A pressure vessel has an airtight liner and a shell. The shell made of fiber reinforced plastic is formed by curing resin impregnated fiber bundles wound outside of the liner. The pressure vessel has a cylindrical portion, a domed end portion on each end of the cylindrical portion and a boss provided at the center of each domed end portion. The shell includes at least two fiber bundle layers which are formed by the resin impregnating fiber bundles and at least one shape correction member arranged between the fiber bundle layers at each domed end portion.
PRESSURE VESSEL, HYDROGEN STORAGE TANK AND METHOD FOR MANUFACTURING PRESSURE VESSEL

TECHNICAL FIELD

[0001] The present invention relates to a pressure vessel, a hydrogen storage tank having an airtight liner and a shell made of fiber reinforced plastic which is formed by winding a resin-impregnated fiber bundle outside of the liner for curing and having a shape consisting of a cylindrical portion with domed end portions on each end, each domed end portion having a boss at its center, and a method for manufacturing the pressure vessel.

[0002] Pressure vessels for containing compressed natural gas (CNG), liquefied natural gas (LNG), or the like, are generally made of steel, aluminum alloy, or the like, and, therefore, they are heavy. Recently, people have gained a growing awareness of the prevention of global warming. This creates rising demands particularly on developing hydrogen-fueled cars such as fuel cell electric vehicles and hydrogen-fueled engine automobiles for reducing carbon dioxide exhausted from vehicles.

[0003] A hydrogen-fueled automobile generally has a hydrogen storage tank, which is filled with hydrogen gas, as a hydrogen supply. In this case, a heavy pressure vessel for the fuel tank of the hydrogen storage tank lowers fuel consumption. To eliminate the above inconvenience, a steel gas cylinder having an airtight liner which is covered with a pressure-resistance shell made of fiber reinforced plastic (FRP) has been proposed.

[0004] The FRP shell is formed so that a resin-impregnated fiber bundle layer, which is wound outside of the liner by a filament winding method (hereinafter, it is occasionally called “FW method”), is cured. A thin-walled pressure vessel which is formed in rotation symmetry has a principal stress in the axial direction and circumferential direction. Thus, for fiber reinforced composite material, it is advantageous to arrange the fibers in the direction of principal stress. Therefore, fibers F are arranged in such a manner that in-plane winding (shown in FIG. 9) or helical winding (not shown) occurs at the domed end portions 51 of the conventional pressure vessel 50, and the combination of in-plane winding or helical winding and hoop winding occurs at the cylindrical portion 52.

[0005] However, in the case of in-plane winding or helical winding, because all fibers contact the boss 53 on each end of the pressure vessel 50 and then turn back, the wall adjacent to the boss 53, that is, the fiber bundle layer of fibers or fiber bundles which contact the boss 53 is thick, and the wall of a shoulder portion (which is adjacent to the boundary between one domed end portion and the cylindrical portion) is thin. Thus, there are redundant fibers F adjacent to each boss 53. This outcome becomes more significant as the ratio of the diameter of the cylindrical portion to the diameter of the boss increases. In such a fiber arrangement, the fibers are concentrated adjacent to each boss, with the result that it causes malformation and increases manufacturing costs due to the redundant fibers.

[0006] To prevent fibers arranged at the domed end portions adjacent to the bosses from being excessively thicker than those arranged at another portion of the domed end portions, as shown in FIG. 10, at the domed end portion 51 of the pressure vessel 50 on which fiber reinforced layer is formed by FW method, fibers F for reinforcement are wound to change a line adjacent to the pole to a line around a lower latitude portion. This is disclosed, for example, in Japanese unexamined patent publication No. 5-79598.

[0007] In the above publication, fibers F for reinforcement are impregnated with epoxy resin and helically wound on the cylindrical body of the aluminum liner with a winding angle of 20 degrees. Then, the fibers F are wound so that the winding line deviates by a predetermined angle from an adjacent pole toward a lower latitude portion. Additionally, the cylindrical portion 52 is wound by hoop winding.

[0008] Japanese unexamined patent publication No. 2000-337594 discloses a pressure vessel that eliminates redundant fibers which are concentrated adjacent to the boss of each domed end portion, reducing the amount of fibers of the vessel as a whole and making it easy to manufacture without side sliding of fibers during winding of the fibers. In the pressure vessel, the arrangement line of the fibers which form the shell that covers the liner at each domed end portion includes two kinds of lines, one of which is in contact with the boss and the other of which is not in contact with the boss.

