(12) UK Patent Application (19) GB (11) 2623549 (13) A

(43) Date of A Publication 24.04.2024

(21) Application No: 2215458.7

(22) Date of Filing: 19.10.2022

(71) Applicant(s):
University of Strathclyde
(Incorporated in the United Kingdom)
McCance Building, 16 Richmond Street, GLASGOW, G1 1XQ, United Kingdom

(72) Inventor(s):
Iain Bomphray

(74) Agent and/or Address for Service:
Marks & Clerk LLP
The Beacon, 176 St. Vincent Street, Glasgow, G2 5SG, United Kingdom

(51) INT CL:
F17C 1/04 (2006.01)

(56) Documents Cited:
EP 3385597 A1
EP 0300931 A1
WO 1997/028401 A1
JP 2010266029 A
JP 2008014342 A
US 10465848

(58) Field of Search:
INT CL **F17C**

(54) Title of the Invention: **Pressure vessel**
Abstract Title: **Hydrogen pressure vessel with strengthening wrap**

(57) A pressure vessel (10) for storing pressurised fluid, and a method of manufacturing a pressure vessel (10). The pressure vessel (10) comprising a body (20), end caps (14) engaging each end of the body (20) to form an enclosure with the body for containing the pressurised fluid, and a wrap (12) covering an engagement interface (19) between the body (20) and the end caps (14), wherein the wrap (12) is formed of composite material. It may also comprise a primary lateral wrap and one or more auxiliary wraps as well as the body comprising multiple chambers and determine a flow path though said chambers.

