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(54) Title: NON-CIRCULAR PRESSURE VESSEL

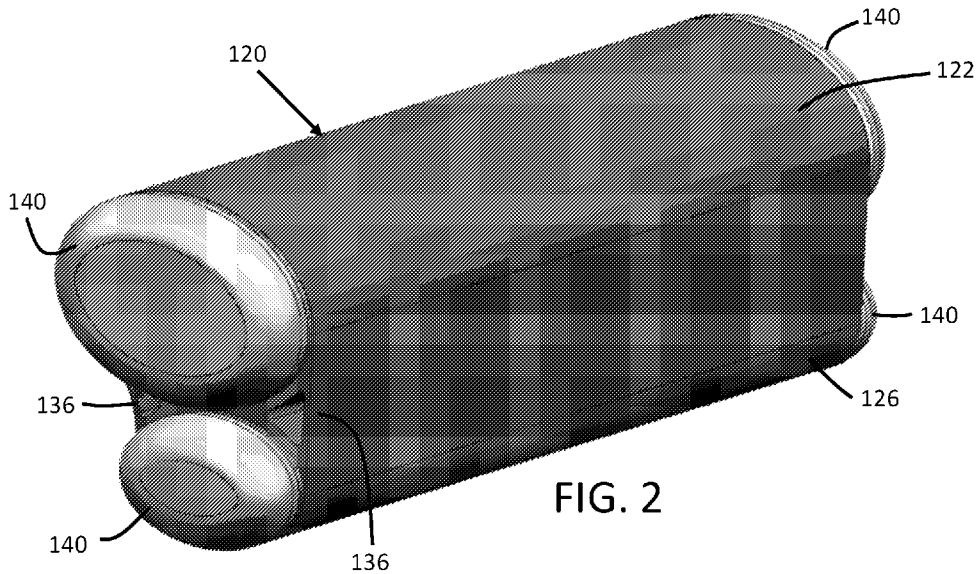


FIG. 2

(57) Abstract: A reservoir assembly includes one or more pressure vessels each having a non-circular cross-sectional shape including a rounded rectangle having four generally flat sides with rounded corners. The pressure vessels may be formed of extruded metal, such as aluminum, and have a generally constant cross-section. The pressure vessels include stiffening ribs and varying wall thicknesses to improve strength and to minimize stresses when pressurized, such as during operation when filled with compressed gas. The stiffening ribs meet in the center of each of the pressure vessels and divide the interior volumes into four equal sections. A cap of stamped aluminum is fitted and fully welded to enclose each end of the pressure vessels. One or both of the caps on each of the pressure vessels has a pressure fitting. Two or more pressure vessels extend parallel to one another and are attached together to form the reservoir assembly.



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## **NON-CIRCULAR PRESSURE VESSEL**

### **CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This PCT International Patent Application claims the benefit of U.S. Provisional Patent Application Serial No. 62/696,897 filed on July 12, 2018, and titled “Non-Circular Pressure Vessel”, the entire disclosure of which is hereby incorporated by reference.

### **FIELD**

[0001] The present disclosure relates generally to pressure vessels such as reservoir tanks for holding a fluid such as compressed air or other gas. Specifically, the present disclosure relates to such pressure vessels having a non-circular cross-section.

### **BACKGROUND**

[0002] Pressure vessels made of extruded metal are commonly constructed having a circular cross-section, which may be produced using drawn-over mandrel extrusions. Such circular pressure vessels are generally good at withstanding elevated pressures of fluid contained therein. However, circular pressure vessels are not optimized for containment volume, particularly where packing requirements are generally rectangular. This causes packaging inefficiencies, which can render circular pressure vessels to be unsuitable where rectangular packaging space must be optimized to meet specific design requirements.

### **SUMMARY**

[0003] A reservoir assembly includes one or more pressure vessels having a non-circular shape. More specifically, one or more of the pressure vessels of the reservoir assembly have a cross-sectional shape of a rounded rectangle, having four generally flat sides with rounded corners. The pressure vessels may be formed of extruded metal, such as aluminum, and may have a generally constant cross-section.

[0004] In accordance with an aspect of the disclosure, the non-circular pressure vessels may each include one or more stiffening ribs.

[0005] In accordance with another aspect of the disclosure, the non-circular pressure vessels may have varying wall thicknesses to improve strength and to minimize stresses when pressurized.

[0006] In accordance with another aspect of the disclosure, a cap of stamped metal may enclose each end of each of the non-circular pressure vessels.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0007] Further details, features and advantages of designs of the invention result from the following description of embodiment examples in reference to the associated drawings.

[0008] FIG. 1 is a cross-sectional view of a reservoir assembly with pressure vessels having oval-shaped cross-sections and fitting within an irregularly-shaped space in accordance with an embodiment of the present disclosure;

[0009] FIG. 2 is a profile view of a reservoir assembly with pressure vessels having generally circular cross-sections in accordance with another embodiment of the present disclosure;

[0010] FIG. 3A is a top view of the reservoir assembly embodiment of FIG. 2 with welders;

[0011] FIG. 3B is another top view of the reservoir assembly embodiment of FIG. 2 with welders;

[0012] FIG. 4 is a profile view of another embodiment of a reservoir assembly with pressure vessels having circular cross-sections;

[0013] FIG. 5 is a cross-sectional view of a reservoir assembly with pressure vessels having circular cross-sections and fitting within the irregularly-shaped space in accordance with an aspect of the present disclosure;

[0014] FIG. 6 is a is a cross-sectional view of a reservoir assembly with pressure vessels having rounded rectangle shaped cross-sections and fitting within an irregularly-shaped space in accordance with another embodiment of the present disclosure;

[0015] FIG. 7A is a cross-sectional CAE view of a first pressure vessel having rounded rectangle shaped cross-sections with stiffening ribs and with varying wall thicknesses and illustrating internal stresses therein;

[0016] FIG. 7B is a cross-sectional CAE view of a second pressure vessel having rounded rectangle shaped cross-sections with stiffening ribs and with varying wall thicknesses and illustrating internal stresses therein;

[0017] FIG. 8 is a dimensional drawing of an embodiment of a reservoir assembly with pressure vessels having rounded rectangle shaped cross-sections with stiffening ribs and with varying wall thicknesses;

[0018] FIG. 9 is a perspective view of an end of a pressure vessel having a rounded rectangle cross-section with stiffening ribs and with a cap disposed thereupon;

[0019] FIG. 10 is a perspective view of the of reservoir assembly embodiment with two pressure vessels each having rounded rectangle shaped cross-sections; and

[0020] FIG. 11 is a flow chart of steps in a method of forming a reservoir assembly in accordance with some embodiments of the present disclosure.

### **DETAILED DESCRIPTION**

[0021] Recurring features are marked with identical reference numerals in the figures, in which example embodiments of a reservoir assembly **20** are disclosed.

