurality of threads simultaneously. In such embodiments, the two or more thread guides 226, thread guide supports 228, and/or second actuators 230 can wind different threads in different regions of a thread pattern simultaneously.

[0106] In some embodiments, winding apparatus 200 can ply two or more threads from different thread spools. In such embodiments, a thread layer or thread pattern can comprise one or more plied threads. As used herein, "plying" two or more threads means coupling the two or more threads together by twisting at least one of the two or more threads. In some embodiments, plying can comprise twisting one or more threads around one or more non-twisted threads. In some embodiments, plying can comprise twisting two or more threads together.

[0107] In some embodiments, a thread tensioner can be a mechanical tensioning device with digitally controlled impedance that is used to dynamically control how tight a thread is fed through thread guide 226. In some embodiments, the tension value for thread can be changed dynamically by adjusting the voltage in the tensioner. In some embodiments, the tensioner can be a manually adjustable tensioner. In some embodiments, the tensioner can comprise a spring configured to adjust the amount of tension applied to thread(s). The spring can be manually controlled or digitally controlled.

[0108] In some embodiments, the tension at which continuous thread 234 is wound can range from 0 centinewtons (cN) to 25 cN, including subranges. For example, in some embodiments, the tension can range from 0.01 cN to 25 cN, from 0.1 cN to 25 cN, from 1 cN to 25 cN, from 5 cN to 25 cN, from 10 cN to 25 cN, or from 15 cN to 25 cN. In some embodiments, the tension at which continuous thread 234 is wound can range from 2 cN to 10 cN. In some embodiments, the tension at which continuous thread 234 is wound can range from 2 cN to 6 cN.

[0109] In some embodiments, a first thread layer (for example, thread layer 410 of FIG. 4) can comprise a continuous thread (for example, continuous thread 402 of FIG. 4) wound at a first tension and a second thread layer disposed over the first thread layer can comprise a continuous thread wound at a second tension greater than the first tension. In some embodiments, the second tension can be at least 0.5 cN greater than the first tension. In some embodiments, the second tension

can be at least 1 cN greater than the first tension.

[0110] FIG. 3 illustrates components that can removably couple anchor points 208, 216 to first and second rims 206, 214, according to some embodiments. As shown in FIG. 3, in some embodiments, a first flexible chain 302 can comprise anchor points 208. Likewise, in some embodiments, a second flexible chain 304 can comprise anchor points 216. First flexible chain 302 and second flexible chain 304 can be flexible between a linear state and a circular state. Accordingly, first flexible chain 302 can be flexed from a linear state to a circular state and coupled to first rim 206. First flexible chain 302 can also be detached from first rim 206 and returned to a linear state, for example, after a thread layer or thread pattern has been wound on winding apparatus 200, as shown in FIG. 6. Likewise, second flexible chain 304 can be flexed from a linear state to a circular state and coupled to second rim 214. Second flexible chain 304 can be detached from second rim 214 and returned to a linear state, for example, after a thread layer or thread pattern has been wound on winding apparatus 200, as shown in FIG. 6. In some embodiments, first flexible chain 302 and second flexible chain 304 can be coupled to first rim 206 and second rim 214, respectively, using clips, protrusions and corresponding apertures (e.g., enabling an interference fit), magnets, etc.

[0111] In some embodiments, flexible portions of first flexible chain 302 and second flexible chain 304 can comprise a plurality of links hingedly connected together. In some embodiments, flexible portions of first flexible chain 302 and second flexible chain 304 can be in the form of a belt or similar flexible component, such as a cable. In some embodiments, first flexible chain 302 and second flexible chain 304 can be formed from steel, aluminum, titanium, copper, or any suitable metal or metal alloy (e.g., comprising sheet metal, a cable, or links). In some embodiments, first flexible chain 302 and second flexible chain 304 can be formed from a polymeric material, for example, thermoplastic polyurethane (TPU), polyethylene (PE), polyurethane (PU), high density polyethylene (HDPE), or ultra-high molecular weight polyethylene (e.g., comprising a thin sheet, a cable, or links).

[0112] In embodiments comprising first flexible chain 302 and second flexible chain 304, a thread layer or thread pattern wound by winding apparatus 200 can be removed from first and second rims 206, 214 after winding, and without cutting the thread layer or thread pattern. In some embodiments, the thread layer or thread pattern can be removed prior to consolidation, for example, prior to bonding thread lines of the thread layer or thread pattern to one another, as described with respect to FIGS. 6 and 7. In such embodiments, the first and second flexible chains 302, 304 may be pulled toward one another under tension and the thread layer or thread pattern can be stretched out again in either the same or a different shape, as desired. Alternatively, in some embodiments, various methods may be used to maintain ten-

sion in the thread layer or thread pattern when removing first and second flexible chains 302, 304 such that the thread layer or thread pattern maintains its shape and characteristics. For example, in some embodiments, pins or gears on a consolidation device (e.g., a flat plate or consolidation frame such as consolidation frame 702 shown in FIG. 7) can engage apertures in first and second flexible chains 302, 304 as they are removed from first and second rims 206, 214, thus maintaining the distance between first and second flexible chains 302, 304 after they are removed from first and second rims 206, 214. In alternative embodiments, a flexible sheet (e.g., flexible sheet 314) may be used in addition to or instead of first and second flexible chains 302, 304 to maintain the distance between anchor points 208 and anchor points 216, as described herein.

[0113] In some embodiments, the thread layer or thread pattern can be removed after consolidation. In some embodiments, the thread layer or thread pattern can be cut to remove the thread layer or thread pattern from winding apparatus 200.

[0114] As shown in FIG. 3, first flexible chain 302 can comprise a first end 306 and a second end 308. In some embodiments, first end 306 can be removably coupled to second end 308, for example, when first flexible chain 302 is coupled to first rim 206. Likewise, second flexible chain 304 can comprise a first end 310 and a second end 312. In some embodiments, first end 310 can be removably coupled to second end 312, for example, when second flexible chain 304 is coupled to second rim 214. Regardless of whether first ends 306, 310 and second ends 308, 312 are coupled to one another, first ends 306, 310 and second ends 308, 312 can contact one another or be directly adjacent one another when first and second flexible chains 302, 304 are coupled to first and second rims 206, 214, respectively. In some embodiments, first ends 306, 310 and second ends 308, 312 may not be coupled to one another, and first and second flexible chains 302, 304 may only be coupled to first and second rims 206, 214.

[0115] As shown in FIG. 3 by dotted lines D and E, in some embodiments, first flexible chain 302 and second flexible chain 304 can optionally be replaced (or supported) by a single flexible sheet 314. In some embodiments, flexible sheet 314 can be sheet metal, for example, steel, aluminum, titanium, copper, or any suitable metal or metal alloy. In some embodiments, flexible sheet 314 can be formed from a polymeric material, for example, thermoplastic polyurethane (TPU), polyethylene (PE), polyurethane (PU), high density polyethylene (HDPE), or ultra-high molecular weight polyethylene. In embodiments comprising flexible sheet 314, flexible sheet 314 can be attached to and detached from first and second rims 206, 214 as described above for first and second flexible chains 302, 304. For example, flexible sheet 314 can be flexed from a linear state to a circular state and coupled to first and second rims 206, 214 to couple anchor points 208, 216 to first and second rims

206, 214. Flexible sheet 314 can be detached from first and second rims 206, 214 and returned to a linear state, for example, after a thread layer or thread pattern has been wound on winding apparatus 200.

[0116] In some embodiments, flexible sheet 314 can comprise anchor points 208, 216. In some embodiments, anchor points 208, 216 can be integrally formed with remaining portions of flexible sheet 314. In some embodiments, anchor points 208, 216 can be formed separately and later attached to remaining portions of flexible sheet 314. In some embodiments, anchor points 208, 216 can be coupled to flexible sheet 314 using first and second flexible chains 302, 304.

[0117] In embodiments comprising flexible sheet 314, when flexible sheet 314 is flexed and attached to first and second rims 206, 214, continuous thread 234 can be wound around flexible sheet 314 such that continuous thread 234 contacts flexible sheet 314. For example, in some embodiments, continuous thread 234 can be wound around the full perimeter of flexible sheet 314 (when attached to first and second rims 206, 214) between first rim 206 and second rim 214 without being wound around any of anchor points 208 or 216. In such embodiments, continuous thread 234 can be wound around the full perimeter of flexible sheet 314 one or more times before being wound around an anchor point 208, 216. In such embodiments, the angle of winding of continuous thread 234 measured relative to first rim 206 or second rim 214 can be as low as 1 degree. In some embodiments, flexible sheet 314 can comprise a textured surface configured to prevent continuous thread 234 from slipping on flexible sheet 314 during winding.

[0118] FIG. 4 illustrates a thread layer 410 in progress on winding apparatus 200, according to some embodiments. For clarity, thread guide 226 and thread guide support 228 are omitted from FIG. 4. However, it should be understood that these features can be included with the components shown in FIG. 4.

[0119] FIG. 4 shows a continuous thread 402 being wound around anchor points 208 and 216. Continuous thread 402 can be the same as continuous thread 234. FIG. 4 also illustrates the various winding patterns that can be effected using winding apparatus 200. For example, FIG. 4 shows a first winding pattern 404, a second winding pattern 406, and a third winding pattern 408.

[0120] As shown in FIG. 4, first winding pattern 404 can comprise thread lines 412 that each extend from an anchor point 208 to an opposite adjacent anchor point 216 (or vice-versa). As used herein, a second anchor point described as "opposite adjacent" to a first anchor point means that the second anchor point lies on an opposite rim from the first anchor point and is the first anchor point's first or second closest anchor point neighbor on the opposite rim. For example, an anchor point 216 is an opposite adjacent anchor point to an anchor point 208 if the anchor point 216 is one of the two anchor points 216 closest to the anchor point 208. An anchor point will typically have two "opposite adjacent" anchor point

neighbors. In some embodiments, an anchor point's first and second closest opposite adjacent anchor points may be located at the same distance from the anchor point.

[0121] In some embodiments, for example, in the "simultaneous mode," first winding pattern 404 can be effected by first and second rims 206, 214 being rotated at a constant rate and in a constant direction while thread guide 226 is caused to reverse direction at regular time intervals. In some embodiments, for example, in the "consecutive" or "partially consecutive mode," first winding pattern 404 can be effected by first and second rims 206, 214 being rotated in a single rotation direction and stopped at regular rotation distance intervals, while thread guide 226 is caused to pass between adjacent anchor points 208, 216 while first and second rims 206, 214 are stationary.

[0122] As shown in FIG. 4, second winding pattern 406 can comprise thread lines 412 that each extend from an anchor point 208 to an opposite distal anchor point 216 (or vice-versa). As used herein, a second anchor point described as "opposite distal" to a first anchor point means that the second anchor point lies on an opposite rim as the first anchor point and is not the first anchor point's first or second closest anchor point neighbor on the opposite rim. For example, an anchor point 216 is an opposite distal anchor point to an anchor point 208 if the anchor point 216 is not one of the two anchor points 216 closest to the anchor point 208. An anchor point will typically have many "opposite distal" anchor point neighbors located at varying distances from the anchor point.

[0123] As further shown in FIG. 4, second winding pattern 406 can comprise thread lines that extend at an angle measured relative to one another and at an angle measured relative to first rim 206 or second rim 214. The angles of thread lines 412 in second winding pattern 406 relative to first rim 206, second rim 214, and one another can be adjusted by increasing or decreasing the constant rate at which first and second rims 206, 214 are rotated in the simultaneous mode or the extent first and second rims 206, 214 rotate while thread guide 226 is between the planes of first and second rims 206, 214 in the consecutive/partially consecutive modes.

[0124] In some embodiments, for example, in the simultaneous mode, second winding pattern 406, like first winding pattern 404, can be effected by first and second rims 206, 214 being rotated at a constant rate and in a constant direction while thread guide 226 is caused to reverse direction at regular time intervals. However, the constant rate of rotation of first and second rims 206, 214 can be higher, relative to the rate of translation of thread guide 226, than the constant rate of rotation used to produce first winding pattern 404. In some embodiments, for example, in the consecutive or partially consecutive mode, second winding pattern 406, like first winding pattern 404, can be effected by first and second rims 206, 214 being rotated in a single rotation direction and occasionally stopped, while thread guide 226 is caused to pass between adjacent anchor points 208, 216 while

first and second rims 206, 214 are stationary. However, first and second rims 206, 214 can be rotated a greater extent while thread guide 226 is between the planes of first and second rims 206, 214 as compared to the corresponding extent of rotation while thread guide 226 is between the planes of first and second rims 206, 214 during the production of first winding pattern 404.

[0125] As shown in FIG. 4, third winding pattern 408 can comprise thread lines 412 that each extend from an anchor point 208 to an opposite distal anchor point 216 (or vice-versa). As further shown in FIG. 4, third winding pattern 408 can comprise thread lines 412 that extend parallel to one another and at an angle measured relative to first rim 206 or second rim 214.

[0126] In some embodiments, for example, in the continuous mode, third winding pattern 408 can be effected by the following combination of movement patterns of thread guide 226 and first and second rims 206, 214: thread guide 226 is caused to reverse direction at regular time intervals; first and second rims 206, 214 are rotated at the same rotation rate(s) between each rotation direction reversal; first and second rims 206, 214 are caused to reverse rotation direction at alternating regular time intervals, where each rotation time interval is followed by a rotation time interval different from the previous rotation time interval (but the same as the second to last rotation time interval). Accordingly, the winding of continuous thread 402 can progress around first rim 206 and second rim 214 while thread lines 412 of third winding pattern 408 run parallel to one another. In some embodiments, for example, in the consecutive or partially consecutive mode, third winding pattern 408 can be effected by the following combination of movement patterns of thread guide 226 and first and second rims 206, 214: first and second rims 206, 214 are caused to reverse rotation direction at alternating regular rotation distance intervals, where each rotation distance interval is followed by a rotation distance interval different from the previous rotation distance interval (but the same as the second to last rotation distance interval); thread guide 226 is caused to pass between adjacent anchor points 208, 216 while first and second rims 206, 214 are stationary, which can be within or at the endpoints of a rotation distance interval.

[0127] The angle of thread lines 412 in third winding pattern 408 measured relative to first rim 206 or second rim 214 can be adjusted by increasing or decreasing at least one of the rotation rate(s) of first and second rims 206, 214 between rotation direction reversals, the alternating regular time intervals, or the alternating regular rotation distance intervals.