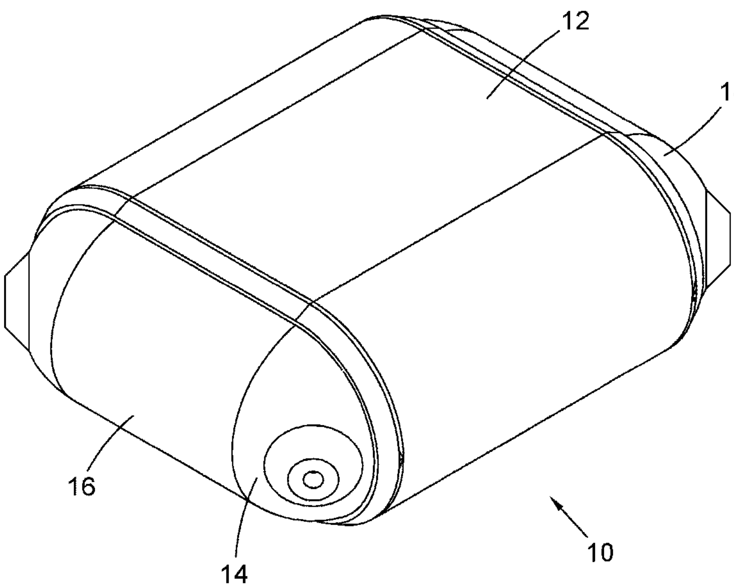


FIG. 1

GB 2623549 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

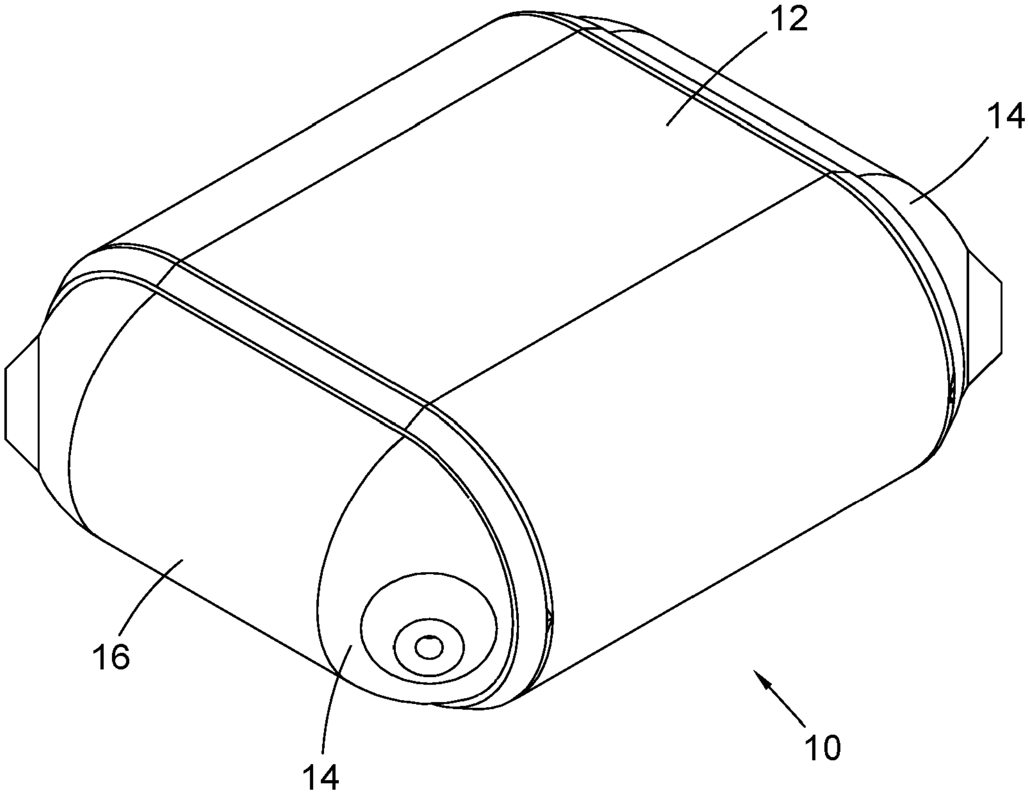


FIG. 1

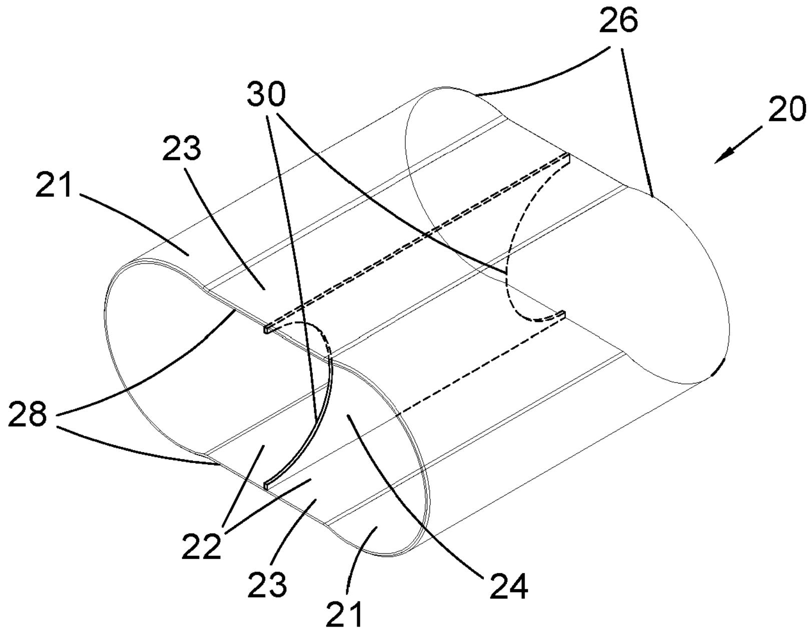


FIG. 2

16 01 24

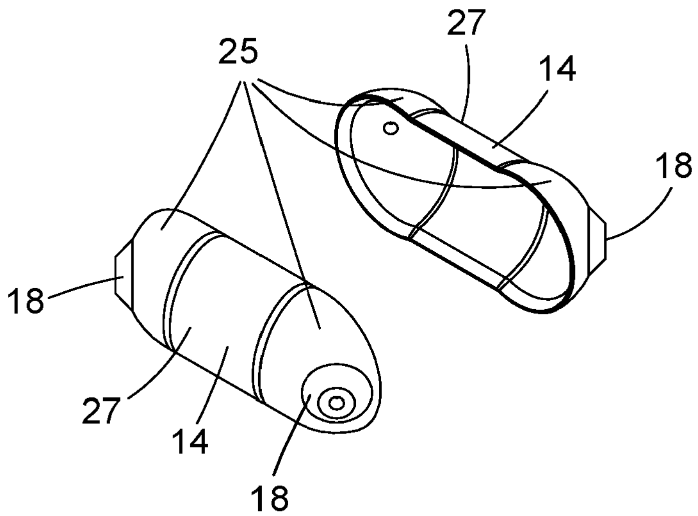


FIG. 3

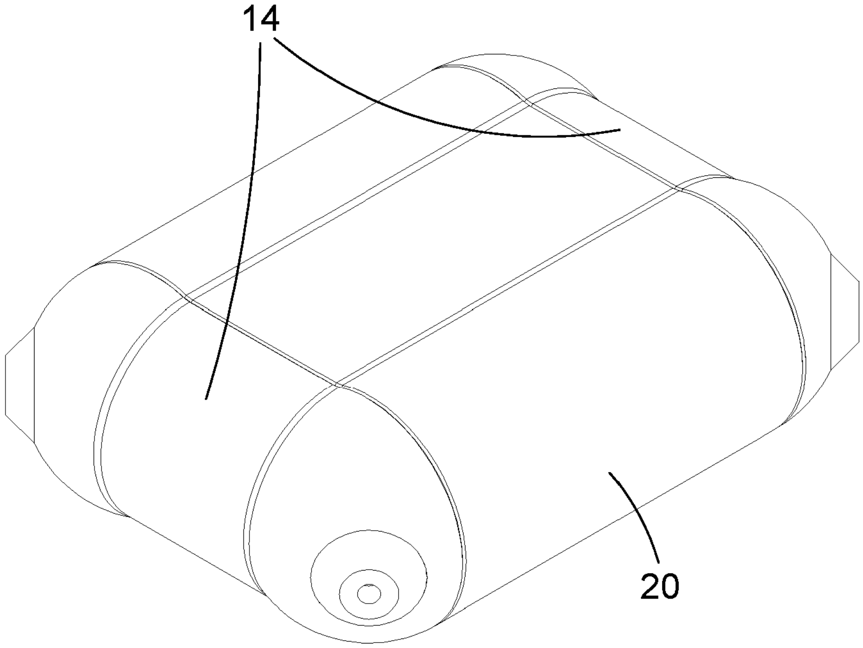


FIG. 4

16 01 24

16 01 24

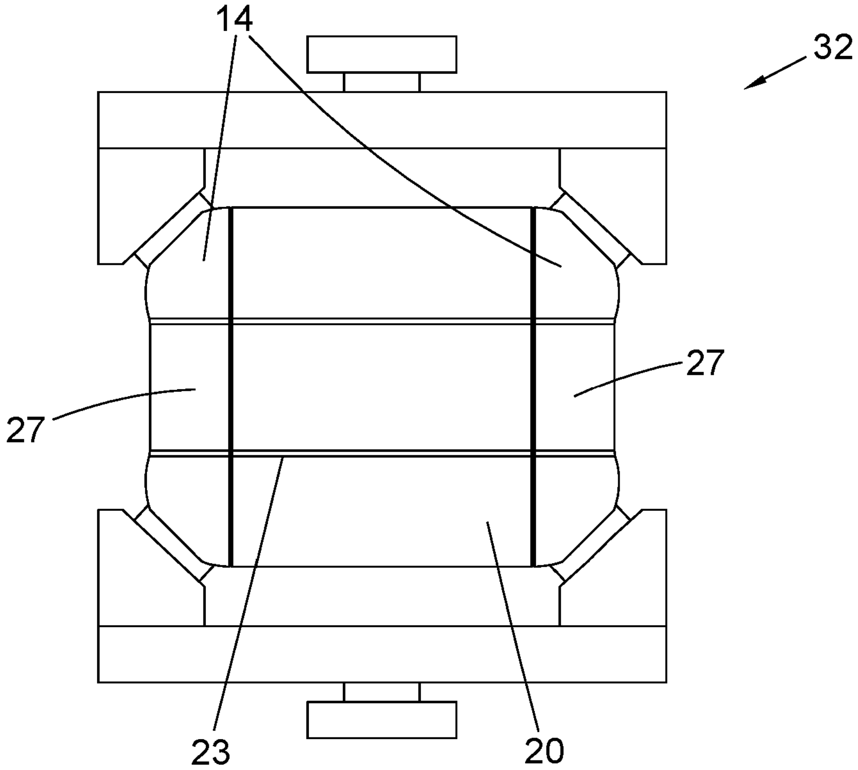


FIG. 5

16 01 24

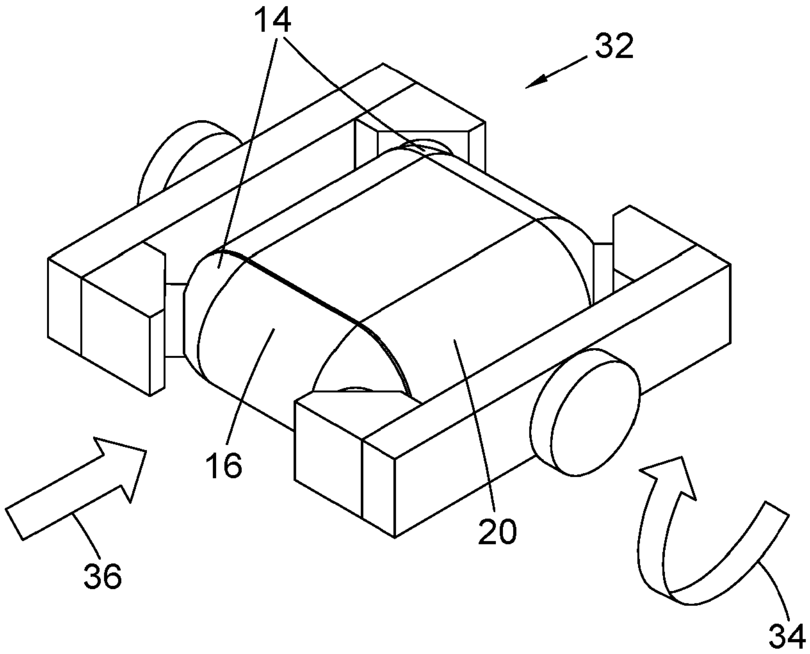


FIG. 6

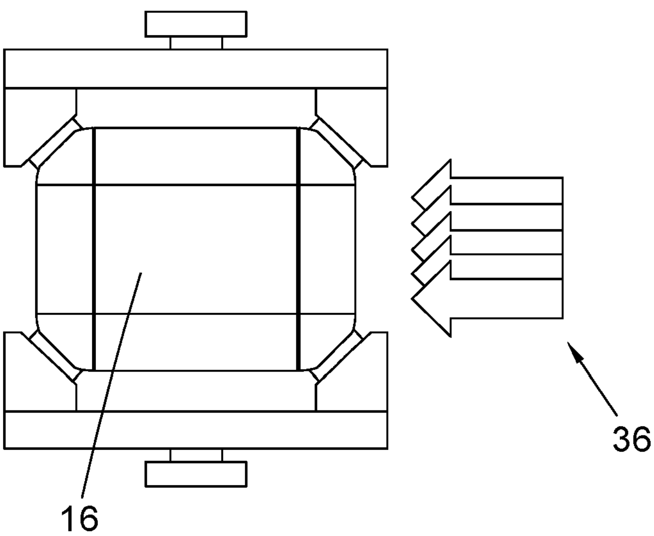


