



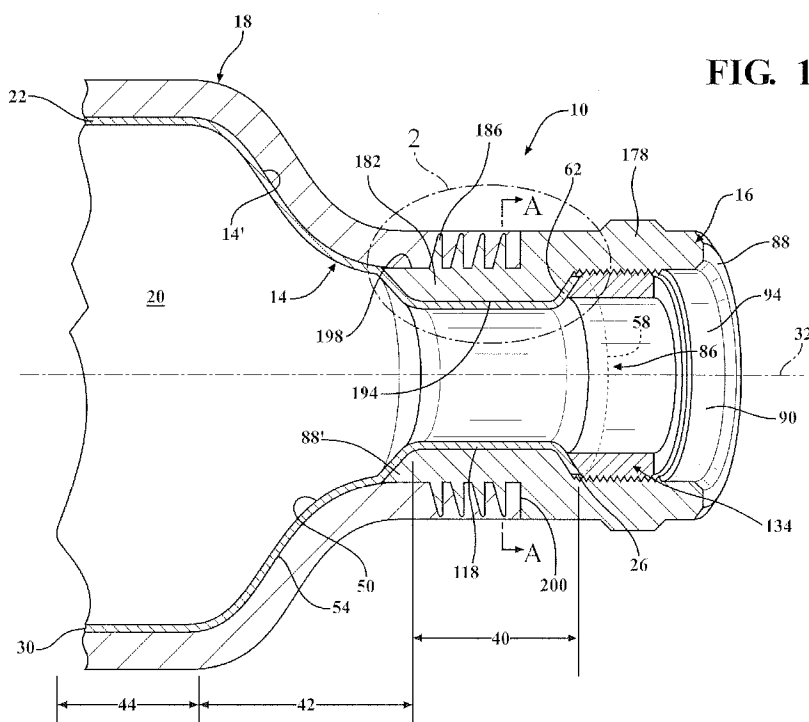
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(54) Titre : PROTUBERANCE TERMINALE POUR RECIPIENT SOUS PRESSION DE TYPE IV
(54) Title: END BOSS FOR TYPE IV PRESSURE VESSEL



(57) **Abrégé/Abstract:**

A type IV conformable pressure vessel has improved mechanical coupling between an outer composite shell and a boss. The pressure vessel comprises an inner polymeric liner having a flare edge fixedly coupled to the boss. The boss has a bore in fluid communication with an interior of the pressure vessel. In addition, the boss has a shank extending between the liner and the outer composite shell. The shank includes a plurality of spikes projecting radially away from the boss. The outer composite shell of resin and fiber surrounds an outer periphery of the liner and an outer periphery of the shank. The spikes are embedded into the outer composite shell to mechanically fasten the outer composite shell to the boss.



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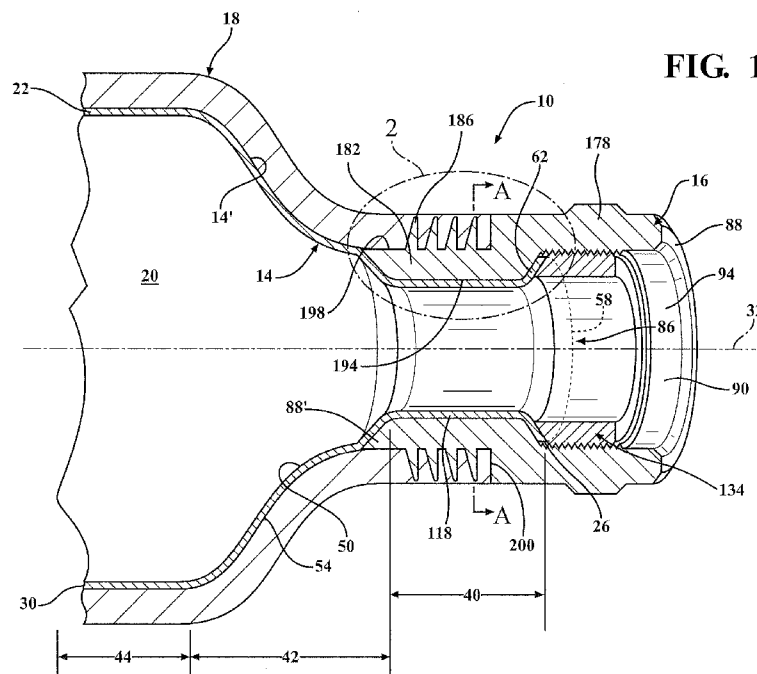
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(54) Title: END BOSS FOR TYPE IV PRESSURE VESSEL

**FIG. 1**

(57) **Abstract:** A type IV conformable pressure vessel has improved mechanical coupling between an outer composite shell and a boss. The pressure vessel comprises an inner polymeric liner having a flare edge fixedly coupled to the boss. The boss has a bore in fluid communication with an interior of the pressure vessel. In addition, the boss has a shank extending between the liner and the outer composite shell. The shank includes a plurality of spikes projecting radially away from the boss. The outer composite shell of resin and fiber surrounds an outer periphery of the liner and an outer periphery of the shank. The spikes are embedded into the outer composite shell to mechanically fasten the outer composite shell to the boss.

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END BOSS FOR TYPE IV PRESSURE VESSEL

CROSS-REFERENCE TO RELATED APPLICATIONS

[001] This application claims priority to United States Provisional Application No. 62/867,910, filed on June 28, 2019.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[002] The present invention relates to a boss for Type IV pressure vessels including Type IV conformable pressure vessels. More particularly, the invention relates to boss designs having spikes embedded into an outer composite shell and wherein the liner is positioned inside of the boss.

2. Description of Related Art

[003] Pressure vessels commonly store fluids and/or gases under pressure, such as natural gas, oxygen, nitrogen, hydrogen, propane, and the like. Type IV pressure vessels or tanks have a metal-free body typically comprising a carbon fiber reinforced polymer composite wound and/or braided over a thermoplastic polymeric liner. A valve is coupled to the vessel for filling the vessel with compressed fluid. However, the valve cannot be connected directly to the polymer liner. Therefore, a boss needs to be provided to couple the valve to the vessel.

[004] A first known method of forming a type IV pressure vessel by attaching a boss to a polymeric liner and an outer composite shell is illustrated in U.S. patent No. 10,180,210. The first known method utilizes an injection molding process to mold the liner around locking features of the boss to mechanically lock the boss to the liner. This first known method provides excellent surface contact between the polymeric liner and the outer surface of the boss. A seal between the liner and the boss is formed by an interface between the liner and the boss. Further, the boss typically includes a lip feature that seals against itself when the boss is pressurized. The gas-tight boss / liner assembly is supported by an outer covering of a composite shell. The sealing mechanism and the mechanical restriction are not coupled. The joint between the boss and the liner is not pre-stressed.

[005] However, this first known method requires molding the liner around the boss prior to wrapping the liner with the composite fibers. Further, the first known method lacks mechanical engagement between the boss and the outer composite shell. As such, the boss can separate from the outer composite shell under stress, allowing the boss to rotate within the outer composite shell and/or slide axially with respect to the outer composite shell. Movement of the boss with respect to the liner and/or the outer composite shell can result in leakage and potentially failure of the connection between the boss and the pressure vessel.

[006] A second known method of forming a boss of a type IV pressure vessel is illustrated in U. S. publication No. 2018/283612, wherein a hose-style crimp, such as a ferrule, is crimped around a layered assembly of an outer composite shell, a polymeric liner, and a boss. The second known method includes a boss that slides within an opening in the liner such that the liner is positioned against an outer surface of the boss. A ferrule is crimped around the boss and the composite shell after the liner is covered with the outer composite shell to fixedly couple the boss to the outer composite shell. The boss can include ridges along an outer surface of the boss to grip an inner surface of the liner. The hose-style crimp fittings rely on crimp pressure to provide composite anchoring and sealing. Gas trying to escape along the liner tends to open a gap between the boss and the liner. The ferrule and the composite are pre-stressed to a state resisting the gap opening. The ferrule is also stressed axially by providing grip on the composite and resisting the stem axial displacement.

[007] However, this second known method relies on the crimp pressure to fixedly couple the boss to the liner. The boss can rotate within the liner under increased load on the boss if there is insufficient crimping force on the joint between the boss and the liner. Further, the second known method lacks mechanical engagement directly between the boss and the outer composite shell and relies on the ferrule to fixedly couple the boss to the outer composite shell. Axial load and rotational load on the boss can weaken the connection between the boss and the outer composite shell. The boss can separate from the outer composite shell under stress, allowing the boss to rotate within the outer composite shell and/or slide axially with respect to the outer composite shell. Movement of the boss with respect to the liner and/or the outer composite shell can result in leakage and potentially failure of the connection between the boss and the pressure vessel.

[008] It is desirable, therefore, to mechanically couple a boss directly to an outer composite shell of a type IV pressure vessel. Further, it is desirable to mechanically couple the boss

directly to a liner of the pressure vessel. It is desirable to form a seal between the liner and the boss. It is also desirable to restrict rotational movement of the boss with respect to the liner and with respect to the outer composite when torque is applied to the boss. Further, it is desirable to restrict axial movement of the boss with respect to the liner and to the outer composite shell when axial force is applied to the boss. In addition, it is desirable to fixedly couple the liner to the boss without using a molding process and without requiring the use of a ferrule to crimp the liner to the boss. Finally, it is desirable to fixedly couple the outer composite shell to the boss without relying on a ferrule to crimp the outer composite shell to the boss.

SUMMARY OF THE INVENTION

[009] A type IV pressure vessel is provided that has improved mechanical coupling between an outer composite shell and a boss. The pressure vessel comprises an inner polymeric liner having a flare edge fixedly coupled to the boss. The boss has a bore in fluid communication with an interior of the pressure vessel. In addition, the boss has a shank extending between the liner and the outer composite shell. The shank includes a plurality of spikes projecting radially away from the boss. The outer composite shell of resin and fiber surrounds an outer periphery of the liner and an outer periphery of the shank. The spikes are embedded into the outer composite shell to mechanically fasten the outer composite shell to the boss.

BRIEF DESCRIPTION OF THE DRAWINGS

[010] Advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[011] Figure 1 is a cross-sectional view of a portion of a type IV pressure vessel having a boss assembled between a polymeric liner and an outer composite shell, according to one embodiment of the present invention;

[012] Figure 2 is an enlarged cross-sectional view of portion 2 of the pressure vessel of Figure 1, illustrating spikes projecting from the boss and embedded into the outer composite shell and illustrating a sealing insert compressing the liner flared section against the boss;

[013] Figure 3A shows a perspective view of the boss of Figure 1 removed from the pressure vessel;

[014] Figures 3B-3D show cut-away views of the boss of Figure 3A illustrating fine ridges, a rough surface texture, and a smooth surface texture, respectively, on a boss cone surface;

[015] Figure 4A shows a cross-sectional view of the sealing insert of Figure 1 removed from the pressure vessel;

[016] Figures 4B-4D show perspective views of a portion of the sealing insert of Figure 4A illustrating fine ridges, a rough surface texture, and a smooth surface texture, respectively on a cone surface of the sealing insert;

[017] Figure 5 illustrates a known method of wrapping a strand of resin impregnated fibers around a liner in a helical pattern;

[018] Figure 6 illustrates a braiding process wherein fiber strands are over-braided around the pressure vessel of Figure 1;

[019] Figure 7 illustrates a cross-sectional view of a second embodiment of the pressure vessel of Figure 1, wherein a shank of the boss extends along a tapered region of the liner;

[020] Figure 8 illustrates a cross-sectional view of a third embodiment of the pressure vessel of Figure 1, wherein the shank of the boss extends partially along the tapered region of the liner;

[021] Figure 9 shows a perspective view of another embodiment of the boss of Figure 3A;

[022] Figure 10 is a perspective view of embodiments of spikes prior to assembly with the boss of Figure 3A;

[023] Figure 11 is a perspective view of embodiments of the spikes of Figure 10 having a cylindrical-shaped pin projecting longitudinally away from a base of each spike;

[024] Figure 12A illustrates an assembly method wherein the cylindrical-shaped spike of Figure 10 is press-fitted into a hole in the boss of Figure 3A;

[025] Figure 12B illustrates an assembly method wherein the cylindrical-shaped spike of Figure 11 is press-fitted into a hole in the boss of Figure 3A;

[026] Figure 12C illustrates an assembly method wherein the cylindrical-shaped spike of Figure 10 is welded to the boss of Figure 3A;

[027] Figure 12D illustrates the pyramid-shaped spike of Figure 10 integrally formed with the boss of Figure 3A;

[028] Figure 13 is sectional view of the pressure vessel of Figure 1 taken along section line A-A, illustrating a row of spikes arranged around the outer periphery of the boss;

[029] Figure 14 illustrates a first embodiment of portion C of the sectional view of the pressure vessel of Figure 13 showing the spike partially embedded into the outer composite shell;

[030] Figure 15 illustrates a second embodiment of the portion C of the sectional view of the pressure vessel of Figure 13 showing the spike embedded in all of the layers of fiber strands forming the outer composite shell;

[031] Figure 16 illustrates a first embodiment of a portion B of the pressure vessel of Figure 6, illustrating tetrahedron-shaped spikes extending through braided fiber strands of the outer composite shell;

[032] Figure 17 illustrates a second embodiment of the portion B of the pressure vessel of Figure 6, illustrating cylindrical-shaped spikes extending through the braided fiber strands of the outer composite shell;

[033] Figure 18 is an exploded view of a liner/boss subassembly, according to one embodiment of the present invention;

[034] Figure 19 is an exploded view of an elongated subassembly comprising a pair of liner/boss subassemblies of Figure 18 and a sacrificial tubing section, according to one embodiment of the present invention;

[035] Figure 20 is a perspective view of the elongated subassembly of Figure 19;

[036] Figure 21 is a perspective view of the elongated subassembly of Figure 19 being passed through the braiding machine of Figure 6;

[037] Figure 22 is a perspective view of the elongated subassembly of Figure 19 that has been over-braided with a plurality of fiber strands; and

[038] Figure 23 is a perspective view of the elongated subassembly of Figure 22 after trimming of the braided fiber strands and removal of the sacrificial tubing section.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[039] Referring to the Figures, wherein like numerals indicate like or corresponding parts throughout the several views, a type IV pressure vessel (with polymeric liner 14 and outer composite shell 18) 10 for containing liquids and/or gases under pressure is shown in Figures 1 and 2, according to one embodiment of the present invention. The pressure vessel 10 is suitable for storage of compressed liquids and/or gases, such as nitrogen, hydrogen, natural gas, helium, dimethyl ether, liquefied petroleum gas, xenon, and the like. A pressure vessel 10 for storage of hydrogen for automotive applications typically is designed for up to 70MPa of nominal working pressure. In comparison, pressure vessels 10 for storage of compressed natural gas are typically designed for up to 25MPa of nominal working pressure.

[040] Referring to Figures 1 and 2, the pressure vessel 10 includes a polymeric liner 14 fixedly coupled to a boss 16 with an outer composite shell 18 surrounding an outer periphery 14' of the polymeric liner 14. The liner 14 comprises an interior hollow body 20 defined by an elongated cylindrical wall 22 extending between a first terminal end 26 and a second terminal end 30. The longitudinal axis of the pressure vessel 10 is shown by element 32. In the embodiment shown in Figure 1, the liner 14 includes a neck region 40, a taper region 42, and a chamber region 44. The polymeric liner 14 includes opposing inner and outer surfaces 50, 54 and an inlet opening 58 at the first terminal end 26. The inlet opening 58 of the liner 14 includes a flare edge 62 that is fixedly coupled to the boss 16 with the sealing insert 134.

[041] The polymeric liner 14, shown in Figure 1, is generally formed from one or more polymeric materials such as Nylon (PA), ethylene-vinyl acetate (EVA), linear low-density polyethylene (LLDPE), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), ethylene vinyl alcohol (EVOH), polytetrafluoroethylene (PTFE), polyurethane (PU), and/or polyvinyl chloride (PVC). The polymeric liner 14 may be formed of a single layer of polymeric material or may comprise a multi-layered structure of two or more polymeric layers and further may include one or more metal layers or additives, as desired for specific applications.

[042] The boss 16 of Figure 1 is shown in Figure 3A removed from the pressure vessel 10. Referring to Figures 2 and 3A, the boss 16 has a bore 86 passing axially through the boss 16 between opposing terminal ends 88, 88' of the boss 16. The longitudinal axis of the boss 16 is shown by element 32 in Figure 3A. The bore 86 is comprised of a neck portion 98, a cone surface 102 and a mating surface 94. The boss cone surface 102 can include one or more fine ridges 102A, a rough surface texture 102B, and/or a smooth surface texture 102C, as illustrated in Figures 3B-3D, respectively. In the embodiment shown in Figures 1 and 2, the flare edge 62 of the liner 14 is fixedly coupled to and sealed against the cone surface 102

[043] The flare edge 62 of the liner 14 conforms to the cone surface 102. The flare edge 62 is formed during liner 14 extrusion process or formed or thermoformed directly against the cone surface 102 of the boss 16. The neck section 118 of the liner 14 conforms to the neck portion 98. The neck section 118 is formed during a liner 14 extrusion process and can be additionally thermoformed against the neck portion 98 to enhance the seal.