[0128] It should be understood that first, second, and third winding patterns 404, 406, and 408 are example winding patterns intended to illustrate methods of producing various winding patterns to achieve a wound material (thread layer or thread pattern) having desired characteristics. Any method described for selecting an angle of any thread line 412 measured relative to first rim 206 or

second rim 214 and relative to other thread lines 412 in any of first, second, and third winding patterns 404, 406, and 408 can be used in combination with other described methods to obtain any desired winding pattern. For example, an angle of any thread line 412 measured relative to first rim 206 or second rim 214 and relative to other thread lines 412 can be controlled by varying one or more of the following conditions: i) rate of rotation of first and second rims 206, 214; ii) direction of rotation of first and second rims 206, 214; iii) rate of translation of thread guide 226; and iv) direction of translation of thread guide 226.

[0129] For example, in some embodiments, such as when support 218 comprises a drum, continuous thread 402 can be wound around the full perimeter of the drum between first rim 206 and second rim 214 without being wound around any of anchor points 208 or 216. In such embodiments, continuous thread 402 can be wound around the full perimeter of the drum one or more times before being wound around an anchor point 208, 216. In such embodiments, the angle of winding of continuous thread 402 measured relative to first rim 206 or second rim 214 can be as low as 1 degree. In some embodiments, support 218 (e.g., a drum) can comprise a textured surface configured to prevent continuous thread 402 from slipping on support 218 during winding.

[0130] In some embodiments in which support 218 comprises a drum, winding apparatus 200 may comprise no anchor points 208, 216. In such embodiments, continuous thread 402 (or multiple continuous threads 402 guided by multiple thread guides 226 or a single thread guide 226) can be wound around support 218 and affixed to support 218. For example, in some embodiments, support 218 can be heated and the continuous thread(s) 402 can be affixed to support 218 by the continuous thread(s) 402 softening and adhering to support 218. A similar process may be used when winding apparatus 200 comprises anchor points 208, 216.

[0131] For ease of illustration, FIG. 4 shows continuous thread 402 being wound around anchor points 208, 216 on only portions of first and second rims 206, 214. However, in some embodiments, continuous thread 402 can be wound around any subset or all of anchor points 208, 216 on first and second rims 206, 214. In some embodiments, continuous thread 402 can be wound around all or some of anchor points 208, 216 but may not cross a line defined by the meeting point of first end 306 and second end 308 of first flexible chain 302 and the meeting point of first end 310 and second end 312 of second flexible chain 304. In such embodiments, a thread layer 410 (or thread pattern) comprising continuous thread 402 can be removed from first and second rims 206, 214 by detaching first and second flexible chains 302, 304 from first and second rims 206, 214, without cutting any part of the thread layer 410 (or thread pattern). The "meeting points" can be points where the first and second ends of first and second flexible chains 302, 304 touch or couple together, or points between the

first and second ends if a space exists between the first and second ends.

[0132] For ease of illustration, FIG. 4 shows a single thread layer 410 wound around anchor points 208, 216. However, winding apparatus 200 can be used to wind multiple thread layers around anchor points 208, 216 to create a thread pattern spanning the space between first rim 206 and second rim 214. The thread pattern can comprise multiple continuous threads wound according to the methods described above for continuous thread 402.

[0133] FIG. 5 illustrates a wound material 502 produced using winding apparatus 200 according to some embodiments. Wound material 502 can be a thread layer (for example, thread layer 410 wound using continuous thread 402) or a thread pattern comprising multiple thread layers wound using multiple continuous threads, according to the methods described above.

[0134] Various features of thread layers and thread patterns that can be produced using winding apparatus 200 will now be described with reference to FIGS. 4-5. Thread layers as described herein (for example, thread layers 108, 110, 112, 410) can each comprise a thread border 114, 414 defined by the space in which thread lines of the thread layer are located. The thread border 114, 414 for a thread layer is the space in which thread lines of the thread layer are located after the thread layer is removed (for example, cut) from anchor points used to wind the thread layer. A plurality of thread lines within a thread pattern can comprise a first end located at a first side of the thread border 114, 414 and a second end located at a second side of the thread border 114, 414. For example, thread lines 412 of thread layer 410 can comprise a first end 416 located at a first side of thread border 414 and a second end 418 located at a second side of thread border 414.

[0135] FIGS. 4-5 illustrate a thread border 414 for a thread layer 410 or thread pattern (wound material 502 may be a thread pattern). For a thread pattern comprising a plurality of thread layers, the thread pattern can comprise a thread pattern border 414 defined by the space occupied by the combination of the individual thread layers.

[0136] As used herein, sides of a perimeter edge or a border refer to top, bottom, right, and left sides of a shape defined by the edge or border. The top, bottom, right, and left sides of the shape are located to the top, bottom, right, and left of a geometrical center of the shape. So, a perimeter edge or border will have a top side defined by the portion of the edge located above the geometrical center, a bottom side defined by the portion of the edge located below the geometrical center, a right side defined by the portion of the edge or border located to the right of the geometrical center, and a left side defined by the portion of the edge or border located to the left of the geometrical center. The top and bottom sides do not overlap. Similarly, the left and right sides do not overlap. The top and left sides overlap at the portion of the edge or

border located to the top-left of the geometrical center. The top and right sides overlap at the portion of the edge or border located to the top-right of the geometrical center. The bottom and left sides overlap at the portion of the edge or border located to the bottom-left of the geometrical center. The bottom and right sides overlap at the portion of the edge or border located to the bottom-right of the geometrical center. For purposes of determining the shape defined by the perimeter edge or border, the material having the edge or border is laid in a flat configuration with no portion of the material overlapping itself.

[0137] As used herein, a first side of a perimeter edge or border can be the top, bottom, right, or left side of the edge or border and a second side of the perimeter edge or border can be the top, bottom, right, or left side of the edge or border, provided that the first and second sides are not the same side. Similarly, a third side of a perimeter edge or border can be the top, bottom, right, or left side of the edge or border and a fourth side of the edge or border can be the top, bottom, right, or left side of the edge or border, provided that the third and fourth sides are not the same, and are not the same as the first or second sides.

[0138] In some embodiments, one or more thread layers (for example, thread layers 108, 110, 112, 410) can comprise a thread defining (i) a plurality of thread lines each extending from a first side of a thread border to a second side of the thread border and crossing over each other at points of overlap between two or more of the thread lines, and (ii) a plurality of thread lines each extending from a third side of the thread border to a fourth side of the thread border and crossing over each other at points of overlap between two or more of the thread lines. The thread lines extending from the first side to the second side can extend continuously from the first side to the second side, and the thread lines extending from the third side to the fourth side can extend continuously from the third side to the fourth side.

[0139] Thread layer 410 comprises a continuous thread 402 wound around anchor points 208, 216. In some embodiments, anchor points 208, 216 can be different sets of anchor points around which different thread layers are wound. In some embodiments, a plurality of thread layers can wound around the same set of anchor points 208, 216. In such embodiments, separate thread layers can be wound over each other, with one thread layer disposed over one or more other thread layers.

[0140] Continuous thread 402 can be wrapped around a plurality of anchor points 208, 216 and comprises a plurality of thread lines 412. Each thread line 412 extends between two respective anchor points 208, 216.

[0141] Continuous thread 402 can be wrapped around a plurality of anchor points 208, 216 in tension such that individual thread lines 412 are in tension when wrapped around anchor points 208, 216. As noted above, in some embodiments, the tension at which thread lines 412 are wound can range from 0 centinewtons (cN) to 25 cN,

including subranges. For example, in some embodiments, the tension at which thread lines 412 are wound can range from 0.01 cN to 25 cN, from 0.1 cN to 25 cN, from 1 cN to 25 cN, from 5 cN to 25 cN, from 10 cN to 25 cN, or from 15 cN to 25 cN. In some embodiments, the tension at which thread lines 412 are wound can range from 2 cN to 10 cN. In some embodiments, the tension at which thread lines 412 are wound can range from 2 cN to 6 cN. In such embodiments, the tension can create the compressive force applied along thread lines as described herein. In some embodiments, the compressive force can range from 0 cN to 25 cN, including subranges. For example, in some embodiments, the compressive force can range from 0.01 cN to 25 cN, from 0.1 cN to 25 cN, from 1 cN to 25 cN, from 5 cN to 25 cN, from 10 cN to 25 cN, or from 15 cN to 25 cN. In some embodiments, the compressive force can range from 2 cN to 10 cN. In some embodiments, the compressive force can range from 2 cN to 6 cN.

[0142] Thread lines 412 directly bonded to surface 104 of base layer 102 can apply a compressive force on the surface 104 along an axis extending from a first end 416 to second end 418 of the thread line 412. This compressive force can be the result of the thread lines 412 being wound around anchor points under tension and being directly bonded to the surface while still under tension.

[0143] In some embodiments, different thread lines 412 can be wrapped around anchor points 208, 216 at different tensions to impart desired characteristics to thread layer 410. In some embodiments, a first set of thread lines 412 can be wound at a first tension in any of the centinewton ranges described above and a second set of thread lines 412 can be wound at a second tension in any of the centinewton ranges described above, where the first tension is greater than or less than the second tension. In some embodiments, the first tension can be at least 0.5 cN greater than or less than the second tension. In some embodiments, the first tension can be at least 1 cN greater than or less than the second tension.

[0144] In embodiments where different thread lines 412 are wound at different tensions, different thread lines 412 of thread layer 410 will be under different values of tension in thread layer 410. The tension of thread lines 412 can be utilized to control characteristics of thread layer 410, and therefore an article of apparel comprising thread layer 410.

[0145] In some embodiments, after winding continuous thread 402 around anchor points but before bonding thread lines 412 to one another and/or to thread lines of another thread layer (discussed herein), first rim 206 and/or second rim 214 of winding apparatus 200 can be rotated independently from one another to adjust the tension and/or structure of wound material 502. For example, in some embodiments, first rim 206 can be rotated in a desired direction and for a desired rotation distance while second rim 214 is stationary, or vice-versa. In some embodiments, first rim 206 and second rim 214 can be rotated in opposing directions each for a desired rotation

distance.

[0146] The number of thread lines 412 for thread layer 410 fixed at an anchor point 208, 216 is defined by the "thread line communication number" of an anchor point 208, 216. As used herein, "thread line communication number" means the number of thread lines extending from an anchor point to different anchor points. Two thread lines extending between the same two anchor points (i.e., overlaying thread lines) only counts as "1" for purposes of calculating a thread line communication number for the anchor points. For example, a thread line communication number of five means that an anchor point has five thread lines extending from it with each of the five thread lines leading to another, different anchor point. As another example, a thread line communication number of six means that an anchor point has six thread lines extending from it with each of the six thread lines leading to another, different anchor point.

[0147] Similarly, the number of thread lines fixed at an anchor point 208, 216 for a thread pattern comprising a plurality of thread layers is defined by the "thread line communication number" of an anchor point 208, 216 for the thread pattern. For a thread pattern, the "thread line communication number" of an anchor point 208, 216 is the total number of thread lines, for the plurality of layers, extending from an anchor point to different anchor points.

[0148] Anchor points 208, 216 can have a thread line communication number of "X" or more for a thread layer or a thread pattern. In some embodiments, two or more respective anchor points 208, 216 can have a thread line communication number of "X" or more. In some embodiments, all the anchor points 208, 216 for a thread layer or a thread pattern can have a thread line communication number of "X" or more. "X" can be, for example, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25, 30, 35, 40, 45, or 50, within a range having any two of these values as end points. For example, in some embodiments "X" can be in a range of 2 to 50, 3 to 50, 4 to 50, 5 to 50, 6 to 50, 7 to 50, 8 to 50, 9 to 50, 10 to 50, 15 to 50, 20 to 50, 25 to 50, 30 to 50, 35 to 50, 40 to 50, or 45 to 50. In some embodiments, "X" can be greater than 50. In some embodiments, "X" can range from 2 to 100, 10 to 100, 20 to 100, 10 to 200, 20 to 200, 50 to 200, 10 to 300, 20 to 300, or 50 to 300.

[0149] A thread layer, for example thread layer 410, can comprise any suitable number of thread lines. In some embodiments, a thread layer can comprise 10 or more thread lines. In some embodiments, a thread layer can comprise 20 or more thread lines. In some embodiments, a thread layer can comprise 50 or more thread lines. In some embodiments, a thread layer can comprise 100 or more thread lines. In some embodiments, a thread layer can comprise 200 or more thread lines. In some embodiments, a thread layer can comprise 300 or more thread lines. In some embodiments, a thread layer can comprise 500 or more thread lines. In some embodiments, a thread layer can comprise a number of thread lines in a range of 10 to 300. For example, a thread layer can comprise 10 to 300, 50 to 300, 100 to 300, or 150 to

300 thread lines. In some embodiments, a thread layer can comprise 10 to 500 thread lines. In some embodiments, a thread layer can comprise 100 to 500 thread lines. In some embodiments, a thread layer can comprise 100 to 1000 thread lines.

[0150] In some embodiments, thread lines 412 can be bonded at anchor points 208, 216. In such embodiments, thread lines 412 can be bonded at anchor points 208, 216 via an adhesive, a bonding layer, thermal (conductive or convective) heat (for example, in a heat press or oven), IR (infrared) heating, laser heating, microwave heating, steam, a mechanical fastener (for example, a clip), hook and loop fasteners, needle-punching, hydro-entanglement, ultrasonic/vibratory entanglement, felting, knotting, chemical bonding with a catalyst of biomaterial, adhesive spraying (for example, CNC adhesive spray deposition), or by pushing one thread line through the other thread line(s).

[0151] In some embodiments, thread lines 412 can be directly bonded together at anchor points 208, 216. In some embodiments, thread lines 412 can be directly bonded together at anchor points 208, 216 via a polymeric material of continuous thread 402. For example, heat and/or pressure can be applied to directly bond thread lines 412 at anchor points 208, 216. In embodiments where heat and/or pressure is utilized to directly bond the polymeric material of thread lines 412, the thread lines 412 can be thermally fused together at one or more anchor points 208, 216. In embodiments comprising direct bonding of thread lines 412 at anchor points 208, 216, thread lines 412 can be directly bonded at anchor points 208, 216 without the use of an adhesive or bonding layer.