[0009] Fibers which pass a line in contact with the boss are wound by in-plane winding. As shown in FIG. 11, the majority of the wound fibers 54 passing on a line which does not contact the boss 53 are arranged so as to pass near a geodesic line at the end of the cylindrical portion 52 through the helical winding 55, which gradually increases its arrangement angle and connects the hoop winding 56, which is arranged at the cylindrical portion 52. The wound fibers 54 passing on the line which does not contact the boss 53 are arranged on a plane perpendicular to tangential line L, which is in a plane including a vertex of the winding portion at the domed end portion 51 and the axis of the liner and also passes a vertex of the winding portion.

[0010] However, when high-pressure gas (for example, 20 MPa or more) is contained in the pressure vessel, it is more effective to increase the amount of fibers (fiber bundles) contributing to enhancing the strength of the pressure vessel in the axial direction which are arranged to pass on the boss by using helical winding or in-plane winding. When arranged as described above, the thickness of the fiber bundle layer adjacent to the boss increases in comparison to a portion adjacent to the cylindrical body of the liner.

[0011] In this case, when the fiber bundles are wound on the fiber bundle layer which is thickly wound on the boss, problems occur such as sliding of the fibers and malformation, thereby causing an undesirable arrangement of fiber bundles to pass on the boss. Additionally, the force pressing the previously wound (arranged) fiber bundles is weakened in the area ranging from the portion adjacent to the boss to the shoulder portion of the pressure vessel.

[0012] To compensate the above weakness, more fiber bundles need to be wound in the area (low latitude portion) ranging from the portion adjacent to the boss to the shoulder portion for shape correction. The fiber bundles wound at this area contribute little to enhance strength in the axial direction. An increase in fiber bundles wound at the domed end portion leads to extra fibers to be wound at the cylindrical
portion. Accordingly, as the amount of fibers increases, the outside diameter of the cylindrical portion becomes larger.

[0013] The present invention is directed to providing a pressure vessel in which the fibers that range from the portion adjacent to the boss of the pressure vessel to the shoulder portion which contribute little to enhancing the strength of the pressure vessel in the axial direction are reduced and the amount of fibers required for ensuring the same pressure resistance are reduced even if the fiber bundles wound at the domed end portion are arranged to pass on the boss.

SUMMARY

[0014] In accordance with the present invention, the pressure vessel has an airtight liner and a shell. The shell made of fiber reinforced plastic is formed by curing resin impregnated fiber bundles wound outside of the liner. The pressure vessel has a cylindrical portion, a domed end portion on each end of the cylindrical portion and a boss provided at the center of each domed end portion. The shell includes at least two fiber bundle layers which are formed by the resin impregnating fiber bundles and at least one shape correction member arranged between the fiber bundle layers at each domed end portion.

[0015] In accordance with the present invention, a method for manufacturing a pressure vessel having a cylindrical portion, a domed end portion on each end of the cylindrical portion and a boss provided at the center of the domed end portion, wherein resin impregnated fiber bundles are wound outside of an airtight liner by filament winding, includes: fixing the liner at a rotation support portion of a filament winding apparatus so as to rotate integrally therewith, performing the filament winding while an annular shape correction member is prepared at a saving position, which does not interfere the filament winding, between the rotation support portion and the liner for adjusting a shape of a fiber bundle layer formed at the domed end portion, moving the shape correction member prepared at the saving position to contact the fiber bundle layer wound by then in the mid course of winding the fiber bundles, and continuing the filament winding.

[0016] Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The features of the present invention that are believed to be novel are set forth with particularity in the appended claims. The invention together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

[0018] FIG. 1 is a cross-sectional view of a pressure vessel according to a first preferred embodiment;

[0019] FIG. 2A is a schematic view showing an arrangement of fiber bundles by helical winding;

[0020] FIG. 2B is a schematic view showing an arrangement of fiber bundles by hoop winding;

[0021] FIG. 3 is a schematic view showing an arrangement (arrangement line) of fiber bundles on a domed end portion by helical winding;

[0022] FIG. 4 is a schematic side view of a winding portion of a filament winding apparatus (or an FW apparatus);

[0023] FIG. 5 is a schematic plan view of the FW apparatus;

[0024] FIG. 6 is a partial cross-sectional view of a pressure vessel according to a second preferred embodiment of the present invention;

[0025] FIG. 7 is a backside view of a shape correction member according to an alternative embodiment of the present invention;

[0026] FIG. 8 is a partial cross-sectional view of a pressure vessel according to an alternative embodiment of the present invention;