[044] A sealing insert 134, shown in Figures 1 and 2, is shaped to fit within and engage with the mating surface 94 of the boss 16. The sealing insert 134 of Figure 1 is shown in Figure 4A prior to assembly with the boss 16. Referring to Figure 4A, the sealing insert 134 has a generally cylindrical main body portion 138 with a mating surface 142 extending around an outer periphery of the cylindrical main body portion 138 configured to meshingly engage with the mating surface 94 by means of threads, press fit, swaging, or the like. The longitudinal axis of the sealing insert 134 is shown by element 32 in Figure 4A.

[045] Further, the sealing insert 134 includes a bore 158 passing axially through the sealing insert 134. Extending from the main body portion 138 of the sealing insert 134 is a cone surface 162 configured to seal against the flare edge 62 of the liner 14. The cone surface 162 can include one or more fine ridges 162A, a rough surface texture 162B, and/or a smooth surface texture 162C, as illustrated in Figures 4B-4D, respectively.

[046] Also shown in Figure 2, when the sealing insert 134 is engaged with the mating surface 94 of the boss 16, the flare edge 62 of the liner 14 is compressed between an outer surface 166 of the sealing insert 134 and the boss cone surface 102 of the bore 86 to provide the seal.

[047] The compression applied by the sealing insert 134 against the flare edge 62 of the liner 14 forms a seal between the liner 14 and the boss cone surface 102 of the boss 16, as

shown in Figure 2. Pinching the liner 14 between the bore 86 and the sealing insert 134 forms an initial seal between the boss 16 and the liner 14. The neck portion 98 forms a seal with the liner 14 outer surface 54 after the liner 14 is pressurized.

[048] Alternatively, one or more supplemental seals, such as an O-ring and the like, can be included adjacent the liner 14, the bore 86, and/or the sealing insert 134 if desired for specific applications. The seal between the liner 14 flare edge 62, the boss cone surface 102, and the sealing insert 134 can be improved by including a rough surface texture 102B, 162B and/or fine ridges 102A, 162A on the boss cone surface 102 and/or on cone surface 162 of the sealing insert 134, if desired for certain embodiments. In other embodiments, a satisfactory seal will be obtained with a smooth surface texture 102C, 162C on both the boss cone surface 102 and the cone surface 162 of the sealing insert 134.

[049] Returning to Figure 3, the boss 16 has a generally cylindrical portion 178 connected to a shank 182. In the embodiment shown in Figures 1-3A, the shank 182 has an outer bearing surface 198 and a generally cylindrical shape. The bearing surface 198 of the shank 182 is located against the outer composite shell 18. The shank 182 shown in Figure 1 extends along the neck region 40 and along a portion of the taper region 42 of the liner 14.

[050] The mechanical fastening between the outer composite shell 18 and the boss 16 is achieved by spikes 186 project radially away from the bearing surface 198 of the shank 182, as shown in Figures 1 and 2. The spikes 186 are at least partially embedded in the outer composite shell 18 to mechanically fasten the boss 16 to the outer composite shell 18. The engagement of the spikes 186 with the outer composite shell 18 allows the boss 16 to oppose the internal pressure and increases the amount of boss torque that can be tolerated without the boss 16 separating from the liner 14 and/or the outer composite shell 18.

[051] The boss 16 optionally includes a flange shoulder 200 that is positioned on an outer surface 202 of the boss 16 between the generally cylindrical portion 178 and the shank 182, as shown in Figures 1-3A. The flange shoulder 200 contacts the outer composite shell 18. Alternatively, the outer composite shell 18 can extend along a portion of the shank 182 without abutting a flange shoulder 200 on the boss 16.

[052] The liner 14 is optionally fabricated with mounting features 206 (shown in Figure 18) that aid with positioning and assembly of the boss 16 with the liner 14. The liner 14 is cut and/or trimmed, if needed, to allow for assembly with the boss 16. After the boss 16 and

other fittings are assembled with the liner 14, the liner 14 and/or the boss 16 are optionally heated to cause the liner 14 to conform and/or adhere to the boss 16.

[053] After the boss 16 and the liner 14 are assembled, the liner 14 and/or the shank 182 can be covered with a resin barrier layer, such as a polymeric film, if desired for a specific application. Additionally, optional breather layers, or a secondary gas barrier layers, can be wrapped around portions and/or the entire length of the liner 14 and the shank 182, as desired for specific applications. Suitable materials for the breather layer include woven glass fiber cloth, non-woven glass fiber cloth, and the like. Suitable gas barrier layers include metalized films, EVOH films, and the like.

[054] The outer composite shell 18 of the pressure vessel 10 is generally formed by disposing resin impregnated fibers 214 onto the liner 14 after the liner 14 and boss 16 have been assembled as shown in Figures 5 and 6.

[055] A first known method of applying resin impregnated fibers 214 to the liner 14 is filament winding, and is illustrated in Figure 5. A plurality of fiber filaments 214 is grouped to form a fiber strand 216. The plurality of fiber filaments 214 can be grouped to form a fiber strand 216 before or during a manufacturing process to apply fibers 214 to the liner 14. Likewise, a single fiber strand 216 or a grouping of a plurality of fiber strands 216 can be applied at given time as desired for the manufacturing process. Fiber strands 216 can be applied to the liner 14 by continuous wrapping one or more fiber strands 216 around the liner 14 in overlapping helical patterns to form one or more wrapped fiber layers 218, as illustrated in Figure 5. The fiber strands 216 can be coated with liquid resin 220 prior to being wrapped on the liner 14, as shown in Figure 5. Alternatively, the fiber strands 216 can be coated with liquid resin 220 after being wrapped on the liner 14 and/or the fiber filaments 214 can be pre-impregnated with resin 220. The resin 220 is cured such that the resin 220 and wrapped fiber layers 218 form a rigid outer composite shell 18 surrounding the liner 14.

[056] A second method of applying resin impregnated fibers 214 to the liner 14 is braiding the fibers 214 as illustrated in Figure 6. As with the first method, a plurality of fiber filaments 214 is assembled to form a fiber strand 216. A plurality of fiber strands 216 are over-braided around the liner 14 to form a braided fiber layer 224 using a braiding machine 226, as illustrated in Figure 6. Further, the fiber strands 216 can be impregnated with resin 220 prior to, during, and/or after braiding the fibers strands 216 around the liner 14.

[057] Over-braiding a plurality of fiber strands 216 around an elongated liner 14 using braiding, a process illustrated in Figure 6 will form a braided fiber layer 224 that conforms to larger diameter cylindrical sections 228, smaller diameter cylindrical sections 232, and tapered transition sections 236 of an elongated liner 14 for a pressure vessel 10. Likewise, the over-braiding process 226 shown in Figure 6 can form braided fiber strands 216 over the shank 182 of the boss 16. The over-braiding process 226 is a preferred method of applying resin impregnated fibers 214 to conformable pressure vessels 10 that can include a plurality of spaced apart larger diameter cylindrical sections 228 with adjacent larger diameter sections 228 being connected by a smaller diameter cylindrical section 232. When the resin 220 is cured, the resin 220 and braided fiber strands 216 form a rigid outer composite shell 18 surrounding the liner 14.

[058] The outer composite shell 18, shown in Figure 1, includes one or more layers of resin impregnated fiber 214. Suitable fibers 214 for the outer composite shell 18 include one or more of carbon fiber, glass fiber, basalt fiber, boron fiber, aramid fiber, high-density polyethylene fiber (HDPE), Zylon™ poly(p-phenylene-2,6-benzobisoxazole fiber (PBO), aramid fiber, Kevlar® poly-paraphenylene terephthalamide fiber, Nylon fiber (PA), polyethylene naphthalate (PEN), polyester fiber (PL), and the like. Suitable resins 220 include one or more of epoxy resin, vinylester resin, polyester resin, thermoplastic resins, urethane, and the like.

[059] The selection of materials and dimensions for the liner 14, as well as the type and amount of resin 220 and fiber 214 forming the outer composite shell 18, are selected based in part on the desired operating conditions of the pressure vessel 10. Further, inclusion of one or more of a breather layer, a barrier layer, and/or a metallic layer between the liner 14 and the outer composite shell 18, as well as the material composition of the additional layers, is based in part on the desired operating conditions of the pressure vessel 10.

[060] The outer composite shell 18 is formed around an outer periphery 198 of the shank 182 with the outer composite shell 18 abutting the flange shoulder 200, as illustrated in Figure 2. The fiber strands 216 are trimmed adjacent the flange shoulder 200 to form a composite free edge 240. The flange shoulder 200 supports and protects the composite free edge 240. If the boss 16 lacks a flange shoulder 200, then the fiber strands 216 are trimmed at a predetermined location to form the composite free edge 240. The composite free edge 240 can be protected and/or reinforced by applying tape 242 covering the flange shoulder 200 and

the composite free edge 240, as shown in Figure 7. Alternatively, the composite free edge 240 near the flange shoulder 200 can be covered by additional fiber strands 216, a crimp ring such as a ferrule, or the like. Suitable fibers 214 for covering the composite free edge 240 include carbon fiber, glass fiber, nylon fiber, and the like. Applying tape, fiber strands 216, and/or a crimp ring over the composite free edge 240 can prevent edge delamination, improve pressure vessel 10 aesthetics, and/or provide a support area for a pressure vessel 10 mount.

[061] Optionally, the inner surface 194 of the shank 182 can be configured to matingly engage with a tapered section 236 of the liner 14, such as illustrated in Figures 7 and 8. Figure 7 shows a second embodiment of the pressure vessel 10 having a boss 16A with a shank 182A that supports the tapered section 236 along the entire tapered region 42 of the liner 14. Optionally, the boss 16A extends along the tapered section 236 all the way past the tapered region 42 and overlaps a portion of the larger diameter cylindrical section 228 of the liner 14. The shank 182A shown in Figure 7 provides full taper anchoring along the tapered section 236. The boss 16A absorbs most of the hoop stress of the liner 14 and reduces load on the tapered section 236 of the liner 14. The increased contact area between the boss 16A and the liner 14 of Figure 7 improves the quality of seal. The amount of boss torque that can be tolerated without the boss 16 separating from the liner 14 and/or the outer composite shell 18 is increased by the addition of spikes 186 projecting radially from the shank 182A.

[062] In contrast to the embodiments shown in Figures 1 and 7, a third embodiment of a boss 16B shown in Figure 8 has a shank 182B that supports the tapered section 236 along a portion of the tapered region 42 of the liner 14. The boss 16B provides partial taper anchoring since the shank 182B only supports a portion of the tapered region 42. The shorter shank 182B shown in Figure 8 provides less support for the tapered section 236 than the longer shank 182A shown in Figure 7. However, the shorter shank 182B has less material cost than the longer shank 182A. Further, the boss 16B of Figure 8 is lighter than the full taper anchoring boss 16A shown in Figure 7. The shape, length, and dimensions of the shank 182, 182A, 182B are selected based in part on the desired operating conditions of the pressure vessel 10 as well as secondary factors such as material cost and component weight, and the like.

[063] Turning to Figure 1, spikes 186 projecting radially away from the shank 182, 182A, 182B and embedded into the outer composite shell 18 mechanically fasten the boss 16, 16A, 16B to the outer composite shell 18. The spikes 186 can be distributed over the entire outer

bearing surface 198 of the shank 182, 182A, 182B. A fourth embodiment is shown in Figure 9 of a boss 16C that illustrates alternate placement of the spikes 186 on a shank 182C. As illustrated by Figure 9, the spikes 186 can be placed in one or more specific zones 238, 238' on the shank 182C. The number, shape, size, and position of the spikes 186 attached to the shank 182 – 182C are selected based on the expected nominal working pressure or boss torque on the pressure vessel 10 during use, the dimensions of the shank 182-182C, the dimensions of the outer composite shell 18, and the like. The spikes 186 can be distributed over the entire outer bearing surface 198 of the shank 182B or the spikes 186 can be placed in specific zones 238, 238' on the shank 182B.

[064] The boss 16C is shown in Figure 9 prior to assembly with the pressure vessel 10. The boss 16C has a shank 182C configured to matingly engage with the tapered section 236 of the liner 14. Thus, the shank 182C has a tapered conical shape and/or a tapered cylindrical shape that abuts the flange shoulder 200. When the boss 16C is assembled with the liner 14 and covered with the outer composite shell 18, spikes 186 projecting radially away from the outer bearing surface 198 of the shank 182C are embedded into the outer composite shell 18 to mechanically fasten the boss 16C to the outer composite shell 18.

[065] Also shown in Figure 9 is an optional vent groove 248 extending longitudinally along the outer bearing surface 198 of the shank 182C and radially along the flange shoulder 200. The boss 16C can include any number and configuration of vent grooves 248, as desired for specific applications, to allow for hydrogen gas venting from the interface between the liner 14 and outer composite shell 18 to the atmosphere. Gas permeates through the liner 14 and collects in a gap between the liner 14 and the outer composite shell 18. The permeate gas is vented to atmosphere through the vent groove 248 to prevent a subsequent collapse of the liner 14.

[066] In addition, since both the liner 14 and the outer composite shell 18 are fixedly coupled to the boss 16, as shown in Figure 1, forces applied to the boss 16 are distributed to the outer composite shell 18. In contrast, when the boss 16 is inserted into an opening in a liner 14 that covered with an outer composite shell 18 followed by crimping a ferrule around the outer composite shell 18, the boss 16 only directly contacts the liner 14. The ferrule is fixedly coupled to the outer composite shell 18 and fixedly coupled to the boss 16. However, the boss 16 is not directly fixedly coupled to the outer composite shell 18. Instead, the connections between the ferrule and the outer composite shell 18 and between the ferrule and

the boss 16 form the mechanical coupling between the boss 16 and the outer composite shell 18. Gaps can form over time between the liner 14 and the outer composite shell 18. Further, the ferrule can separate from the outer composite shell 18 and/or from the boss 16. Rotational and axial loads on the boss 16 can potentially weaken the adhesion of the liner 14 to the outer composite shell 18, weaken the ferrule crimp, and/or increase gaps that form between the liner 14 and the outer composite shell 18. If the ferrule crimp is loosened sufficiently, then the boss 16 can rotate within the ferrule. Movement of the boss 16 with respect to the outer composite shell 18 due to the weakened ferrule crimp can further cause the boss 16 to separate from the liner 14. Replacing the ferrule with the spikes 186 on the boss 16 directly couples the boss 16 to the outer composite shell 18 when the spikes 186 are embedded into the outer composite shell 18. In some embodiments, the spikes 186 can be combined with the ferrule to increase the mechanical coupling between the boss 16 and the outer composite shell 18. The inclusion of the spikes 186 embedded into the outer composite shell 18 can be combined with a number of different fastening methods that attach the boss 16 to the liner 14 and to the outer composite shell 18 if desired and/or required depending on the expected load on the boss 16.

[067] The spikes 186 can have various shapes, such as illustrated in Figure 10. Variations in suitable spikes 186 include cylindrical-shaped spikes 264, tetrahedron-shaped spikes 268, pyramid-shaped spikes 270, and conical-shaped spikes 274, as non-limiting examples. The tetrahedron-shaped spikes 268 have three lateral faces 280. The pyramid-shaped spikes 270 have four or more lateral faces 280, including but not limited to five, six, seven, or more lateral faces 280. Each spike 186, 264, 268, 270, 274 has a spike main body 278 extending between a spike tip 282 and a spike base 286. The spike tip 282 can be peak-shaped, as illustrated by the pyramid spike 270. Alternatively, the spike tip 282 can have a rounded shape, as illustrated by the spike tip 282 of the conical spike 274. Any shape of spike 186 suitable for an intended application can be used, including a mixture of spike 186 shapes and sizes.

[068] The spike base 286 can include a cylindrical-shaped pin 288 projecting longitudinally away from the spike base 286, as illustrated in Figure 11. Figure 11 shows non-limiting embodiments of a cylindrical-shaped spike 264, a tetrahedron-shaped spike 268, a pyramid-shaped spike 270, and a conical-shaped spike 274 having a cylindrical-shaped pin 288 projecting away from the spike base 286. The pin 288 allows for mounting different shaped

spikes 186, 264, 268, 270, 274 into circular holes 290 in the shank 182, as illustrated in Figure 12B. The circular holes 290 can be recessed cavities, through holes, and/or combinations of cavities and through holes. Further, the pin 288 and the holes 290 can be non-circular in some embodiments.