[0152] In some embodiments, thread lines 412 can be bonded together via a bonding layer. In some embodiments, thread lines 412 can be bonded together at anchor points 208, 216 via a bonding layer. In such embodiments, the bonding layer can be, for example, a laminated layer, an adhesive layer, a stitched layer, a cured layer, a screen-printed layer, or a blown fiber layer. In some embodiments, the blown fiber layer can comprise polymeric fibers that can bond thread lines 412.

[0153] In some embodiments, thread lines 412 can be bonded together without the use of a bonding layer. For example, in some embodiments, thread lines 412 can be directly bonded together via, for example, but not limited to, direct local bonding via material(s) of thread lines 412, needle punching, hydro-entanglement, and ultrasonic/vibratory entanglement.

[0154] In some embodiments, thread lines 412 can be bonded at points where two or more thread lines 412 overlap in thread layer 410 (i.e., intersection points 420). Thread lines 412 can be bonded at intersection points 420 via an adhesive, a bonding layer, thermal (conductive or convective) heat (for example, in a heat press or oven), IR (infrared) heating, laser heating, microwave heating, steam, a mechanical fastener (for example, a clip), hook and loop fasteners, needle-punching, hydro-

entanglement, ultrasonic/vibratory entanglement, felt-ing, knotting, chemical bonding with a catalyst of biomaterial, adhesive spraying (for example, CNC adhesive spray deposition), or by pushing one thread line through the other thread line(s). Intersection points 420 for thread lines can be referred to as "overlap points" or "points of overlap."

[0155] In some embodiments, thread lines 412 can be directly bonded together at intersection points 420. In some embodiments, thread lines 412 can be directly bonded together at intersection points 420 via the polymeric material of continuous thread 402. In embodiments comprising direct bonding of thread lines 412 at intersection points 420, thread lines 412 can be bonded at intersection points 420 without the use of an adhesive or bonding layer. For example, heat and/or pressure can be applied to thread layer 410 to directly bond thread lines 412 at intersection points 420. In embodiments where heat and/or pressure is utilized to directly bond the polymeric material of thread lines 412, the thread lines 412 can be thermally fused together at one or more intersection points 420.

[0156] In some embodiments, a bonding layer can bond thread lines 412 together at a plurality of intersection points 420 within thread layer 410. In such embodiments, the bonding layer can be, for example, a laminated layer, an adhesive layer, a stitched layer, a cured layer, a screen-printed layer, or a blown fiber layer comprising polymeric fibers that can bond thread lines 412.

[0157] In some embodiments, continuous thread 402 can comprise overlaying thread lines 412. As used herein, "overlaying thread lines" means two or more thread lines that follow the same path between two respective anchor points. Overlaying thread lines need not be overlaid directly over each other. Two or more thread lines are considered overlaying as long as they extend between the same two anchor points.

[0158] In some embodiments, the thread lines 412 of thread layer 410 may not be woven or knitted together. In such embodiments, thread lines 412 can be referred to as "non-woven" and "non-knitted" thread lines. In some embodiments, the thread lines 412 of thread layer 410 may not be embroidered threads stitched to a base layer. In such embodiments, thread lines 412 may be referred to as "non-embroidered" thread lines.

[0159] In some embodiments, continuous thread 402 can be a polymer thread. As used herein, "polymer thread" means a thread composed at least in part of a polymeric material. In some embodiments, a polymer thread can be composed entirely of one or more polymeric materials. In some embodiments, a polymer thread can comprise a polymeric material coated around a core (which may or may not be composed of a polymeric material). In such embodiments, the core can be encapsulated by the coating material. In some embodiments, a polymer thread can comprise a non-polymer core coated, covered, or encapsulated with a polymeric material. In some embodiments, a polymer thread can comprise a

polymer core coated, covered, or encapsulated with a non-polymeric material. In some embodiments, a polymer thread can be a braided thread with one or more braids composed of a polymeric material. In some embodiments, the polymeric material(s) of a polymer thread can be thermoplastic material(s). In some embodiments, continuous thread 402 can be a thread coated with an activatable agent, for example a heat activated adhesive or a UV-activated adhesive. In some embodiments, a CNC machine for winding a continuous thread 402 with an activatable agent coating can comprise a robotic arm for activating the coating as continuous thread 402 is being wound around anchor points 208, 216. In some embodiments, the coating can be activated by thread guide 226.

[0160] Suitable polymeric materials for polymer threads discussed herein comprise, but are not limited to, thermoplastic polyurethane (TPU), a rubber, and silicone. In some embodiments, the TPU can be recycled TPU. In some embodiments, the polymeric material can be a photo-reactive (infrared or ultraviolet light reactive) polymeric material, such as a photo-reactive TPU. In some embodiments, the polymeric material can be soluble (for example, water-soluble). In embodiments comprising polymer threads with a coated core, suitable materials for the core comprise, but are not limited to, polyester, nylon, ultra-high molecular weight polyethylene (for example, DYNEEMA® (a type of ultra-high molecular weight polyethylene)), carbon fiber, KEVLAR® (a type of para-aramid), bioengineered woven, knit or layered materials (for example, synthetic spider silk), woven, knit or layered plant based materials, cotton, wool, and natural or artificial silk. In some embodiments, polymer threads can be thermoplastic polyurethane coated polyester threads. In some embodiments, continuous thread 402 can be a non-polymer thread composed of non-polymer materials, such as carbon fiber, cotton, wool, or silk. In some embodiments, continuous thread 402 can be a thread composed of a biomaterial, such as mango yarn or bio-silk. In some embodiments, polymer threads can be a thermoplastic melt yarn, polymer yarn with non-melt core, and other similar types of yarn.

[0161] In some embodiments, the polymeric material for polymer threads can comprise a melting temperature in a range of greater than or equal to 110 °C to less than or equal to 150 °C. In such embodiments, the polymeric material can be referred to as a "low melting temperature polymeric material."

[0162] In some embodiments, continuous thread 402 can be a plied thread. In some embodiments, the plied thread can be plied while winding continuous thread 402. For example, winding apparatus 200 can ply the thread using thread from a plurality of thread spools. In some embodiments, the plied thread can be a pre-plied thread spooled around a thread spool.

[0163] In some embodiments, continuous thread 402 of thread layer 410 can have a denier in the range of from

1 denier to 3000 denier, including subranges. For example, continuous thread 402 can have a denier of 1, 10, 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2500, or 3000 denier, or within any range having any two of these values as endpoints. For example, in some embodiments, continuous thread 402 can have a denier in the range of from 10 denier to 2500 denier, from 50 denier to 2000 denier, from 100 denier to 1900 denier, from 200 denier to 1800 denier, from 300 denier to 1700 denier, from 400 denier to 1600 denier, from 500 denier to 1500 denier, from 600 denier to 1400 denier, from 700 denier to 1300 denier, from 800 denier to 1200 denier, from 900 denier to 1100 denier, or from 900 denier to 1000 denier.

[0164] Thread patterns as described herein can comprise any number of thread layers. For example, a thread pattern can comprise two or more, three or more, four or more, five or more, six or more, seven or more, eight or more, nine or more, ten or more, fifteen or more, or twenty or more thread layers. For example, a thread pattern can comprise thread layer 410 and additional thread layers wound using winding apparatus 200.

[0165] Like continuous thread 402, continuous threads for other thread layers can comprise a plurality of thread lines wound around and extending between two respective anchor points. In some embodiments, continuous threads of different thread layers can be the same thread material. In some embodiments, continuous threads of different thread layers can be composed of different thread materials. In such embodiments, the materials for different continuous threads in a thread pattern can be selected to provide targeted characteristics to areas of a thread pattern, and therefore an article of apparel. In some embodiments, the denier of continuous threads in different thread layers within a thread pattern can be selected to provide varying degrees of a characteristic (for example, strength or stretchability) to different areas of the thread pattern.

[0166] In embodiments comprising a thread pattern with a plurality of thread layers, the plurality of thread layers can be layered over each other. For example, thread layer 410 can define a first layer of a thread pattern and a second thread layer wound using winding apparatus 200 can define a second layer of the thread pattern. Different thread layers of a thread pattern can be disposed over each other in areas of overlap between the two thread layers. For example, a first thread layer can be disposed over second thread layer, or vice versa, in areas of overlap between the two thread layers.

[0167] In embodiments comprising a thread pattern with a plurality of thread layers, the plurality of thread layers can be bonded to each other in the thread pattern. In some embodiments, one or more of the layers can be directly bonded to each other via the polymeric material of a continuous thread defining thread lines for at least one of the layers. In some embodiments, one or more of the layers can be bonded via a bonding layer. In such embodi-

ments, the bonding layer can be, for example, a laminated layer, an adhesive layer, a stitched layer, a cured layer, a screen-printed layer, or a blown fiber layer.

[0168] In some embodiments, one or more thread layers of a thread pattern can serve to bond other thread layers of the thread pattern together. In such embodiments, these one or more thread layers can be wound using a polymeric thread, which when heated, bonds other layers of the thread pattern together at anchor points and/or intersection points between continuous threads. For example, in a thread pattern comprising three thread layers, one of the three thread layers (for example, the middle thread layer) can be wound using a polymeric thread that serves to bond all three thread layers together. In some embodiments, one or more thread layers of a thread pattern can be defined by a wound continuous thread coated or impregnated with an adhesive. In some embodiments, the adhesive can be activated with the application of heat. In some embodiments, the adhesive can be a dissolvable adhesive that, when contacted with a solvent, such as water, fully or partially dissolves to bond thread layers together.

[0169] FIG. 6 illustrates a method of consolidating wound material 502 by bonding thread lines within wound material 502 to one another according to some embodiments. In some embodiments, first and second flexible chains 302, 304 and/or flexible sheet 314 can be detached from first and second rims 206, 214, and wound material 502 can be laid flat. In some embodiments, a consolidation sheet 602 can be laid over wound material 502 and the combination of consolidation sheet 602 and wound material 502 can be pressed and heated. In some embodiments, consolidation sheet 602 can comprise silicone. In some embodiments, the combination of consolidation sheet 602 and wound material 502 can be pressed and heated using a heat press. In such embodiments, a silicone consolidation sheet can prevent wound material 502 from adhering to the heat press when pressed. Furthermore, multiple consolidation sheets 602 and wound material 502 layers can be stacked to simultaneously press and heat multiple wound materials 502, without the wound material 502 layers adhering to one another or the heat press.

[0170] In some embodiments, the heat press can apply pressure and heat to wound material 502 to bond continuous thread(s) at locations of intersection points between thread lines. In some embodiments, the heat press can provide heat at a predetermined temperature equal to or above the melting point of polymeric material(s) of polymer thread(s) of wound material 502. In some embodiments, the heat press can provide heat at a predetermined temperature below the melting point of polymeric material(s) of polymer thread(s) of a thread layer or thread pattern, but high enough to cause the polymeric material(s) to bond (fuse) together, or to other materials of the wound material 502.

[0171] Heat can be applied to wound material 502 in a heat press in one or more ways, such as but not limited to,

radio frequency heat sealing (welding), high frequency heat sealing (welding), infrared welding, and steaming. Heat transfer between wound material 502 and a heat press can be via conduction and/or convection. In some embodiments, heat can be applied to a single outer surface of wound material in the heat press. In some embodiments, heat can be applied to both outer surfaces of wound material 502 in the heat press.

[0172] In some embodiments, heat can be uniformly applied to wound material 502 within the heat press. In such embodiments, the temperature at which wound material 502 is consolidated within the heat press can be substantially the same across all portions of wound material 502. In some embodiments, heat can be non-uniformly applied to wound material 502 within the heat press. In such embodiments, the temperature at which wound material 502 is consolidated within the heat press is different for different portions and/or regions of wound material 502. By varying the bonding temperature of different portions and/or regions of wound material 502 in the heat press, characteristics of wound material 502 in different portions and/or regions of an article of apparel can be varied.

[0173] While bonding can be implemented using a heat press as described above, bonding can also be implemented without a heat press, for example, using radio frequency (RF) heating or steam heating alone. Accordingly, wound material 502 may just be heated to effect consolidation, with no pressure being applied.

[0174] FIG. 7 illustrates another method of consolidating wound material 502 according to some embodiments. In some embodiments, first and second flexible chains 302, 304 and/or flexible sheet 314 can be detached from first and second rims 206, 214, and then reattached to another structure that maintains the original 3D shape of wound material 502. For example, first and second flexible chains 302, 304 and/or flexible sheet 314 can be attached to a consolidation frame 702. In some embodiments, consolidation frame 702 can be a cylinder. In some embodiments, consolidation frame 702 can be shaped to mold wound material 502 into a desired shape. For example, consolidation frame 702 can comprise a bulge or depression on a surface of consolidation frame 702 that contacts wound material 502. In some embodiments, consolidation frame 702 can be solid. In some embodiments, consolidation frame 702 can be hollow.

[0175] Regardless of the shape or construction of consolidation frame 702, consolidation frame 702 can provide stiffness such that tension on thread lines of wound material 502 does not pull first flexible chain 302 and second flexible chain 304 together, resulting in the decoupling of thread lines from anchor points on first and second flexible chains 302, 304. In some embodiments, consolidation frame 702 can comprise a surface on which wound material 502 can be pressed and heated. A heat press may be applied to consolidate wound material 502 on consolidation frame 702 according to any of the methods described above with respect to FIG. 6. In some

embodiments, a consolidation sheet 602 can be placed between wound material 502 and consolidation frame 702.

[0176] As noted above for FIG. 6, while the method illustrated in FIG. 7 may be implemented using a heat press, the method may also be implemented without a heat press, for example, using RF heating or steam heating alone. Accordingly, wound material 502 may just be heated to effect consolidation, with no pressure being applied, while wound material 502 is supported by consolidation frame 702.

[0177] While FIGS. 6-7 depict consolidation of wound material 502 after removal from first and second rims 206, 214, in some embodiments, consolidation of wound material 502 can be performed while wound material 502 is coupled to first and second rims 206, 214 via first and second flexible chains 302, 304 and/or flexible sheet 314. For example, wound material 502 can be consolidated using RF heating, steam heating, infrared (IR) heating, laser heating, microwave heating, steam, chemical bonding with a catalyst of biomaterial, adhesive spraying (for example, CNC adhesive spray deposition), or any other method disclosed herein, while wound material 502 is coupled to first and second rims 206, 214 via first and second flexible chains 302, 304 and/or flexible sheet 314. In some embodiments, consolidation frame 702 can comprise first and second rims 206, 214 and support 218. In some of such embodiments, these components can be separated from the remaining components of winding apparatus 200 and moved to a different location for consolidation of wound material 502. In some of such embodiments, consolidation can be performed without separating first and second rims 206, 214 and support 218 from the remaining components of winding apparatus 200.