FIG. 7

16 01 24

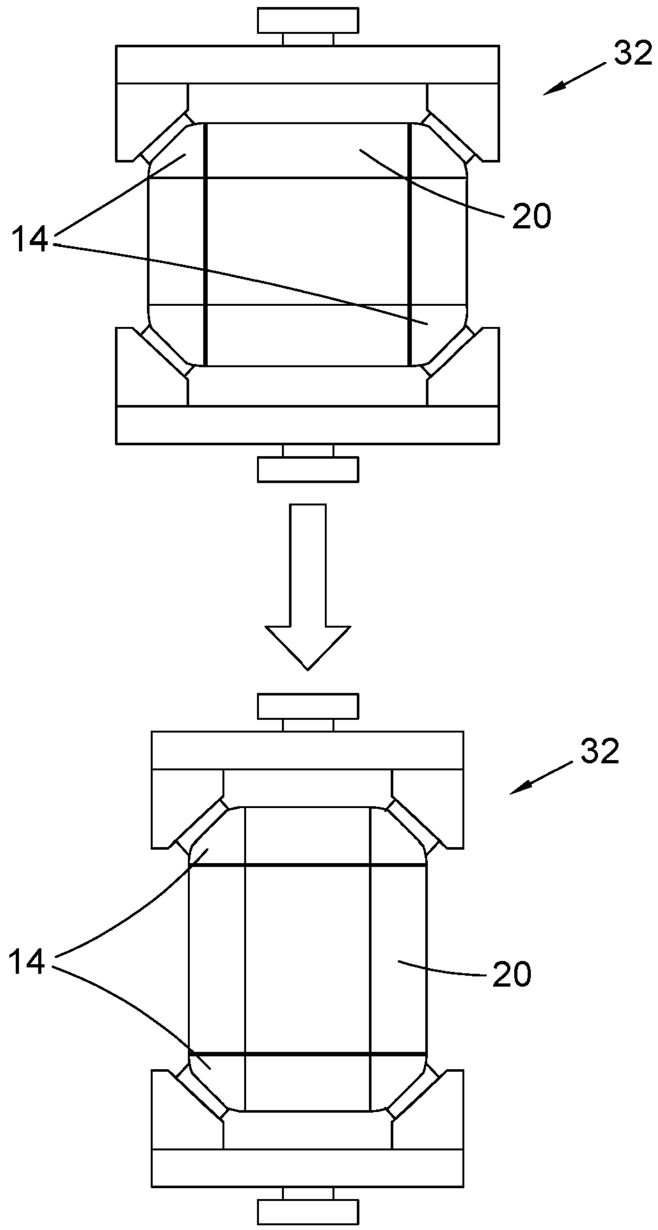


FIG. 8

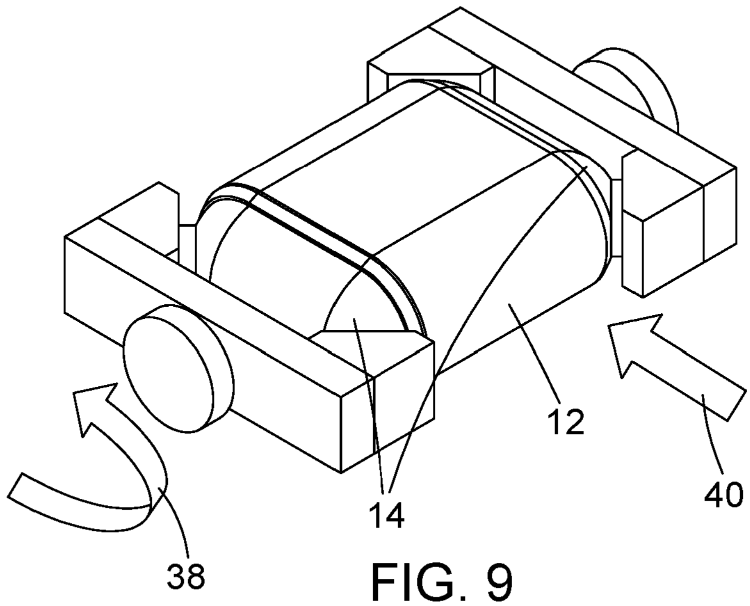


FIG. 9

16 01 24

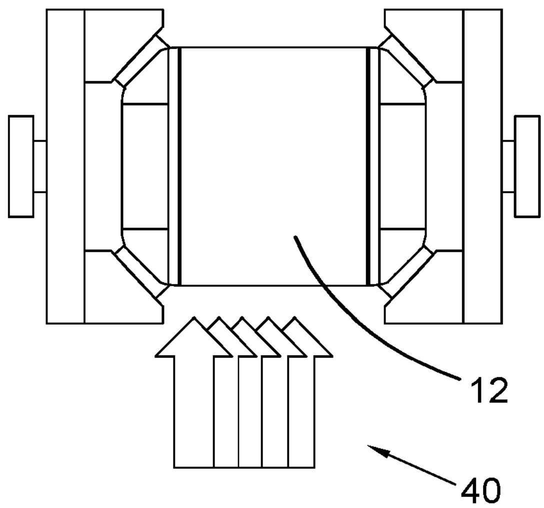


FIG. 10

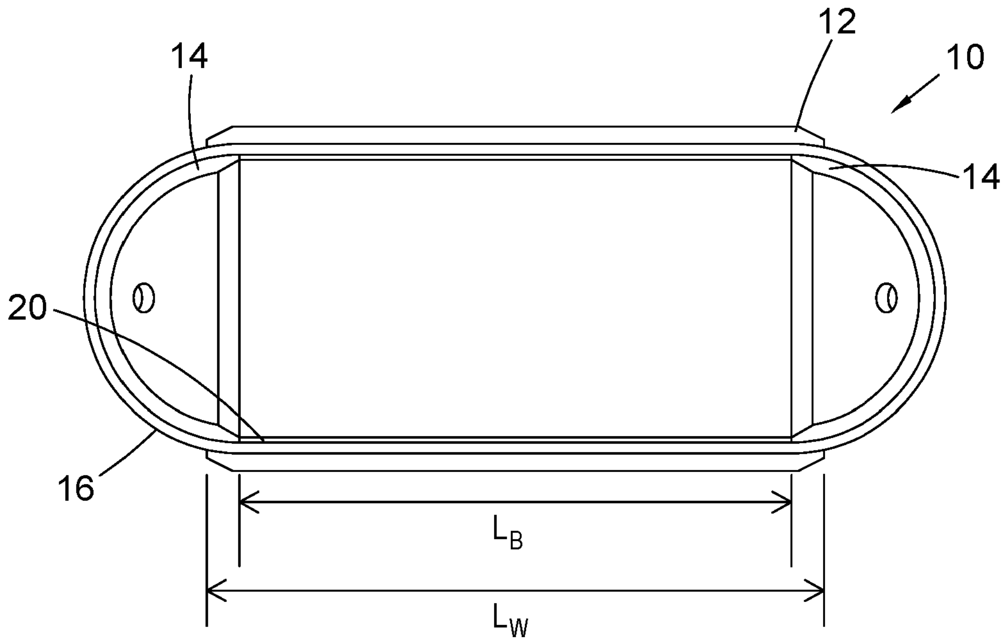


FIG. 11

16 01 24

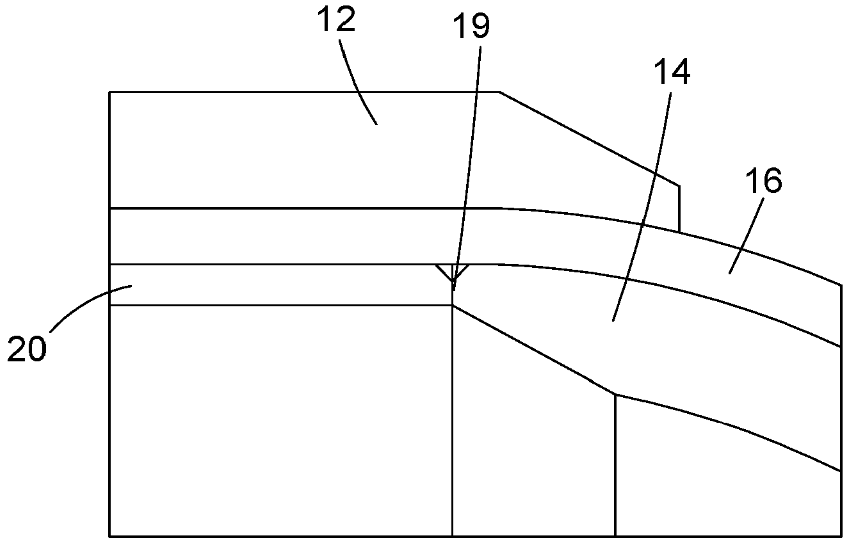


FIG. 12

16 01 24

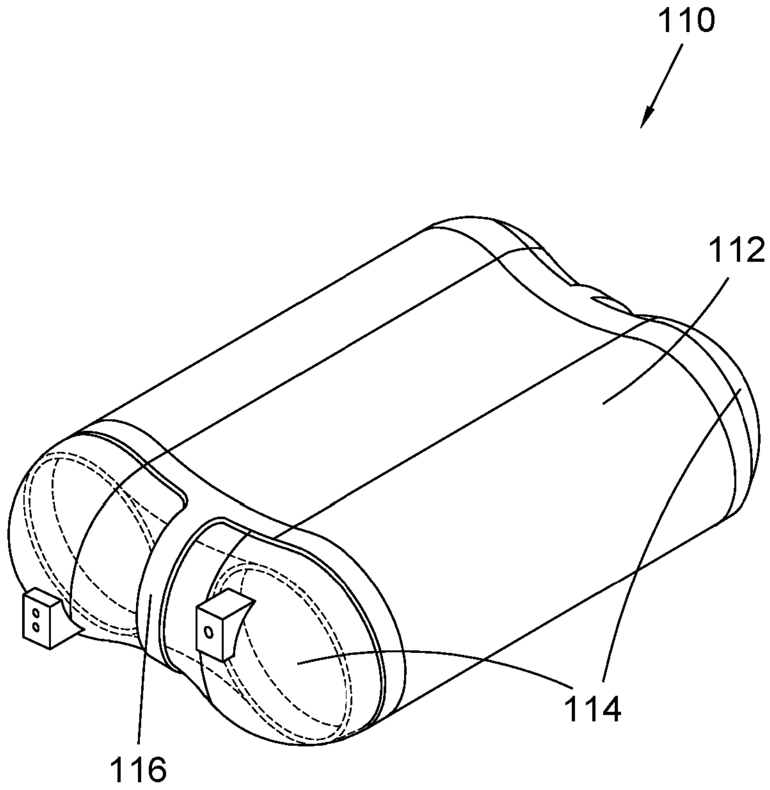


FIG. 13

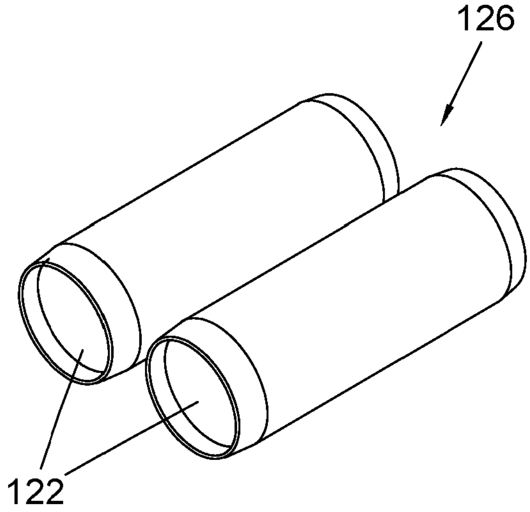


FIG. 14

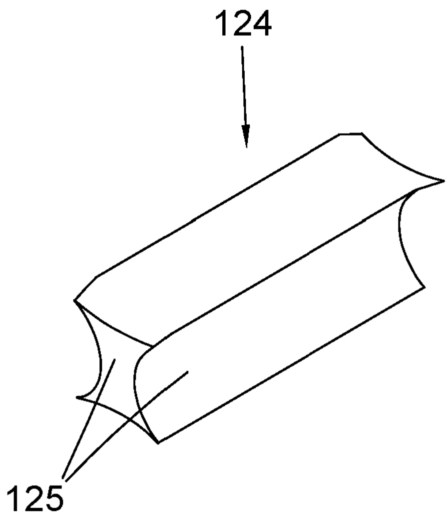


FIG. 15

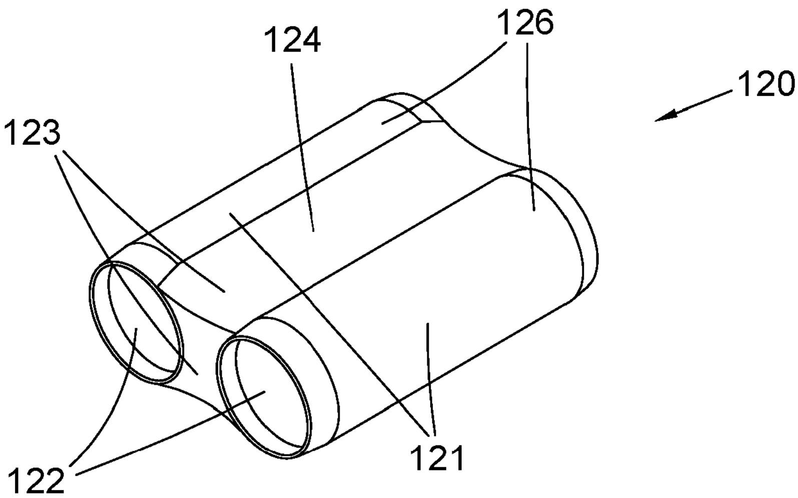