[069] Figures 12A-12D illustrate methods of attaching the spikes 186, 264, 268, 270, 274 to the shank 182. Pressing cylindrical-shaped spike 264 into a circular hole 290 in the shank 182, as illustrated by arrow D, is shown in Figure 12A. The cylindrical-shaped spike 264 can be press-fitted (illustrated by arrow D) into a circular hole 290 sized to matingly receive the cylindrical-shaped spike 264. The circular hole 290 can be a partial depth hole 290 or a through-hole 290, as desired for a specific application.

[070] The second attachment method shown in Figure 12B is similar to the attachment method shown in Figure 12A. The cylindrical-shaped spike 264, the tetrahedron-shaped spike 268, the pyramid-shaped spike 270, and the conical-shaped spike 274 can include a cylindrical-shaped pin 288 projecting away from spike base 286, as shown in Figure 11. The pin 288 is press-fitted (illustrated by arrow E) into a circular hole 290 in the shank 182 having an inner diameter sized to matingly engage with the pin 288, as shown in Figure 12B. The addition of the pin 288 to the spike base 286 allows for press-fitting non-cylindrical spikes 268, 270, 274 to the shank 182 using circular holes 290.

[071] Welding the spike 186 to the shank 182 is a third attachment method illustrated in Figure 12C. The spike base 286 of each of spikes 186, 264, 268, 270, 274 can be welded 286A and/or adhered to the shank 182. Figure 12C illustrates welding a spike base 286 of a cylindrical-shaped spike 264 to the outer bearing surface 198 of the shank 182. A weld line 286A is formed around the base 286 of the spike 186. While the weld line 286A increases the diameter of the spike 186, it is unlikely to cause problems during the over-braiding process 226 since the weld line 286A is adjacent the shank 182. In some embodiments, the spikes 186 can be adhered to the shank 182 with an adhesive. Welding and adhering attachment methods can accommodate a variety of spike 186 shapes, including the cylindrical-shaped spike 264, the tetrahedron-shaped spike 268, the pyramid-shaped spike 270, and the conical-shaped spike 274 shown in Figure 11, as well as other shapes of spikes 186.

[072] A fourth method, illustrated in Figure 12D, is machining and/or molding the spike 186 when the shank 182 is formed. The fourth method can be used to form cylindrical-shaped

spikes 264, tetrahedron-shaped spikes 268, pyramid-shaped spikes 270, and conical-shaped spikes 274, as non-limiting examples. During a machining process, material is removed around the spike 186 to form the spike 186. Alternatively, the spikes 186 can be integrated into a molding tool when the boss 16 is formed during a molding process.

[073] Referring to Figure 3A, a plurality of spikes 186 are fixedly coupled to the shank 182 of the boss 16. In the embodiment shown in Figure 3A, the spikes 186 are distributed around the outer periphery 198 of the shank 182. The spikes 186 can be arranged in a plurality of rows 294, 294' of spikes 186 with four rows 294, 294' of spikes 186 shown in the exemplary embodiment of Figure 3A.

[074] As shown in Figure 3A, a row 294, 294' of spikes 186 is defined as a plurality of spikes 186 spaced around an outer periphery 198 of the shank 182 wherein the axial distance measured between a terminal end 88' of the boss 16 and a center of each spike tip 282 within the row 294, 294' of spikes 186 is within a range defined by a predefined amount. In one embodiment, the predefined amount may be a multiple of the maximum width 186' of the spikes 186 comprising the row 294, 294' of spikes 186, wherein the multiple is 1, 2, 3, or more, as a non-limiting example.

[075] Adjacent rows 294, 294' of spikes 186 are spaced apart in an axial direction of the boss 16, as shown in Figure 3A. The axial distance 294A between adjacent rows 294, 294' of spikes 186 can be uniform between the rows 294, 294' or the spacing can be non-uniform, i.e., some of the rows 294, 294' being spaced closer together than the spacing between other rows 294, 294' of spikes 186.

[076] Further, the spikes 186 in a first row 294 are aligned in an axial direction of the boss 18 with spikes 186 in a second row 294' of spikes 186 in the embodiment shown in Figure 3A. However, it will be understood that any number of spikes 186, any number of rows 294, 294' of spikes 186, as well as relative alignment of spikes 186 in a first row 294 with respect to the positional alignment of spikes 186 in an adjacent row 294', can vary without altering the scope of the invention. Spikes 300A-300D illustrate alternate exemplary spike 186 locations on the shank 182 of Figure 3A. With the inclusion of spikes 300A and 300B, the second row 294' of spikes 186 will have more spikes 186 than present in the first row 294 of spikes 186. Further, spikes 300A and 300B are offset from the spikes 186 forming the first row 294 of spikes 186. Spikes 300C and 300D are positioned near spike 300E to create a

local zone 238 with additional spikes 300C-300E. In addition, spikes 186 in a first row 294 of spikes 186 can be circumferentially offset from the spikes 186 in an adjacent row 294' of spikes 186, as illustrated in Figure 16 described below, if desired for a specific application.

[077] An exemplary arrangement of spikes 186 around the outer circumference 198 of the shank 182 is illustrated in Figure 13. Figure 13 is a sectional view of the pressure vessel 10 of Figure 1 taken along section line A-A. Figure 13 shows twelve spikes 186 forming a row 294 of spikes 186 attached to the shank 182. The spikes 186 are shown in Figure 13 positioned equidistant around the outer periphery 198 of the shank 182. However, the spikes 186 can be positioned such that the spikes 186 are not spaced equidistant around the outer periphery 198 of the shank 182. The spikes 186 shown in Figure 13 are fully embedded into the outer composite shell 18. However, in certain embodiments the spikes 186 can be configured to penetrate partially into the outer composite shell 18.

[078] Further, the number of spikes 186 can be selected based on the requirements of specific applications. Preferably, the shank 182 includes at least four spikes 186. While generally cylindrical-shaped spikes 264 are shown in Figure 13, tetrahedron-shaped spikes 268, pyramid-shaped spikes 270, conical-shaped spikes 274, and the like, can be used in place of the cylindrical-shaped spikes 264 if desired for a specific application. In addition, the spikes 186 can include one or more shapes of spikes 186, i.e., a first portion of the spikes 186 can be selected to be cylindrical-shaped spikes 264 with the remaining spikes 186 being pyramid-shaped spikes 270, as a non-limiting example.

[079] Further, spikes 186 can be distributed in one or more local zones 238, 238' on the shank 182, as shown in Figure 9, instead of distributing the spikes 186 around the outer periphery 198 of the shank 182, as illustrated in Figure 13. Alternatively, the spikes 186 can be distributed into two or more local zones 238, 238' on the shank 182 wherein the two or more local zones 238, 238' being spaced apart on the outer bearing surface 198 of the shank 182. Optionally, the two or more zones 238, 238' can be in selected locations around the outer periphery 198 of the shank 182. In addition, the two or more zones 238, 238' can be positioned equidistant apart on the outer periphery 198 of the shank 182 if desired for a specific application.

[080] Referring to Figures 14 and 15, the overall length of the spikes 186 can be selected based on the thickness of the outer composite shell 18, the nominal working pressure, or the

expected amount of torque on the boss 16, the dimensions of the boss 16, and the number of spikes 186 attached to the shank 182. Figures 14 and 15 show enlarged views of portion C of the pressure vessel 10 shown in Figure 13 illustrating variations in spike 186 length compared to the thickness of outer composite shell 18. Referring to Figure 14, the outer composite shell 18 is shown as comprising an exemplary three fiber layers 224A-224C. The spike 186 of Figure 16 extends through the first fiber layer 224A. In contrast, Figure 18 shows the spike 186 having a length sufficient to penetrate through all three fiber layers 224A-224C. Various embodiments of the pressure vessel 10 can include more or less fiber layers 224A-224C than shown in Figures 14 and 15. Thus, the spikes 186 can be sized to project into and/or through any desired number of fiber layers 224A-224C, including both braided fiber layers 224 and wrapped fiber layers 218. Further, the spikes 186 can be embedded in and/or project through supplemental layers of materials between the liner 14 and the outer composite shell 18, including barrier layers, breather layers, metallic film layers, and the like.

[081] Referring to Figures 10-15, the overall shape of the spikes 186, maximum outer diameter 186' of the spikes 186, contour of the spike tips 282, overall height of the spikes 186, circumferential distance between adjacent spikes 186, number of spikes 186, and arrangement of spikes 186 on the shank 182, and the like, are selected based in part on the expected rotational and axial forces on the boss 16, the method of applying fiber 214 to the liner 14, as well as based in part on dimensions of the shank 182, the outer composite shell 18, and the inclusion of supplemental layers between the liner 14 and the outer composite shell 18. For example, a greater number of spikes 186 having an increased overall length may be fixedly coupled to the shank 182 when elevated rotational and/or axial loads are expected on the boss 16 during use. For specific applications with lower expected rotational and axial loads on the boss 16, fewer and/or shorter spikes 186 may be selected.

[082] The placement, shape, and overall dimensions of the spikes 186 are selected, based in part, on the over-braiding process 226 illustrated in Figure 6. A conformable pressure vessel 10 is shown in Figure 6 having a liner 14 with a larger diameter cylindrical section 228 that is connected to a smaller diameter cylindrical section 232 by a tapered cylindrical section 236. The flare edge 62 of the liner 14 has been previously fixedly coupled to the bore 86 of the boss 16 prior to the fibers 214 being over-braided around the liner 14. A plurality of fiber filaments 214 are grouped into a fiber strand 216. A plurality of fiber strands 216 are over-braided around the liner 14 using a braiding machine 226, as shown in Figure 6. The braided

fiber strands 216 conform to the outer surface 54 of the liner 14 with the density of the braided fiber strands 216 on the surface 54 of the liner 14 changing as the outer diameter of the liner 14 varies. The braided fiber strands 216 transition smoothly from the liner 14 to cover the shank 182 without affecting the over-braiding process 226.

[083] The over-braiding process 226 can form the braided layer 224 of fiber strands 216 around the spikes 186 projecting from the shank 182, as illustrated in Figures 16 and 17. Each of Figures 16 and 17 show an enlarged view of portion B shown in Figure 6. Figure 16 illustrates tetrahedron-shaped spikes 268 and Figure 17 illustrates cylindrical-shaped spikes 264. Referring to Figure 16, each fiber strand 216 comprises a plurality of fiber filaments 214. The exemplary embodiment shown in Figure 6 has shank 182 outer bearing surface 198 diameter of about 25 mm, the fiber strands 216 have a nominal strand width 216' of about 4 mm, and the outer composite shell 18 comprises a plurality of braided layers 224 of fiber strands 216 with the outer composite shell 18 being about 5 mm in thickness. However, the radial thickness of the outer composite shell 18 can be larger or smaller than about 5 mm if desired based on the boss diameter and on requirements of a specific application.

[084] Referring to Figure 16, preferably, the maximum outer diameter 186' of each spike 186 is less than the nominal strand width 216' of the fiber strands 216 used to form the braided fiber layer 224. More preferably, the maximum outer diameter 186' of the spike main body 278 and of the spike tip 282 of each spike 186 is equal to or less than about half of the nominal strand width 216' of the fiber strands 216. Most preferably, the maximum outer diameter 186' of the spike tip 282 and of the spike main body 278 of each spike 186 is between about 0.2 mm and about 2.0 mm. The spike base 286 of each spike 186 can be larger than the above ranges if desired and further depending on the spike 186 attachment method to the shank 182. For example, spikes 186 attached to the shank 182 may have a flared base 286A larger than the spike main body 278 caused by a welding process. For spikes 186 having non-cylindrical shapes, such as the tetrahedron-shaped spikes 268, the pyramid-shaped spikes 270, and the like, the maximum outer dimensions 186' of the spike base 286 of each spike 186, 268, 270 is preferably equal to or less than the nominal strand width 216' of the fiber strands 216, more preferably equal to or less than half the nominal strand width 216' of the fiber strands 216, and most preferably between about 0.2 mm and about 2.0 mm. However, spikes 186 having larger and/or smaller diameters 186' may be selected for specific applications if desired.

[085] Referring to Figures 10-15, preferably, the length of each spike 186 is between about 0.5 mm to about 5 mm, as measured between the spike tip 282 and the spike base 286. More preferably, the length of each spike 186 is sized to at least embed in a first fiber layer 224A that forms the outer composite shell 18, as shown in Figure 14. However, each spike 186 can selectively have an overall length sufficient to penetrate any desired number of fiber layers 224, 224A-224C, 218, including both braided fiber layers 224 and wrapped fiber layers 218. Further, the length of the spikes 186 can be selected to penetrate optional supplemental layers such as one or more of a barrier layer, a breather layer, and the like, if desired for a specific application.

[086] Adjacent spikes 186A, 186B shown in Figure 16, are preferably spaced apart by at least one nominal strand width 216' of the fiber strand 216. The nominal strand width 216' of the fiber strand 216 is defined as an approximate width 216' of a fiber strand 216, as illustrated in Figure 16. For the exemplary embodiment shown in Figure 6 having a nominal width 216' of fiber strands 216 of about 4 mm, the preferred minimum spacing between adjacent spikes 186 is at least 4 mm, i.e. the preferred minimum spacing being equal or greater than the nominal strand width 216' of the fiber strands 216. Individual spikes 186 can be spaced closer together than the nominal strand width 216' of the fiber strands 216 as long as the minimum distance between adjacent spike tips 282 is preferably equal or greater than the nominal strand width 216' of the fiber strands 216. The number of spikes 186 can be as few as about four with a maximum amount of spikes 186 determined by the outer diameter and length of the shank 182 while positioning the spikes 186 at least a nominal strand width 216' of the fiber strands 216 apart. Further, when the boss 16 includes a plurality of rows 294, 294' of spikes 186, preferably adjacent rows 294, 294' are spaced at least one nominal strand width 216' of the fiber strands 216 apart.

[087] The fiber strands 216 are braided around the spikes 186, such as illustrated by relative positions of fiber strands 216A-216D and spike 186A, as shown in Figures 16 and 17. When fiber strands 216, 216E align with the spikes 186, such as illustrated by fiber strand 216E and spike 186E shown in Figures 16 and 17, some of the fiber filaments 214 of the fiber strands 216E will be laid down around the spikes 186E, e.g., the fiber strand 216E is split into groups of filaments 214 as illustrated by 214E and 214F. The engagement between the fiber strands 216A-216E and the spikes 186, 186A, 186E interlock the braided fiber layer 224A with the spikes 186, 186A, 186E. Additional braided fiber layers 224B, 224C will interlock with the

spikes 186, 186A, 186E in a similar method. Each braided fiber layer 224A-224C that is braided around the spikes 186, 186A, 186E will increase the strength of the mechanical connection between the boss 16 and the outer composite shell 18. The mechanical connection between the boss 16 and the outer composite shell 18 is further strengthened by the curing of the resin 220 impregnated into the fiber strands 216, 216A-216E. The fiber strands 216, 216A-216E will be similarly interlocked with the spikes 186, 186A, 186E when the fiber strands 216, 216A-216E are helically wrapped around the shank 182 forming wrapped fiber layers 218.

[088] Figures 18-23 illustrate a method of continuous manufacturing of pressure vessels 10, particularly conformable pressure vessels 10 with over-braided outer composite shells 18. An exploded view of a liner/boss subassembly 318, 318' is shown in Figure 18. The liner/boss subassembly 318, 318' comprises a liner 14, 14A a boss 16, 16D and a sealing insert 134, 134'. The longitudinal axis of the liner/boss subassembly 318, 318' is shown by element 32 in Figure 18. The liner 14, 14A optionally includes a locating feature 206 integrated into the cylindrical neck region 118 of the liner 14, 14A for locating the boss 16, 16D during assembly. The locating feature 206 can include a recessed channel, a ridge, protrusions, and the like as non-limiting examples. The shank 182 of the boss 16, 16D is slid over the liner 14, 14A such that the flare edge 62 of the liner 14, 14A is inserted into the bore 86 of the boss 16, 16D until the terminal end 88' of the boss 16, 16D engages with the locating feature 206 on the liner 14, 14A. The sealing insert 134, 134' is assembled with the bore 86 of the boss 16, 16D such that the cone surface 162 of the sealing insert 134, 134' pinches the liner 14, 14A against the boss cone surface 102 of the bore 86. Assembling the boss 16, 16D, the liner 14, 14A and the sealing insert 134, 134' forms the liner/boss subassembly 318, 318' illustrated in Figure 19.

[089] Referring to Figure 19, a liner/boss subassembly 318, 318' is fastened to each terminal end 322, 322' of a sacrificial tubing section 324 to form an elongated subassembly 332. The sacrificial tubing section 324 is defined by a cylindrical wall 336 extending between the opposing terminal ends 322, 322'. Further, the terminal end 88 of each boss 16, 16D and the terminal ends 322, 322' of the sacrificial tubing section 324 are configured to matingly engage and fixedly couple and/or releasably couple the liner/boss subassemblies 318, 318' to the sacrificial tubing section 324. Figure 20 illustrates the elongated subassembly 332 of a pair of liner/boss subassemblies 318, 318' coupled to the opposing terminal ends 322, 322' of

the sacrificial tubing section 324. Any number of liners/boss subassemblies 318, 318' can be coupled together with sacrificial tubing section 324 to form the elongated assembly 332 prior to passing the liner/boss subassemblies 318, 318' through one or more braiding machines 226.