[0178] In some embodiments, winding apparatus 200 may not comprise first or second flexible chains 302, 304 or flexible sheet 314, such that the consolidation of wound material 502 is performed without removing wound material from first and second rims 206, 214.

[0179] FIG. 8 illustrates a winding assembly 800 according to some embodiments. Winding assembly 800 can comprise a plurality of winding apparatuses 200, for example, winding apparatus 200a, winding apparatus 200b, winding apparatus 200c, and winding apparatus 200d. In some embodiments, the plurality of winding apparatuses 200 can be supported by a shared frame 802.

[0180] While FIG. 8 shows four winding apparatuses 200 supported by frame 802, frame 802 can support fewer or more winding apparatuses 200, such as one, two, three, five, six, seven, eight, nine, or ten winding apparatuses 200.

[0181] FIG. 9 provides a system diagram for winding assembly 800 shown in FIG. 8 according to some embodiments. As shown in FIG. 9, in some embodiments, first actuators 224 and second actuators 230 of winding apparatuses 200 can be controlled by a single control

system 232. In such embodiments, first actuators 224 can be operationally coupled. For example, control system 232 can control a single torque generating element, for example, a motor, that is mechanically coupled to components within each of first actuator 224a, first actuator 224b, first actuator 224c, and first actuator 224d. For example, a single motor controlled by control system 232 can be coupled via one or more belts, chains, racks, or cables to support 218 of each of winding apparatuses 200. Activation of the motor can turn all of supports 218. In some embodiments, activation of the motor can turn all of supports 218 at substantially the same rotation rate and in the same rotation direction. In some embodiments, due to varying the size and/or number of gears, sheaves, or pulleys among coupled first actuators 224, activation of the motor can turn supports 218 at different rotation rates and/or in different directions.

[0182] Second actuators 230 can also be operationally coupled or can operate as a single second actuator 230. For example, control system 232 can control a single translation generating element, for example, a component of an electromechanical linear actuator, a hydraulic linear actuator, or a pneumatic linear actuator that is mechanically coupled to components within each of second actuator 230a, second actuator 230b, second actuator 230c, and second actuator 230d. For example, a single motor within an electromechanical linear actuator controlled by control system 232 can be coupled via one or more belts, chains, racks, or cables to thread guide support 228 of each of winding apparatuses 200, or via any other elements for producing linear motion from rotational motion. In some embodiments, the single translation generating element can be coupled to a single thread guide support 228 that spans all four winding apparatuses 200 and supports all of thread guides 226 of the winding apparatuses. In some embodiments, activation of the translation generating element can move all of thread guides 226 at substantially the same rate and in the same direction. In some embodiments, due to varying the size and/or number of gears, sheaves, or pulleys among coupled second actuators 230, activation of the translation generating element can move thread guides 226 at different rates and/or in different directions.

[0183] In some embodiments, first actuators 224 being operationally coupled and second actuators 230 being operationally coupled can reduce the complexity of programming required to control winding apparatuses 200. For example, a single set of instructions can be provided to control system 232 that determines winding patterns for all of winding apparatuses 200 during production of wound materials 502. Furthermore, in some embodiments, first actuators 224 being operationally coupled and second actuators 230 being operationally coupled can reduce the mechanical cost and complexity of winding assembly 800, requiring fewer components. Additionally, first actuators 224 being operationally coupled and second actuators 230 being operationally coupled can make winding assembly 800 more energy efficient,

since winding assembly 800 can comprise fewer energy-consuming components.

[0184] While the above discussion focuses on embodiments in which first actuators 224 are operationally coupled and second actuators 230 are operationally coupled, in some embodiments, first actuators 224 can be independently controlled by control system 232 and second actuators 230 can be independently controlled by control system 232. In such embodiments, a set of instructions can be provided to control system 232 for each of winding apparatuses 200 of winding assembly 800. The sets of instructions can determine winding patterns for each of winding apparatuses 200 during production of wound materials 502. Such embodiments can provide for increased customization of wound materials 502. For example, wound materials with different characteristics and properties can be produced using the same winding assembly 800.

[0185] FIG. 9B shows a system diagram for winding assembly 800 shown in FIG. 8 according to some embodiments. As shown in FIG. 9, in embodiments in which first actuators 224 are independently controlled and second actuators 230 are independently controlled, first actuators 224 and second actuators 230 of winding apparatuses 200 can be controlled by separate control systems 232. Control system 232a can control first actuator 224a and second actuator 230a, control system 232b can control first actuator 224b and second actuator 230b, control system 232c can control first actuator 224c and second actuator 230c, and control system 232d can control first actuator 224d and second actuator 230d. In some embodiments, each of control systems 232 can comprise an interface (for example, display interface 1102) on frame 802 that a user can interact with to provide instructions to the control systems 232.

[0186] FIG. 10 illustrates a method 1000 of making an article of apparel (for example, article of apparel 100) according to some embodiments.

[0187] Unless stated otherwise, the steps of method 1000 need not be performed in the order set forth herein. Additionally, unless specified otherwise, the steps of method 1000 need not be performed sequentially. The steps can be performed in a different order or simultaneously. As one example, step 1004 of method 1000 need not be performed before step 1006. Rather, step 1004 can be performed simultaneously with step 1006. As another example, step 1006 need not be performed after step 1002. Rather, step 1006 can be performed simultaneously with step 1002. As another example, step 1010 need not be performed after step 1008. Rather, step 1010 can be performed before step 1008. Further, method 1000 may not comprise all the steps illustrated. As one example, method 1000 may not comprise step 1008. As another example, method 1000 may not comprise step 1012.

[0188] Step 1002 can comprise rotating a first rim (for example, first rim 206) and a second rim (for example, second rim 214). In some embodiments, the first rim and

the second rim can be coupled together and spaced apart by a support (for example, support 218, which can, for example, be an axle). The first rim can be coupled to a first plurality of anchor points (for example, anchor points 208, which can be projections) that extend from a perimeter of the first rim. The second rim can be coupled to a second plurality of anchor points (for example, anchor points 216, which can be projections) that extend from a perimeter of the second rim.

[0189] Step 1004 can comprise dispensing a continuous thread (for example, continuous thread 234 or continuous thread 402) via a thread guide (for example, thread guide 226). In some embodiments, the continuous thread can be fixed to the first or second rim (for example, at an anchor point 208 or 216) prior to dispensing the continuous thread and winding the continuous thread around further anchor points 208, 216.

[0190] Step 1006 can comprise moving the thread guide to wind the continuous thread around projections on the first and second rims (for example, to wind the continuous thread around a plurality of the first plurality of projections and around a plurality of the second plurality of projections). As noted above, the projections can be anchor points (for example, anchor points 208, 216). In some embodiments, moving the thread guide can comprise moving the thread guide along an axis parallel to the axle (for example, and axis parallel to rotation axis A). In some embodiments, moving the thread guide can comprise moving the thread guide only along a single axis during winding of the continuous thread. In some embodiments, moving the thread guide can comprise moving the thread guide between projections of the first and second pluralities of projections (for example, as shown in FIG. 2 and illustrated by anchor points 208a-c). In some embodiments, moving the thread guide can comprise moving the thread guide while rotating the first and second rims (for example, in "simultaneous" or "partially consecutive" modes as described above). In some embodiments, moving the thread guide can comprise moving the thread guide while the first and second rims are stationary (for example, in "consecutive" or "partially consecutive" modes as describe above).

[0191] In some embodiments, method 1000 can comprise changing at least one of a rotation rate or a rotation direction of the first and second rims while moving the thread guide (for example, in "simultaneous" or "partially consecutive" modes as described above) or while the thread guide is stationary (for example, in "consecutive" or "partially consecutive" modes as described above). In some embodiments, the rotation rate and/or rotation direction can be changed using control system 232. In some embodiments, changing the rotation rate and/or rotation direction can change a winding pattern (for example, first winding pattern 404, second winding pattern 406, or third winding pattern 408) for a thread layer. In some embodiments, method 1000 can additionally or alternatively comprise changing at least one of a translation rate or a translation direction of the thread guide while

rotating the first and second rims or while the first and second rims are stationary. In some embodiments, changing the translation rate and/or translation direction can change a winding pattern for a thread layer. In some embodiments, method 1000 can comprise changing one or more of the rotation rate, rotation direction, translation rate, or translation direction while keeping one or more of the rotation rate, rotation direction, translation rate, or translation direction constant.

[0192] Step 1008 can comprise removing a first flexible chain (for example, first flexible chain 302) and a second flexible chain (for example, second flexible chain 304) from the first rim and the second rim after winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections. In such embodiments, the first flexible chain can comprise the first plurality of projections and the second flexible chain can comprise the second plurality of projections. In such embodiments, winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections can comprise not crossing the continuous thread over a line defined by the meeting point of a first end (for example, first end 306) and second end (for example, second end 308) of the first flexible chain and the meeting point of a first end (for example, first end 310) and a second end (for example, second end 312) of the second flexible chain. Alternatively, in some embodiments, winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections can comprise crossing the continuous thread over the line defined by the meeting point of the first end and second end of the first flexible chain and the meeting point of the first end and the second end of the second flexible chain, but cutting a resulting thread layer or thread pattern along the line before removing the first flexible chain and second flexible chain.

[0193] As described herein, winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections in step 1006 can form a thread layer (for example, thread layer 410) comprising a plurality of thread lines (for example, thread lines 412), with each thread line extending between one of the first plurality of projections and one of the second plurality of projections. In some embodiments, the thread layer can comprise a plurality of winding patterns. In some embodiments, the thread layer can comprise a single winding pattern.

[0194] In some embodiments, step 1006 can comprise winding multiple thread layers. In such embodiments, method 1000 can comprise winding a second continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections to form a second thread layer comprising a second plurality of thread lines, with each thread line of the second plurality of thread lines extending between one of the first plurality of projections and one of the

second plurality of projections. In some embodiments, the second thread layer can comprise a plurality of winding patterns. In some embodiments, the second thread layer can comprise a single winding pattern.

[0195] Step 1010 can comprise bonding thread lines of the plurality of thread lines to one another after removing the first and second flexible chains from the first and second rims. In some embodiments, the bonding can be performed in a 2-D, for example, by removing the first and second flexible chains from the first and second rims, laying them flat, and bonding the thread lines of the plurality of thread lines to one another by applying heat and/or pressure. In such embodiments, a consolidation sheet (for example consolidation sheet 602) can be laid over the thread layer. In some embodiments, the bonding can be performed in 3-D, for example, by removing the first and second flexible chains from the first and second rims, attaching them to a consolidation frame (for example, consolidation frame 702), and bonding the thread lines of the plurality of thread lines to one another by applying heat and/or pressure.

[0196] In some embodiments, the bonding in step 1010 can be performed without removing the first and second flexible chains from the first and second rims. In some embodiments, winding apparatus can comprise no first or second flexible chains, such that bonding the thread lines of the plurality of thread lines to one another is performed without removing the thread layer from first and second rims.

[0197] In some embodiments, bonding can be facilitated by steps 1002-1006 comprising winding a bonding continuous thread. The bonding continuous thread can be configured to attach to other continuous threads within a thread layer or thread pattern according to any of the methods described herein. In some embodiments, the bonding continuous thread can comprise a material, for example, a polymeric material as described herein, that can be softened via heat or other treatment to attach to other continuous threads within a thread layer or thread pattern. In some embodiments, the bonding continuous thread can be wound simultaneously with the continuous thread through the same thread guide 226. In such embodiments, the bonding continuous thread can remain separate from the continuous thread, while in some embodiments, the bonding continuous thread and the continuous thread can be plied together into a multifilament thread that is wound as a single thread. In some embodiments, the continuous thread can be wound into a thread layer and a second thread layer comprising the bonding continuous thread can be wound on top of the thread layer comprising the continuous thread, or vice-versa.

[0198] Step 1012 can comprise cutting the thread layer. In some embodiments, cutting the thread layer in step 1012 can be performed after removing the first and second flexible chains from the first and second rims. In some embodiments, cutting the thread layer in step 1012 can be performed before removing the first and second

flexible chains from the first and second rims. In some embodiments, the thread layer can be cut adjacent the first flexible chain and adjacent the second flexible chain (for example, along thread border 414). In some embodiments, winding apparatus can comprise no first or second flexible chains, such that cutting the thread layer is performed while the thread layer is attached to the first and second rims. In such embodiments, the thread layer can be cut adjacent the first rim and the second rim.

[0199] In some embodiments, the material produced using all or a subset of steps 1002-1012 can be added to or shaped into an article of apparel (for example, article of apparel 100). In some embodiments, shaping the material can comprise joining the material to itself at a seam. In some embodiments, adding the material produced using steps 1002-1012 to the article of apparel can comprise attaching the material to one or more additional pieces of material to form the article of apparel. In some embodiments, attaching the material to the one or more additional pieces of material can comprise seaming the material to one or more of the additional pieces of material at one or more seams. In some embodiments, the one or more of the additional pieces of material can be made using method 1000. In some embodiments, the one or more of the additional pieces of material can be a piece of material without a thread layer or thread pattern as described herein.

[0200] FIG. 11 illustrates an exemplary computer system 1100 by which embodiments, or portions thereof, can be implemented as computer-readable code, according to some embodiments. For example, aspects of the methods discussed herein can be implemented by computer system 1100 using hardware, software, firmware, tangible computer readable media having instructions stored thereon, or a combination thereof and can be implemented by one or more computer systems or other processing systems.

[0201] If programmable logic is used, such logic can execute on a commercially available processing platform or a special purpose device. One of ordinary skill in the art can appreciate that embodiments of the disclosed subject matter can be practiced with various computer system configurations, including multi-core multiprocessor systems, minicomputers, and mainframe computers, computer linked or clustered with distributed functions, as well as pervasive or miniature computers that can be embedded into virtually any device.

[0202] For instance, at least one processor device and a memory can be used to implement the above-described embodiments. A processor device can be a single processor, a plurality of processors, or combinations thereof. Processor devices can have one or more processor "cores."