[0027] FIG. 9 is a schematic view showing an arrangement of fibers by in-plane winding;

[0028] FIG. 10 is a schematic view showing an arrangement of fibers on the domed end portion of a pressure vessel according to the prior art;

[0029] FIG. 11 is a schematic view showing an arrangement of fibers by helical winding according to another prior art disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0030] A first preferred embodiment according to the present invention will now be described with reference to FIGS. 1 through 5. FIG. 1 is a schematic cross-sectional view of a pressure vessel 11. FIG. 2A is a schematic view showing an arrangement of fiber bundles by helical winding. FIG. 2B is a schematic view showing an arrangement of fiber bundles by hoop winding. FIG. 3 is a schematic view showing an arrangement (arrangement line) of fiber bundles by helical winding at a domed end portion 13 of the pressure vessel 11. FIG. 4 is a schematic side view of a winding portion of a filament winding apparatus (or FW apparatus). FIG. 5 is a schematic plan view of the FW apparatus.

[0031] As shown in FIG. 1, the pressure vessel 11 is formed to have the domed end portion 13 at each end of the cylindrical portion 12, and has a boss 14 at the center of each domed end portion 13. The pressure vessel 11 includes an airtight liner 15 and a shell 16 made of fiber reinforced plastic (FRP), covering the outside of the liner 15.

[0032] The liner 15 has a cylindrical body 15a and a dome 15b on each end of the body 15a, and has a boss 14 at the center of each dome 15b. When the pressure vessel 11 is used as a hydrogen storage tank, the liner 15 is, for example, made of aluminum alloy. The boss 14 has a thread hole 14a for screwing a plug of a conduit or the like.

[0033] The shell 16 is formed so that resin-impregnated fiber bundles (hereinafter, it may be simply referred to as fiber bundles) are wound outside of the liner 15 and then cured. In this embodiment, carbon fiber is used as a reinforcement fiber of FRP and epoxy resin is used as a resin.
Each domed end portion 13 includes a shape correction member 18 between a first fiber bundle layer 17a, which is precessedly wound, and a second fiber bundle layer 17b, which is subsequently wound. Namely, each shape correction member 18 is interposed between the first fiber bundle layer 17a and the second fiber bundle layer 17b. The shape correction member 18 has a smaller outside diameter than the portion of the first fiber bundle layer 17a on the body 15 of the liner 15 and its outer surface has such a hardness that fiber bundles wound outside of the shape correction member 18 do not bite thereinto. The shape correction member 18 has a hole at the center thereof. The hole has the same or a slightly larger diameter as the first fiber bundle layer 17a adjacent to the boss 14. In this embodiment, the shape correction member 18 is made of epoxy resin. The shape correction member 18 is formed so that the surface of the shape correction member 18 adjacent to the liner 15 is shaped so as to line along the surface of the first fiber bundle layer 17a and arranged to fill in a recess 19 of the surface in a cross-section of the pressure vessel 11 taken along the axis thereof. The shape correction member 18 has a convex surface on the side opposite to the liner 15 and the curvature of the convex surface is smaller than that of the outer surface of the dome 15a of the liner 15. The portion of the first fiber bundle layer 17a adjacent to the boss 14 and the shoulder portion thereof are smoothly connected by a curved surface.

The fiber bundles which form the shell 16 are sequentially wound on the outer surface of the liner 15 to form a fiber bundle layer with a predetermined thickness. The fiber bundles 20 include one wound by helical winding as shown in FIG. 2A and the other wound by hoop winding as shown in FIG. 2B. Hoop winding is made only along a portion on the body 15a.

The fiber bundles 20 which form the helical winding are arranged so that its arrangement line at the domed end portion 13 (or on the dome 15b) extends along the tangential direction of the boss 14 as shown in FIG. 3 or slightly winds on the boss 14 as shown by the dotted line in FIG. 3. This depends on pressure resistance required for the pressure vessel 11, however. The winding angle of the fiber bundles 20 which form the helical winding preferably, for example, ranges from 10 degrees to 25 degrees. The language “winding angle” means an angle between the fiber bundles 20 and the axial direction on the cylindrical portion 12.