[090] Figure 21 illustrates a process of feeding the elongated assembly 332 through a braiding machine 226, as illustrated by arrow G. Each liner 14, 14A includes one or more larger diameter cylindrical sections 228, smaller diameter cylindrical sections 232, and tapered liner sections 236 extending between adjacent larger and smaller diameter sections 228, 232. The braiding machine 226 over-braids a plurality of fiber strands 216 around the outer periphery 54' of the liner 14, 14A. The braiding process 226 automatically braids the fiber strands 216 over the outer periphery 54' of the elongated assembly 332 with the braided fiber layer 224 following the outer contour 54, 54' of the liner 14. As the elongated assembly 332 passes through the braiding machine 226, fiber strands 216 are braided around the outer periphery 54, 54' of the liner 14, 14A the boss 16, 16D and the sacrificial tubing section 324 as these components 14, 14A, 16, 16D, 324 pass through the braiding machine 226. The elongated assembly 332 can be passed sequentially through a plurality of braiding machines 226 with each braiding machine 226 configured to over-braid a single layer 224 of braided fiber strands 216.

[091] The elongated assembly 332 can be wrapped with one or more of barrier layers, breather layers, metallic film layers, and the like, prior to over-braiding fiber strands 216 around the elongated assembly 332. Further, one or more of barrier layers, breather layers, metallic film layers, and the like, can be applied to the elongated assembly 332 after and/or before over-braiding individual fiber layers 224, 224A-224C. As a non-limiting example, a breather layer can be wrapped around the entire elongated assembly 332 prior to over-braiding a first fiber layer 224, 224A around the outer periphery 54' of the elongated assembly 332. As another example, a metallic film layer can be wrapped around the liner 14, 14A around the outer periphery 54' of the first braided fiber layer 224A followed by over-braiding additional fiber layers 224B, 224C around the elongated assembly 332.

[092] Figure 22 illustrates the elongated assembly 332 after passing through the braiding machine 226 and before the braided fiber layer 224 is trimmed adjacent the flange shoulder 200 of each boss 16, 16D. As shown in Figure 22, the entire elongated assembly 332 is over-braided with the fiber strands 216. The braided fiber layer 224 is trimmed (as illustrated by

arrows K shown in Figure 22) adjacent the flange shoulder 200 of each boss 16, 16D to form a composite free edge 240. The sacrificial tubing section 324 is removed from each boss 16, 16D after the braided fiber layer 224 is trimmed. Figure 23 shows the elongated assembly 332 after trimming to form separate pressure vessels 10, 10'. The composite free edge 240 on each boss 16, 16D can be covered with tape 242 and/or a crimped ferrule if desired.

[093] One benefit of a pressure vessel 10 having a liner 14 fixedly coupled to a boss 16 having spikes 186 projecting outward from the boss 16 embedded in an outer composite shell 18 is the boss 16 is mechanically coupled directly to the outer composite shell 18 as well as mechanically coupled to the liner 14. A second benefit is a seal is achieved between the liner 14 and the boss 16 by fixedly coupling the liner 14 to a boss cone surface 102 of a bore 86 passing axially through the boss 16. A third benefit is the embedded spikes 186 in the outer composite shell 18 restrict rotation of the boss 16 with respect to the outer composite shell 18. A fourth benefit is the embedded spikes 186 in the outer composite shell 18 restrict axial motion of the boss 16 with respect to the outer composite shell 18 since the boss 16 and the outer composite shell 18 are mechanically coupled by the spikes 186. A fifth benefit is fixedly coupling the liner 14 to the boss 16 without using a molding process and without using a ferrule to crimp the liner 14 to the boss 16. A sixth benefit is fixedly coupling the outer composite shell 18 to the boss 16 without relying on a ferrule to crimp the outer composite shell 18 to the boss 16.

[094] The invention has been described in an illustrative manner, and it is to be understood that the terminology, which has been used, is intended to be in the nature of words of description rather than of limitation. Many modifications and variations of the present invention are possible in light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed is:

1. A pressure vessel for containing liquids and/or gases under pressure, said pressure vessel comprising:

a polymeric liner comprising a hollow body defined by an elongated cylindrical wall having opposing inner and outer surfaces extending between a first terminal end and a second terminal end of said liner, said liner including an inlet opening near said first terminal end of said liner, said inlet opening defined by a flare edge of said liner;

an outer composite shell comprising resin and fibers, said outer composite shell surrounding an outer periphery of said liner;

a boss having a bore passing axially through said boss, said bore defined by a cylindrical wall having an interior surface, said bore in fluid communication with an interior of said pressure vessel;

said boss having a shank with opposing inner and outer bearing surfaces, said inner bearing surface oriented towards said outer surface of said liner, and said outer bearing surface oriented towards said outer composite shell;

said shank including a plurality of spikes fixedly coupled to said shank and projecting radially away from said outer bearing surface, each of said plurality of spikes being at least partially embedded into said outer composite shell; and

said flare edge of said polymeric liner being fixedly coupled to said boss.

2. The pressure vessel as set forth in claim 1, wherein:

said plurality of spikes comprises four or more spikes.

3. The pressure vessel as set forth in claim 2, wherein:

at least a first portion of said plurality of spikes forming a first row of spikes spaced around an outer periphery of said shank.

4. The pressure vessel as set forth in claim 2, wherein:

said plurality of spikes being distributed across at least one zone on said outer surface of said shank.

5. The pressure vessel as set forth in claim 4, wherein:

said plurality of spikes being distributed across two or more zones on said outer surface of said shank; and

said two or more zones being spaced apart on said outer periphery of said shank.

6. The pressure vessel as set forth in claim 3, wherein:

a second portion of said plurality of spikes forms a second row of spikes spaced around said outer periphery of said shank; and

said second row of spikes being spaced apart from said first row of spikes in an axial direction of said boss.

7. The pressure vessel as set forth in claim 6, wherein:

each spike of said second row of spikes being circumferentially offset from said spikes of said first row of spikes.

8. The pressure vessel as set forth in claim 3, wherein:

said outer composite shell formed by braiding a plurality of fiber strands around said liner and said shank of said boss to form a layer of braided fiber strands.

9. The pressure vessel as set forth in claim 8, wherein:

each of said plurality of fiber strands comprises a plurality of fiber filaments, said each of said plurality of fiber strands having a nominal strand width; and

each pair of adjacent spikes having respective spike tips being spaced apart by at least said nominal strand width.

10. The pressure vessel as set forth in claim 9, wherein:

a second portion of said plurality of spikes form a second row of spikes spaced around said outer periphery of said shank;

said second row of spikes being spaced apart from said first row of spikes in an axial direction of said boss; and

said first row of spikes and said second row of spikes being spaced apart by an axial distance of said boss of at least said nominal strand width.

11. The pressure vessel as set forth in claim 9, wherein:

each spike of said plurality of spikes having a spike main body defined between a spike base and a spike tip of said spike, said spike base being fixedly coupled to said shank;

said spike tip of each spike of said plurality of spikes having a maximum width of less than said nominal strand width; and

said spike main body of each spike of said plurality of spikes having a maximum width of less than said nominal strand width.

12. The pressure vessel as set forth in claim 11, wherein:

each spike of said plurality of spikes having a maximum cross-sectional width between about 0.2 mm and about 2.0 mm.

13. The pressure vessel as set forth in claim 12, wherein:

each spike of said plurality of spikes having a spike length defined between said spike base and said spike tip, said spike length being between about 0.5 mm to about 5 mm.

14. The pressure vessel as set forth in claim 13, wherein said spike base of each spike of said plurality of spikes being welded and/or adhered to said shank of said boss.

15. The pressure vessel as set forth in claim 13, wherein each spike of said plurality of spikes being press-fit into holes in said shank of said boss.

16. The pressure vessel as set forth in claim 15, wherein at least one spike of said plurality of spikes includes a pin projecting axially away from said spike base, said pin configured to be press-fitted into holes in said shank of said boss.

17. The pressure vessel as set forth in claim 13, wherein at least one spike of said plurality of spikes being a cylindrical-shaped spike.

18. The pressure vessel as set forth in claim 13, wherein at least one spike of said plurality of spikes being a tetrahedron-shaped spike.

19. The pressure vessel as set forth in claim 13, wherein at least one spike of said plurality of spikes being a pyramid-shaped spike having four or more lateral faces.

20. The pressure vessel as set forth in claim 13, wherein at least one spike of said plurality of spikes being a conical-shaped spike.

21. The pressure vessel as set forth in claim 13, wherein at least one of said plurality of spikes has a rounded spike tip.

22. The pressure vessel as set forth in claim 3, wherein:

said boss including a flange shoulder formed on an outer portion of said boss; and
said flange shoulder abutting said outer composite shell.

23. The pressure vessel as set forth in claim 3, wherein:

said flare edge of said polymeric liner extending axially into said bore of said boss to form a profiled neck; and

said liner being fixedly coupled to said interior surface of said bore of said boss.

24. The pressure vessel as set forth in claim 23, wherein:

said bore of said boss including an inner cylindrical neck portion formed on said interior surface of said boss and a boss cone surface formed on said interior surface of said boss adjacent said inner cylindrical neck portion; and

said flare edge of said polymeric liner extending axially into said bore of said boss to form said profiled neck, said profiled neck of said liner including a cylindrical neck region that bends outward to form a cone-shaped flare edge that substantially conforms to said inner cylindrical neck portion and said boss cone surface of said boss.

25. The pressure vessel as set forth in claim 24, said pressure vessel including a sealing insert shaped to fit within and engage with said bore of said boss, said sealing insert having a cone surface configured to matingly engage with said boss cone surface;

wherein when said sealing insert is engaged with said bore of said boss, said flare edge of said liner is radially compressed between said cone surface of said sealing insert and said boss cone surface of said boss.

26. The pressure vessel as set forth in claim 25, wherein said boss cone surface has one or more ridges extending across said boss cone surface.

27. The pressure vessel as set forth in claim 25, wherein at least a portion of said boss cone surface has a rough surface texture.

28. The pressure vessel as set forth in claim 25, wherein at least a portion of said boss cone surface has a smooth surface.

29. The pressure vessel as set forth in claim 25, wherein:

said sealing insert being fixedly coupled to said boss by a crimped joint and/or press-fit joint.

30. The pressure vessel as set forth in claim 25, wherein:

said sealing insert being coupled to said bore of said boss by a threaded joint.

31. A method of forming a type IV pressure vessel, said method comprising:

forming a first polymeric liner having a first elongated cylindrical wall extending between opposing first and second terminal ends, a first flare edge near said first terminal end, and a first inlet opening in said first flare edge;

forming a first boss having a first cylindrical portion connected to a first shank, a first bore passing axially through said first boss, and a first plurality of spikes projecting radially away from said first shank;

fixedly coupling said first flare edge of said first liner to said first bore of said first boss to form a first liner/boss subassembly; and

braiding a first plurality of fiber strands around at least a portion of an outer periphery of said first liner/boss subassembly to form a first braided fiber layer.

32. The method as set forth in claim 31, said method comprising:

forming a second polymeric liner having a second elongated cylindrical wall extending between opposing first and second terminal ends, a second flare edge near said first terminal end, and a second inlet opening in said second flare edge;

forming a second boss having a second cylindrical portion connected to a second shank, a second bore passing axially through said second boss, and a second plurality of spikes projecting radially away from said second shank;

fixedly coupling said second flare edge of said second liner to said second bore of said second boss to form a second liner/boss subassembly;

forming a sacrificial tubing section having a third cylindrical wall extending between a first tubing terminal end and a second tubing terminal end;

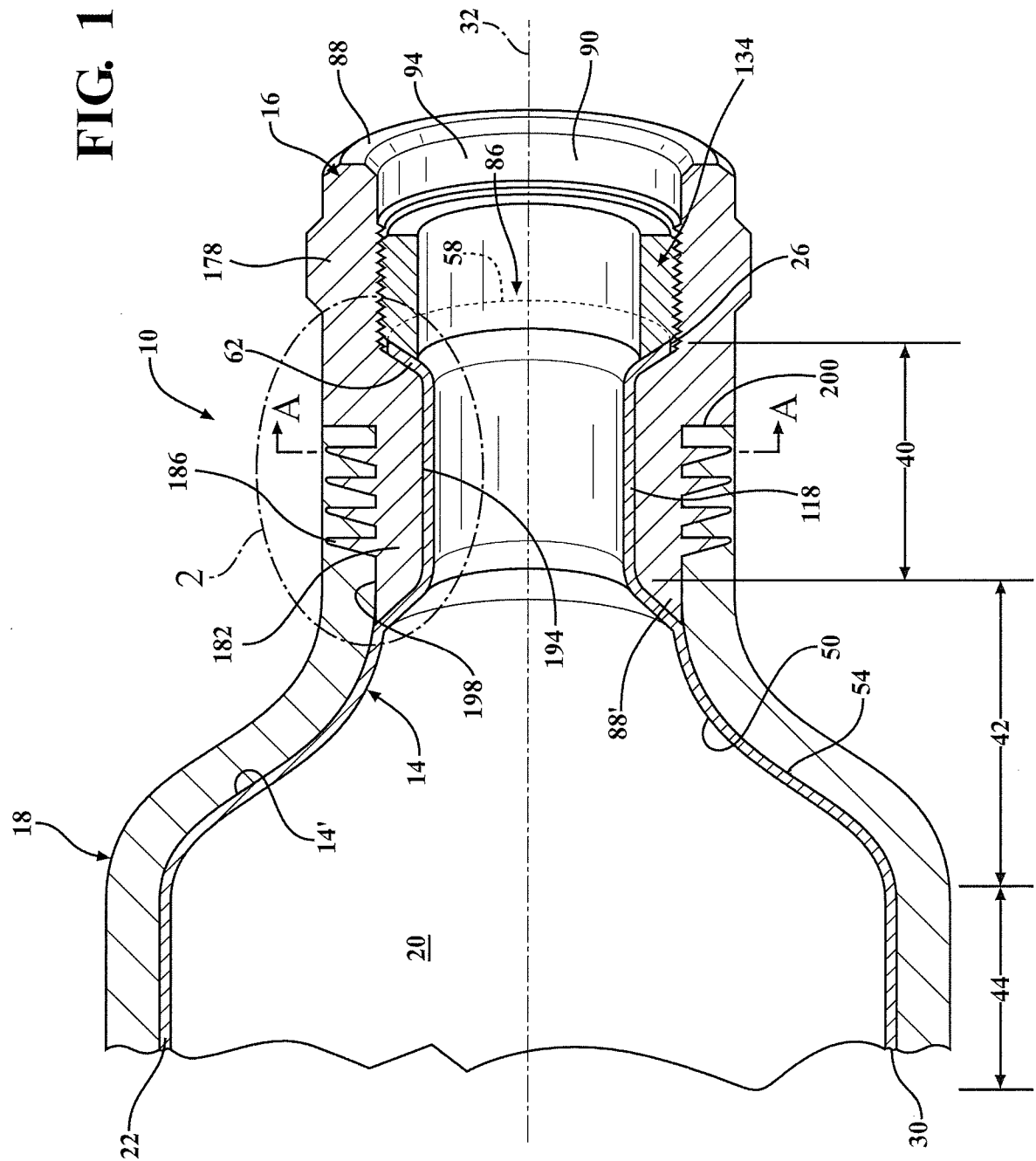
fixedly coupling said first liner/boss subassembly and said second liner/boss subassembly to said first terminal end and said second terminal end, respectively of said sacrificial tubing section to form an elongated assembly;

braiding a second plurality of fiber strands around an outer periphery of said elongated assembly to form a braided fiber layer;

trimming said braided fiber layer; and

removing said sacrificial tubing section from said elongated assembly to form individual pressure vessels.