[0203] Various embodiments described herein can be implemented in terms of this example computer system 1100. After reading this description, it will become apparent to a person skilled in the relevant art how to implement one or more of the embodiments using other

computer systems and/or computer architectures. Although operations can be described as a sequential process, some of the operations can in fact be performed in parallel, concurrently, and/or in a distributed environment, and with program code stored locally or remotely for access by single or multi-processor machines. In addition, in some embodiments the order of operations can be rearranged without departing from the spirit of the disclosed subject matter.

[0204] Processor device 1104 can be a special purpose or a general-purpose processor device. As will be appreciated by persons skilled in the relevant art, processor device 1104 can also be a single processor in a multi-core/multiprocessor system, such system operating alone, or in a cluster of computing devices operating in a cluster or server farm. Processor device 1104 is connected to a communication infrastructure 1106, for example, a bus, message queue, network, or multi-core message-passing scheme.

[0205] Computer system 1100 also comprises a main memory 1108, for example, random access memory (RAM), and can also comprise a secondary memory 1110. Secondary memory 1110 can comprise, for example, a hard disk drive 1112, or removable storage drive 1114. Removable storage drive 1114 can comprise a floppy disk drive, a magnetic tape drive, an optical disk drive, a flash memory, a Universal Serial Bus (USB) drive, or the like. The removable storage drive 1114 reads from and/or writes to a removable storage unit 1118 in a well-known manner. Removable storage unit 1118 can comprise a floppy disk, magnetic tape, optical disk, etc. which is read by and written to by removable storage drive 1114. As will be appreciated by persons skilled in the relevant art, removable storage unit 1118 comprises a computer usable storage medium having stored therein computer software and/or data.

[0206] Computer system 1100 (optionally) comprises a display interface 1102 (which can comprise input and output devices such as keyboards, mice, etc.) that forwards graphics, text, and other data from communication infrastructure 1106 (or from a frame buffer not shown) for display on display unit 1130.

[0207] In additional and/or alternative implementations, secondary memory 1110 can comprise other similar means for allowing computer programs or other instructions to be loaded into computer system 1100. Such means can comprise, for example, a removable storage unit 1122 and an interface 1120. Examples of such means can comprise a program cartridge and cartridge interface (such as that found in video game devices), a removable memory chip (such as an EPROM, or PROM) and associated socket, and other removable storage units 1122 and interfaces 1120 which allow software and data to be transferred from the removable storage unit 1122 to computer system 1100.

[0208] Computer system 1100 can also comprise a communication interface 1124. Communication interface 1124 allows software and data to be transferred between

computer system 1100 and external devices. Communication interface 1124 can comprise a modem, a network interface (such as an Ethernet card), a communication port, a PCMCIA slot and card, or the like. Software and data transferred via communication interface 1124 can be in the form of signals, which can be electronic, electromagnetic, optical, or other signals capable of being received by communication interface 1124. These signals can be provided to communication interface 1124 via a communication path 1126. Communication path 1126 carries signals and can be implemented using wire or cable, fiber optics, a phone line, a cellular phone link, an RF link or other communication channels.

[0209] In this document, the terms "computer program medium" and "computer usable medium" are used to generally refer to media such as removable storage unit 1118, removable storage unit 1122, and a hard disk installed in hard disk drive 1112. Computer program medium and computer usable medium can also refer to memories, such as main memory 1108 and secondary memory 1110, which can be memory semiconductors (for example, DRAMs, etc.).

[0210] Computer programs (also called computer control logic) are stored in main memory 1108 and/or secondary memory 1110. Computer programs can also be received via communication interface 1124. Such computer programs, when executed, enable computer system 1100 to implement the embodiments as discussed herein. In particular, the computer programs, when executed, enable processor device 1104 to implement the processes of the embodiments discussed here. Accordingly, such computer programs represent controllers of the computer system 1100. Where the embodiments are implemented using software, the software can be stored in a computer program product and loaded into computer system 1100 using removable storage drive 1114, interface 1120, and hard disk drive 1112, or communication interface 1124.

[0211] Embodiments described herein also can be directed to computer program products comprising software stored on any computer useable medium. Such software, when executed in one or more data processing device, causes a data processing device(s) to operate as described herein. Embodiments described herein can employ any computer useable or readable medium. Examples of computer useable mediums comprise, but are not limited to, primary storage devices (for example, any type of random access memory), secondary storage devices (for example, hard drives, floppy disks, CD ROMs, ZIP disks, tapes, magnetic storage devices, and optical storage devices, MEMS, nanotechnological storage device, etc.).

[0212] FIG. 12 illustrates winding apparatus 200 for winding and bonding continuous thread(s) according to some embodiments. The components of winding apparatus 200 la-beled in FIG. 12 can be substantially the same as the corresponding components described with respect to FIG. 2, including all the various embodiments

described.

[0213] FIG. 12 illustrates a support 218 comprising a drum comprising first and second rims 206, 214. In some embodiments, first and second rims 206, 214 can be integrally formed with the drum. In such embodiments, winding apparatus 200 can comprise no first or second flexible chains 302, 304 or flexible sheet 314. In such embodiments, anchor points 208, 216 of winding apparatus 200 may not be detachable from first and second rims 206, 214.

[0214] In some embodiments, winding apparatus 200 can comprise first and second flexible chains 302, 304 and/or flexible sheet 314. In such embodiments, anchor points 208, 216 of winding apparatus 200 can be detachable from first and second rims 206, 214 of the drum.

[0215] In some embodiments, support 218 can comprise a textured surface configured to prevent a continuous thread from slipping on support 218 during winding. In some embodiments, support 218 can be heated such that a continuous thread wound around support 218 can be bonded to other portions of the continuous thread or another continuous thread of wound material 502 during winding.

[0216] In some embodiments, as shown in FIG. 12, winding apparatus 200 can comprise a roller 1206. In some embodiments, roller 1206 can be substantially cylindrical. In some embodiments, roller 1206 can additionally or alternatively be heated such that a continuous thread wound around support 218 can be bonded to other portions of the continuous thread or another continuous thread of wound material 502 during winding via heat and/or pressure from roller 1206.

[0217] In some embodiments, winding apparatus 200 can comprise a first blade 1202 and a second blade 1204. First blade 1202 can be arranged adjacent first rim 206 and second blade 1204 can be arranged adjacent second rim 214. In some embodiments, first and second blades 1202, 1204 can cut wound material 502 (e.g., along lines 414 shown in FIG. 5) after it is wound and consolidated (e.g., thread lines of wound material 502 are bonded to one another) such that wound material 502 can be removed from support 218 and roller 1206 as a sheet. In some embodiments, first and second blades 1202, 1204 can comprise cutting wheels that rotate as support 218 rotates. In alternative embodiments, first and second blades 1202, 1204 can comprise stationary blades.

[0218] As shown in FIG. 12, in some embodiments, the rotation axes of support 218 and roller 1206 can be arranged parallel to one another. In some embodiments, the axes can be substantially perpendicular to the gravity vector. In some embodiments, support 218 and roller 1206 can be arranged such that they each are simultaneously in contact with wound material 502.

[0219] In some embodiments, support 218 and roller 1206 can comprise substantially the same diameter. In some embodiments, support 218 and roller 1206 can comprise different diameters. In some embodiments, support 218 and roller 1206 can rotate such that their

surfaces in contact with wound material 502 move at substantially the same speed.

[0220] It is to be appreciated that the Detailed Description section, and not the Summary and Abstract sections, is intended to be used to interpret the claims. The Summary and Abstract sections may set forth one or more but not all exemplary embodiments of the present invention(s) as contemplated by the inventor(s), and thus, are not intended to limit the present invention(s) and the appended claims in any way.

[0221] The present invention(s) have been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed.

[0222] The foregoing description of the specific embodiments will so fully reveal the general nature of the invention(s) that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present invention(s). Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance.

[0223] The breadth and scope of the present invention(s) should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

[0224] Further embodiments:

1. A winding apparatus for manufacturing an article of apparel, the winding apparatus comprising:

- a first rim;
- a second rim coupled to and spaced apart from the first rim, the first and second rims rotatable on a rotation axis;
- a first plurality of projections coupled to and extending from a perimeter of the first rim;
- a second plurality of projections coupled to and extending from a perimeter of the second rim;
- a thread guide configured to dispense a continuous thread, the thread guide moveable along a second axis parallel to the rotation axis;
- a first actuator configured to rotate the first and second rims; and
- a second actuator configured to move the thread guide along the second axis and between pro-

- jections of the first and second pluralities of projections.
2. The winding apparatus of embodiment 1, wherein the rotation axis is parallel or perpendicular to a gravity vector during operation. 5
3. The winding apparatus of embodiment 1 or 2, further comprising: 10
- a first flexible chain comprising the first plurality of projections, the first flexible chain removably coupled to the first rim; and
 - a second flexible chain comprising the second plurality of projections, the second flexible chain removably coupled to the second rim. 15
4. The winding apparatus of embodiment 3, wherein the first and second flexible chains are flexible between a linear state and a circular state to couple the first and second flexible chains to the first and second rims. 20
5. The winding apparatus of any one of the preceding embodiments, wherein the first and second rims are each coupled to a plurality of spokes. 25
6. The winding apparatus of any one of the preceding embodiments, wherein the first and second rims are spaced apart by a distance between 5 cm and 3 m. 30
7. The winding apparatus of any one of the preceding embodiments, wherein each projection of the first and second pluralities of projections extends at an angle relative to the rotation axis, the angle being from 45 degrees to 180 degrees. 35
8. The winding apparatus of embodiment 7, wherein the angle is from 95 degrees to 175 degrees. 40
9. The winding apparatus of any one of the preceding embodiments, further comprising a support, the support comprising: 45
- a first end coupled to the first rim; and
 - a second end coupled to the second rim.
10. The winding apparatus of any one of the preceding embodiments, further comprising: 50
- a flexible sheet comprising the first plurality of projections and the second plurality of projections, the flexible sheet removably coupled to the first and second rims.
11. The winding apparatus of embodiment 10, wherein the flexible sheet is flexible between a linear state and a circular state to couple the first and second pluralities of projections to the first and sec-

ond rims.

12. A method of making an article of apparel, the method comprising:

- rotating a first rim and a second rim coupled together and spaced apart by a support, the first rim coupled to a first plurality of projections that extend from a perimeter of the first rim, and the second rim coupled to a second plurality of projections that extend from a perimeter of the second rim;
- dispensing a continuous thread via a thread guide; and
- moving the thread guide along an axis parallel to the support and between projections of the first and second pluralities of projections to wind the continuous thread around a plurality of the first plurality of projections and around a plurality of the second plurality of projections.

13. The method of embodiment 12, further comprising changing at least one of a rotation rate or a rotation direction of the first and second rims while moving the thread guide.

14. The method of embodiment 12 or 13, further comprising rotating at least one of the first rim or the second rim independently from one another after winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections.

15. The method of any one of the preceding embodiments 12 to 14, wherein:

- a first flexible chain comprises the first plurality of projections, the first flexible chain removably coupled to the first rim; and
- a second flexible chain comprises the second plurality of projections, the second flexible chain removably coupled to the second rim; and
- wherein the method further comprises removing the first and second flexible chains from the first and second rims after winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections.

16. The method of embodiment 15, wherein winding the continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections forms a thread layer comprising a plurality of thread lines, with each thread line extending between one of the first plurality of projections and one of the second plurality of projections.

17. The method of embodiment 16, further comprising bonding thread lines of the plurality of thread lines to one another after removing the first and second flexible chains from the first and second rims.

18. The method of embodiment 16 or 17, further comprising cutting the thread layer after removing the first and second flexible chains from the first and second rims.

19. The method of any one of the preceding embodiments 16 to 18, further comprising winding a second continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections to form a second thread layer comprising a second plurality of thread lines, with each thread line of the second plurality of thread lines extending between one of the first plurality of projections and one of the second plurality of projections.

Claims

1. A winding apparatus (200, 200a-d) for manufacturing an article of apparel, the winding apparatus (200, 200a-d) comprising:

a first rim (206);
 a second rim (214) coupled to and spaced apart from the first rim (206), the first and second rims (214) rotatable on a rotation axis;
 a first plurality of projections coupled to and extending from a perimeter of the first rim (206);
 a second plurality of projections coupled to and extending from a perimeter of the second rim (214);
 a thread guide (226) configured to dispense a continuous thread (234, 402), the thread guide moveable along a second axis parallel to the rotation axis;
 a first actuator (224, 224a-d) configured to rotate the first and second rims (214); and
 a second actuator (230, 230a-d) configured to move the thread guide (226) along the second axis and between projections of the first and second pluralities of projections.

2. The winding apparatus (200, 200a-d) of claim 1, wherein the rotation axis is parallel or perpendicular to a gravity vector during operation.

3. The winding apparatus (200, 200a-d) of claims 1 or 2, further comprising:

a first flexible chain (302) comprising the first plurality of projections, the first flexible chain (302) removably coupled to the first rim (206);

and

a second flexible chain (304) comprising the second plurality of projections, the second flexible chain (304) removably coupled to the second rim (214).

4. The winding apparatus (200, 200a-d) of claim 3, wherein the first and second flexible chains (304) are flexible between a linear state and a circular state to couple the first and second flexible chains (304) to the first and second rims (214).

5. The winding apparatus (200, 200a-d) of any one of the preceding claims, wherein the first and second rims (214) are each coupled to a plurality of spokes (204, 212), wherein the first and second rims (214) are preferably spaced apart by a distance between 5 cm and 3 m.

6. The winding apparatus (200, 200a-d) of any one of the preceding claims, wherein each projection of the first and second pluralities of projections extends at an angle relative to the rotation axis, the angle being from 45 degrees to 180 degrees, wherein the angle is preferably from 95 degrees to 175 degrees.

7. The winding apparatus (200, 200a-d) of any one of the preceding claims, further comprising a support (218, 228), the support (218, 228) comprising:

a first end (220, 306, 310, 416) coupled to the first rim (206); and
 a second end (222, 308, 312, 418) coupled to the second rim (214).

8. The winding apparatus (200, 200a-d) of any one of the preceding claims, further comprising:

a flexible sheet (314) comprising the first plurality of projections and the second plurality of projections, the flexible sheet (314) removably coupled to the first and second rims (214), wherein the flexible sheet (314) is preferably flexible between a linear state and a circular state to couple the first and second pluralities of projections to the first and second rims (214).