FIG. 16

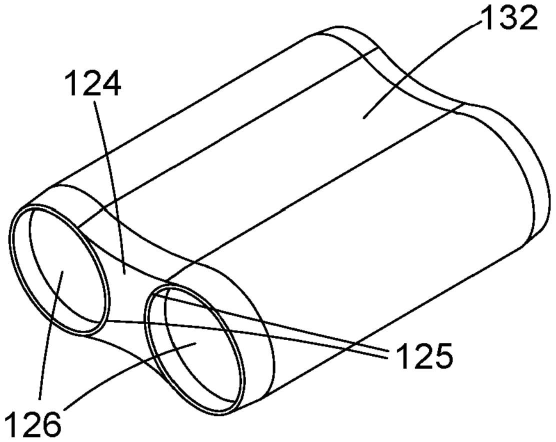


FIG. 17

16 01 24

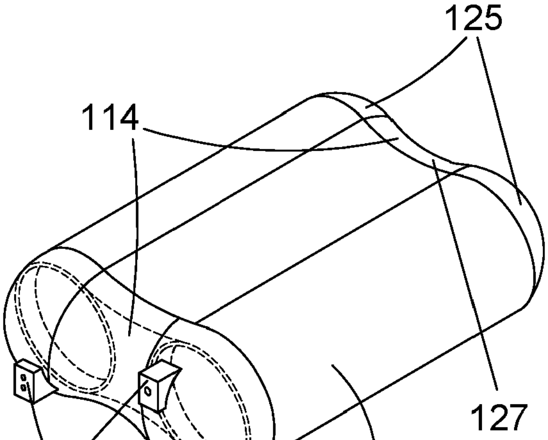


FIG. 18

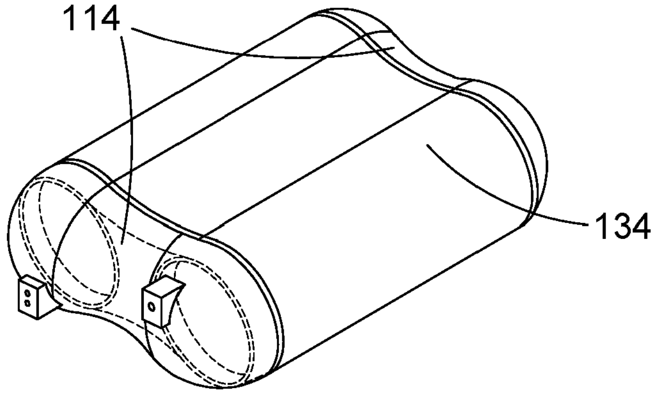


FIG. 19

16 01 24

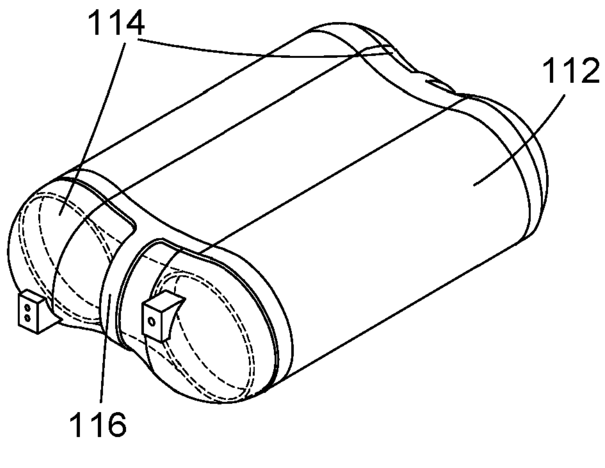


FIG. 20

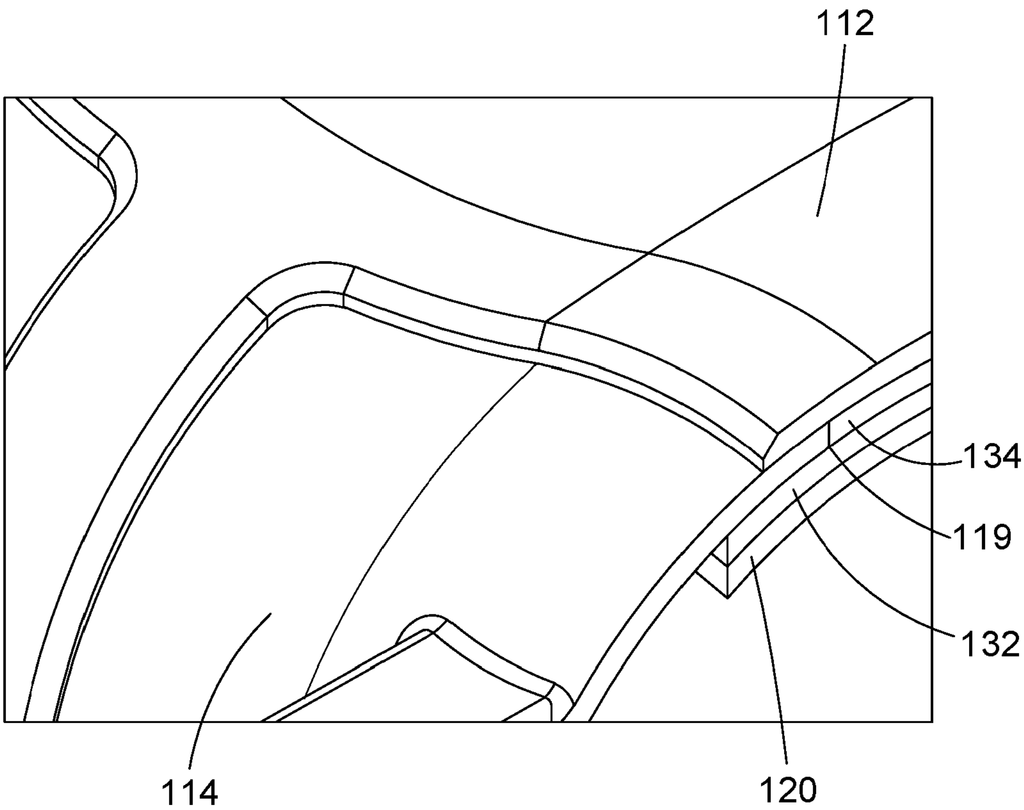


FIG. 21

16 01 24

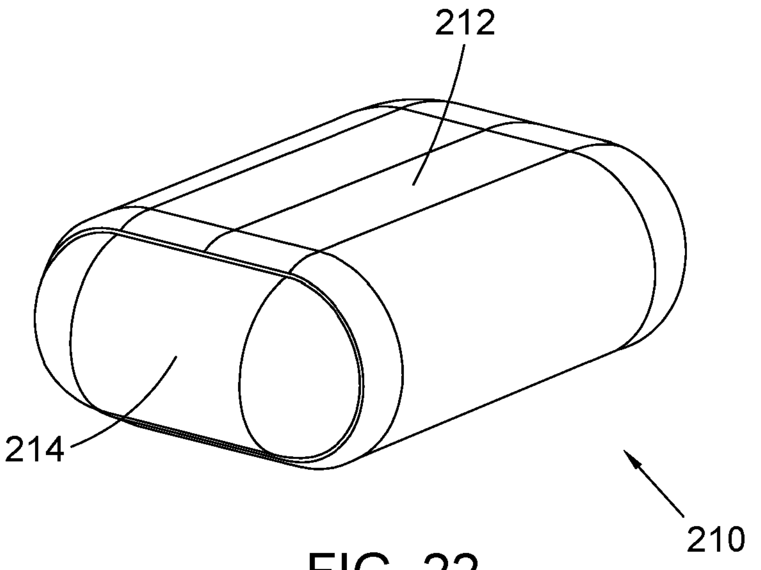


FIG. 22

16 01 24

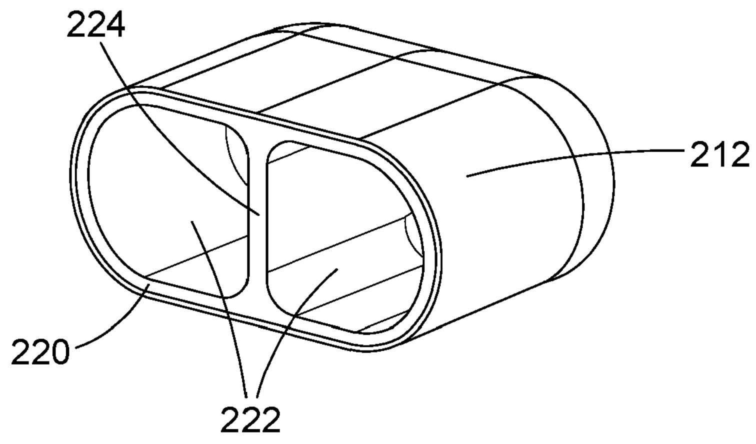
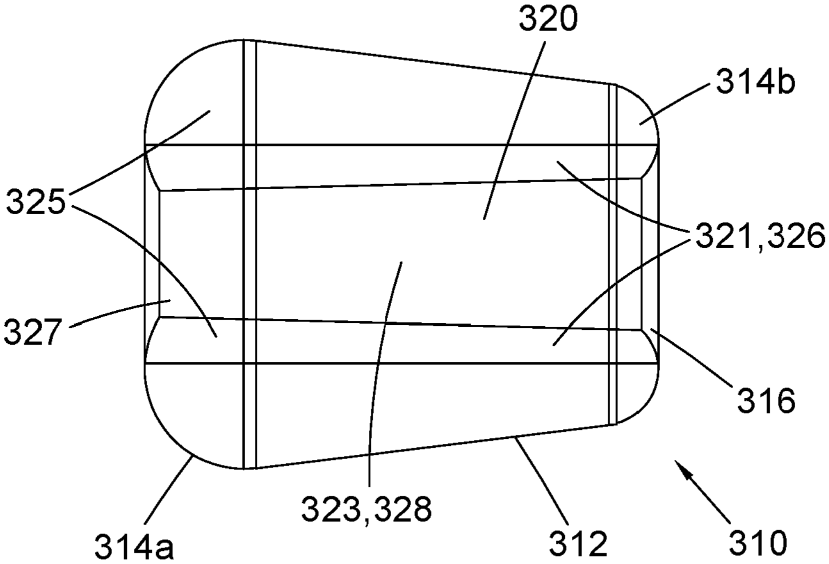
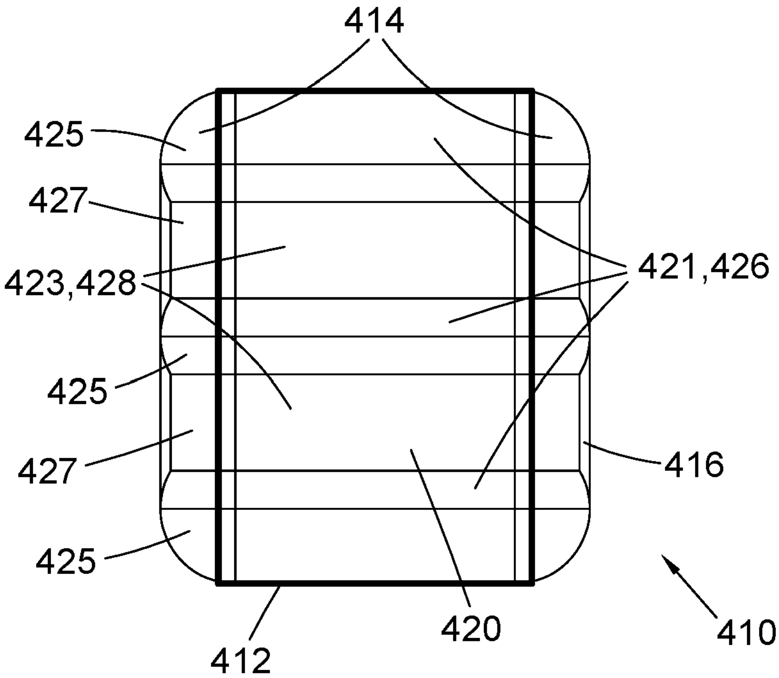