[0022] As shown in the cross-sectional view of FIG. 1, a reservoir assembly **20** includes a first pressure vessel **22** enclosing a first volume **24** for holding a pressurized fluid, such as compressed air. The reservoir assembly **20** also includes a second pressure vessel **26** enclosing a second volume **28** for holding a pressurized fluid, such as compressed air. The two pressure vessels **22**, **26** may be isolated from one another for example, to contain different fluids or for containing fluid at two different pressures. Alternatively, the two pressure vessels **22**, **26** may be in fluid communication with one another to provide a larger capacity than either of them alone.

[0023] As also shown in FIG. 1, the two pressure vessels **22**, **26** may have different sizes, with the first pressure vessel **22** being larger than the second pressure vessel **26**. This provides for the reservoir assembly **20** to fit within an irregularly-shaped space **30** having a first region **32** holding the first pressure vessel **22**, and a second region **34** that is smaller than the first region **32** and which holds the second pressure vessel **26**. Each of the regions **32**, **34** of the irregularly-shaped space **30** may be generally rectangular, and adjoining one another. Some irregularities, such as angles and rounded portions may be present on one or more edges and/or corners of the irregularly-shaped space **30**. Brackets **36** join the pressure vessels **22**, **26** and may be integrally formed therewith, for example, as a single extrusion with the pressure vessels **22**, **26**. The pressure vessels **22**, **26** of the reservoir assembly **20** shown in the embodiment of FIG. 1, each have an oval-shaped cross-section.

[0024] Design requirements may call for each of the pressure vessels **22**, **26** to have different volumes. In some embodiments, the second volume **28** enclosed by the second pressure vessel **26** may be between 25% and 50% of the first volume **24** that is enclosed by the first pressure vessel **22**. In one example, the first volume **24** may be about 11 L, and the second volume **28** may be about 4 L. Each of the pressure vessels **22**, **26** have a design operating pressure that may be the same or different for the two pressure vessels **22**, **26**.

The operating pressure may be between 5 and 20 Bar. Likewise, each of the pressure vessels **22**, **26** have maximum rated burst pressure. The maximum rated burst pressure may be about three (3) times the operating pressure. In some embodiments, the maximum rated burst pressure may be between 30 and 50 Bar. For example, one or both of the pressure vessels **22**, **26** may have maximum rated burst pressure of 35 Bar. The combination of design operating pressure, maximum burst pressure, and packaging constraints of the irregularly-shaped space **30**, may preclude use of oval-shaped cross-sections for the pressure vessels **22**, **26**.

[0025] Another embodiment of a reservoir assembly **120** is shown in profile view in FIG. 2. The reservoir assembly **120** includes two pressure vessels **122**, **126** having a generally circular cross-section, and which are integrally formed with brackets **136** between them as a single extruded piece, which may be formed, for example, of extruded aluminum. FIG. 2 also shows caps **140** attached to the ends of each of the pressure vessels **122**, **126** to enclose the interior volumes **24**, **28** within them. The caps **140** may be formed, for example, of stamped aluminum that is welded around the ends of each of the pressure vessels **122**, **126**.

[0026] As illustrated in FIGS. 3A and 3B, the reservoir assembly **120** embodiment shown in FIG. 2 may present challenges in access for welders **142** needed to weld the caps **140** to the ends of each of the pressure vessels **122**, **126**. This may inhibit the ability to complete a weld 360-degrees, completely around each of the caps **140**. In order to provide clearance required for welding, the radius of the caps **140** or the distance between each of the pressure vessels **122**, **126** would have to be increased. Each of those options would significantly reduce the volume within the pressure vessels **122**, **126**.

[0027] Another embodiment a reservoir assembly **220** is shown in profile view in FIG. 4. The reservoir assembly **220** includes two pressure vessels **222**, **226** having a

generally circular cross-section, and which are formed separately, with caps **240** installed on the ends of each of the pressure vessels **222**, **226**, which are joined with brackets **236** between them. The pressure vessels **222**, **226**, may each be, for example, a segment of extruded aluminum tube. The caps **240** may be welded in a 360-degree weld around each of the ends of the pressure vessels **222**, **226**. Once the caps **240** are joined to the pressure vessels **222**, **226**, the pressure vessels **222**, **226** may be joined to one-another, for example, by welding each of them to one or more brackets **236**. The reservoir assembly **220** illustrated in FIG. 4 includes two brackets **236** between the pressure vessels **222**, **226**.

[0028] As shown in FIG. 5, the reservoir assembly **220** of FIG. 4, with pressure vessels **222**, **226** having circular cross-sections, is shown within the irregularly-shaped space **30**. Fig. 5 illustrates the reservoir assembly **220** not substantially filling the particular irregularly-shaped space **30** provided.

[0029] FIG. 6 illustrates a cross-sectional view of another embodiment for a reservoir assembly **320** that includes pressure vessels **322**, **326** each having a non-circular shape. More specifically, the pressure vessels **322**, **326** of the reservoir assembly **320** are each shaped as rounded rectangles, having four generally flat sides with rounded, or radiused corners. The pressure vessels **322**, **326** may be formed of extruded metal, such as aluminum, and may have a generally constant cross-section. The radius of the rounded corners may be determined by the pressure requirements, such as operating pressure, and/or maximum burst pressure of the pressure vessels **322**, **326**. As shown in FIG. 6, this reservoir assembly **320** embodiment provides for a more substantial filling of the irregularly-shaped space **30**, therefore allowing the reservoir assembly **320** to meet the design requirements for volumetric capacity, while fitting within the packaging requirements in the irregularly-shaped space **30**.

[0030] FIGS. 7A and 7B show Computer-Aided Engineering (CAE) studies of the reservoir assembly 320 that includes pressure vessels 322, 326 with the addition of stiffening ribs 350 and with varying wall thicknesses to improve strengths and to minimize stresses when pressurized, such as during operation when filled with compressed gas. The specific wall thickness may depend on the pressure requirements, such as operating pressure, and/or maximum burst pressure of the pressure vessels 322, 326.

[0031] Still referring to FIGS. 7A and 7B, the stiffening ribs 350 meet in the center of each of the pressure vessels 322, 326 and divide the interior volumes 324, 328 into four equal sections 352. In other words, one or more of the stiffening ribs 350 may extend outwardly from a center to a midpoint of an associated one of the generally flat sides of each of the pressure vessels 322, 326. The stiffening ribs 350 may take other forms or arrangements. FIG. 8 shows the reservoir assembly 320 with varying wall thicknesses. The design of the reservoir assembly 320 embodiment shown in FIGS. 7A-7B and FIG. 8A-8B provides for the design requirement volumes to be met within the packaging requirements. Alternatively or additionally, the sections 352 of the interior volumes 324, 328 may be joined in fluid communication with one another at one or more of the ends of the pressure vessels 322, 326 and within the caps 340. An example of this is illustrated in FIG. 9.