9. A method (1000) of making an article of apparel, the method (1000) comprising:

rotating a first rim (206) and a second rim (214) coupled together and spaced apart by a support (218, 228), the first rim (206) coupled to a first plurality of projections that extend from a perimeter of the first rim (206), and the second rim (214) coupled to a second plurality of projections that extend from a perimeter of the second rim

- (214);
dispensing a continuous thread (234, 402) via a thread guide (226); and
moving the thread guide (226) along an axis parallel to the support (218, 228) and between projections of the first and second pluralities of projections to wind the continuous thread (234, 402) around a plurality of the first plurality of projections and around a plurality of the second plurality of projections.
10. The method (1000) of claim 9, further comprising changing at least one of a rotation rate or a rotation direction of the first and second rims (214) while moving the thread guide (226).
11. The method (1000) of claim 9 or 10, further comprising rotating at least one of the first rim (206) or the second rim (214) independently from one another after winding the continuous thread (234, 402) around the plurality of the first plurality of projections and around the plurality of the second plurality of projections.
12. The method (1000) of any one of the preceding claims 9 to 11, wherein:
- a first flexible chain (302) comprises the first plurality of projections, the first flexible chain (302) removably coupled to the first rim (206); and
a second flexible chain (304) comprises the second plurality of projections, the second flexible chain (304) removably coupled to the second rim (214); and
wherein the method (1000) further comprises removing the first and second flexible chains (304) from the first and second rims (214) after winding the continuous thread (234, 402) around the plurality of the first plurality of projections and around the plurality of the second plurality of projections.
13. The method (1000) of claim 12, wherein winding the continuous thread (234, 402) around the plurality of the first plurality of projections and around the plurality of the second plurality of projections forms a thread layer (108, 110, 112, 410) comprising a plurality of thread lines (412), with each thread line (412) extending between one of the first plurality of projections and one of the second plurality of projections, wherein the method is preferably further comprising bonding thread lines (412) of the plurality of thread lines (412) to one another after removing the first and second flexible chains (304) from the first and second rims (214).
14. The method (1000) of claim 13, further comprising
- cutting the thread layer (108, 110, 112, 410) after removing the first and second flexible chains (304) from the first and second rims (214).
15. The method (1000) of claims 13 or 14, further comprising winding a second continuous thread around the plurality of the first plurality of projections and around the plurality of the second plurality of projections to form a second thread layer (110) comprising a second plurality of thread lines (412), with each thread line (412) of the second plurality of thread lines (412) extending between one of the first plurality of projections and one of the second plurality of projections.