FIG. 23



320
314b
325
321,326
327
316
314a
323,328
312
310

FIG. 24



414
425
427
423,428
421,426
425
427
416
425
420
410
412

FIG. 25

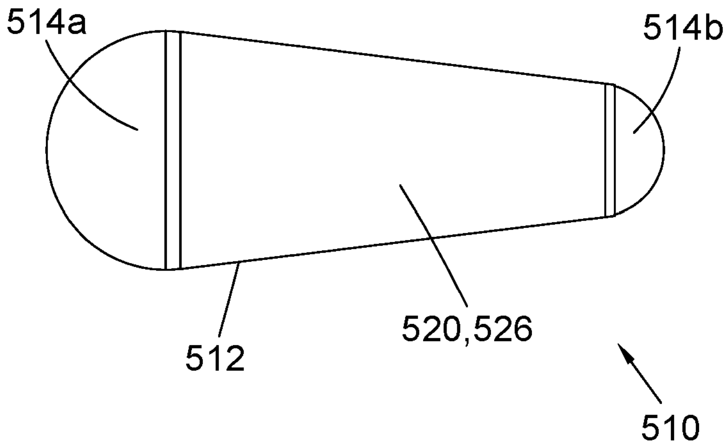


FIG. 26

16 01 24

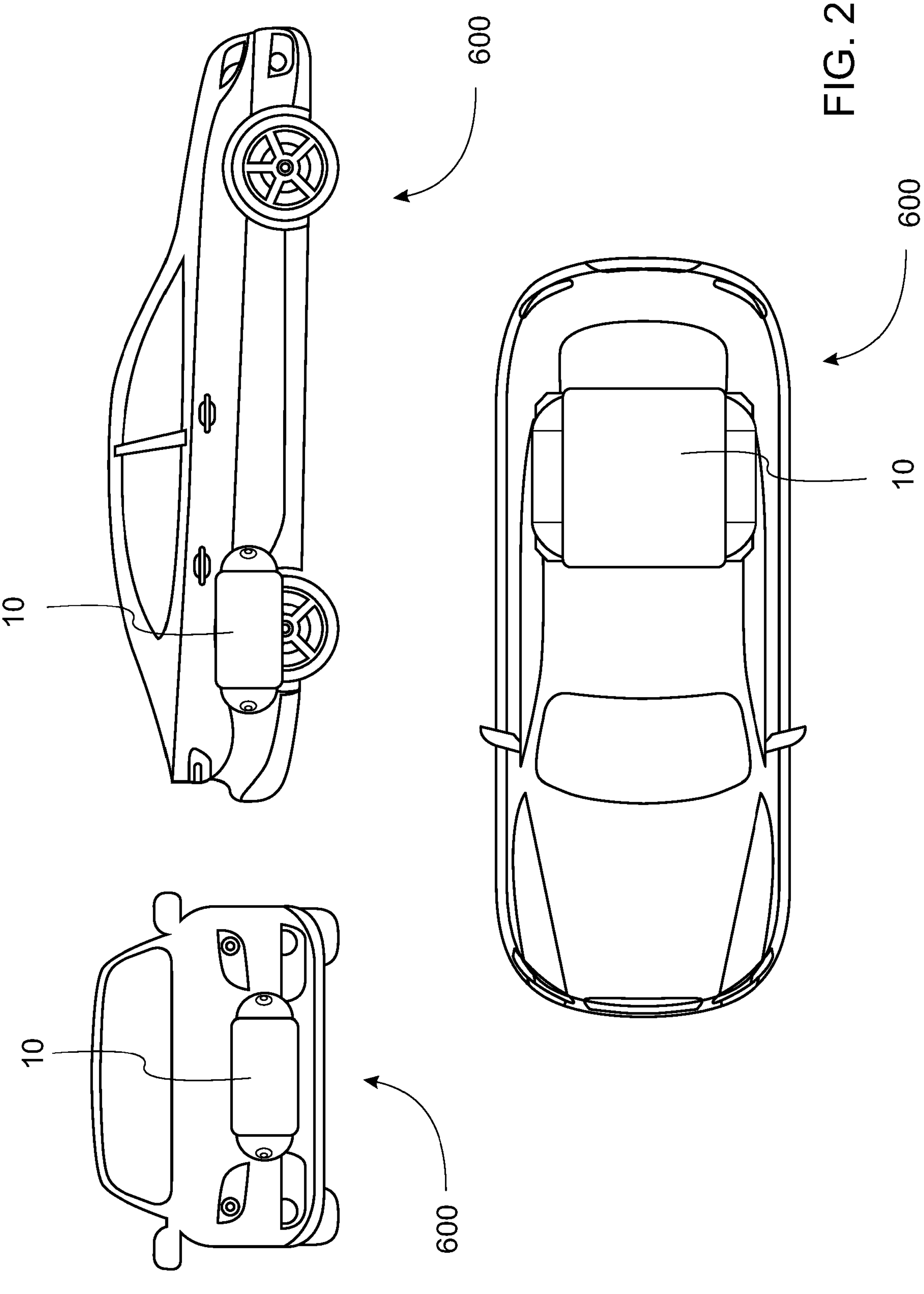


FIG. 27

16 01 24

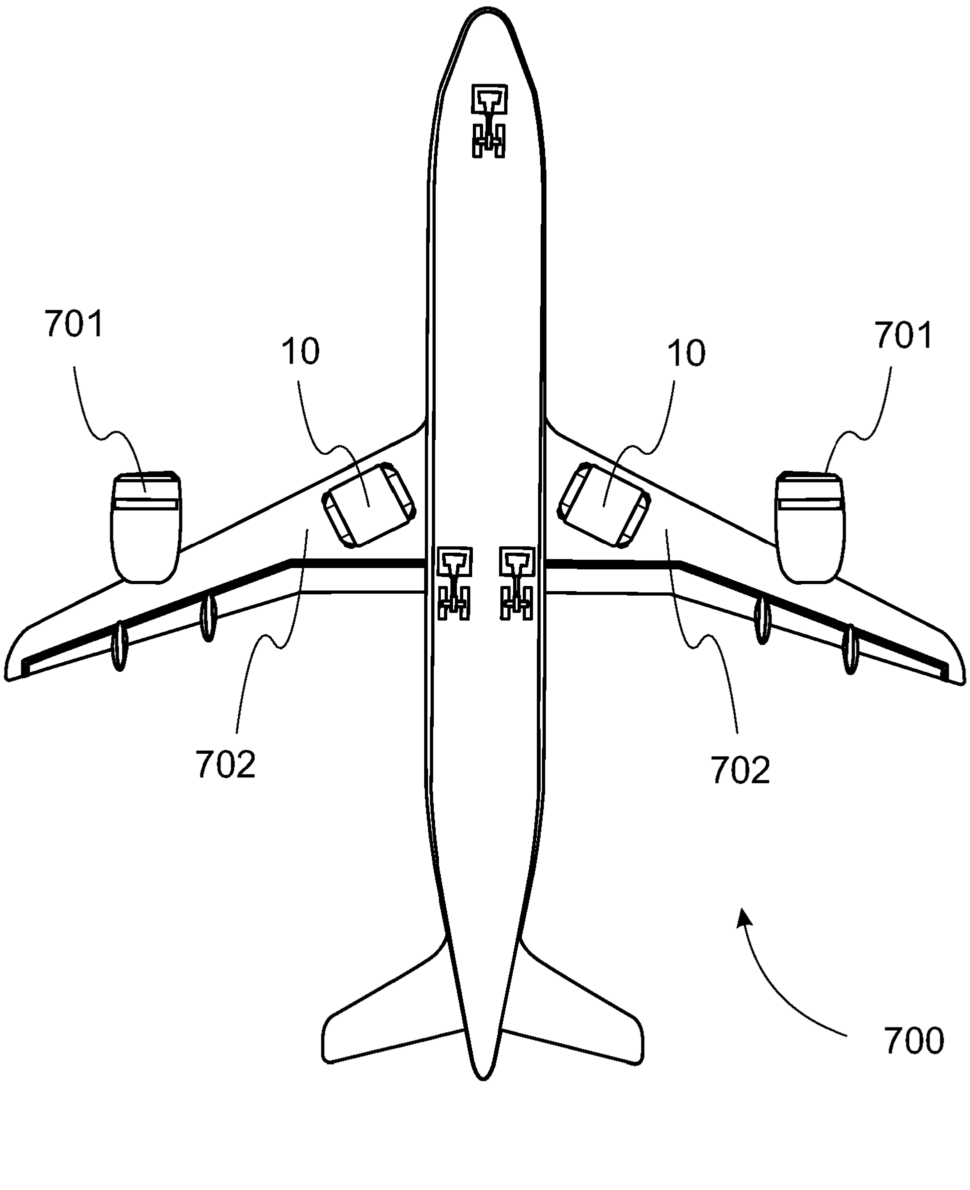


FIG. 28

16 01 24

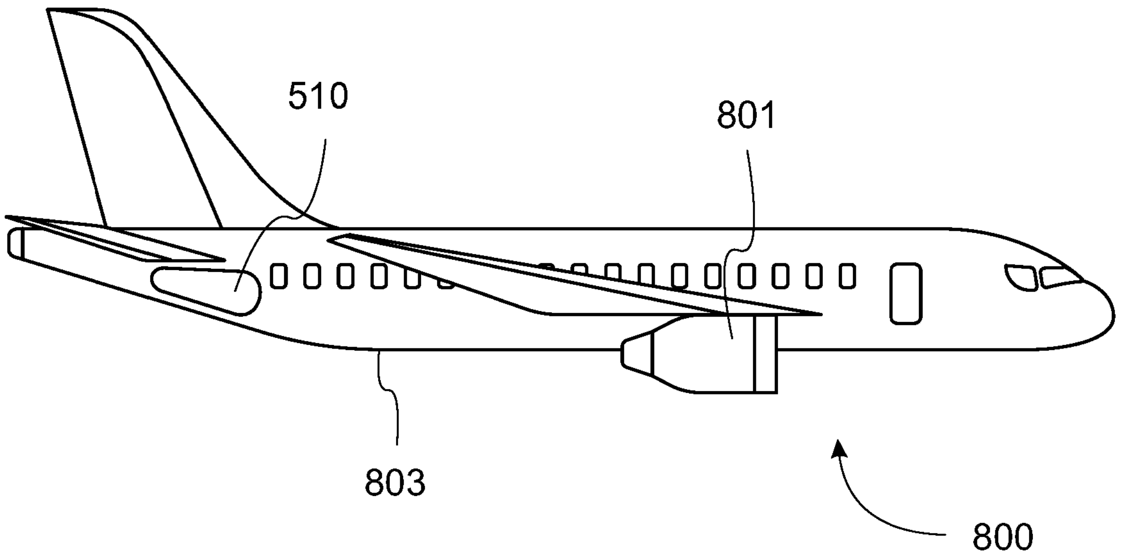


FIG. 29

PRESSURE VESSEL

FIELD

This relates to a pressure vessel for storing a pressurised fluid such as hydrogen, to a vehicle comprising one or more of the pressure vessels, and to a method of manufacturing said pressure vessel(s).

BACKGROUND

Pressure vessels are used in a vast array of applications, both domestic and industrial, to store pressurised fluids (liquid and/or gas). A typical pressure vessel comprises a cylindrical body and dome shaped ends which together define a storage chamber for the pressurised fluid. This allows the pressure vessel to be readily manufactured using simple manufacturing techniques while also providing the required mechanical properties to safely and reliably store the pressurised fluid contained within the storage chamber.

One particular example of the use of pressure vessels is in the storage of hydrogen onboard hydrogen-powered vehicles. In striving to move away from the reliance on fossil fuels, vehicles that are powered by hydrogen have and continue to be developed, but there remains significant technical challenges associated with the storage of the hydrogen fuel required to power the vehicles. Indeed, the development of hydrogen storage tanks is seen as a key component to the successful development of hydrogen-powered vehicles.

Traditionally, pressure vessels are constructed from metal. Metals have beneficial properties such as uniformity and transverse shear strength. However, metal is generally heavy and therefore not conducive to energy efficiency in a vehicle. Pressure vessels constructed using composite materials have also been developed. Composite materials have beneficial properties such as directional properties, and high specific strength and stiffness (per unit of mass). However, since composite materials are generally orthotropic, the through thickness properties of the laminate structure of composite materials are generally weak. Additionally, the construction of pressure vessels using composite materials is slow, costly and sometimes complex.

SUMMARY

Aspects of the present disclosure relate to a pressure vessel for storing a pressurised fluid such as hydrogen, to a vehicle comprising one or more of the pressure vessels and a method of manufacturing said pressure vessel(s).

In a first aspect, there is provided a pressure vessel for storing a pressurised fluid, the pressure vessel comprising:

a body;

end caps engaging respective ends of the body,

the body and the end caps forming an enclosure for containing therein the pressurised fluid to be stored; and

a wrap disposed around the body,

wherein the wrap covers an engagement interface between the body and the end caps, and

wherein the wrap is formed of composite material.

In use, the pressure vessel is configured and/or operable to store high pressure and/or low temperature fluid (liquid and/or gas). In particular embodiments, the pressure vessel may be configured and/or operable to store hydrogen. However, it will be understood that the pressure vessel may be configured and/or operable to store a variety of fluids such as nitrogen, carbon dioxide, liquefied natural gas, oxygen, etc.

The pressure vessel provides significant benefits over conventional equipment. For example, the pressure vessel may facilitate the storage of the pressurised fluid at a higher volumetric energy density than conventional pressure vessels.

Pressurised fluids stored in pressure vessels are typically stored in liquid form at low temperature (e.g. cryogenic liquid) or in gaseous form at high pressure. By way of example, hydrogen may be stored in liquid form at a temperature of -252.87°C and a density of 71 kg/m^3, such that 5 kg of hydrogen can be stored in a 75 Litre pressure vessel. Alternatively, hydrogen may be stored in gaseous form at a pressure of 700 bar and a density of 42 kg/m^3, such that 5 kg of hydrogen can be stored in a 125 Litre pressure vessel. In each case, the pressure vessel may provide approximately 500 to 600 km of range in a hydrogen-powered vehicle.

In the case of the present pressure vessel, the wrap that overlaps the engagement interface between the body and the end caps and which is formed of composite material provides a seal of sufficient strength to withstand the pressurised contents and prevent leakage at the engagement interface. By ensuring effective sealing of the pressure vessel, the pressurised fluid may be stored at a higher pressure and/or lower temperature, which, for hydrogen in particular, may improve the volumetric energy density of the pressurised fluid.

The pressure vessel may form, or form part of, a fuel tank. More particularly, but not exclusively, the pressure vessel may form, or form part of, a fuel tank for a vehicle such as a hydrogen-powered vehicle. The vehicle may be, for example, an automobile, an aircraft, a train, an agricultural vehicle, etc.

When the pressure vessel is used as a fuel tank in a vehicle, the greater volumetric energy density may enhance the range capabilities of the vehicle compared to known fuel tanks with the same envelope and/or may provide equivalent range capabilities of the vehicle from a smaller fuel tank envelope.

The body may be formed of a first material. The first material may be a metal or a composite material. The end caps may be formed of a second material. The second material may be a metal or a composite material. The first material and the second material may be different to the composite material of the wrap. The first material and the second material may be the same or different. Beneficially, the wrap may provide sealing and containment at the engagement interface between dissimilar first and second materials. The wrap being formed of composite material may provide a seal that is strong but lightweight.

The pressure vessel may have or take the form of a hybrid construction, e.g. the pressure vessel may comprise or may be formed of composite materials and metal.

Beneficially, the structure of the pressure vessel, comprising both metal and composite material, may optimise the strength-to-weight efficiency of the vessel by applying selected materials in areas of the vessel where their properties are most effective. The volumetric energy density of the pressure vessel may also be further improved by optimising the strength and weight of the pressure vessel.

The metal may comprise aluminium. The metal may comprise titanium. The metal may be an alloy.

The composite material may comprise or be formed of a composite unidirectional material, with or without a dry binder or powder resin. The composite material may comprise or be formed of unidirectional (UD) tows or tape. The composite material may comprise or be formed of a prepreg. The prepreg may comprise fibers impregnated with a polymer matrix. The composite material may comprise or be formed of a composite dry fabric and/or a non-crimp fabric. The dry fabric may comprise woven fibres, e.g. off-axis woven fibres. The composite material may comprise or be formed of bulk moulding compound. The bulk moulding compound may comprise strands of glass fibers, styrene, an initiator, filler and thermoset resin.

The composite material may comprise metallic material, e.g. metal particles. The composite material may comprise or be formed of a metal matrix composite.

The body may be formed of composite material. The body may be formed of bulk moulding compound. The body may comprise or be formed of a prepreg.

Beneficially, composite material may be provide greater specific strength and/or stiffness (per unit of mass).

Alternatively, the body may be formed of metal. The body may be formed of aluminium. The body may be formed of titanium. Beneficially, metal may have a higher density and higher transverse shear and flexural properties.

The body may have a generally elongate cross-sectional shape. The body may have asymmetric lateral dimensions, e.g. a first lateral dimension of the body may be smaller than a second lateral dimension of the body. The body may have a rounded-rectangle or ellipse cross-sectional shape. Alternatively, the body may have a generally circular cross section. Alternatively, the body may have an irregularly shaped cross section. The body may have a uniform cross section along the axial length of the body. Alternatively, the body may have a transitioning cross section along the axial length of the body. The body may have an increasing or decreasing cross sectional size along the axial length of the body, e.g. the body may be axially tapered. Beneficially, the shape of the body may conform to a storage area for the pressure vessel in a vehicle, and therefore facilitate easy storage in a vehicle to provide fuel for said vehicle.

The body may be an integral structure. Alternatively, the body may comprise connected components. The components may be connected via welding, bonding, one or more fixings, etc.

The body may define one or more chambers within the body. The body may define one, two, three or more chambers. The one or more chambers may extend axially. The one or more chambers may be open at each axial end. The one or more chambers may have a circular cross-section or an irregular shaped cross-section e.g. a truncated ellipse or a half rounded-rectangle. Where the body comprises two chambers, the chambers may be generally symmetrical. The one or more chambers may have a uniform cross section along their axial length. Alternatively, the one or more chambers may have a transitioning cross section along their axial length, e.g. the one or more chambers may be axially tapered.

The chambers may be in fluid communication with each other. A flow path between the chambers may be provided in the body and/or via the end caps. The flow path may enable pressure within the body to be equalised throughout the body.