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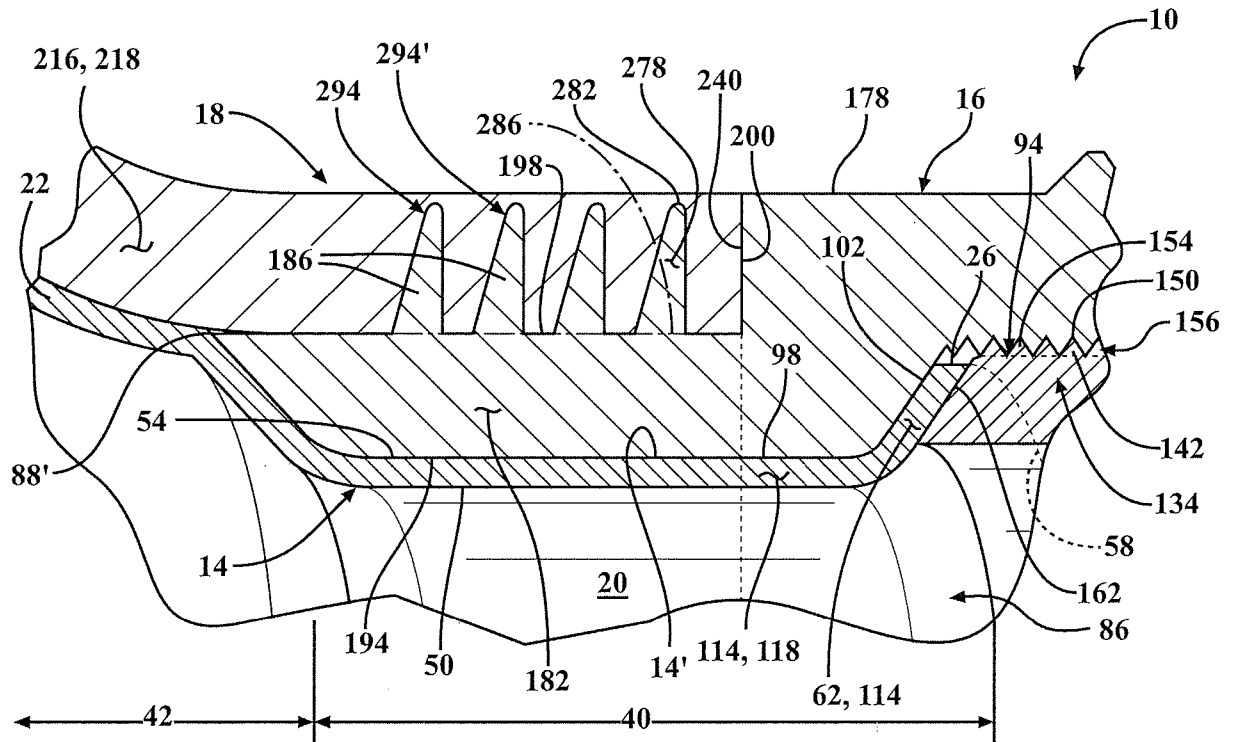
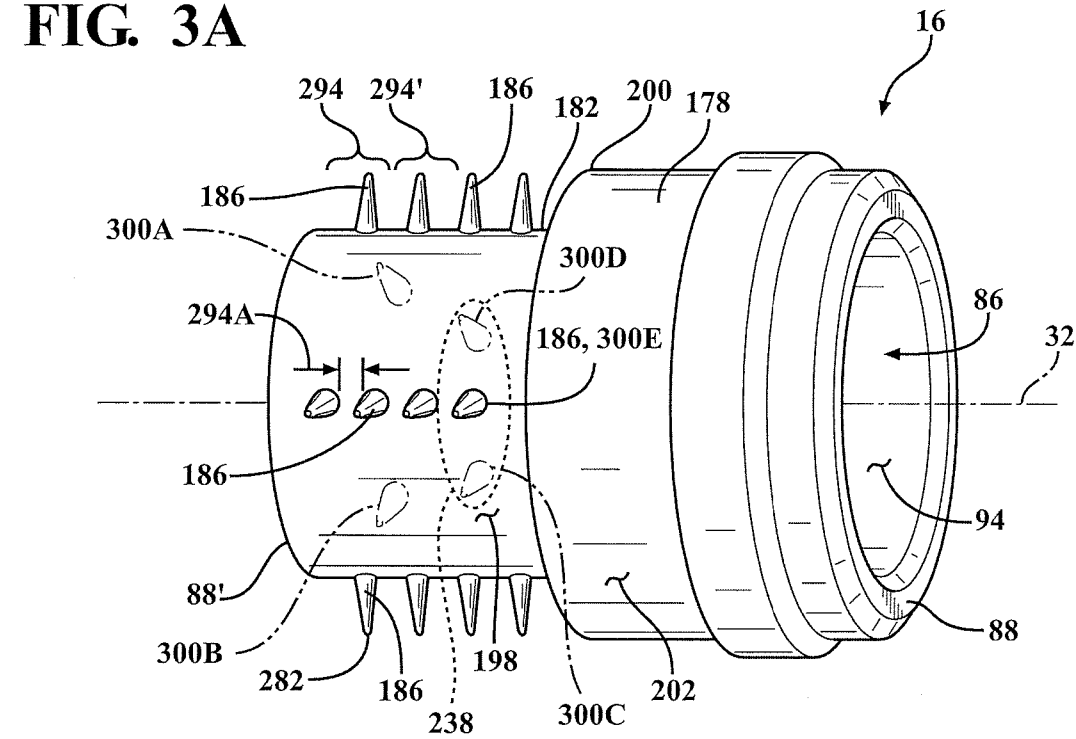
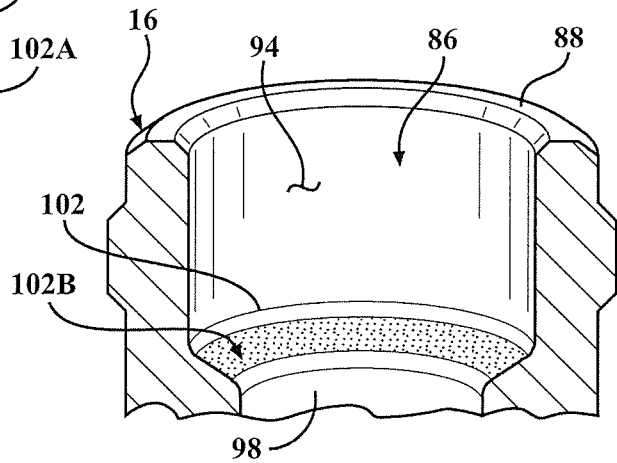
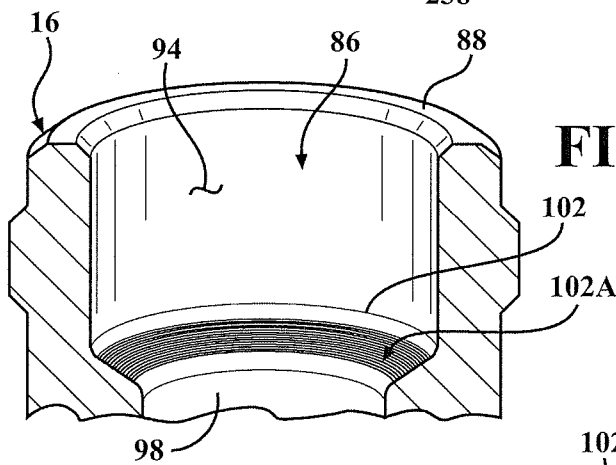
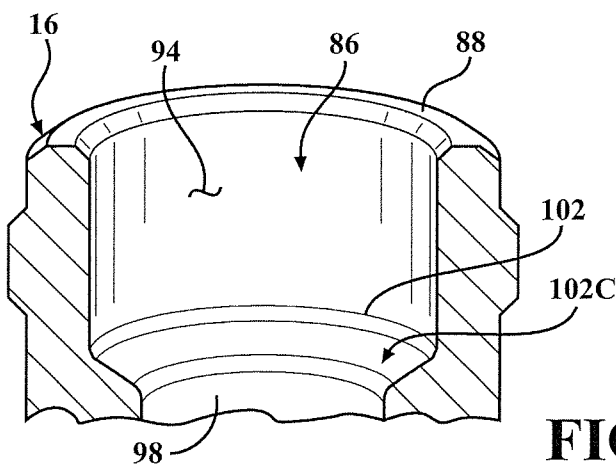
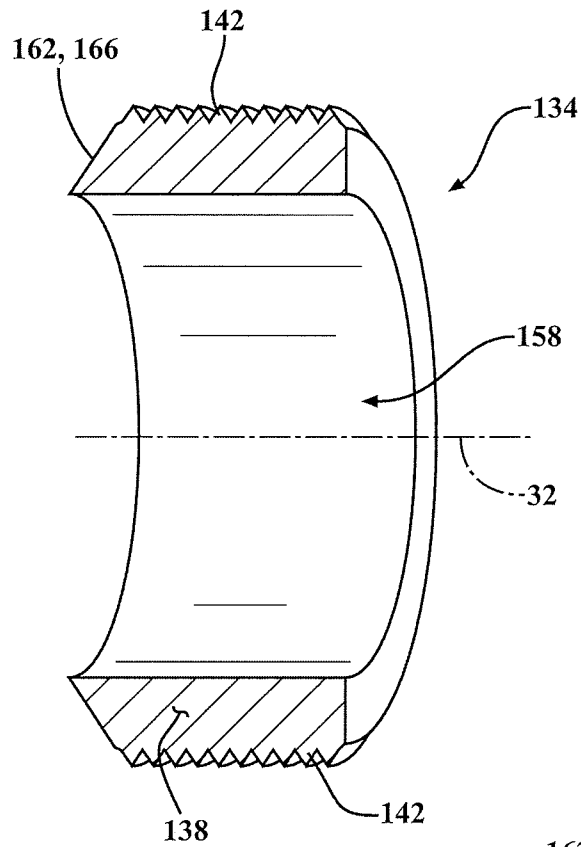
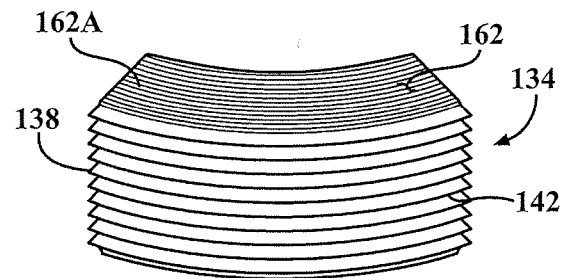
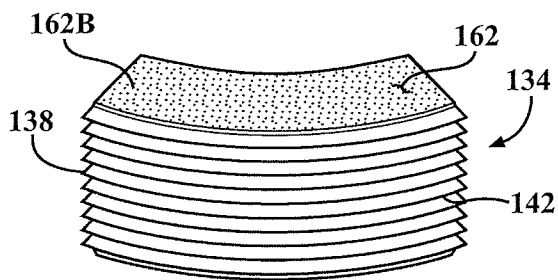
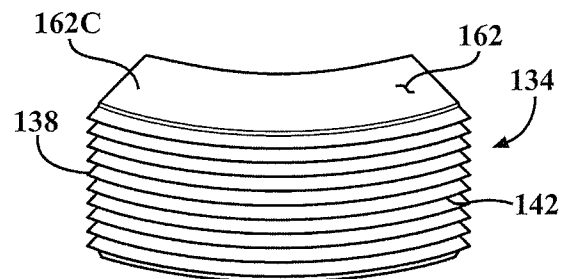


FIG. 2

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FIG. 3A**FIG. 3B****FIG. 3C****FIG. 3D**

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**FIG. 4A****FIG. 4B****FIG. 4C****FIG. 4D**

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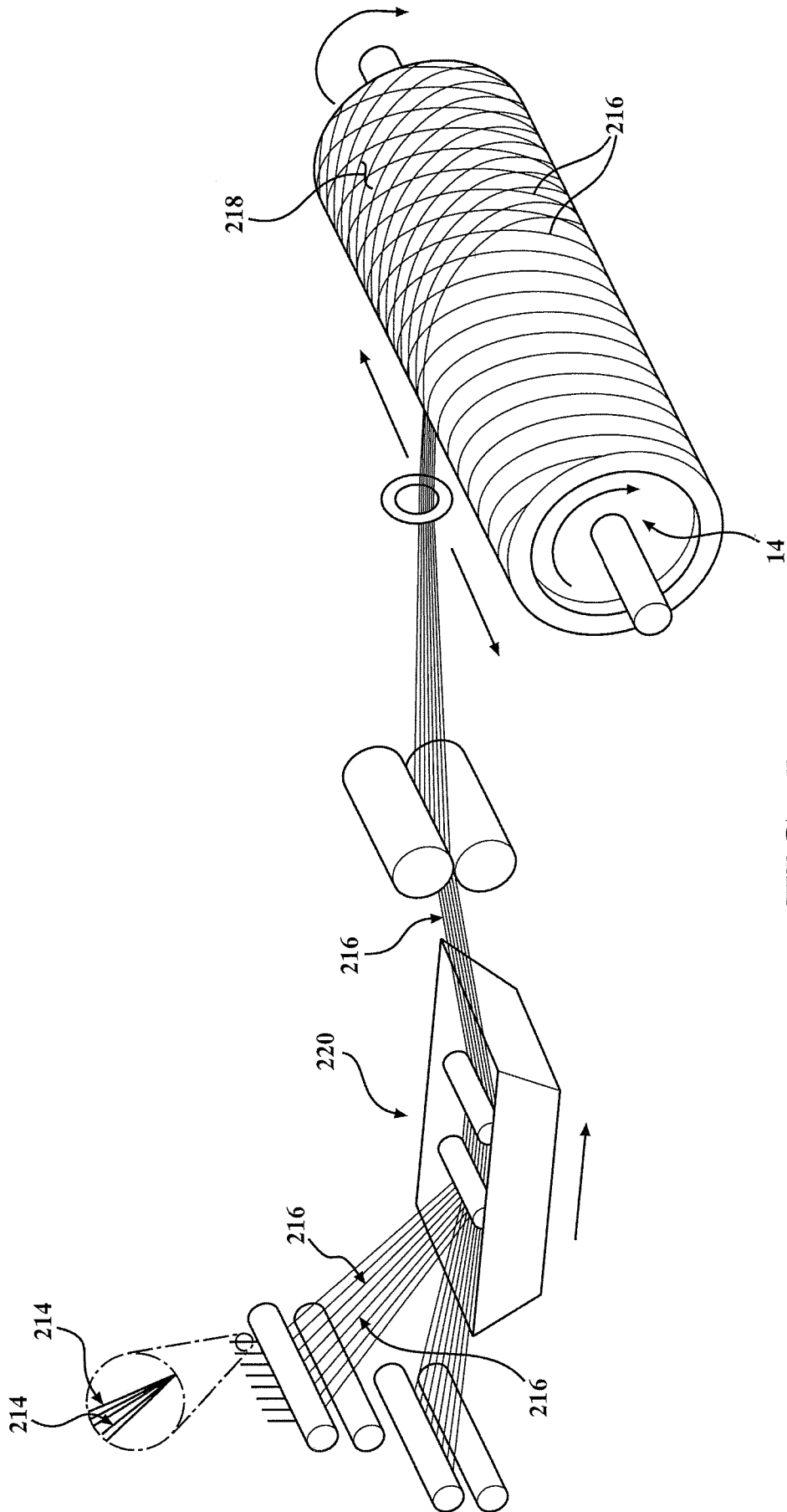