[0032] FIG. 9 illustrates the reservoir assembly 320 embodiment shown in FIGS. 7A, 7B and FIG. 8 with a cap 340 to enclose an end of one of the pressure vessels 322, 326. Similar caps 340 may be installed on each of the ends of each of the pressure vessels 322, 326. The caps 340 preferably provide a tight fit on the pressure vessels 322, 326 with a gap that is configured to meet welding requirements and to provide a completely sealed joint. For example, the gap between each of the caps 340 and the corresponding one of the pressure vessels 322, 326 may be 1 mm or less. The ends of the pressure vessels 322, 326 may be machined to provide for a consistent and precise size and shape to allow for optimal

fitting of the caps **340** thereupon. The caps **340** may be fitted and welded to enclose each of the pressure vessels **322**, **326**. One or more fittings (not shown in the FIGS.) may extend through one or both of the caps **340** on each of the pressure vessels **322**, **326** to provide access to the interior volumes **324**, **328** for charging and for discharging fluid therefrom.

[0033] FIG. 10 shows the reservoir assembly **320** of FIGS. 7A-7B and FIGS. 8-9 in a more complete form. The pressure vessels **322**, **326** of the reservoir assembly **320** may extend parallel to one-another and may be welded or otherwise attached to one-another to provide the reservoir assembly **320** as a single unit. In other embodiments, the pressure vessels **322**, **326** of the reservoir assembly **320** may be not directly attached to one another and may be independently secured to one or more portions of a larger structure. In the example embodiment shown in FIG. 10, the reservoir assembly **320** features two multi-void aluminum extrusions, each of which having two caps **340** of stamped aluminum that are fully welded to the respective one of the aluminum extrusions. One or both cap(s) **340** on each of the aluminum extrusions may have a pressure fitting to provide fluid communication to the internal volume of the respective one of the aluminum extrusions.

[0034] A method **400** of forming a reservoir assembly **320** is shown in the flow chart of FIG. 11. The method **400** includes forming a first pressure vessel **22**, **222**, **322** surrounding a first volume **24**, **324** and having a constant cross-section of a rounded rectangle having four generally flat sides with rounded corners along a first length between two ends at step **402**. In some embodiments, the step of **402** forming the first pressure vessel **22**, **222**, **322** further includes extruding aluminum into the constant cross-section of a rounded rectangle at sub step **402A**. In some embodiments, the step of **402** forming the first pressure vessel **22**, **222**, **322** further includes forming stiffening ribs **350** within the constant cross-section of the rounded rectangle at sub step **402B**.

[0035] The method **400** also includes sealing each of the two ends with a cap **340** to enclose the first volume **24, 324** at step **404**. In some embodiments, the step of **404** sealing each of the two ends with a cap **340** further includes welding the caps **340** onto each of the two ends at sub step **404A**. In some embodiments, the method **400** further includes machining one or both of the two ends at step **403** prior to sealing each of the two ends with the caps **340** at step **404**. For example, the surface profile of one or both of the two ends may be machined. This step **403** may be necessary as a result of tolerances in forming the first pressure vessel **22, 222, 322**, such as extrusion tolerances that are not within the welding requirements and to provide a completely sealed joint.

[0036] The method **400** also includes forming a second pressure vessel **26, 226, 326** surrounding a second volume **28, 328** and having a constant cross-section of a rounded rectangle having four generally flat sides with rounded corners along a second length between two ends at step **406**.

[0037] The method **400** also includes attaching the second pressure vessel **26, 226, 326** to the first pressure vessel **22, 222, 322** at step **408**. The first pressure vessel **22, 222, 322** and the second pressure vessel **26, 226, 326** may be attached by welding or using an adhesive and/or with one or more fasteners. One or more brackets **236**, braces, or other support structures may be used for coupling the pressure vessels **22, 222, 322, 26, 226, 326** together. It should be appreciated that the reservoir assembly **320** may include any number of the pressure vessels **22, 222, 322, 26, 226, 326** that may be attached and/or not attached to one another.

[0038] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be

used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

### CLAIMS

What is claimed is:

Claim 1. A reservoir assembly comprising:  
a first pressure vessel surrounding a first volume and having a constant cross-section along a first length between two ends; and  
wherein the constant cross-section defines a closed shape of a rounded rectangle having four generally flat sides with rounded corners.

Claim 2. The reservoir assembly of Claim 1, further comprising:  
a second pressure vessel enclosing a second volume outside of the first volume, the second pressure vessel having a constant cross-section defining a closed shape of a rounded rectangle extending along a second length that extends parallel to the first length.

Claim 3. The reservoir assembly of Claim 1, wherein the first pressure vessel is formed of extruded metal.

Claim 4. The reservoir assembly of Claim 1, wherein the constant cross-section of the first pressure vessel includes a stiffening rib within the rounded rectangle.

Claim 5. The reservoir assembly of Claim 4, wherein the stiffening rib is one of a plurality of stiffening ribs within the rounded rectangle, with each of the stiffening ribs extending outwardly from a center of the constant cross-section of the first pressure vessel to divide the first volume of the first pressure vessel into equal sections.

Claim 6. The reservoir assembly of Claim 5, wherein each of the stiffening ribs extends to a midpoint of an associated one of the generally flat sides.

Claim 7. The reservoir assembly of Claim 1, wherein the first pressure vessel has a varying wall thickness.

Claim 8. The reservoir assembly of Claim 1, further comprising a cap enclosing each of the two ends of the first pressure vessel for sealingly enclosing the first volume.

Claim 9. The reservoir assembly of Claim 1, further comprising:  
a second pressure vessel enclosing a second volume outside of the first volume, the second pressure vessel having a constant cross-section defining a closed shape of a rounded rectangle extending along a second length that extends parallel to the first length; and

Claim 10. The reservoir assembly of Claim 9, wherein the second pressure vessel is attached to the first pressure vessel to define a constant cross-section of the reservoir assembly configured to fit within an irregularly shaped space.

Claim 11. A method of forming a reservoir assembly comprising:  
forming a first pressure vessel surrounding a first volume and having a constant cross-section of a rounded rectangle having four generally flat sides with rounded corners along a first length between two ends; and  
sealing each of the two ends with a cap to enclose the first volume.

Claim 12. The method of Claim 11, wherein forming the first pressure vessel further includes extruding aluminum into the constant cross-section of a rounded rectangle; and

wherein forming the first pressure vessel further includes forming stiffening ribs within the constant cross-section of the rounded rectangle.

Claim 13. The method of Claim 11, wherein sealing each of the two ends further includes welding the cap onto each of the two ends.

Claim 14. The method of Claim 13, further comprising machining each of the two ends prior to sealing each of the two ends.

Claim 15. The method of Claim 11, further comprising:  
forming a second pressure vessel surrounding a second volume and having a constant cross-section of a rounded rectangle having four generally flat sides with rounded corners along a second length between two ends; and  
attaching the second pressure vessel to the first pressure vessel.