Each chamber may be defined by one or more components of the body.

The body may comprise one or more tube portions, e.g. one, two, three or more tube portions. The tube portions may comprise or be formed of metal and/or composite material. The tube portions may extend axially. Each tube portion may at least partially define one of the chambers within the body.

The body may comprise one or more webs. The one or more webs may be between the tubular portions. The one or more webs may extend laterally between sides of the body. The one or more webs may extend between the sides of the body that define the first lateral dimension of the body. The one or more webs may extend axially. The one or more webs may partially define the chambers. Each web may be between adjacent chambers. Each web may separate adjacent chambers. The one or more webs may at last partially define the flow path between the chambers.

The one or more webs may be formed of a composite material, e.g. a bulk moulding compound. Alternatively, the one or more webs may be formed of a metal.

The one or more webs may provide the body with support. The one or more webs may support lateral sides of the body. The one or more webs may resist lateral compression and/or expansion of the body, e.g. the one or more webs may prevent the first lateral dimension of the body from increasing or decreasing during use. The one or more webs may prevent the pressure vessel from ‘panting’, e.g. flexing in and out. The one or more webs may allow the pressure vessel to resist expansion due to internal pressure.

The tube portions and the one or more webs may be integral or connected. The tube portions and the one or more webs may be connected via welding, bonding, adhesion, one or more fixings, etc.

Each tube portion may define a chamber. Alternatively, a tube portion and a web may collectively define a chamber.

Alternatively, the tube portions and the one or more webs may be held together by a body wrap of the body. The body wrap may be a lateral wrap, e.g. the body wrap may be wrapped around the body in a lateral direction. The body wrap may be wrapped around the tube portions and the one or more webs. The body wrap may retain the one or more webs between the tube portions. The body wrap may be formed of a composite material. The body may comprise UD tows. The body wrap may be formed of a dry fabric or a prepreg. Beneficially, the dry fabric may be cost effective.

Each tube portion may be a liner tube. Each liner tube may define one of the chambers. Each liner tube may be generally cylindrical. Beneficially, the liner tubes may be an efficient geometric shape to support internal pressure.

Alternatively, each tube portion may comprise a partial tube portion. Each tube portion may comprise one or more joining plate members. Adjacent partial tube portions may be joined by joining plate members. The partial tube portions and the joining plate members may be integral or connected. The partial tube portions and the joining plate members may be connected via welding, bonding, adhesion, one or more fixings, etc. Each web may extend laterally between joining plate members. The web and the joining plate members may be integral or connected. The web and the joining plate members may be connected via welding, bonding, adhesion, one or more fixings, etc. The web may support the joining plate members. Each chamber may be defined by at least one partial tube portion, at least two joining plate members and at least one web.

The body may comprise bulbous portions. The tube portions may define the bulbous portions, in particular the partial tube portions. he tube portions may be bulbous portion components of the body. The body may comprise a recessed portion between adjacent bulbous portion. Each recessed portion may be on a lateral side of the body. Each recessed portion may be defined by a joining plate member or a web. The joining plate members and the web may be recessed portion components of the body. Each web may extend between recessed portions of the body.

The body may comprise one or more internal baffles. Each baffle may extend into the one or more chambers. Each baffle may be integral with or connected to one or more of the body components. Beneficially, the baffles may prevent slosh of the fluid within the pressure vessel.

The end caps may be formed of composite material, e.g. a bulk moulding compound. Beneficially, composite material may provide greater specific strength and/or stiffness (per unit of mass).

Alternatively, the end caps may be formed of metal. Beneficially, metal may have a higher density and higher transverse shear and flexural properties.

The end caps may be shaped to engage the ends, e.g. axial ends, of the body. The end caps may close the body. The end caps may have a generally elongated dome shape. Each end cap may comprise bulbous portions conforming to the bulbous portions of the body. Each end cap may comprise one or more recessed portions conforming to recessed portions of the body.

Each end cap may comprise one or more boss. The bosses may be configured for receiving a fitting to insert or remove fluid (e.g. liquid and/or gas) in the pressure vessel. Each boss may be on a bulbous portion of the end cap.

The end caps may abut or overlap the body.

The end caps may at least partially define the flow path between the chambers of the body. The flow path may be defined by the end caps and the one or more webs.

The body and/or the end caps may comprise an internal 'slosh' coating, e.g. a barrier coating. Beneficially, the internal coating may seal the inside of the pressure vessel.

The wrap may comprise or be formed of UD tape. The wrap may comprise or be formed of dry fabric. The wrap may comprise wire or fibre for transmitting signals. Beneficially, the wire or fibre may transmit signals received by a sensor, e.g. to facilitate health and/or leak monitoring of the pressure vessel.

The wrap may be a lateral wrap, e.g. the wrap may be wrapped around the body in a lateral direction. The wrap may be disposed around the body at least once. The wrap may comprise one or more layers, e.g. windings, around the body.

The wrap may cover the body. The wrap may at least partially cover the end caps. The wrap may overlap the end caps. The wrap may have a width greater than an axial length of the body. The width of the wrap may be greater than an axial distance between the end caps.

The wrap may be a primary wrap. The pressure vessel may comprise one or more auxiliary wraps. Adjacent wraps may be disposed around the body in different directions, e.g. transverse directions. Each wrap may comprise one or more windings. The one or more auxiliary wraps may be integral or contiguous with the primary wrap. Alternatively, the one or more auxiliary wraps may be formed separately from the primary wrap.

The one or more auxiliary wraps may be formed of composite material. The one or more auxiliary wraps may comprise UD tows, UD tapes or UD hoop plies. The one or more auxiliary wraps may comprise woven plies, e.g. off-axis woven plies. Beneficially, the UD hoop plies may provide strength. The one or more auxiliary wraps may comprise or be formed of a dry fabric. Beneficially, dry fabric may be cost effective. The one or more auxiliary wraps may be infused or powdered with resin. The one or more auxiliary wraps may be formed of a prepreg.

The one or more auxiliary wraps may comprise an axial wrap, e.g. a wrap which is wrapped in an axial direction. The axial wrap may extend around the end caps and the body. The axial wrap may retain the end caps in engagement with the body. Beneficially, the axial wrap may provide resistance to internal pressure and thus relieve strain on the engagement interface between the end caps and the body. The axial wrap may resist thermal expansion of the body and end caps, and thus minimise issues of thermal expansion of dissimilar materials.

The axial wrap and the primary wrap may collectively fully encapsulate the body and the end caps.

The axial wrap may be layered between the primary wrap and the body. The axial wrap may be an inner wrap, e.g. the wrap closest to the body. Alternatively, the axial wrap may be layered over the first wrap. The axial wrap may be an outer wrap, e.g. an outermost wrap, e.g. a wrap furthest from the body.

The axial wrap may be configured to fill one or more of the recessed portions of the body and the corresponding recessed portions of the end caps, e.g. the axial wrap may have a depth or number of windings sufficient to fill the groove portion. Beneficially, the axial wrap filling the recessed portions may allow for ease of manufacture, in particular ease of transitioning from winding the axial wrap to winding the primary lateral wrap.

The one or more auxiliary wraps may comprise an auxiliary lateral wrap around the body, e.g. an additional wrap that is disposed in a lateral direction around the body.

The auxiliary lateral wrap may have a different width to the primary wrap.

The auxiliary lateral wrap may be axially between the end caps, e.g. the auxiliary lateral wrap may have a width equal to the axial distance between the end caps.

The auxiliary lateral wrap may be disposed between the body and the primary wrap.

In a second aspect, there is provided a vehicle comprising a pressure vessel of the first aspect.

The vehicle may be an automobile, an aircraft, a train, an agricultural vehicle, etc.

Where the vehicle is an aircraft, the body of the pressure vessel may be shaped to conform to a fuselage of the aircraft. Beneficially, this may allow for convenient and efficient storage of the pressure vessel in the aircraft.

The vehicle may comprise a power generation device. The pressurised vessel may be in fluid communication with the power generation device. The pressurised vessel may supply fluid (e.g. liquid and/or gas) to the power generation device.

The pressure vessels may store hydrogen. The vehicle may be a hydrogen-powered vehicle, e.g. a hydrogen fuel cell vehicle. The power generation device may be a hydrogen fuel cell.

In a third aspect, there is provided a method of manufacturing a pressure vessel for containing pressurised fluid, the method comprising:

forming an enclosure for containing therein the pressurised fluid by engaging end caps with respective ends of a body, and

disposing a wrap around the body and covering an engagement interface between the body and the end caps with the wrap, wherein the wrap is formed of composite material.

Beneficially, the structure of the pressure vessel may be optimised to ease manufacture. Thus the cost and speed of manufacture may be reduced. In particular, components of the pressure vessel, e.g. the body and the end caps, may be manufactured separately and in parallel before assembly which may allow for production optimization and more opportunities for quality control.

The pressure vessel may have a hybrid construction, e.g. the pressure vessel may comprise composite material components and metal components. The composite material components may be formed by braiding, winding, automated fibre placement, pick & place, press moulding, etc. The metal components may be formed by flow forming, forging, casting, etc.

The method may comprise forming the body and/or the end caps.

The method may comprise forming the body from metal or composite material.

The body may comprise a plurality of connected components. The method may comprise assembling the plurality of components of the body. The method may comprise connecting the components of the body using a paste or film adhesive, prepreg material, or welding. The method of connecting the components of the body may depend on the respective materials of the components of the body. The components of the body be formed of composite material and/or metal.

The body may comprise one or more tube portions, e.g. a pair of tube portions. The body may comprise one or more web. The method may comprise assembling a plurality oftube portions and one or more web. The method may comprise connecting the web to the tube portions using a paste or film adhesive, prepreg material, or welding. The method of connecting the web to the tube portions may depend on the respective materials of the tubular portions and the web.

The tube portions may be liner tubes. The method may comprise disposing liner tubes either side of each web. The method may comprise retaining the liner tubes in engagement with the web by disposing a body wrap around the liner tubes and the web. The body wrap may be disposed in a lateral direction around the liner tubes and the web. The body wrap may form part of the body.

The tube portions may be partial tube portions. The partial tube portions may be connected by joining plate members. The method may comprise assembling the partial tube portions and the joining plate members. The method may comprise connecting the partial tube portions and the joining plate members using a paste or film adhesive, prepreg material or welding. The method of connecting the partial tube portions and the joining plate members may depend on the respective materials of the partial tube portions and the joining plate members.

The method may comprise assembling the web and the joining plate members. The method may comprise connecting the web and the joining plate members using a paste or film adhesive, prepreg material or welding. The method of connecting the web and the joining plate members may depend on the respective materials of the partial tube portions and the joining plate members.

The method may comprise forming the end caps from metal or composite material.

The method may comprise forging the end caps from metal, e.g. titanium, aluminium or an alloy. Alternatively, the method may comprise press moulding the end caps from a bulk moulding compound. Beneficially, manufacturing the pressure vessel may be improved by eliminating the need for winding composite material to form end caps.

Each end cap may comprise one or more boss. Forming each end cap may comprise forming the one or more boss.

The method may comprise using the body as a mandrel to dispose the wrap around the body and cover the engagement interface between the body and the end caps with the wrap. Beneficially, the straight composite run time may be maximised with movement being mainly from the body being rotated. Using the body as a mandrel may comprise rotating the body. The method may comprise holding the end cap bosses to rotate the body.

The wrap may be a primary wrap. The pressure vessel may further comprise one or more auxiliary wraps. The method may further comprise disposing the one or more auxiliary wraps around the body.

The primary wrap may be a lateral wrap. The one or more auxiliary wraps may comprise an auxiliary lateral wrap. The method may comprise wrapping the auxiliary lateral wrap laterally around the body. The method may comprise wrapping the auxiliary lateral wrap axially between the end caps. The method may comprise using the body as a mandrel to wrap the auxiliary lateral wrap around the body Beneficially, the straight composite material run time may be maximised with movement being mainly from the body being rotated. Using the body as a mandrel may comprise rotating the body. The method may comprise holding the end cap bosses to wrap the auxiliary lateral wrap around the body. The method may comprise wrapping the auxiliary lateral wrap around the body first. The method may comprise wrapping the auxiliary lateral wrap before wrapping the primary wrap.