FIG. 5
PRIOR ART

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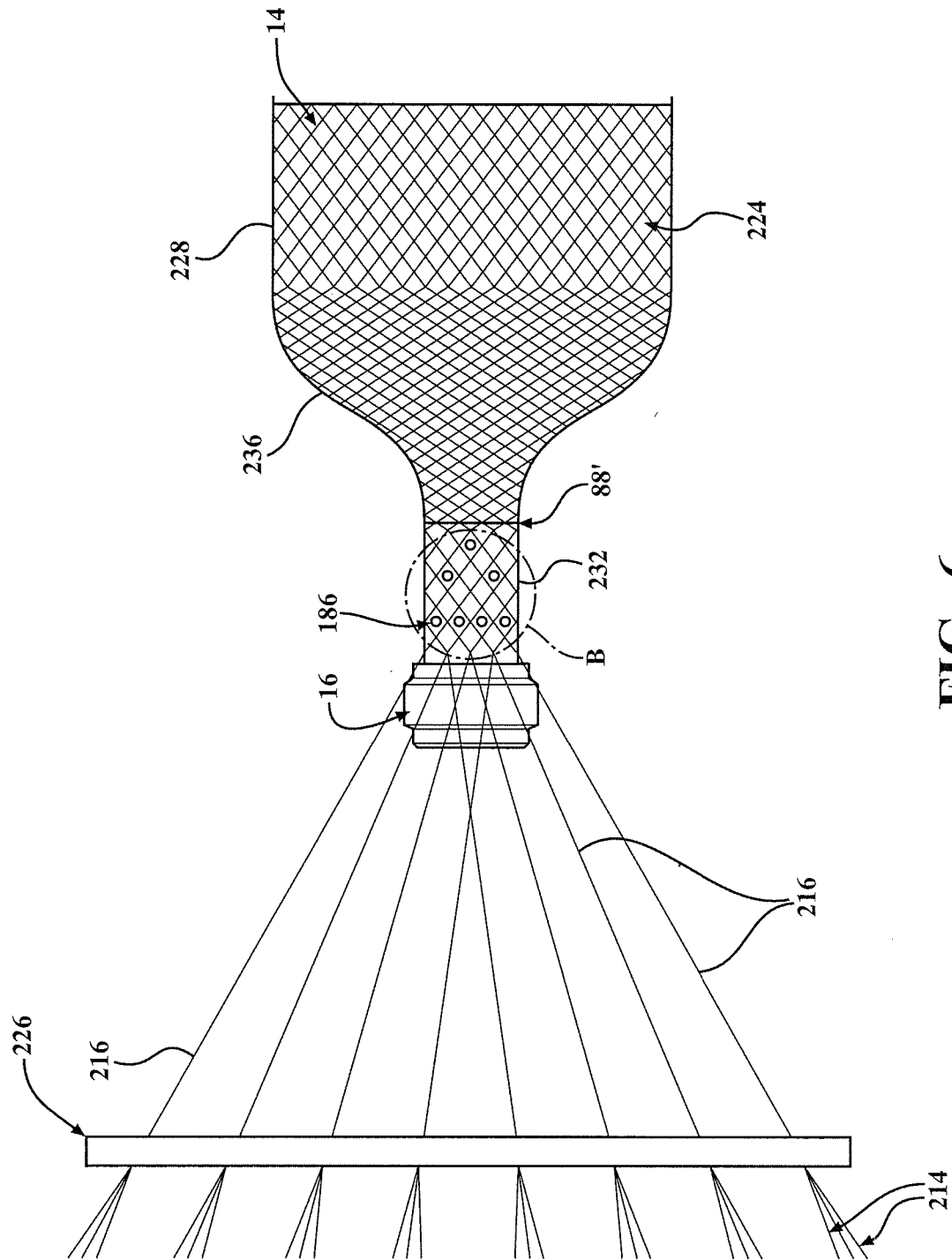
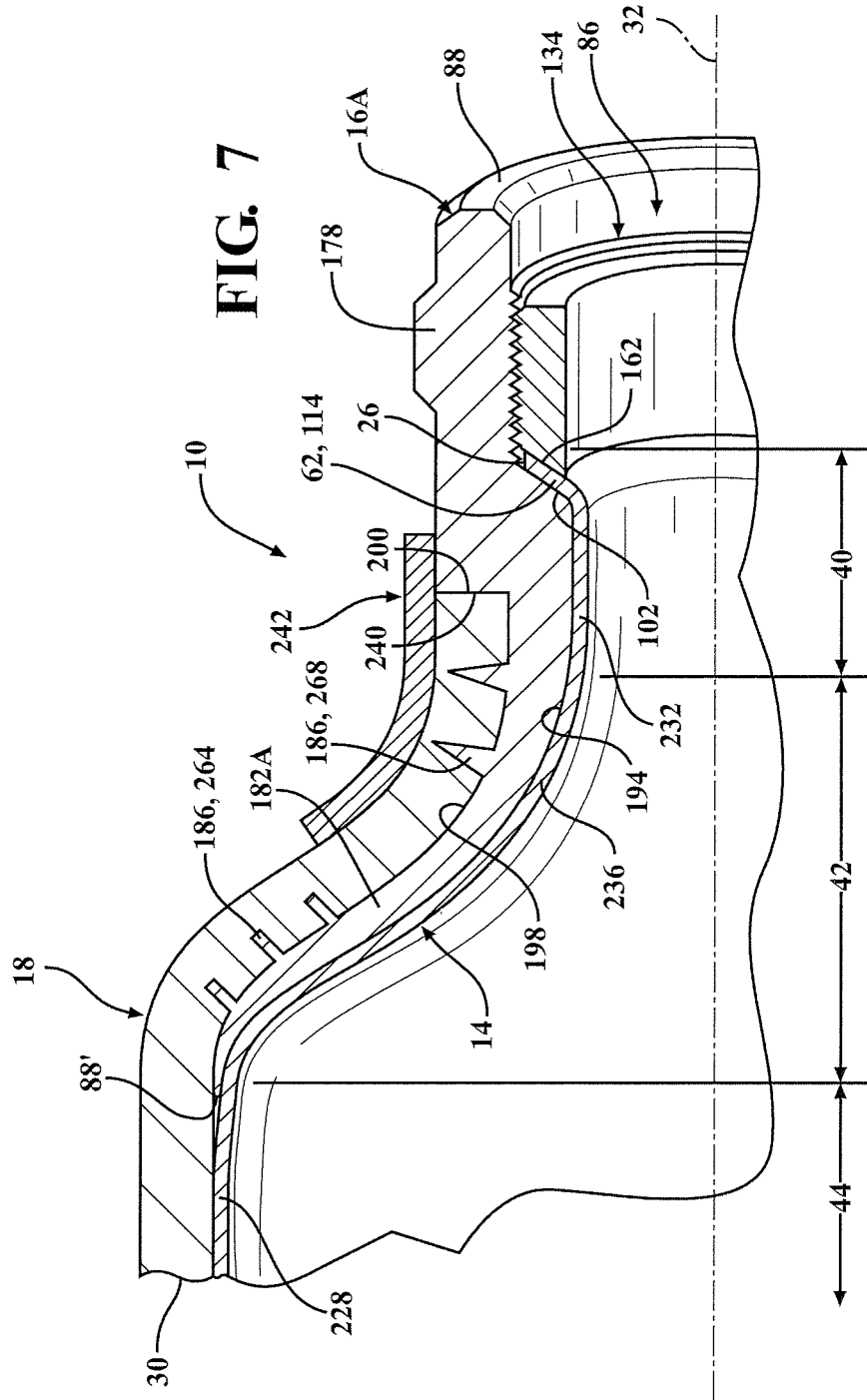
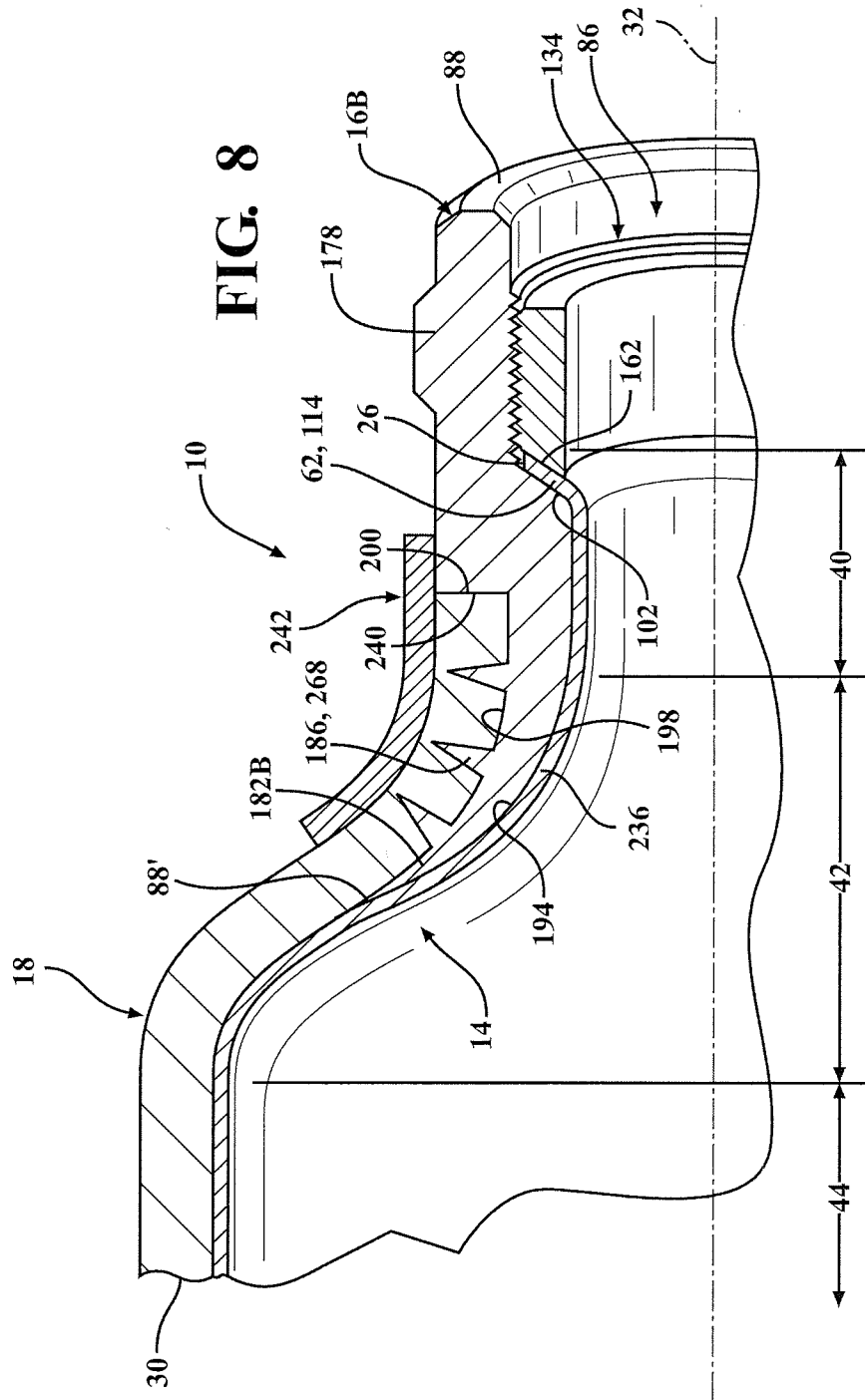


FIG. 6

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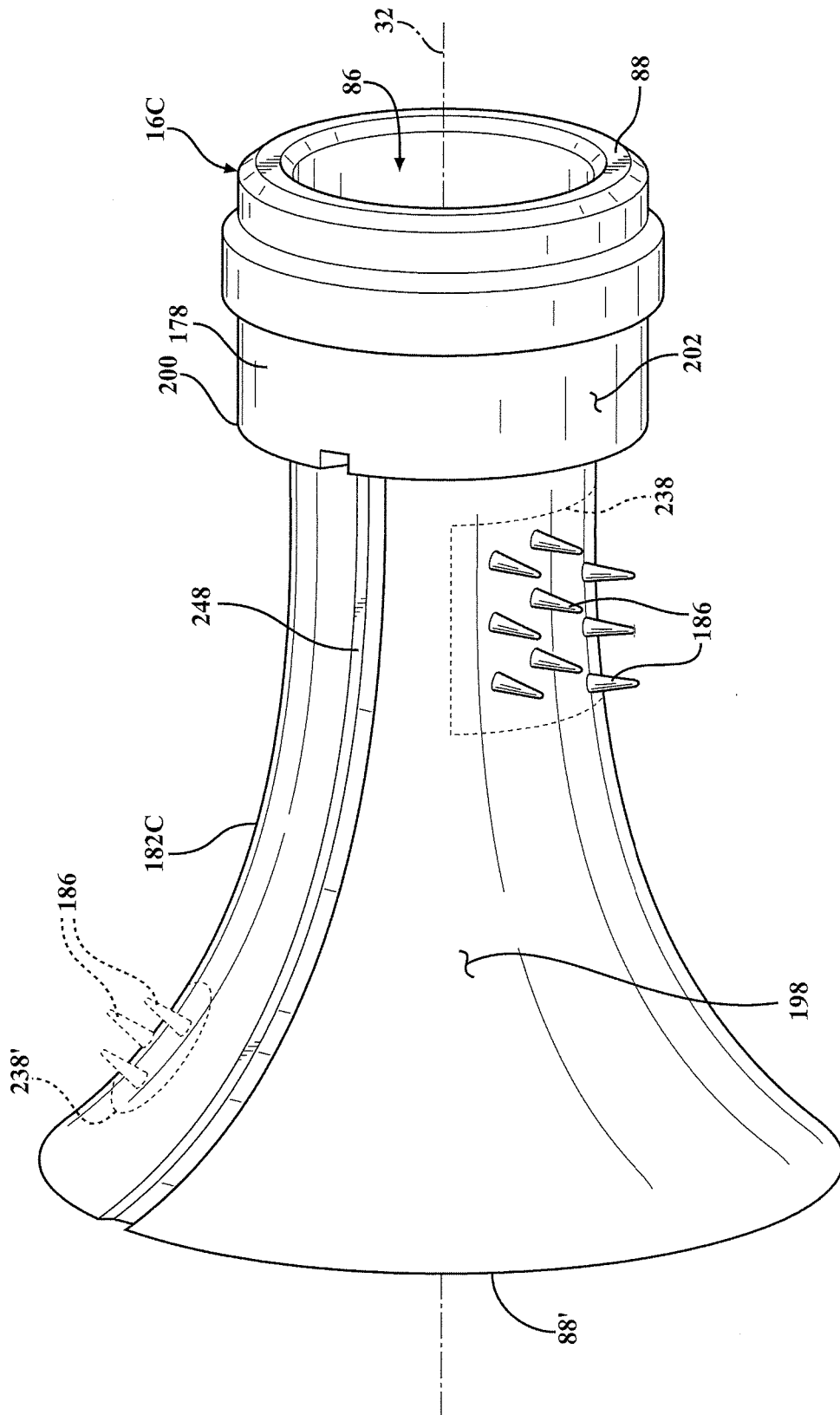