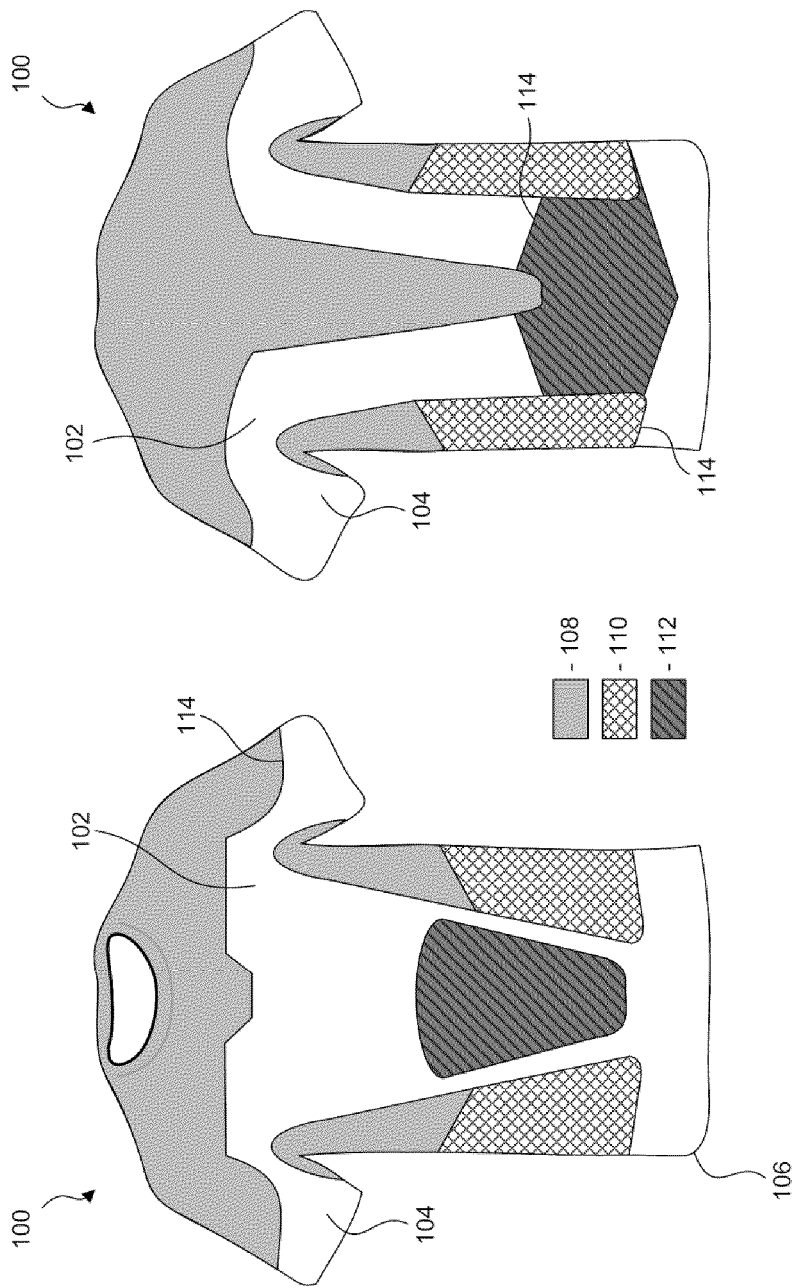


FIG. 1A

FIG. 1B

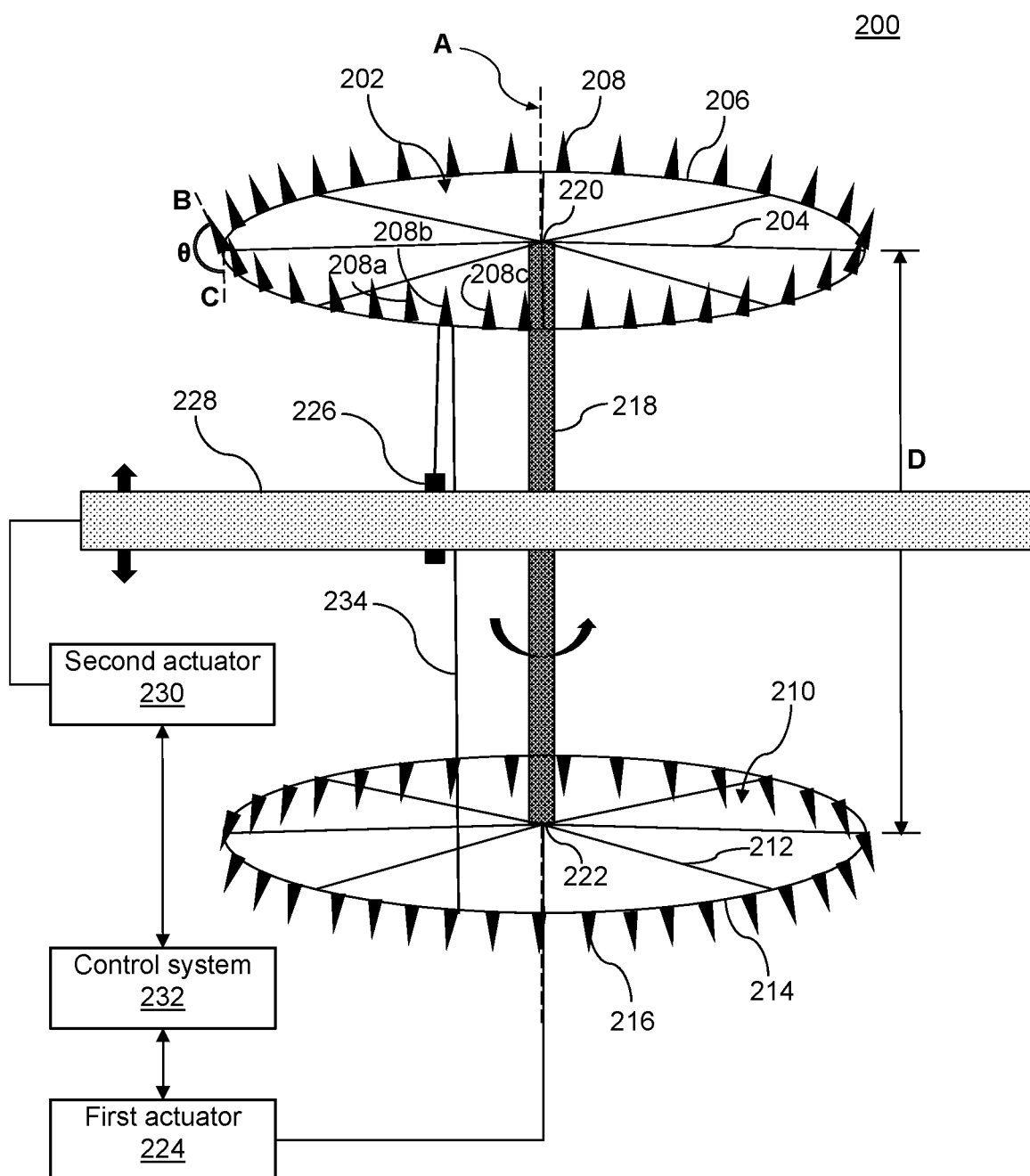


FIG. 2

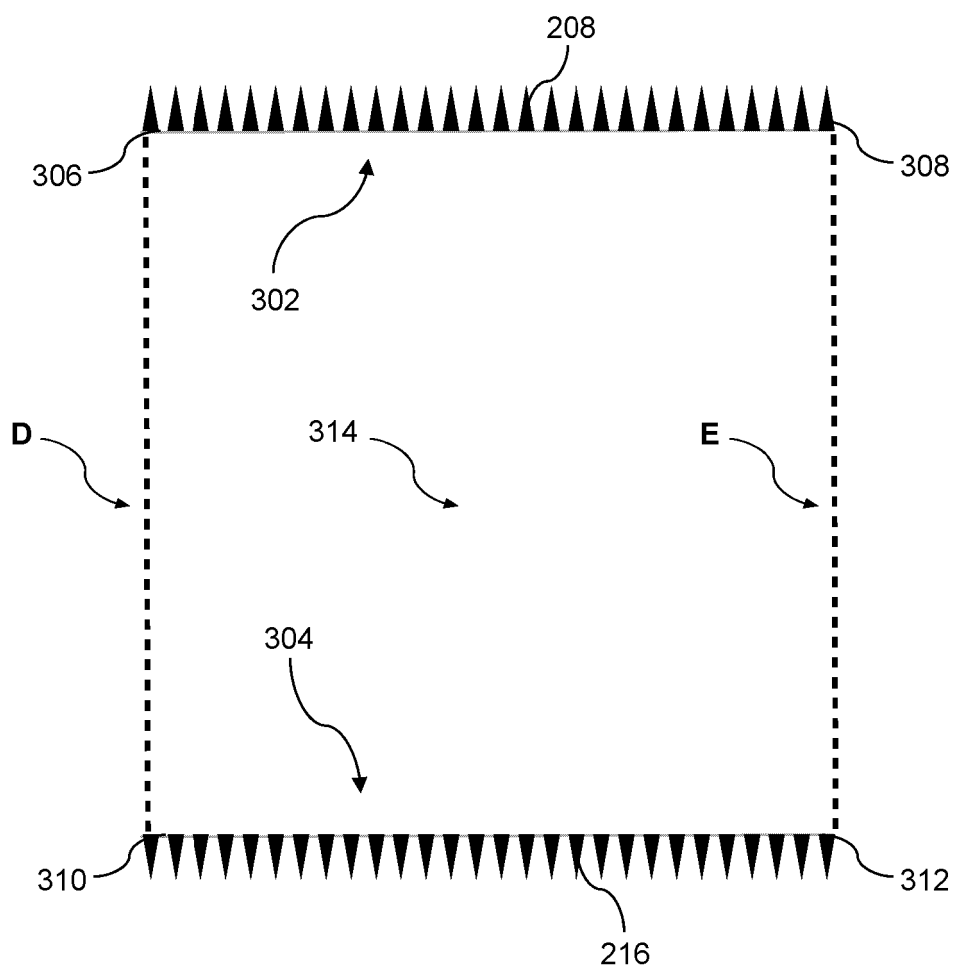


FIG. 3

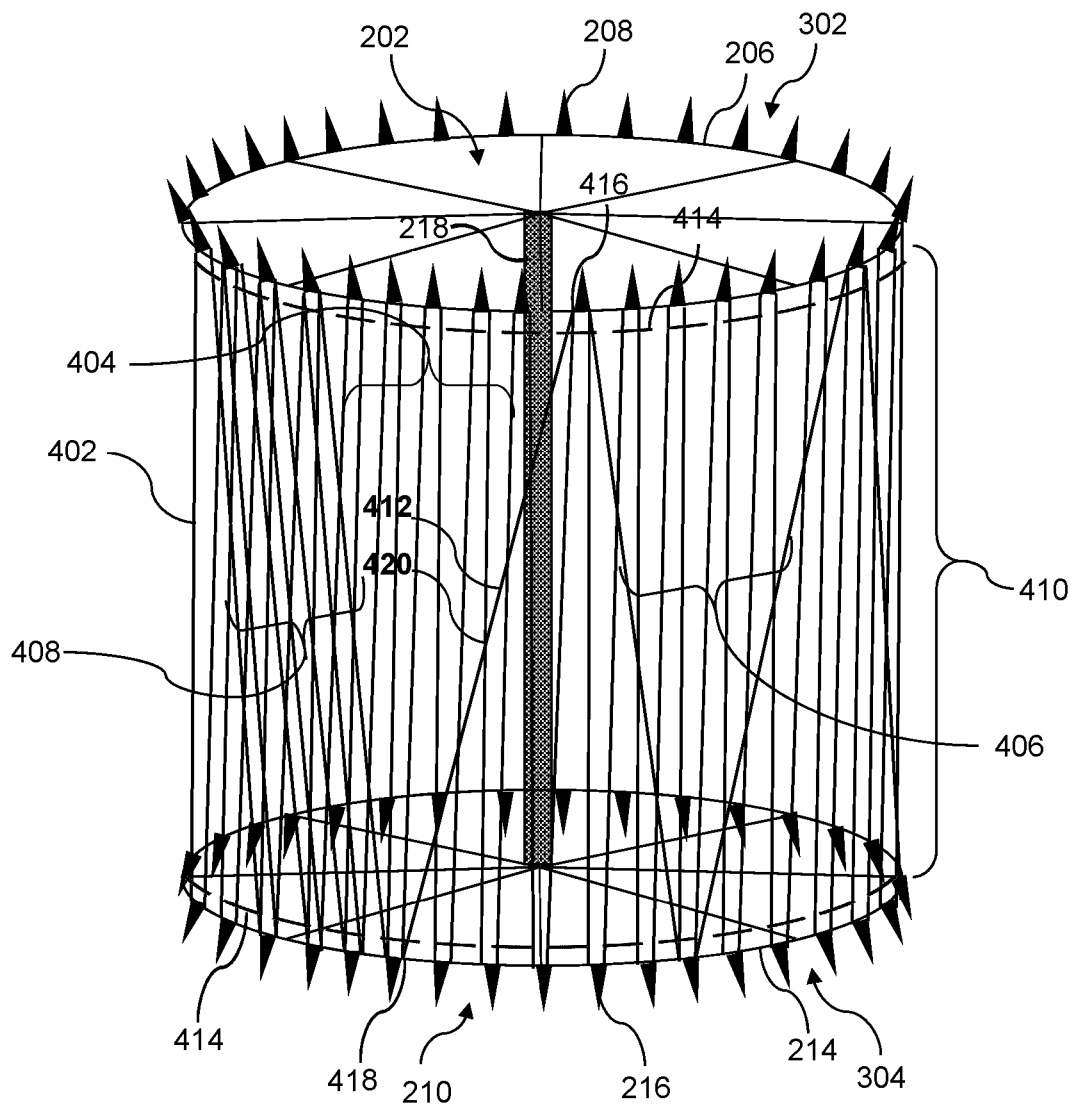


FIG. 4

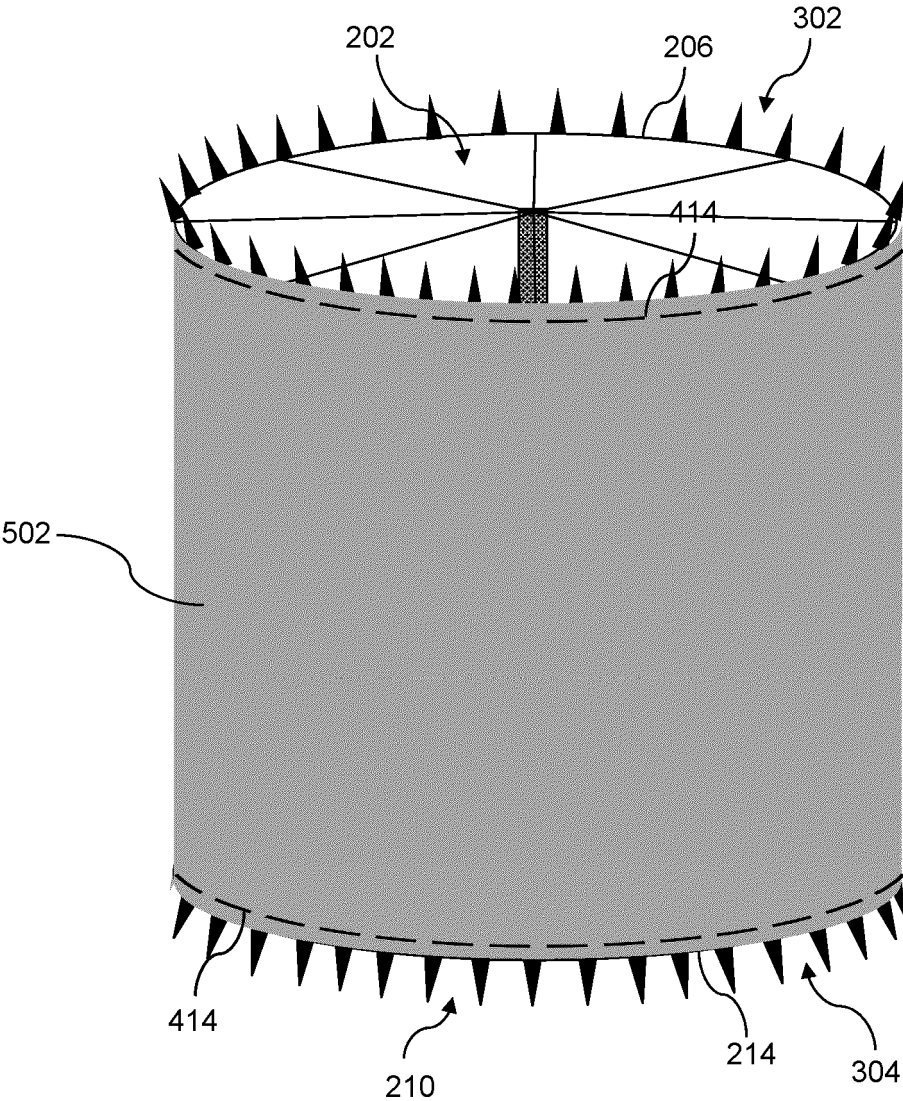


FIG. 5

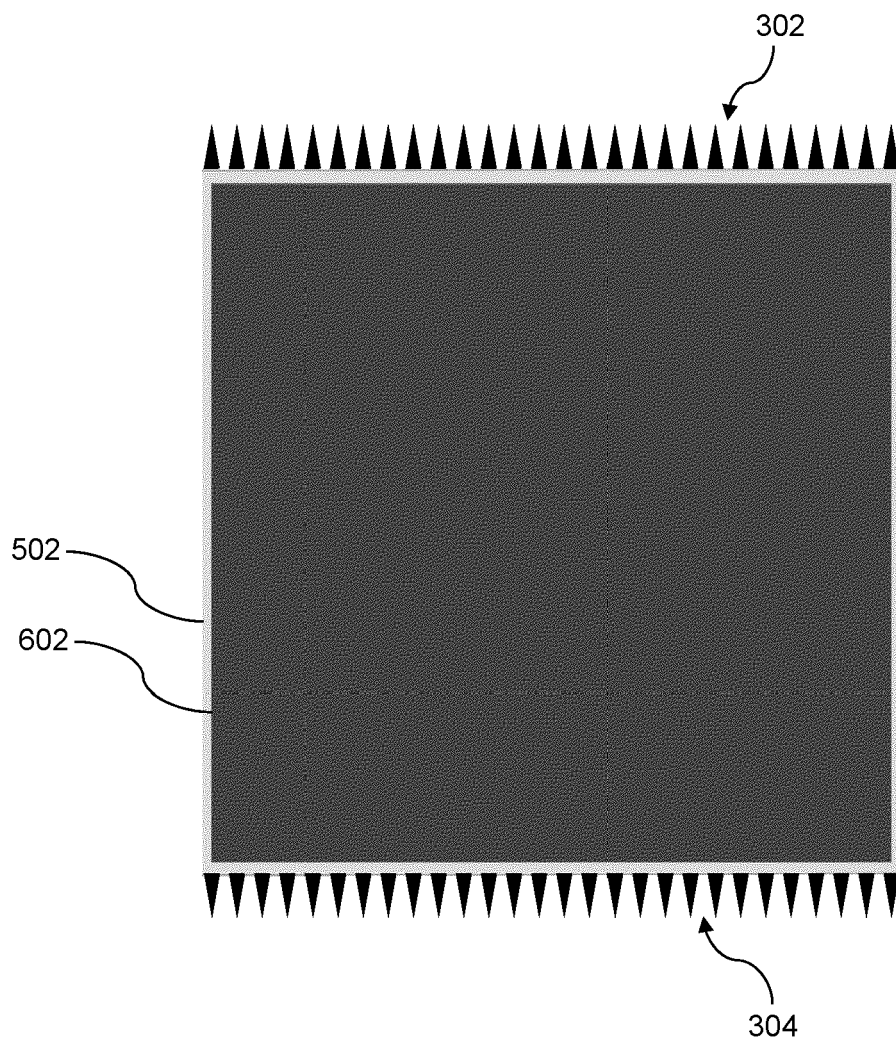


FIG. 6

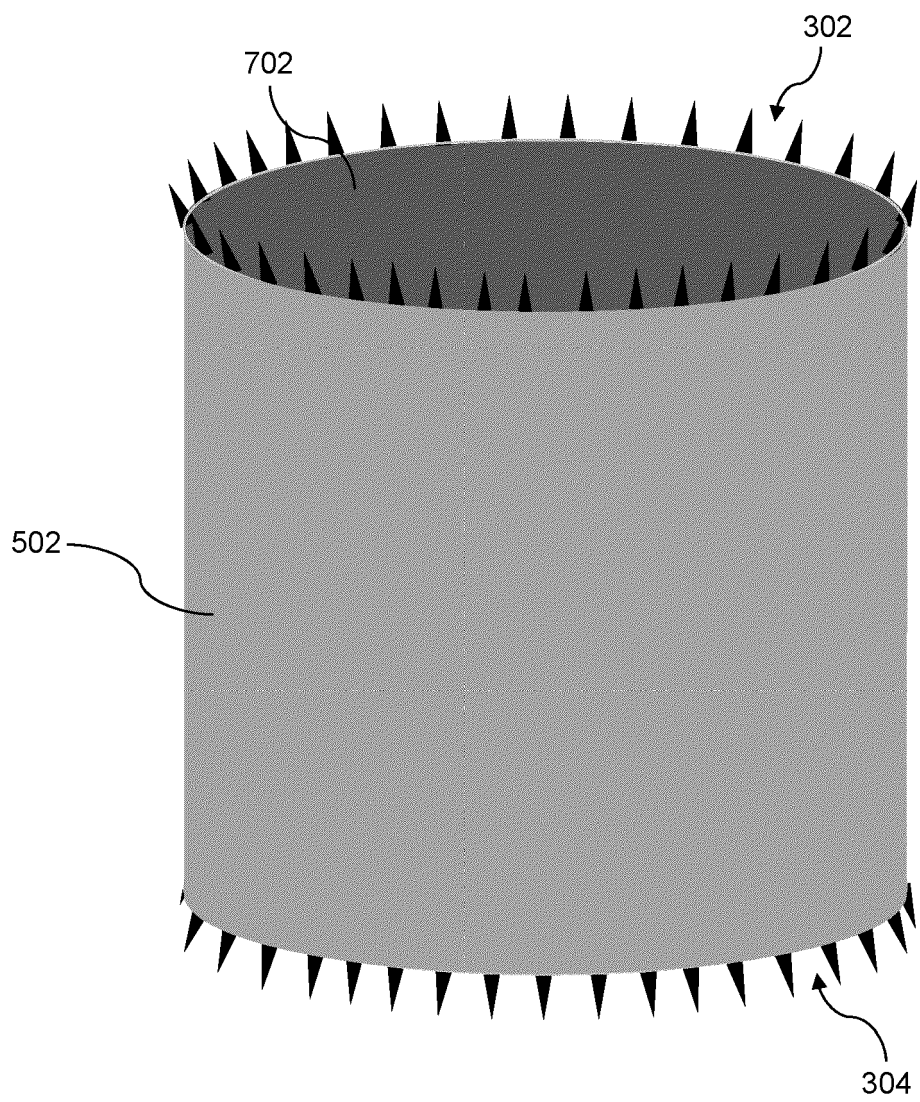


FIG. 7

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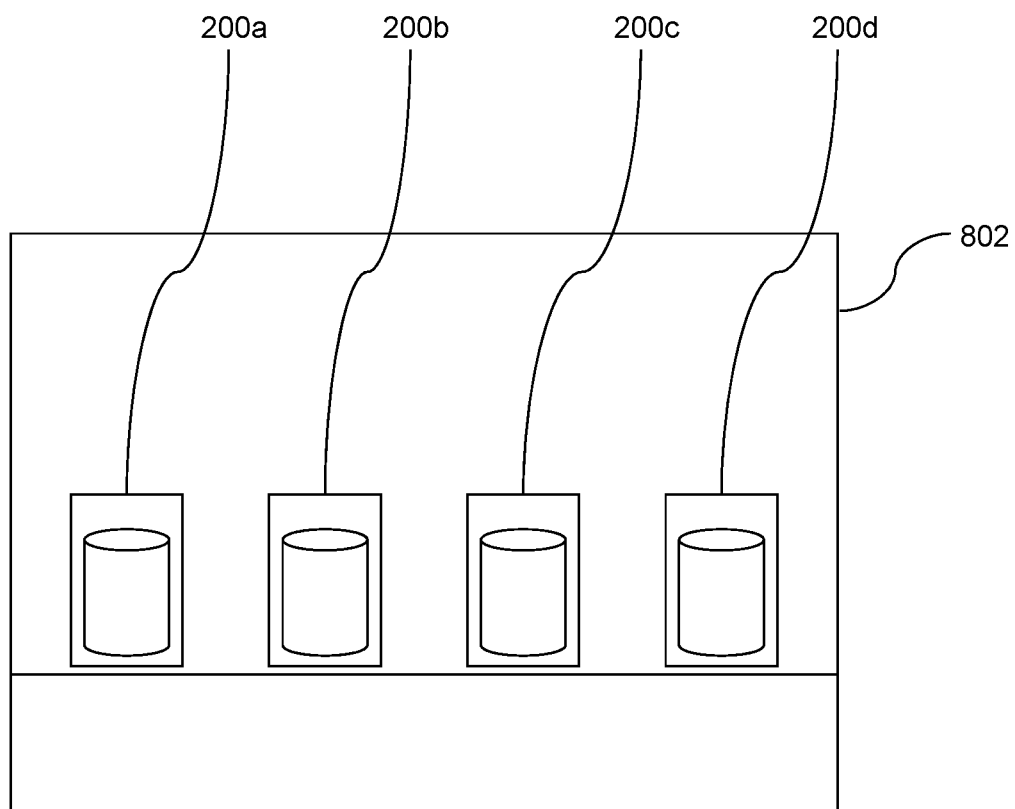