The one or more auxiliary wraps may comprise an axial wrap. The method may comprise wrapping the axial wrap around the body and the end caps in an axial direction. The method may comprise wrapping the axial wrap before or after the primary wrap. The method may comprise wrapping the axial wrap around the body first. Alternatively, the method may comprise wrapping the axial wrap after the auxiliary lateral wrap. The method may comprise wrapping the axial wrap last.

Examples of the order in which the wraps are disposed on the body are as follows:

- 1. axial wrap, 2. primary wrap;
- 1. auxiliary lateral wrap, 2. primary wrap, 3. axial wrap;
- 1. auxiliary lateral wrap, 2. axial wrap, 3. primary wrap;
- 1. primary wrap.

Adjacent wraps may be wrapped in a different direction, e.g. transversely. The wraps may be disposed on the body contiguously, e.g. using a continuous piece of composite wrap material.

The one or more auxiliary wraps may be formed of composite material. The wraps may comprise UD tape. The wraps may be formed of dry fabric. The method may comprise infusing the wraps with resin. The wraps may be infused with resin in a closed mould. The wraps may be infused with resin after wrapping on the pressure vessel.

The invention is defined by the appended claims. However, for the purposes of the present disclosure it will be understood that any of the features defined above or described below may be utilised in isolation or in combination. For example, features described above in relation to one of the above aspects or below in relation to the detailed description below may be utilised in any other aspect, or together form a new aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects will now be described by way of example with reference to the accompanying drawings, of which:

Figure 1 is a perspective view of a pressure vessel;

Figure 2 is a transparent perspective view of the body of the pressure vessel of Figure 1;

Figure 3 is a perspective view of the end caps of the pressure vessel of Figure 1;

Figures 4 is a perspective view of the assembled body of Figure 2 and end caps of Figure 3;

Figure 5 is a plan view of the assembled body and end caps of Figure 4 installed in the winding apparatus;

Figure 6 is a perspective view of the assembled body and end caps of Figure 4 in the winding apparatus after a first wrap is disposed around the body;

Figure 7 is a plan view of the assembled body and end caps of Figure 4 in the winding apparatus after a first wrap is disposed around the body;

Figure 8 is a plan view of the assembled body and end caps with the first wrap disposed thereon being changed winding orientation in the winding apparatus;

Figure 9 is a perspective view of the assembled body and end caps in the winding apparatus after a second wrap is disposed around the body;

Figure 10 is a plan view of the assembled body and end caps in the winding apparatus after a second wrap is disposed around the body;

Figure 11 is a cross-sectional view of the pressure vessel of Figure 1;

Figure 12 is a detailed cross-sectional view of the engagement interface between the body and an end cap of the pressure vessel of Figure 1;

Figure 13 is a perspective view of another pressure vessel;

Figure 14 is a perspective view of the liner tubes of the pressure vessel of Figure 13;

Figure 15 is a perspective view of a web of the pressure vessel of Figure 13;

Figure 16 to 20 are perspective views of the pressure vessel of Figure 13 in consecutive stages of manufacturing;

Figure 21 is a detailed perspective cross-sectional transparent view of the engagement interface between the body and an end cap of the pressure vessel of Figure 13;

Figure 22 is a perspective view of another pressure vessel; and

Figure 23 is a perspective cross-sectional view of the pressure vessel of Figure 22;

Figure 24 is a plan view of another pressure vessel;

Figure 25 is a plan view of another pressure vessel;

Figure 26 is a plan view of another pressure vessel;

Figure 27 shows a schematic view of the pressure vessel of Figure 1 configured as a fuel tank in an automobile;

Figure 28 shows a schematic view of two pressure vessels of Figure 1 configured as fuel tanks in an aircraft;

Figure 29 shows a schematic view of the pressure vessel of Figure 26 configured as a fuel tank in an aircraft.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring first to Figure 1 of the accompanying drawings, there is shown a pressure vessel 10 for storing a pressurised fluid (liquid and/or gas). In use, the pressure vessel 10 is configured and/or operable to store a high pressure or low temperature gas and/or liquid, such as hydrogen or nitrogen is shown in Figure 1 of the accompanying drawings.

As shown in Figure 1, the pressure vessel 10 comprises an enclosure for containing the pressurised liquid and /or gas. The enclosure is defined by a body (not visible) and end caps 14. The pressure vessel 10 comprises a lateral wrap 12 (a primary wrap) around the body and overlapping the end caps 14, e.g. the lateral wrap 12 covers the whole of the body and part of the end caps 14 in order to seal an engagement interface (not visible) between the body and the end caps 14 and provide resistance to internal pressure. The pressure vessel 10 further comprises an axial wrap 16 (an auxiliary wrap) which axially retains the body and the end caps 14 in engagement.

The body 20 is shown in Figure 2. The body 20 is a rounded-rectangular prism shape. The body 20 is prefabricated from a composite material. In other pressure vessels the body can be formed from metal.

The body 20 comprises chambers 22. The chambers 22 extend axially and are open at each axial end. The chambers 22 have a uniform cross-section along their axial length. The chamber 22 therefore define the axial direction. The lateral direction is transverse to the chambers 22. The chambers 22 are defined by a web 24 and tube portions in the form of partial tube portions 26 connected by joining plate members 28. The partial tube portions 26 and the joining plate members 28 are adhered together using a paste or film adhesive. In pressure vessels having a metal body, the partial tube and the joining plate members can be welded together.

The body 20 comprise bulbous portions 21 which are defined by the partial tube portions 26. The body further comprises recessed portions 23 which are defined by the joining plate members 28.

The web 24 is in the form of a plate. The web 24 extends between the joining plate members 28. The web 24 is adhered to joining plate members 28 using a paste or film adhesive. In pressure vessels having a metal body, the web and the joining plate members can be welded together. The web 24 provides the body with lateral support in order to resist compression and expansion of the body 20. The web 24 comprises notches 30 at each axial end of the web in order to provide a flow path between the chambers 22.

The end caps 14 are shown in Figure 3. The end caps 14 have a generally elongated dome shape. Each end cap 14 comprises bulbous portions 25 corresponding to the bulbous portions 21 of the body 20. Each end cap 14 comprises a recessed portion 27 corresponding to the recessed portions 23 of the body 20. The end caps 14 comprise bosses 18 for connection with fittings which can be used to insert or remove liquid and/or gas in the pressure vessel. The end caps 14 are formed of composite material. The end caps 14 are press moulded from a bulk moulding compound. In other pressure vessels, the end caps can be forged from metal.

Consecutive stages of manufacturing the pressure vessel are shown in Figures 4 to 11. Figure 4 shows the end caps 14 assembled with the body 20. The end caps 14 are shaped and dimensioned to engage each axial end of the body 20. Figure 5 shows the assembled end caps 14 and body 20 installed in a winding apparatus 32. The winding apparatus 32 engages the bosses (not visisble) to support the assembled end caps 14 and body 20. As indicated in Figure 6, the winding apparatus 32 rotates the assembled end caps 14 and body 20 in the direction indicated by the curved arrow

34 to dispose the axial wrap 16 around the body 20 and the end caps 14. The axial wrap 16 extends along the axial length of the body 20 and around the end caps 14. The axial wrap 16 is fed onto the assembled end caps 14 and body 20 in the axial direction, as shown by the straight arrow 36. The axial wrap 16 retains the end caps 14 in engagement with the axial ends of the body 20. The axial wrap 16 comprises five layers, e.g. five axial windings, as indicated by the plurality of straight arrows 36 in Figure 7. The axial wrap 16 fills the recessed portions 23 (visible in Figure 5) of the body 20 and the recessed portions 27 (visible in Figure 5) of the end caps 14. The axial wrap 16 is formed of composite material. The axial wrap 16 comprises dry fabrics and UD tows. The body 20 is used as a mandrel to facilitate wrapping of the axial wrap 16 from a straight run of tows. Figure 8 shows the assembled end caps 14 and body 20 being reoriented in the winding apparatus 32 after the axial wrap 16 has been disposed around the assembled end caps 14 and body 20. The assembled end caps 14 and body 20 are turned through 90° during the reorientation. Figures 9 and 10 show the lateral wrap 12 disposed around the body (not visible) and overlapping the end caps 14. The winding apparatus 32 rotates the assembled end caps 14 and body in the direction indicated by the curved arrow 38 to dispose the lateral wrap 12 around the body. The lateral wrap 12 extends around the body in the lateral direction. The lateral wrap is fed onto the body in the lateral direction, as shown by the straight arrow 40. The lateral wrap 12 comprises five layers, e.g. five lateral windings, as indicated by the plurality of straight arrows 40 in Figure 10. The lateral wrap 12 is formed of composite material. The lateral wrap 12 comprises fabric and UD tape. The body is used as a mandrel to facilitate wrapping of the lateral wrap 12 from a straight run of tape.

The layering of the components forming the pressure vessel 10 can be seen in Figure 11, and in particular the layers at the engagement interface 19 between the body 20 and the end caps 14 which is shown in Figure 12. Both the axial wrap 16 and the lateral wrap 12 cover the engagement interface 9 between the body 20 and the end caps 14. The axial wrap 16 encapsulates the body 20 and the end caps 14. The lateral wrap 12 has a width L_W greater than an axial length L_B of the body so that the lateral wrap 12 overlaps the end caps 14. The layering of the axial wrap 16 and the lateral wrap 12 over the engagement interface 19 between the body 20 and the end caps 14 seals the engagement interface 19 and provides resistance to the internal pressure.

Another pressure vessel 110 for storing pressurised liquid and/or gas, e.g. high pressure or low temperature gas or liquid, such as hydrogen or nitrogen is shown in Figure 13. The pressure vessel comprises an enclosure for containing the pressurised liquid and/or gas. The enclosure is defined by a body (not visible) and end caps 114. The pressure vessel 110 comprises a primary lateral wrap 112 around the body and overlapping the end caps 114, e.g. the primary lateral wrap 112 covers the whole of the body and part of the end caps 114 in order to seal an engagement interface (not visible) between the body and the end caps 114 and provide resistance to internal pressure. The pressure vessel 110 further comprises an axial wrap 116 which axially retains the body and the end caps 114.

Figures 14, 15 and 16 of the accompanying drawings show the body 120 and the components that make up the body 120. The body 120 shown in Figure 16 comprises tube portions in the form of liner tubes 126 shown in Figure 10, and a web 124 shown in Figure 15. The liner tubes 126 are formed of metal. The liner tubes 126 are geometrically efficient for supporting internal pressure. The liner tubes 126 are cylindrical and define chambers 122 of the body 120. The chambers 122 extend axially and are open at each axial end. The chambers 122 define the axial direction of the pressure vessel 110. The lateral direction of the pressure vessel 10 is transverse to the chambers 122. The web 124 is in the form of a prism. The web 124 is formed of composite material. The web 124 is press moulded from a bulk moulding compound. The web 124 comprises axial grooves 125 shaped to conform to the liner tubes 126. The lateral height of the web 124 corresponds to the diameter of the liner tubes 126. As shown in Figure 16, the liner tubes 126 fit in the grooves 125 of the web 124 to form a generally rounded-rectangular prism shaped body 120. The liner tubes 126 form bulbous portions 121 of the body 120. The web 124 forms recessed portions 123 of the body 120.