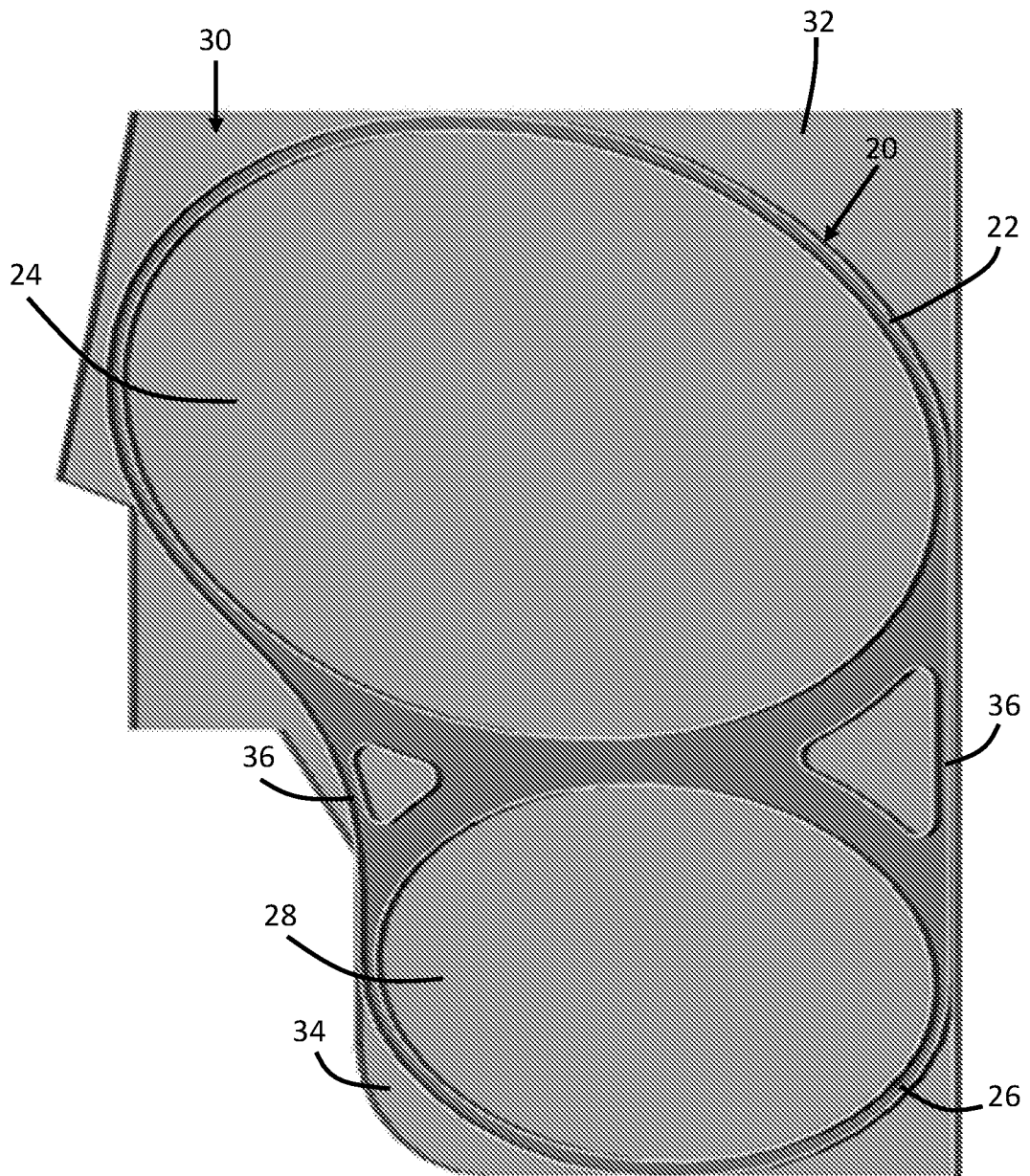


FIG. 1

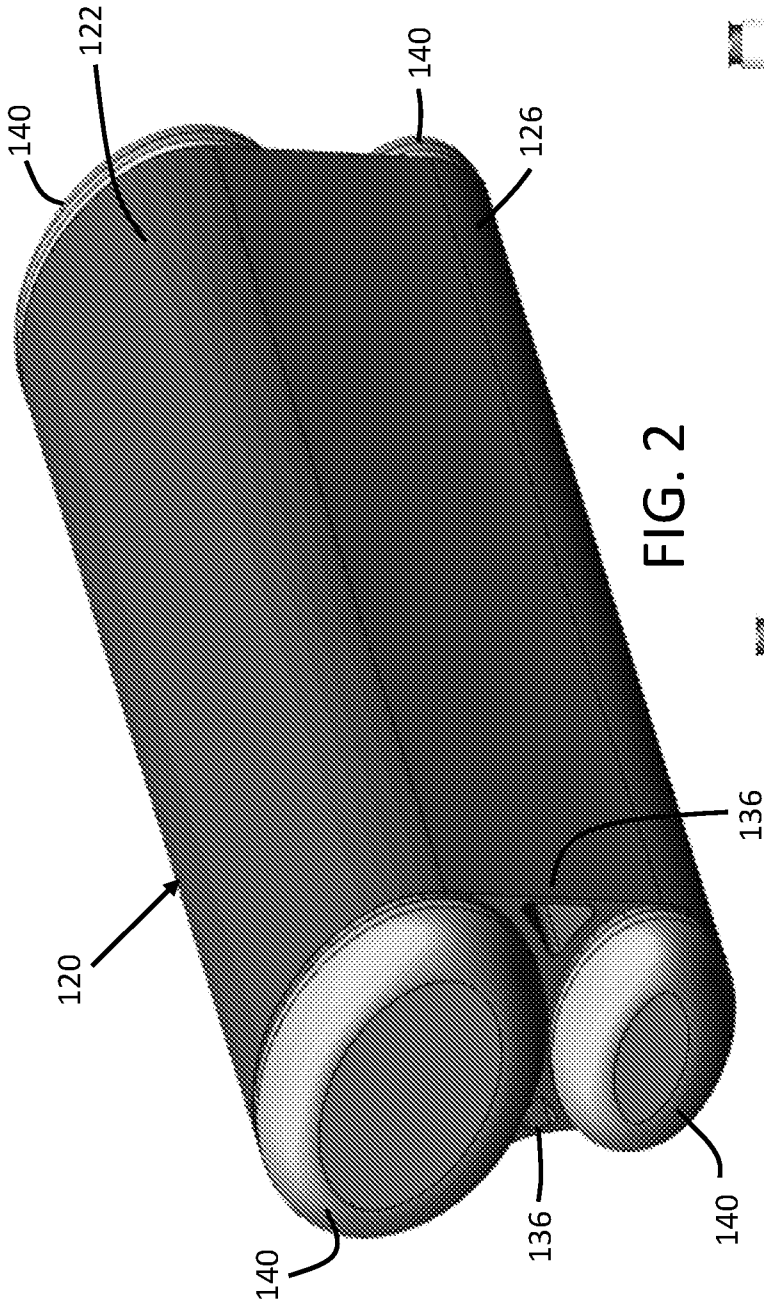


FIG. 2

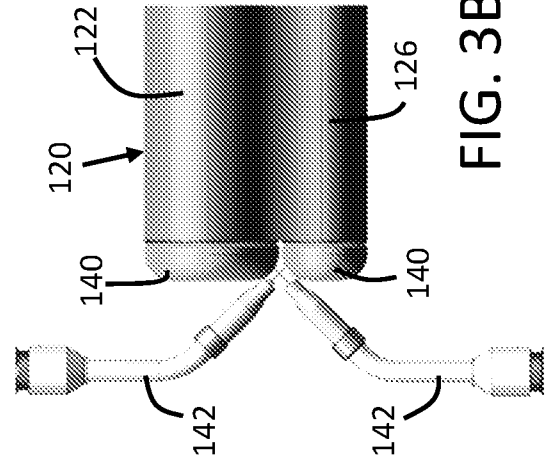


FIG. 3B

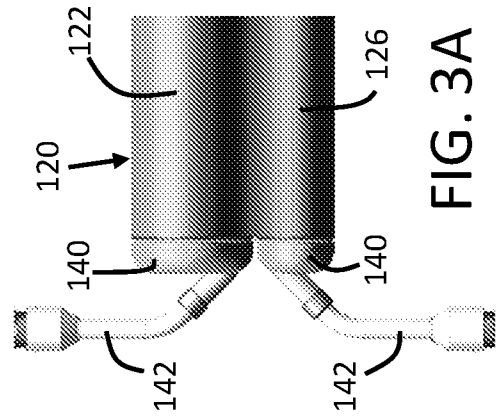


FIG. 3A

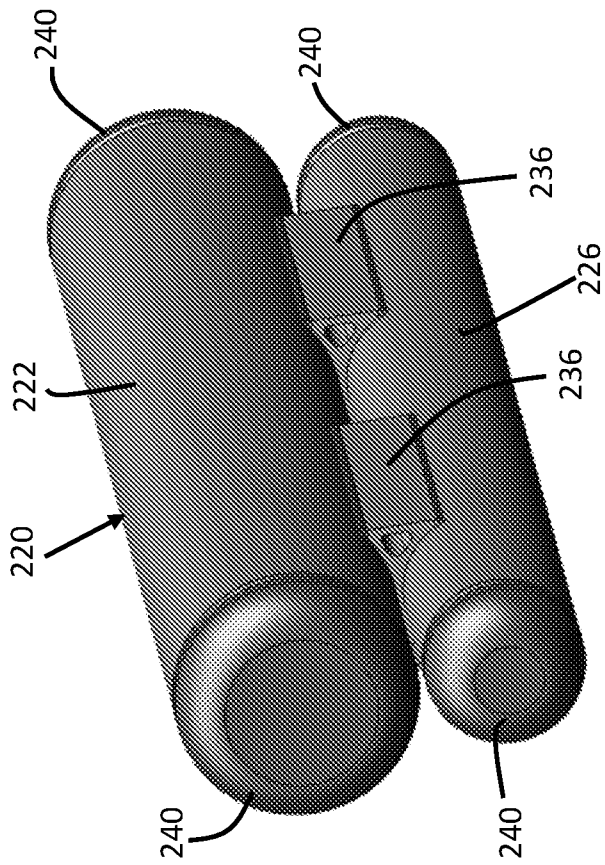


FIG. 4

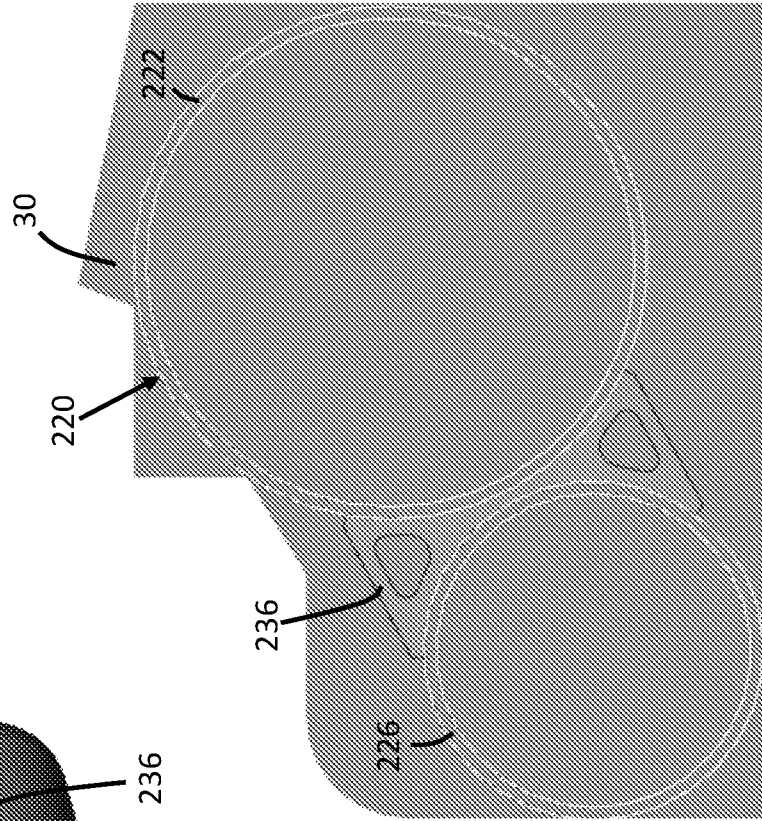


FIG. 5

4 / 9

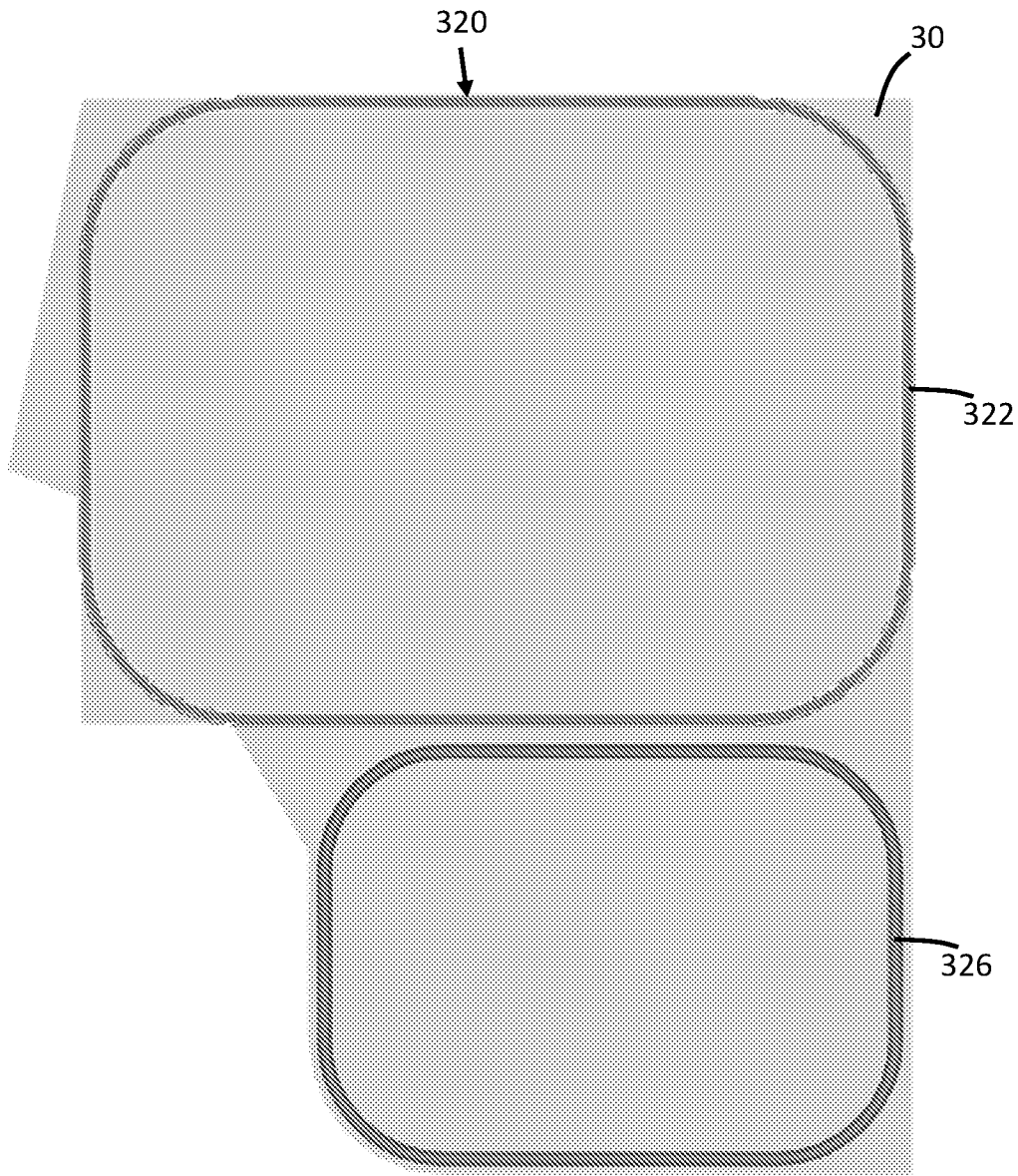


FIG. 6