FIG. 8

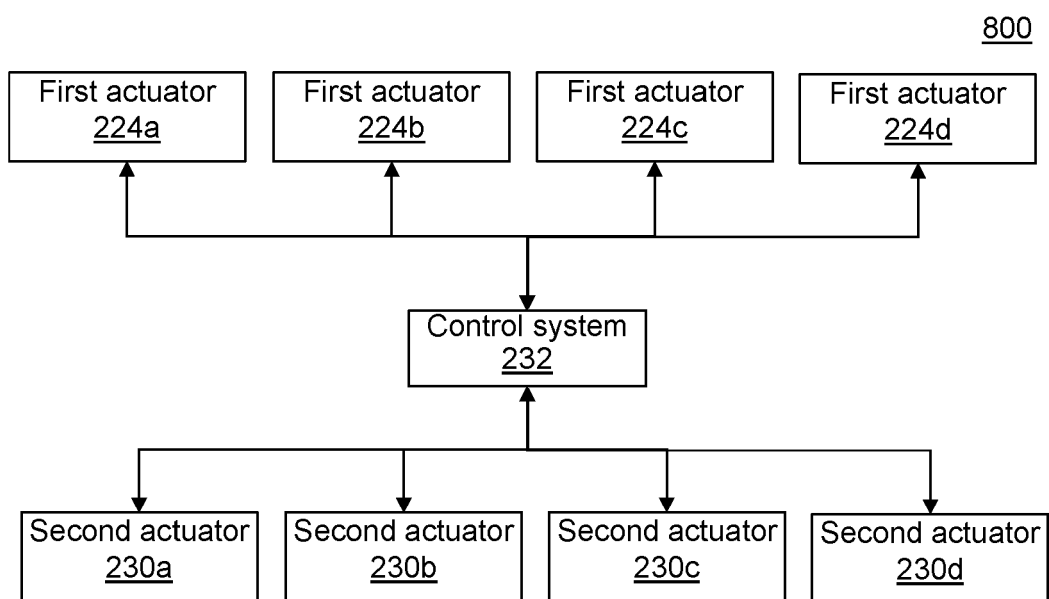


FIG. 9A

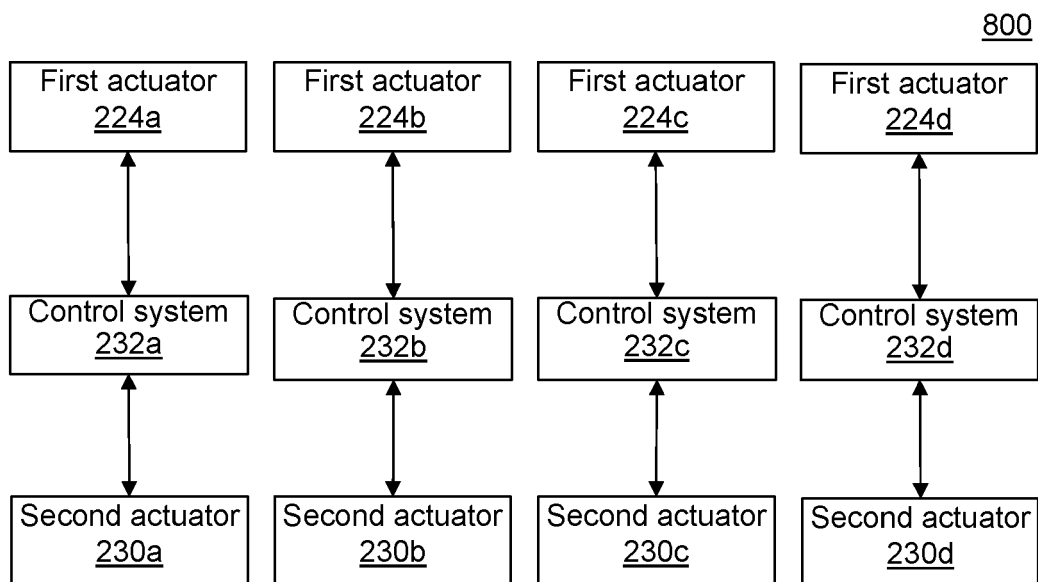
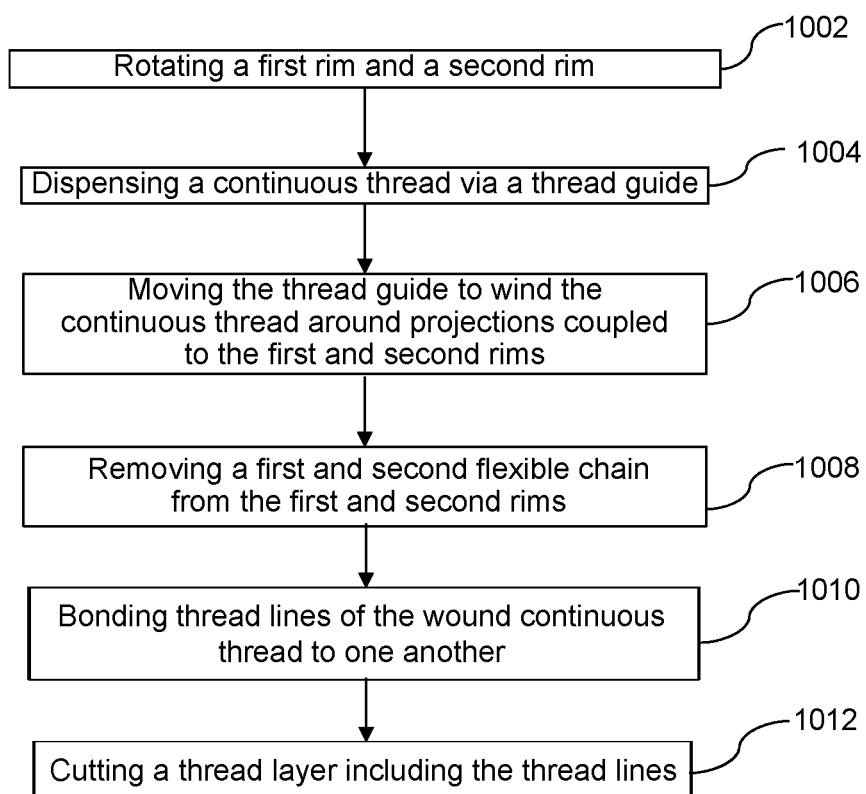


FIG. 9B

1000**FIG. 10**

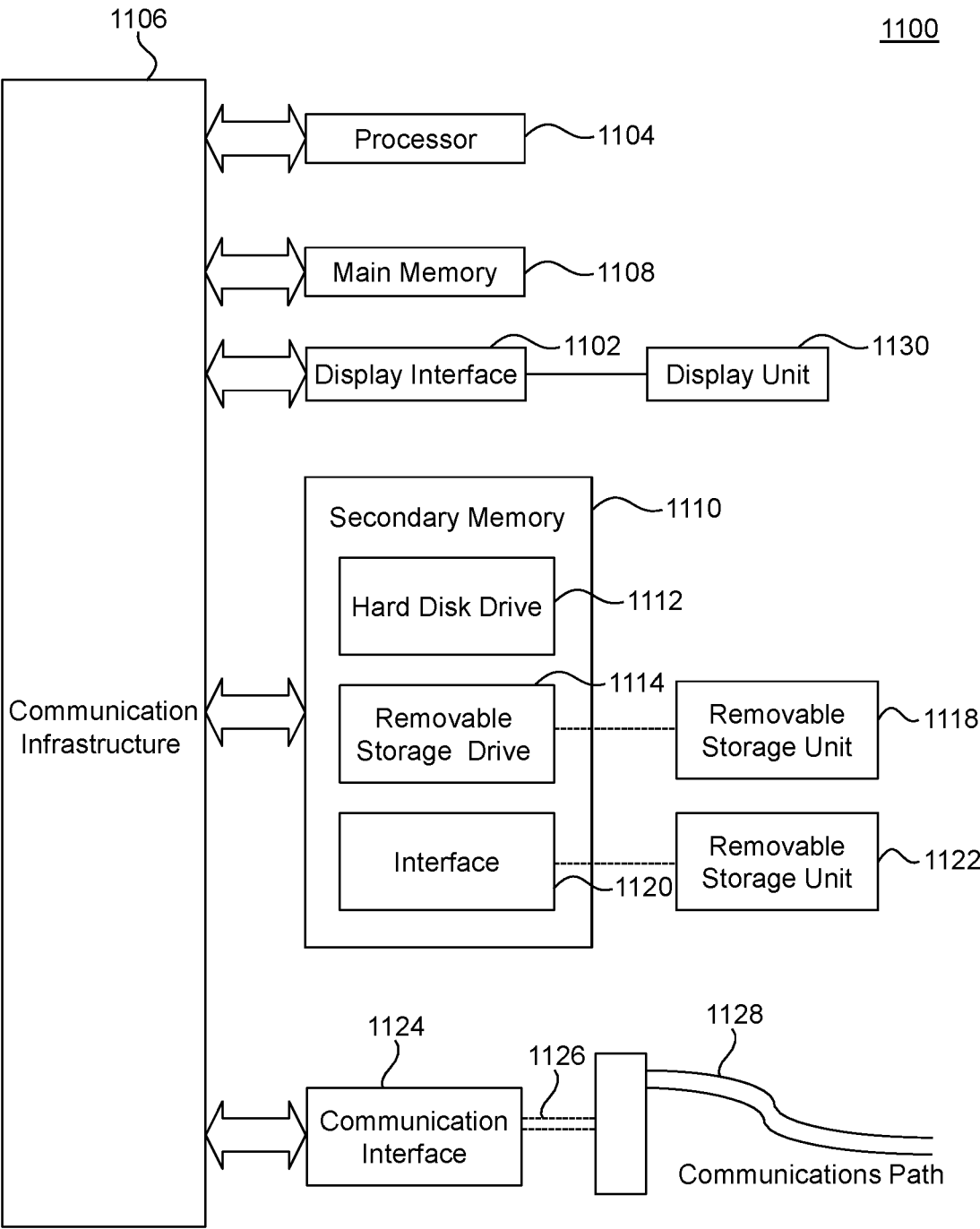


FIG. 11

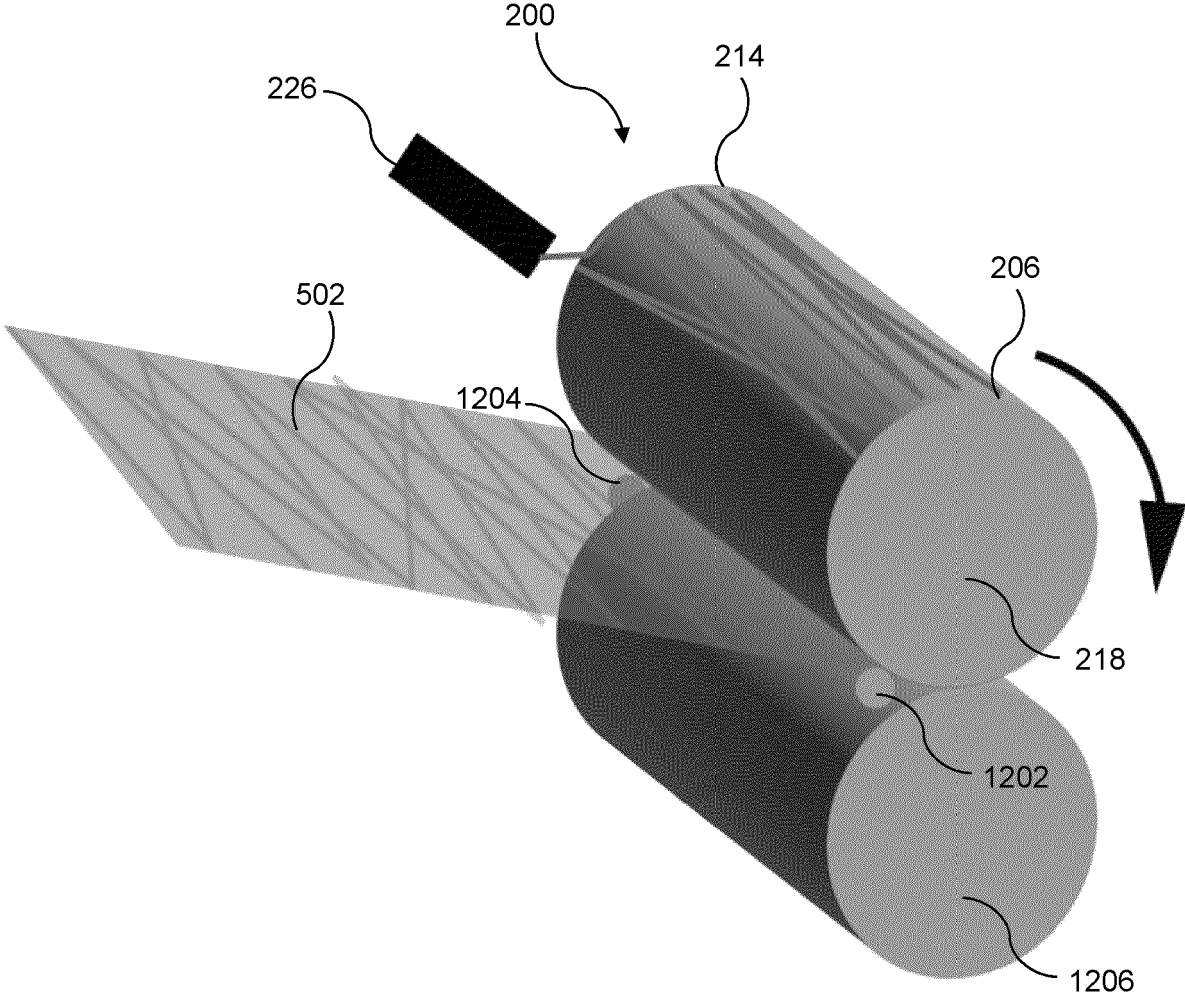


FIG. 12



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Application Number

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	* column 5, line 25 - column 6, line 3 *		
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	* page 15, line 1 - page 16, line 29 *		
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Place of search			Examiner
Munich			Kirner, Katharina
Date of completion of the search			
5 March 2025			
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