Consecutive stage of manufacturing the pressure vessel are shown in Figures 17 to 20. Figure 17 shows a body wrap 132. The body wrap 132 is formed of composite material. The body wrap 132 is formed of dry fabric and UD tows. The body wrap 132 is wrapped laterally around the body 120. The body wrap 132 retains the liner tubes 126 in the grooves 125 of the web 124. Figure 18 shows an end cap 114 engaged with each axial end of the body 120. The end caps 114 have a generally elongated dome shape. The end caps 114 are dimensioned to overlap the body wrap 132, e.g. the end caps 114 fit over the body wrap 132. The end caps 114 comprise bulbous portions 125 corresponding to the bulbous portions 121 of the body 120. Each end cap comprises a recessed portion 127 corresponding to the recessed portions 123 of the body 120. The end caps 114 are formed of metal. The end caps 114 comprise bosses 118 for connection with fittings which can be used to insert or remove liquid and/or gas in the pressure vessel. Figure 19 shows an auxiliary lateral wrap 134 around the body 120. The auxiliary lateral wrap 134 is between the end caps 114, e.g. the width of the auxiliary lateral wrap 134 is substantially the same as the axial distance between the end caps 114. The auxiliary lateral wrap 134 is formed of composite material. The auxiliary lateral wrap 134 comprises UD hoop plies. The auxiliary lateral wrap 134 is infused with resin in a closed mould once it is wrapped around the body 120. Figure 20 shows the primary lateral wrap 112 around the body 120 and overlapping the end caps 114, and the axial wrap 116 around the body 120 and the end caps 114. The axial wrap 116 retains the end caps 114 in engagement with the axial ends of the body 120. The primary lateral wrap 112 and the axial wrap 116 are formed of composite material. The auxiliary lateral wrap 116 and the axial wrap 116 are formed of fabric and UD tape. The primary lateral wrap 112 and the axial wrap 116 are integral, e.g. the axial wrap 116 is an axial extension from the primary lateral wrap 112. In other pressure vessels the primary lateral wrap may be layered underneath or on top of the axial wrap.

The layering of the components forming the pressure vessel 110 at the engagement interface 119 between the body 120 and the end caps 114 is shown in Figure 21. The end caps 114 are sandwiched between the body wrap 132 and the primary lateral wrap 112. The axial distance between the end caps 114 is less than width of the primary lateral wrap 112. The axial distance between the end caps 114 is less than the axial length of the body 120 and the body wrap 132. The axial offset of the end caps 114 to the primary lateral wrap 112 and the body wrap 132 seals the engagement interface 119 between the end caps 114 and the body 120. The auxiliary lateral wrap 134 is also sandwiched between the body wrap 132 and the primary lateral wrap 112. The auxiliary lateral wrap 134 has substantially the same thickness as the end cap 114.

Another pressure vessel 210 for storing pressurised liquid and/or gas, e.g. high pressure or low temperature gas or liquid, such as hydrogen or nitrogen is shown in Figures 22 and 23. The pressure vessel comprises an enclosure for containing the pressurised liquid and/or gas. The enclosure is defined by a body 220 and end caps 214. The pressure vessel 210 comprises a lateral wrap 212 around the body and overlapping the end caps 214, e.g. the lateral wrap 212 covers the whole of the body and part of the end caps 214 in order to seal an engagement interface (not visible) between the body 220 and the end caps 214 and provide resistance to internal pressure.

The body 220 is a rounded-rectangular prism shape. The body 220 is an integral structure which defines chambers 222 separated by a web 224. The chambers 222 extend axially and are open at each axial end. The chambers 222 define an axial direction. The lateral direction is transverse to the chambers 222. The web 224 provides the body with lateral support in order to resist compression and expansion of the body 220. The end caps 214 have a generally elongated dome shape.

The lateral wrap 212 is formed of composite material, e.g. dry fabrics and UD tape. The lateral wrap 212 covers the engagement interface between the body 220 and the end caps 214. The lateral wrap 212 has a width greater than an axial length of the body 220 so that the lateral wrap 212 overlaps the end caps 214.

Another pressure vessel 310 for storing pressurised liquid and/or gas, e.g. high pressure or low temperature gas or liquid, such as hydrogen or nitrogen is shown in Figure 24. The pressure vessel 310 comprises an enclosure for containing the pressurised liquid and/or gas. The enclosure is defined by a body 320 and end caps 314a, 314b. The pressure vessel 310 comprises a lateral wrap 312 around the body and overlapping the end caps 314, e.g. the lateral wrap 312 covers the whole of the body and part of the end caps 314 in order to seal an engagement interface between the body 320 and the end caps 314 and provide resistance to internal pressure.

The body 320 is tapered along its axial extend, e.g. the cross-section of the body 320 narrows along its axial length. The body 320 comprises bulbous portions 321 defined by partial tube portions 326. The bulbous portions 321 are tapered along their axial extent, e.g. the cross-section of the partial tube portions 326 narrows along their axial length. The body further comprises recessed portions 323 defined by joining plate members 328. The recessed portions 323 are uniform along their axial extent, e.g. the joining plate members have a uniform width along their axial length.

The pressure vessel 310 further comprises an axial wrap 316 which retains the end caps 314a, 314b in engagement with either end of the body 320. A first end cap 314a is larger than a second end caps 314b to account for the tapered body 320. Each end cap 314a, 314b comprises bulbous portions 325 corresponding to the bulbous portions 321 of the body 320. Each end cap 314 comprises a recessed portion 327 corresponding to the recessed portions 323 of the body 320. The axial wrap 316 fills the recessed portions 323 of the body 320 and the recessed portions 327 of the end caps 314.

Another pressure vessel 410 for storing pressurised liquid and/or gas, e.g. high pressure gas or low temperature liquid, such as hydrogen, nitrogen or oxygen, is shown in Figure 25. The pressure vessel 410 comprises an enclosure for containing the pressurised liquid and/or gas. The enclosure is defined by a body 420 and end caps 414. The pressure vessel 410 comprises a lateral wrap 412 around the body and overlapping the end caps 414, e.g. the lateral wrap 412 covers the whole of the body and part of the end caps 414 in order to seal an engagement interface (not visible) between the body 420 and the end caps 414 and provide resistance to internal pressure.

The body 420 comprises three bulbous portions 421 defined by partial tube portions 426. In other embodiments, the body may comprise more than three bulbous portions, e.g. to increase the size of the pressure vessel. The body further comprises recessed portions 423 defined by joining plate members 428. Each recessed portion 423 is between adjacent bulbous portions 421.

The pressure vessel may further comprise an axial wrap 416 which retains the end caps 414 in engagement with either end of the body 420. Each end cap 414 comprises bulbous portions 425 corresponding to the bulbous portions 421 of the body 420. Each end cap 414 comprises recessed portions 427 corresponding to the recessed portions 423 of the body 420. The axial wrap 416 is formed in two strips.

Each strip of the axial wrap 416 fills respective recessed portions 423 of the body 420 and recessed portions 427 of the end caps 414.

Another pressure vessel 510 for storing pressurised liquid and/or gas, e.g. high pressure or low temperature gas or liquid, such as hydrogen or nitrogen is shown in Figure 26. The pressure vessel 510 comprises an enclosure for containing the pressurised liquid and/or gas. The enclosure is defined by a body 520 and end caps 514a, 514b. The pressure vessel 510 comprises a lateral wrap 512 around the body and overlapping the end caps 514a, 514b, e.g. the lateral wrap 512 covers the whole of the body and part of the end caps 514a, 514b in order to seal an engagement interface between the body 520 and the end caps 514a, 514b and provide resistance to internal pressure. The body 520 generally takes the form of a truncated cone defined by a tube portion in the form of a tapered liner tube 526. The end caps 514a, 514b are generally dome shaped. A first end cap 514a is larger than a second end cap 514b to account for the tapered body 520.

Figure 27 schematically shows an automobile 600 comprising the pressure vessel 10. The pressure vessel 10 is configured as a fuel tank for supplying fuel fluid to a power generation device of the automobile 600. The rounded rectangular shape of the pressure vessel 10 allows for convenient storage of the pressure vessel in the automobile 600, e.g. mounted on a chassis of the automobile 600.

Figure 28 schematically shows an aircraft 700 comprise two pressure vessels 10. Each pressure vessel 10 is configured as a fuel tank for supplying fuel fluid to a respective power generation device 701. The rounded rectangular shape of the pressure vessels 10 allows for convenient storage of the pressure vessels 10 in the wings 702 of the aircraft under which each power generation device 701 is mounted.

Figure 29 schematically shows an aircraft 800 comprising the pressure vessel 510. The pressure vessel 510 is configured as a fuel tank for supplying fuel fluid to a power generation device 801. The conical shape of the pressure vessel 510 allows for convenient storage of the pressure vessel 510 in the fuselage 803 of the aircraft 800.

Features defined above in accordance with any aspect, embodiment or specific example may be utilized, either alone or in combination with any other defined feature, in any other aspect, embodiment or example or to form a further aspect, embodiment or example.

CLAIMS

1. A pressure vessel for storing a pressurised fluid, comprising:

a body;

end caps engaging respective ends of the body,

the body and the end caps forming an enclosure for containing therein the pressurised fluid to be stored; and

a wrap disposed around the body,

wherein the wrap covers an engagement interface between the body and the end caps, and

wherein the wrap is formed of composite material.

2. The pressure vessel of claim 1, wherein the body is formed of metal or composite material.

3. The pressure vessel of claim 1 or 2, wherein the end caps are formed of metal or composite material.

4. The pressure vessel of any preceding claim, wherein the wrap is a primary lateral wrap and the pressure vessel further comprises one or more auxiliary wraps.

5. The pressure vessel of claim 4, wherein the one or more auxiliary wraps comprises an axial wrap retaining the end caps in engagement with the body.

6. The pressure vessel of claim 4 or 5, wherein the one or more auxiliary wraps comprises an auxiliary lateral wrap around the body between the end caps

7. The pressure vessel according to any preceding claim, wherein the end caps overlap the body.

8. The pressure vessel according to any preceding claim, wherein the body has asymmetric lateral dimensions.

9. The pressure vessel according to any preceding claim, wherein the body defines a pair of chambers.

10. The pressure vessel according to claim 9, wherein the body comprises tube portions and a web, wherein the tube portions and/or the web at least partially define the pair of chambers.

11. The pressure vessel according to claim 9 or 10, wherein the body and/or the end caps define a flow path for the pressurised fluid between the chambers.

12. The pressure vessel according to any preceding claim, wherein the body and/or the end caps comprise an internal barrier coating.

13. A vehicle comprising a pressure vessel according to any preceding claim.

14. A method of manufacturing a pressure vessel for containing pressurised fluid, the method comprising:

forming an enclosure for containing therein the pressurised fluid by engaging end caps with respective ends of a body, and

disposing a wrap around the body and covering an engagement interface between the body and the end caps with the wrap, wherein the wrap is formed of composite material.

15. The method of claim 14, further comprising forming the body from metal or composite material.

16. The method of claim 14 or 15, further comprising forming the end caps from metal or composite material.

17. The method of any of claims 14 to 16, wherein disposing the wrap around the body comprises using the body as a mandrel.

18. The method of any of claims 14 to 17, further comprising infusing the wrap with resin after disposing the wrap around the body.

Intellectual Property Office

Application No:	GB2215458.7	**Examiner:**	Mr James Welsh
Claims searched:	1-18	**Date of search:**	24 April 2023

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-8, 13-18	WO 97/28401 A1 (LOCKHEED CORP) See figures 3a-3j and abstract.
X	1-3, 7, 8, 13-18	JP 2010266029 A (TOYOTA MOTOR CORP) See figure 1 and abstract.
X	1-8, 13-18	EP 0300931 A1 (HEMBERT CLAUDE LEON) See figures and abstract.
X	1-3, 7, 8, 13-18	JP 2008014342 A (TOYOTA MOTOR CORP) See figures 1 and 2 and abstract.
X	1-3, 7-18	US 10465848 B1 (NEWHOUSE) See figures 1-3, 5, 7, 10 and abstract.
X	1-3, 7-18	EP 3385597 A1 (UNITED TECHNOLOGIES CORP) See figures 1-3, 5 and abstract.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F17C

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

Intellectual
Property
Office

International Classification:

Subclass	Subgroup	Valid From
F17C	0001/04	01/01/2006