The following will describe a method of manufacturing the pressure vessel 11. The FW apparatus is used for manufacturing the pressure vessel 11. As shown in FIG. 4, the FW apparatus 31 has a pair of chucks 32 as a rotation support portion for rotatably supporting a wound member such as a liner. As shown in FIG. 5, the FW apparatus 31 has a fiber bundle feeder 33, a resin impregnating apparatus 34, a fiber bundle guide 35 and a fiber bundle feeding head 36. The fiber bundle feeding head 36 is movable longitudinally (in the lateral direction in FIG. 5) of the fiber bundle wound member (the liner 15 in this embodiment) which is supported by the chucks 32. The fiber bundle feeding head 36 ties fiber bundles 20 fed from a plurality of bobbins B and shapes it into a flat ribbon to be wound outside of the liner 15.

A known structure is used for an actuator 37 for reciprocating the fiber bundle feeding head 36, in which a ball screw is used and a movable body 37a, which is integrally movable with a nut, is moved in one axial direction. A raising and lowering actuator (not shown) is fixedly mounted on the movable body 37a, and the fiber bundle feeding head 36 is mounted on the raising and lowering actuator 37.

The fiber bundle feeder 33 is formed so that a plurality of bobbins B (three in this embodiment), on which fiber bundles 20 are wound, are supported by respective spindles 33a connected to a tension control (not shown). A powder brake or a permanent torque which applies a load on the spindles 33a by over current is, for example, used as a tension control. The fiber bundles 20 are, for example, made of carbon fiber non-twisted multifilament, which has a filament number of about 3000 through about 96000.

The resin impregnating apparatus 34 has a resin tank 34a and a spreading roller 34b, and is provided with a roller (not shown) for guiding fiber bundles 20 which are drawn from the bobbins B to a predetermined position and a roller (not shown) for guiding fiber bundles 20, which are impregnated with resin in the resin tank 34a, above the resin tank 34a. The fiber bundle guide 35 has a guide portion (not shown) having the shape of the teeth of a comb for guiding the fiber bundles 20, which are drawn from a plurality of the bobbins B so as to be treated with resin impregnation separately.

The chucks 32 rotatably support a fiber bundle wound member around the axis of the member and are driven by a variable speed motor which is controlled by a controller (not shown). The moving speed of the fiber bundle feeding head 36 is made synchronous with the rotation of the variable speed motor. Thus, the winding angle of the fiber bundles 20 to the fiber bundle wound member may be set to an optional angle.

Then, the liner 15 is supported by the chucks 32 of the FW apparatus 31 so as to be rotated integrally therewith, and the shape correction members 18 are prepared at their respective saving positions shown in FIG. 4, which do not interfere with filament winding, between the chucks 32 and the liner 15. In this embodiment, a support member 39 for temporarily supporting the shape correction member 18 extends over the chuck 32 from each side of the FW apparatus 31 to a portion adjacent to the boss 14 of the liner 15, which is supported by the chucks 32. The distal end portion 39a of each support member 39 is used as a saving position for the shape correction member 18. The shape correction member 18 is supported so that it is hung at the distal end portion 39a of the support member 39.

In this embodiment, the liner 15 is not directly supported at the bosses 14 by the chucks 32 but is supported through rods 38 by the chucks 32. Each rod 38 has a small-diameter external thread portion which is screwed into the threaded hole 14a of the boss 14 at its distal end. The boss 14 is elongated so that the external thread portion is screwed into the boss 14 of the liner 15.

The operator draws fiber bundles 20 from the fiber bundle feeding portion 33, guides them to the fiber bundle feeding head 36 through the resin impregnating apparatus 34, the fiber bundle guide 35, and the like, and then fixes the end of the fiber bundles 20 at a predetermined position of the liner 15 after the fiber bundles 20 are inserted into the fiber
bundle feeding head 36. Fixing work of the end of the fiber bundles 20 is manually performed by the operator, and, for example, performed by using adhesive tape. The operator inputs the rotation speed during filament winding, the width of reciprocation during winding operation of the fiber bundle feeding head 36, and the like, to a controller (not shown). The filament winding is thus performed under such a situation.

[0045] The fiber bundles 20 are arranged by helical winding so as to be in contact with the boss 14, and the wound positions are deviated for every winding on both domes 15b. The fiber bundles 20 are wound on the domes 15b until they cover the entirety of the domes 15b. Thus, a single helical winding layer is formed on each dome 15b, while two helical winding layers are formed on the body 15a. The hoop winding layer is formed on the body 15a with a predetermined thickness.