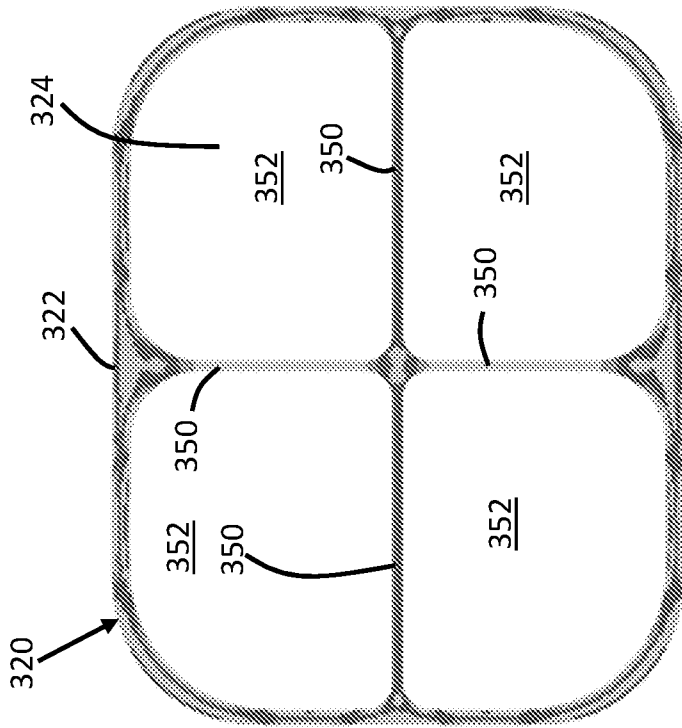


FIG. 7A

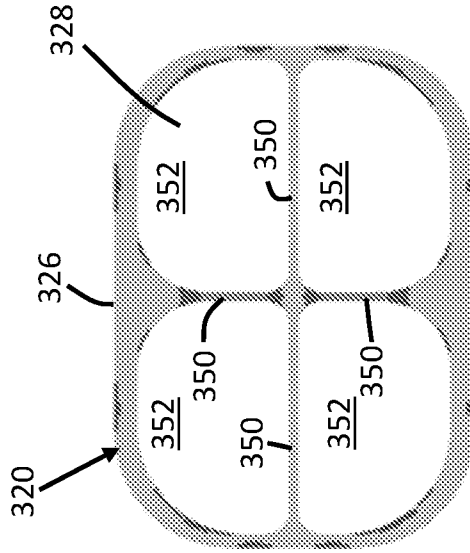


FIG. 7B

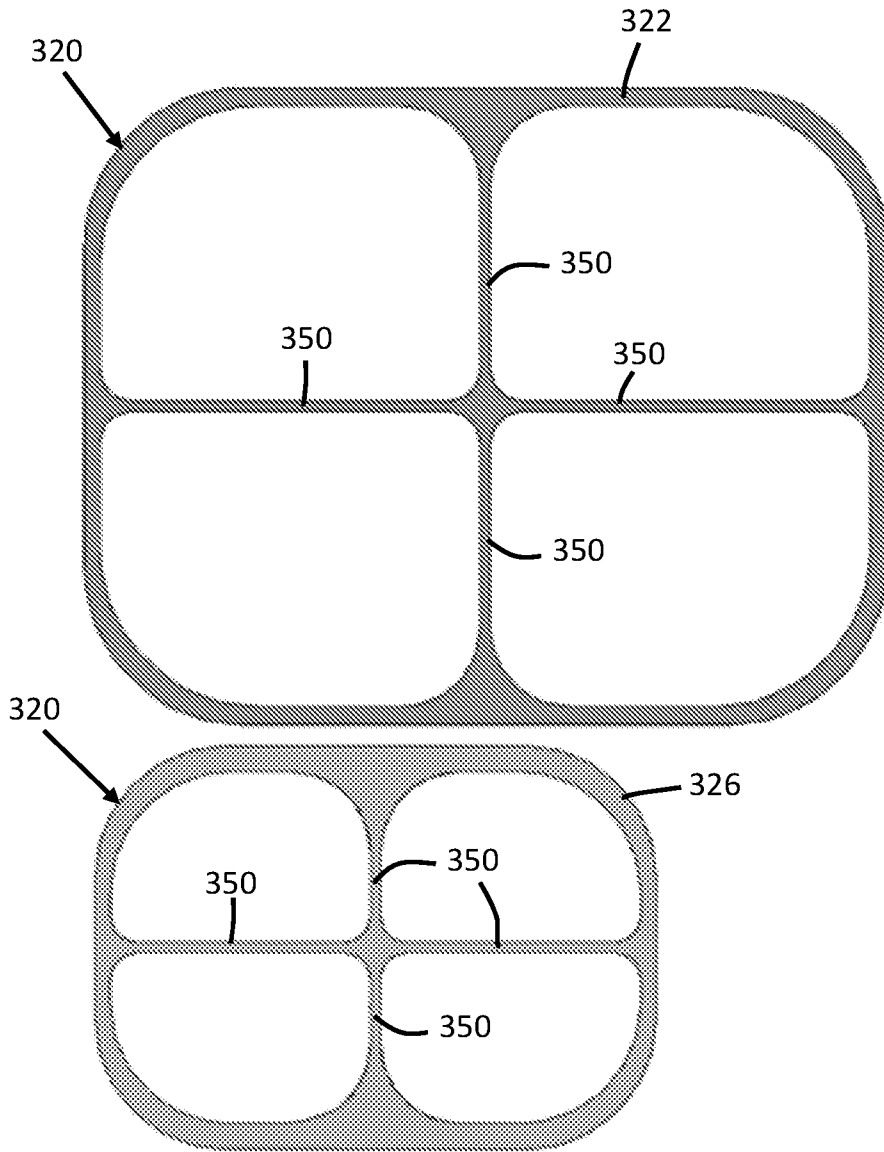


FIG. 8

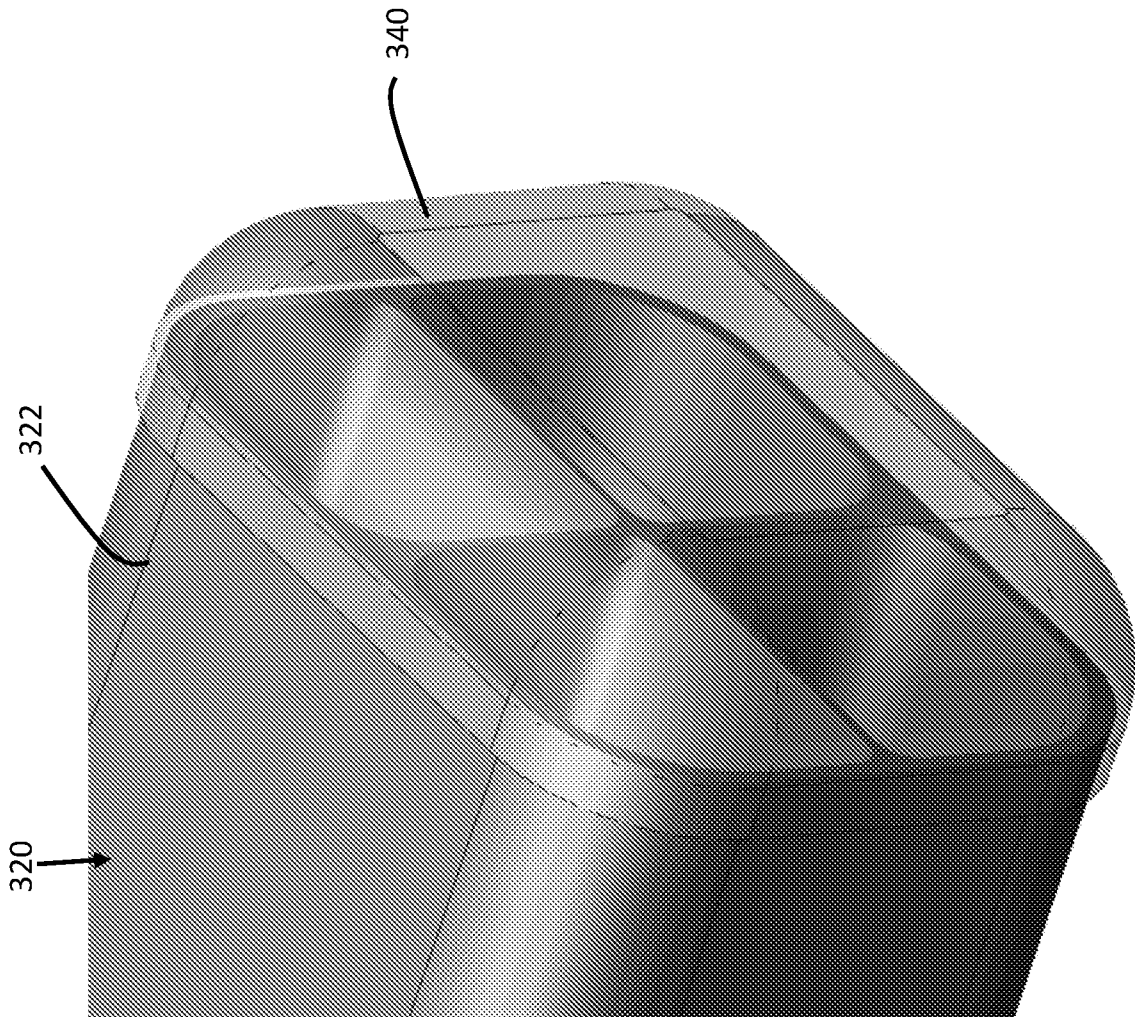


FIG. 9

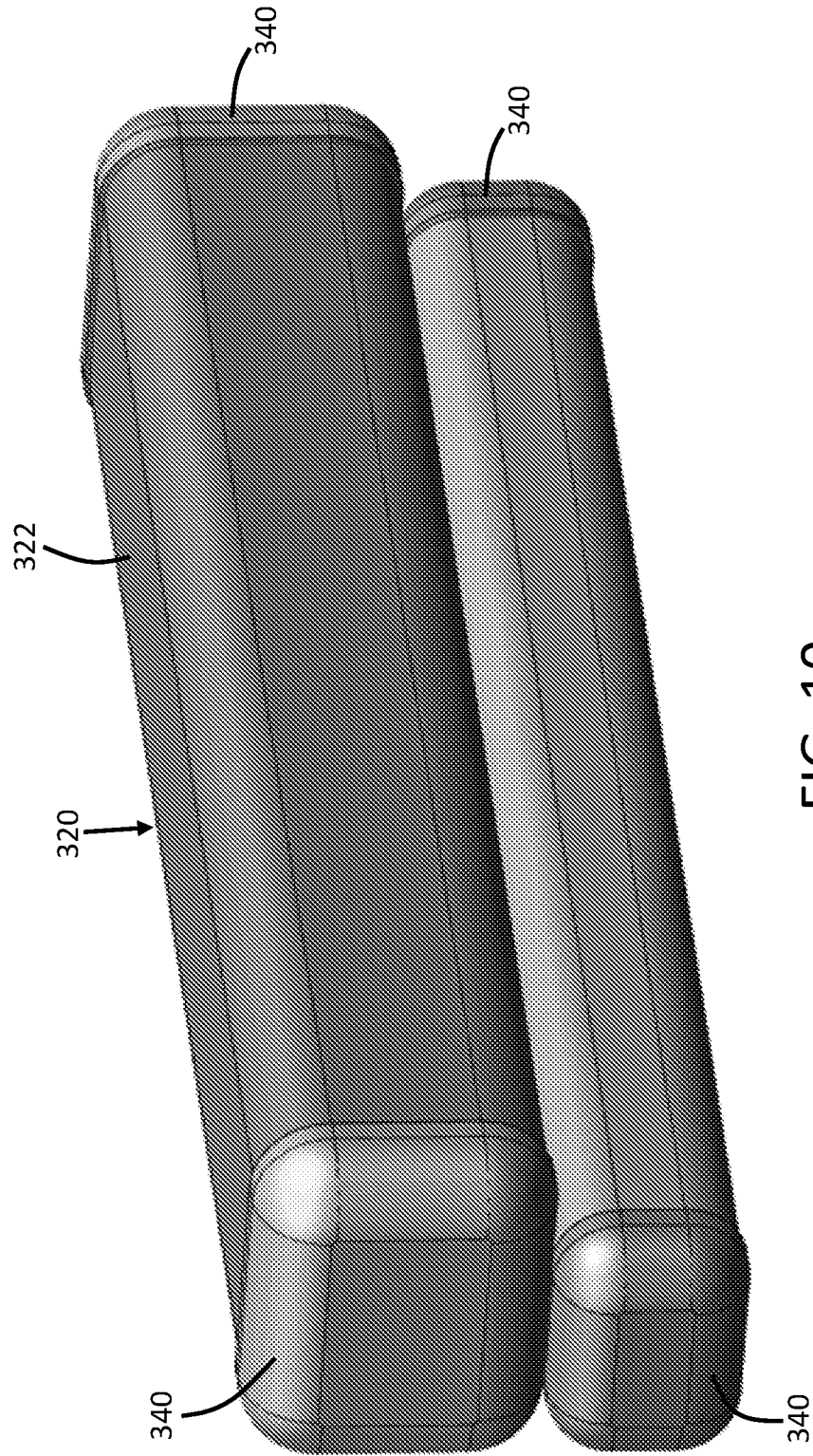


FIG. 10

9 / 9

400  
↓

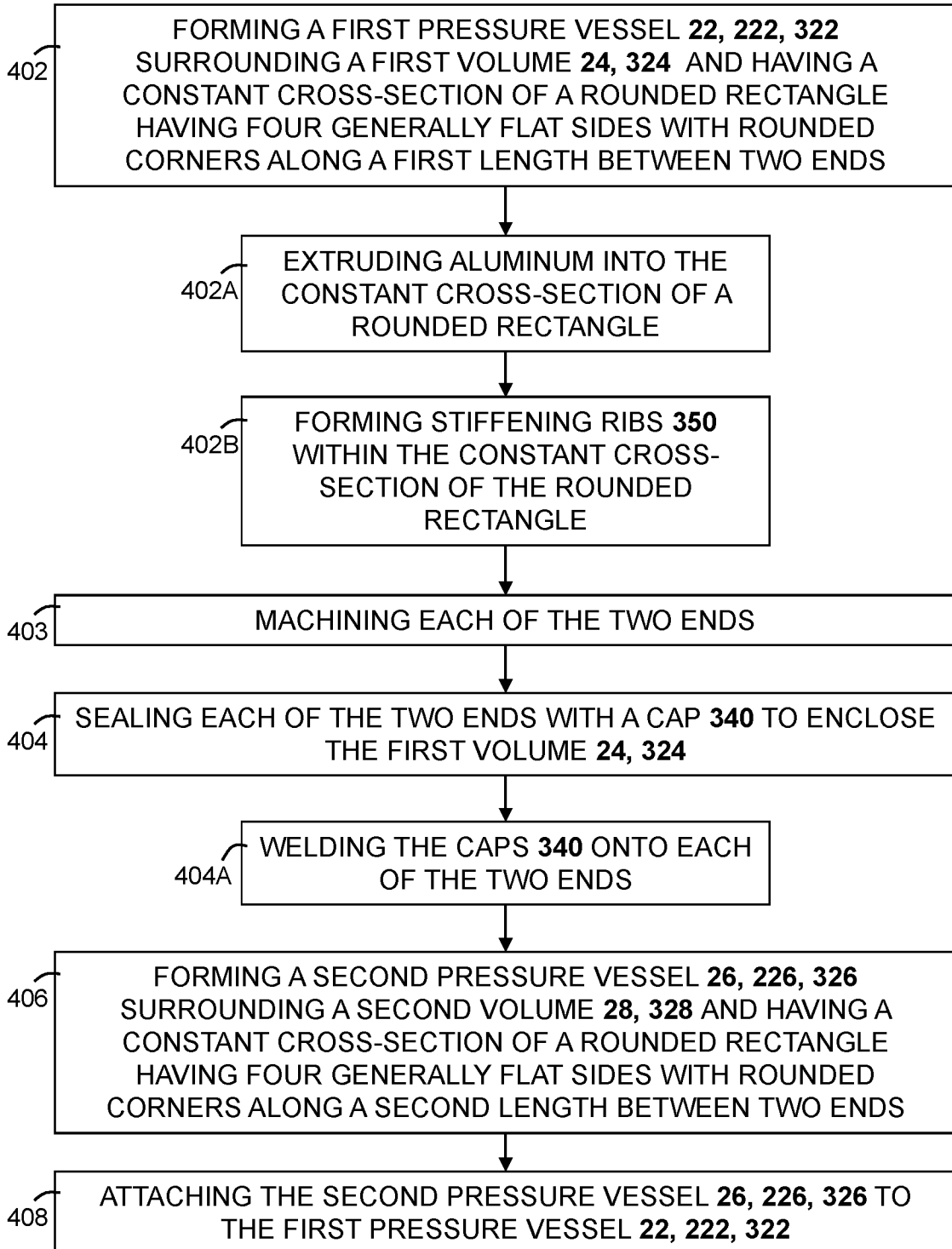


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2019/041572

A. CLASSIFICATION OF SUBJECT MATTER  
 IPC(8) - F17C 1/00; F17C 1/02; F17C 13/00 (2019.01)  
 CPC - F17C 1/08; F17C 2201/0147; F17C 2201/0166; F17C 2203/012; F17C 2205/013 (2019.08)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 206/0.6; 220/565; 220/581 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---	US 2008/0237240 A1 (HAUSBERGER) 02 October 2008 (02.10.2008) entire document	1, 3-6, 8, 11-14 ---
Y		7
Y	US 2,280,501 A (STEPHENSON) 21 April 1942 (21.04.1942) entire document	7
A	US 5,577,630 A (BLAIR et al) 26 November 1996 (26.11.1996) entire document	1-15
A	US 5,217,507 A (SPIRIG) 08 June 1993 (08.06.1993) entire document	1-15

Further documents are listed in the continuation of Box C.  See patent family annex.

\* Special categories of cited documents:  
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Date of the actual completion of the international search

02 September 2019

Date of mailing of the international search report

30 SEP 2019

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Authorized officer  
 Blaine R. Copenheaver

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