FIG. 9

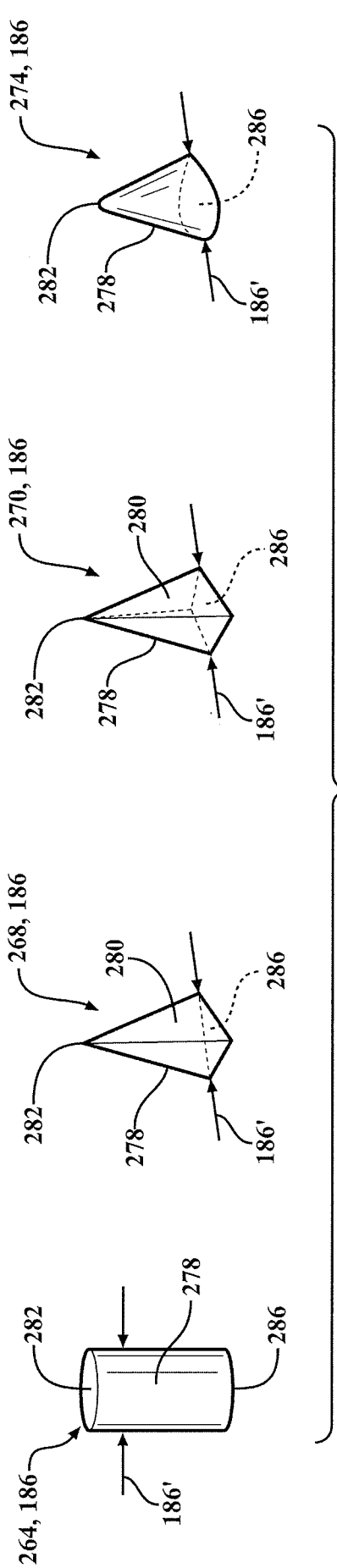


FIG. 10

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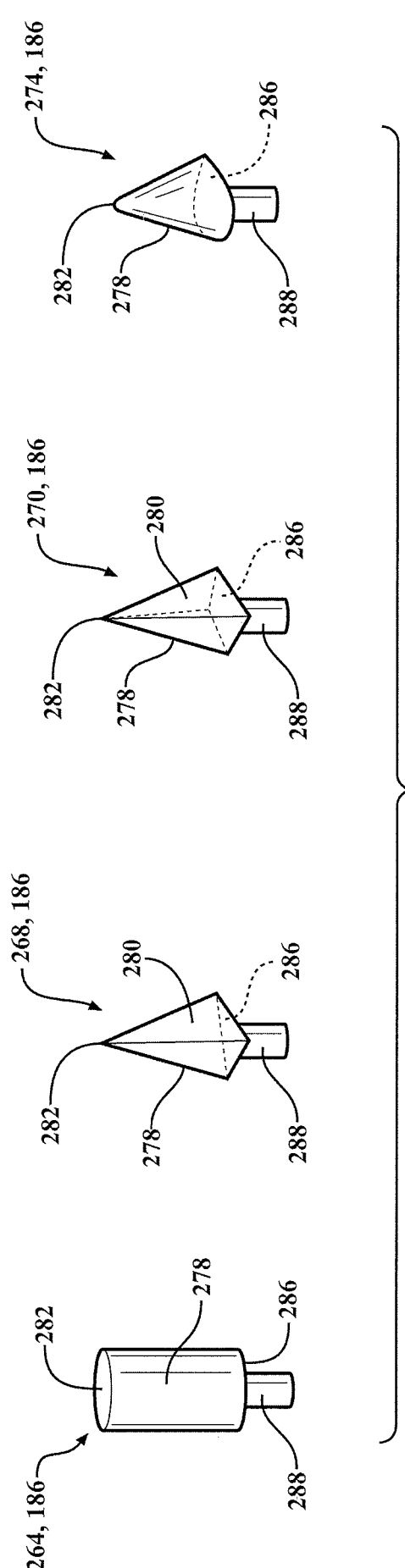
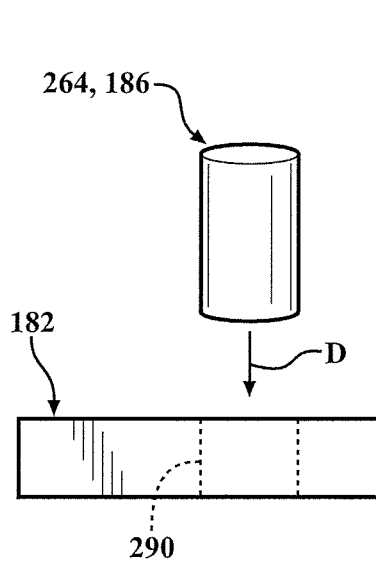
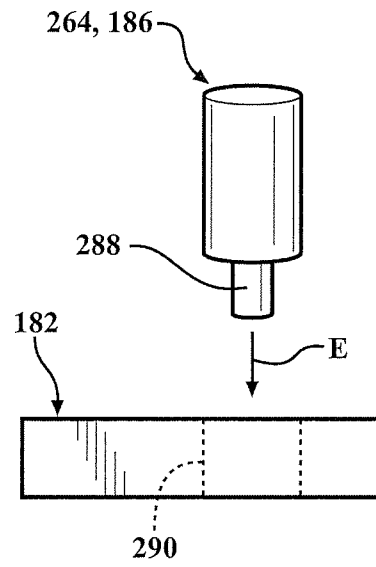
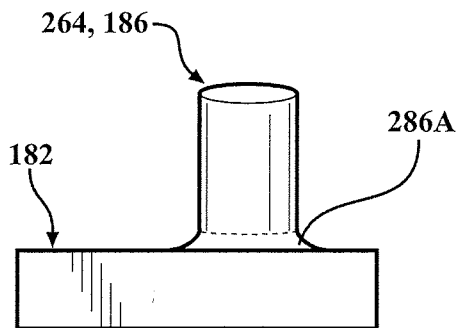
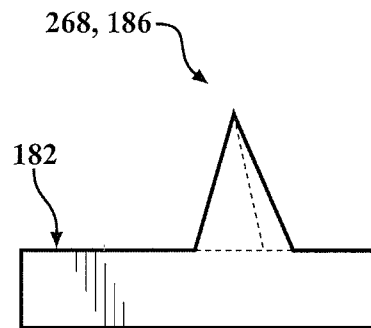
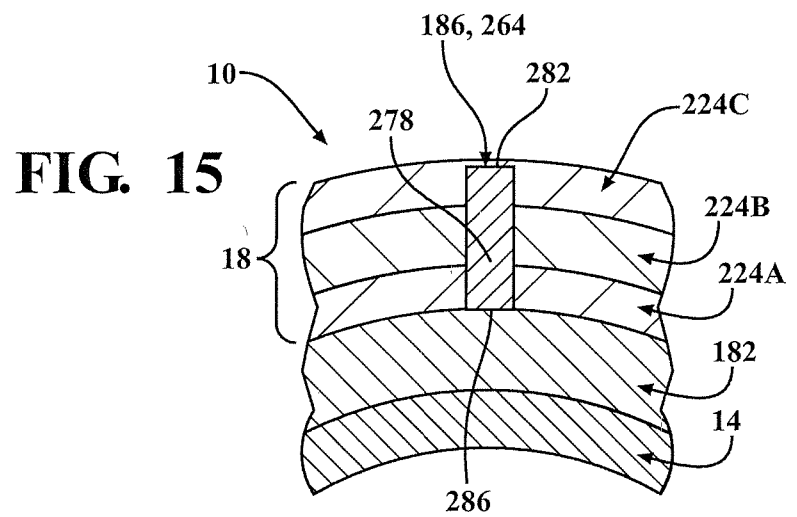
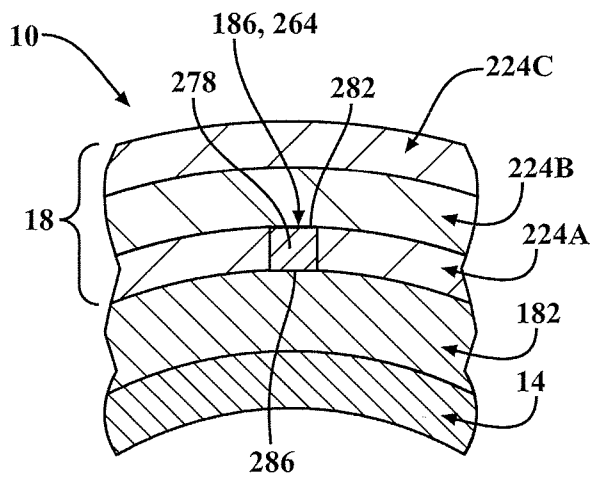
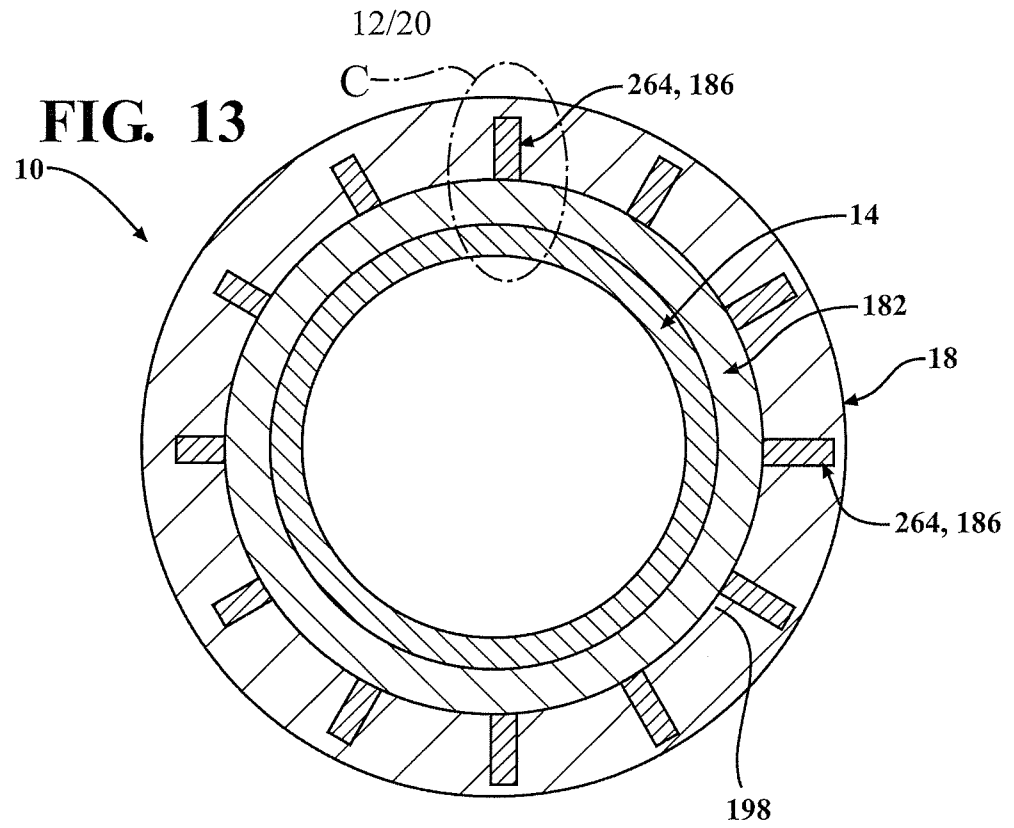


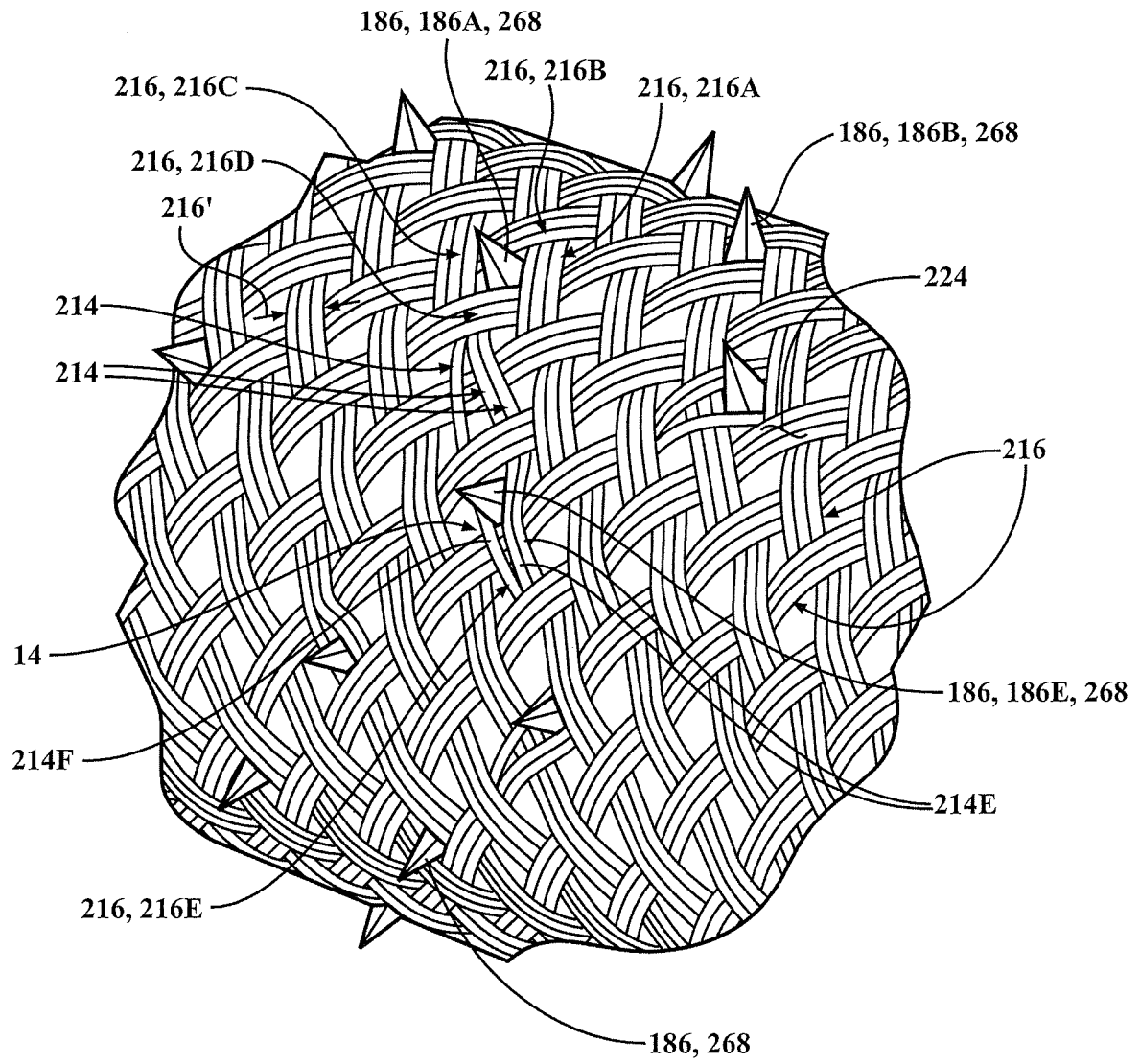
FIG. 11

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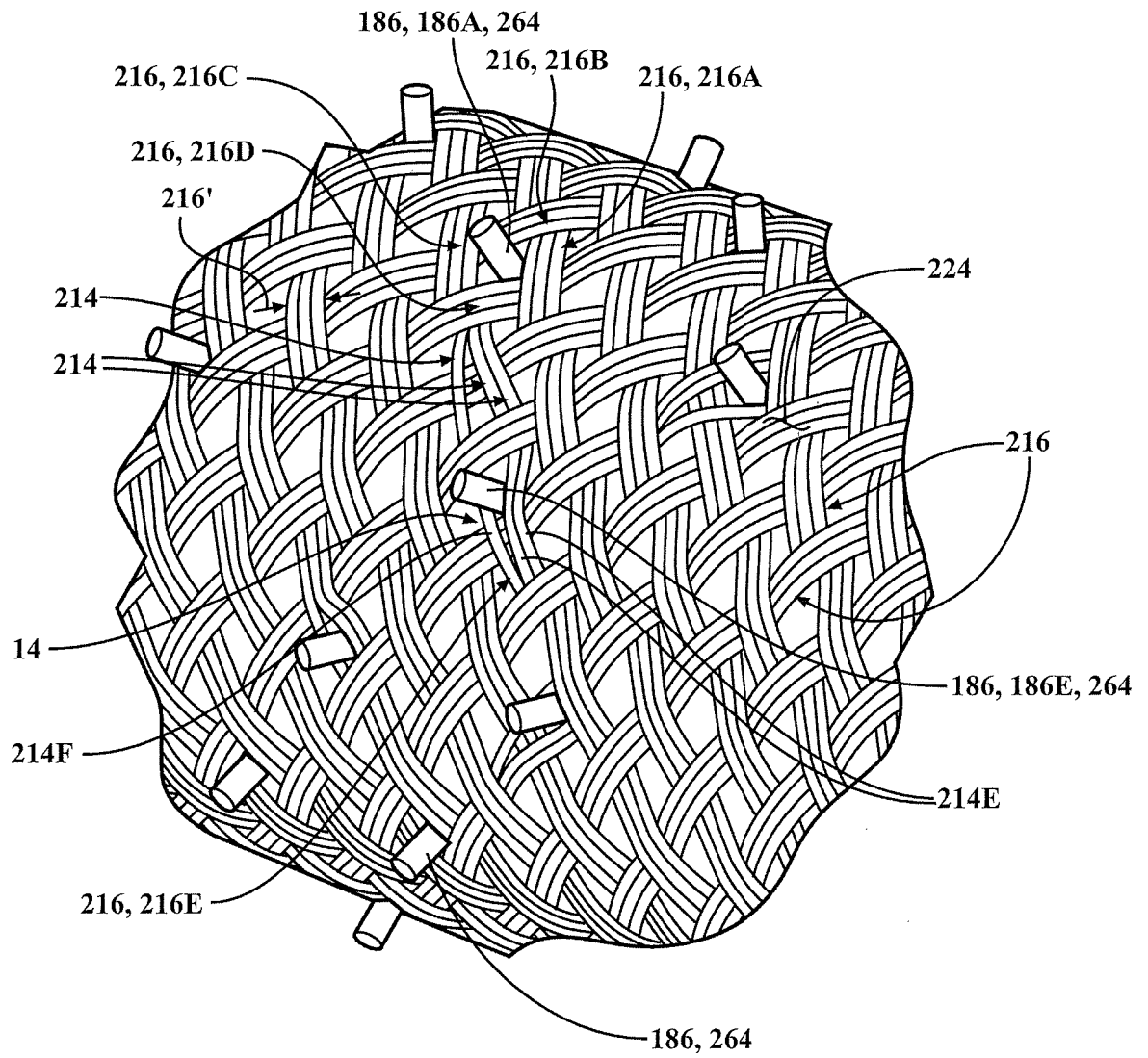
**FIG. 12A****FIG. 12B****FIG. 12C****FIG. 12D**



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**FIG. 16**

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**FIG. 17**

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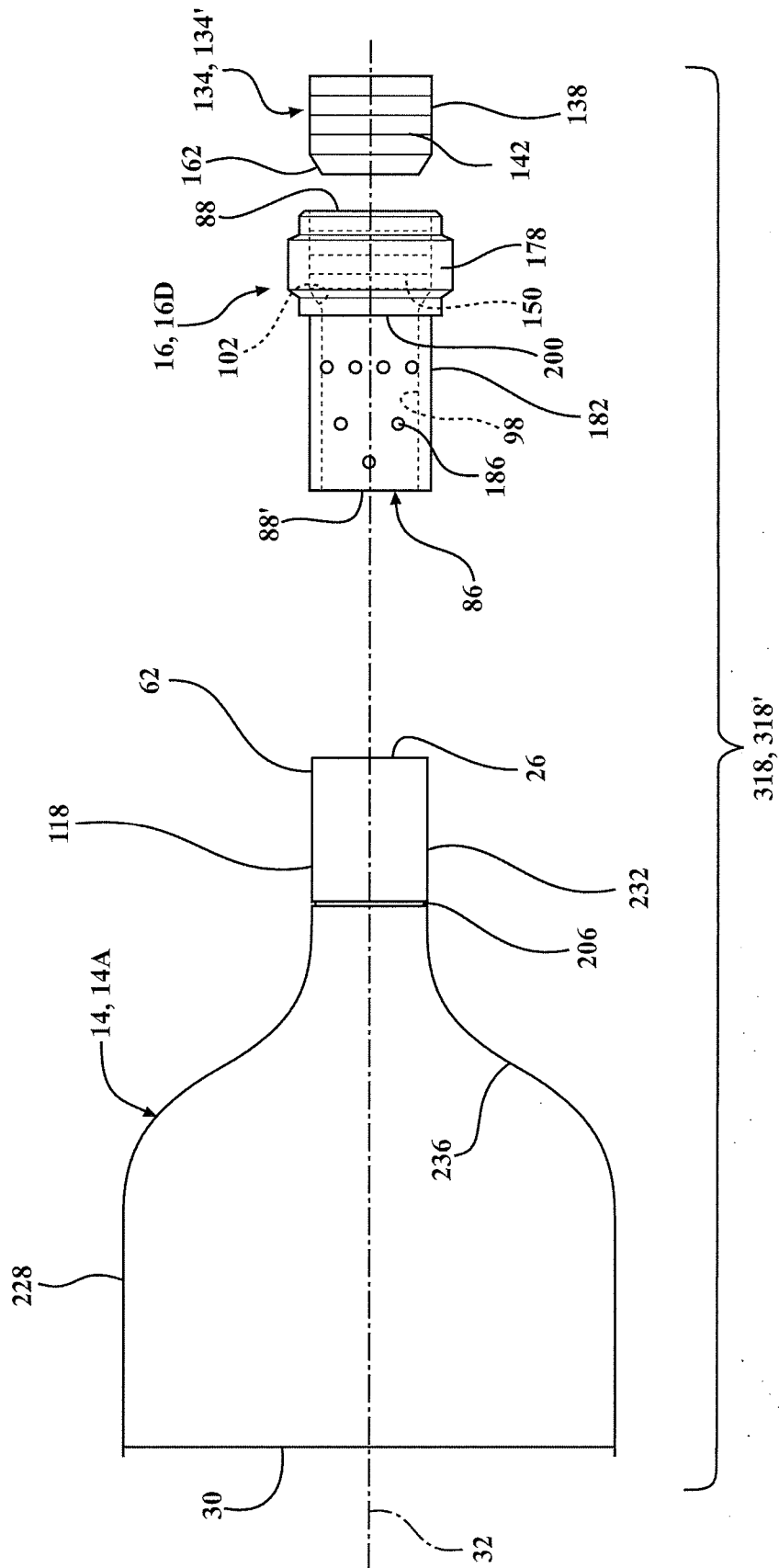


FIG. 18

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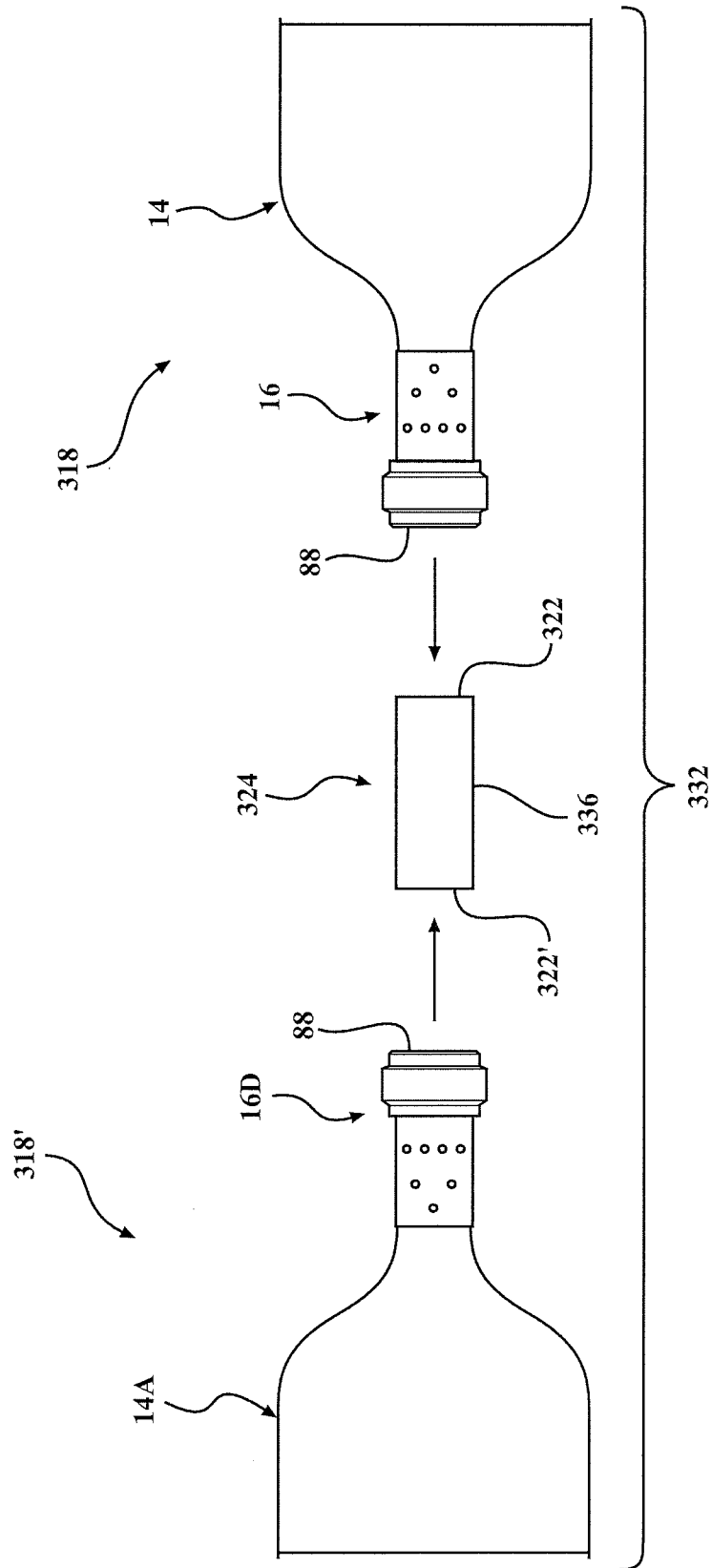


FIG. 19

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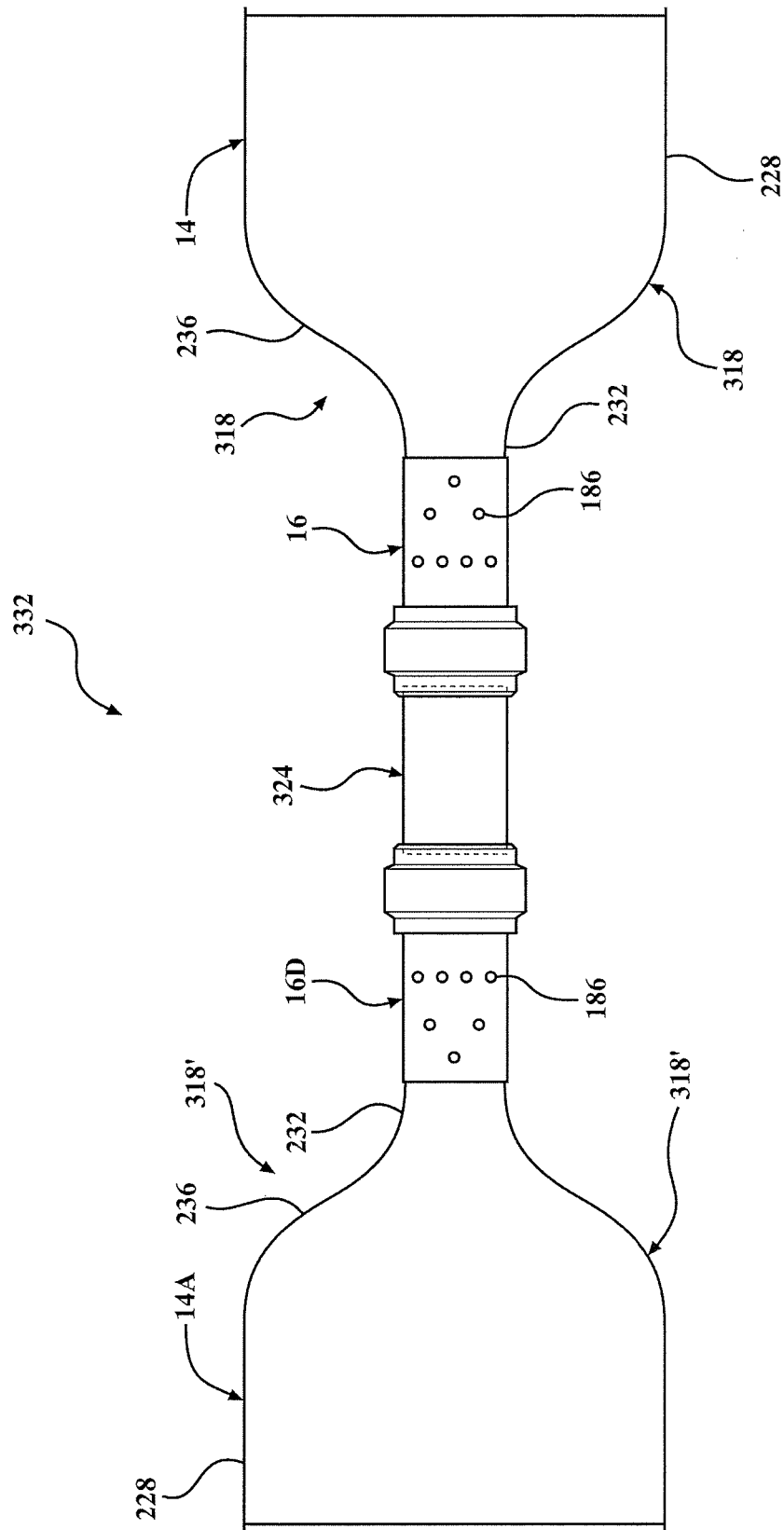


FIG. 20

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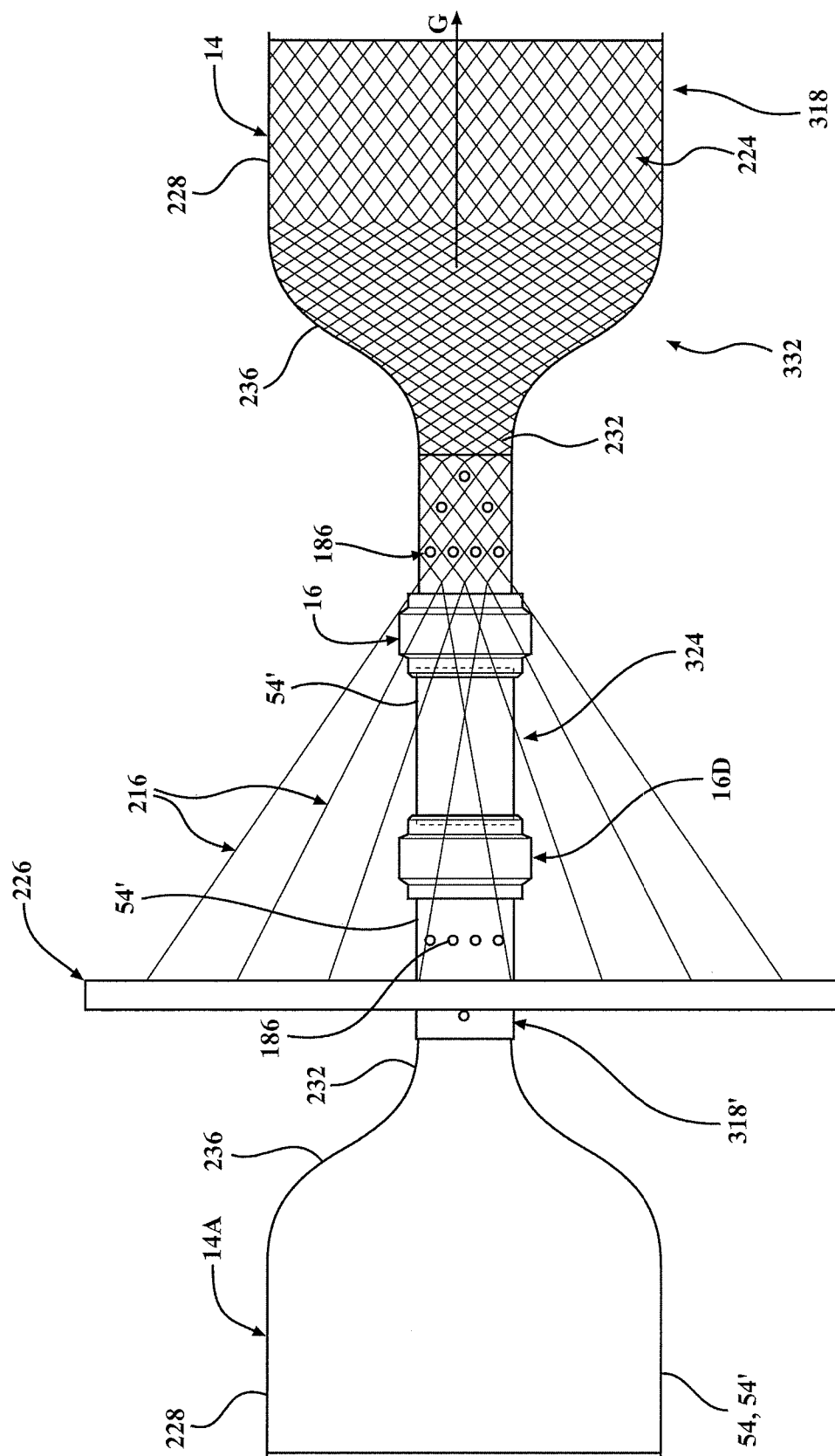


FIG. 21

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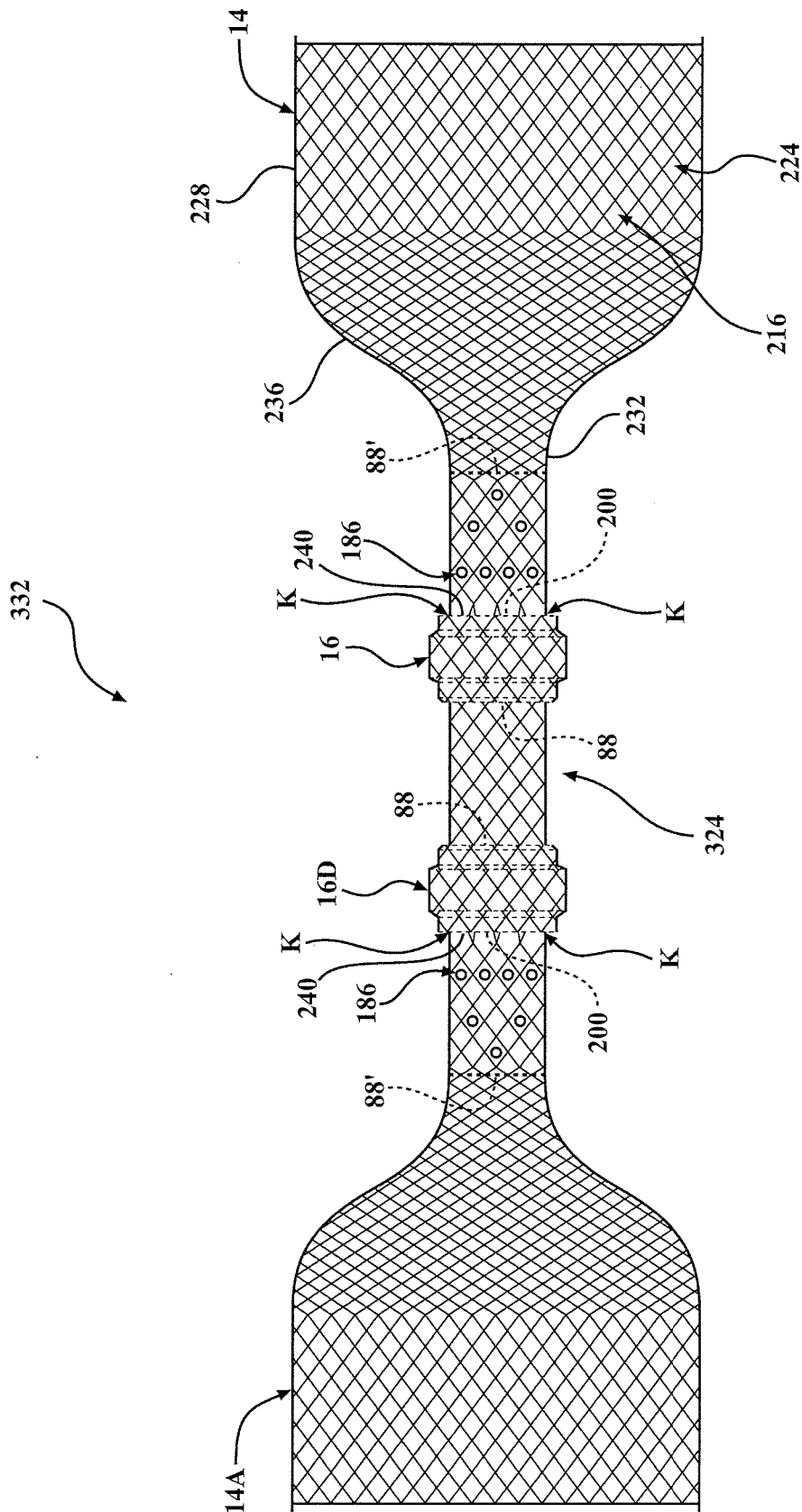


FIG. 22

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