[0046] As a predetermined amount of fiber bundles is wound on the domes 15b by helical winding, filament winding is interrupted, thus finishing winding of the first fiber bundle layer 17a. In this embodiment, the language “predetermined amount” means that in the fiber bundle layer wound on the domes 15b the ratio of the thickness of the portion adjacent to the boss 14 to the thickness of a portion spaced apart from the boss 14 is so determined that, when the winding of the fiber bundles 20 is continued, the fiber bundles 20 will not be in contact with the previously wound fiber bundles 20 or contact with little pressure. This predetermined amount is calculated by experiment in advance. In a state where the amount of helical winding has reached a predetermined amount, the surface of the first fiber bundle layer 17a is adjacent to the boss 14 and has a rounded shape which concaves inwardly to the liner 15 to form a recess 19 as seen in a cross-section taken along the axis of the pressure vessel 11. As a result, adjacent to the boss 14, the fiber bundles 20 wound on the surface of the first fiber bundle layer 17a may not be in contact with the first fiber bundle layer 17a or may contact it with little contact pressure. It is noted that the thickness of the fiber bundle layer means the length of the fiber bundle layer in the direction perpendicular to the surface of the dome 15b.

[0047] The shape correction member 18, which is located at the saving position, is moved along the rod 38 to be arranged at a position where it is in contact with the wound first fiber bundle layer 17a which has been wound by then. The shape correction member 18 has a surface adjacent to the liner 15, the surface being shaped along the surface of the first fiber bundle layer 17a so as to fill the recess 19. After that, the filament winding is continued, and the helical winding is performed as described above to form the second fiber bundle layer 17b. Thus, the second fiber bundle layer 17b has the required thickness for ensuring desired pressure resistance is formed, and the winding of fiber bundles 20 is finished.

[0048] After the winding has finished, the wound body including the liner 15 is removed from the FW apparatus 31 and then placed in a furnace for curing the resin at a predetermined temperature. Curing temperature varies for resin. For example, epoxy resin has a curing temperature of about 80 degrees C. to 180 degrees C. The shelf 16 made of FRP is formed by heat curing. After cooling and then removing the burr and the like, a plug and the like for filling with hydrogen and connecting an exhaust conduit is screwed into the threaded hole 14a of the boss 14 thereby forming the pressure vessel 11.

[0049] When helical winding or in-plane winding is performed by filament winding so that the arrangement line of the fiber bundles 20 wound outside of the liner 15 having the domes 15b contacts the bosses 14 on the domes 15b, the portion adjacent to the bosses 14 has a thicker fiber bundle layer than the portion adjacent to the body 15a of the liner 15. As the amount of fiber bundle layer wound on the domes 15b is increased, the rate of fiber bundles 20 adjacent to the boss 14 increases, with the result that the surface of the fiber bundle layer does not have a rounded shape which convexes outwardly, as seen in a cross-section taken along the axis of the pressure vessel 11, but has the recess 19 adjacent to each boss 14. Therefore, the fiber bundles 20 which are wound subsequently press weakly against the fiber bundle layer which is wound (arranged) precedently. However, in this embodiment, the shape correction member 18 is arranged to fill in the recess 19, and the fiber bundles 20 wound outside of the shape correction member 18 has a rounded shape which convexes outwardly, that is, spaced apart from the liner 15. Thus, the fiber bundles 20 are wound tightly around the domes 15b. As a result, the strength of the pressure vessel 11 increases.

[0050] According to the preferred embodiment, the following advantages are obtained.

[0051] (1) The pressure vessel 11 has a shell 16 made of fiber reinforced plastic outside the airtight liner 15, including a cylindrical portion 12, domed end portions 13 on both ends of the cylindrical portion 12, and a boss 14 provided at the center of each domed end portion 13. The shape correction member 18 is provided between the first and second fiber bundle layers 17a, 17b at each domed end portion 13. Accordingly, the fiber bundles which form the domed end portions 13 may further be arranged to pass on the bosses and wind tightly to sufficiently press the fiber bundles which are precedently wound (arranged). As a result, even if the fiber bundles 20 wound at the domed end portions 13 are arranged to pass on the bosses 14, fibers that contribute little to increasing the strength of the pressure vessel 11 in the axial direction from the portion adjacent to the bosses 14 to the shoulder portions may be reduced, and the amount of fibers required for ensuring the same pressure resistance may also be reduced. Thus, a light weight pressure vessel 11 and a thin-walled cylindrical portion 12 are achieved. The thin-walled cylindrical portion 12 allows the pressure vessel to be compact.

[0052] (2) The first and second fiber bundle layers 17a, 17b which form the domed end portions 13 are formed only of the fiber bundles 20 which are wound in contact with the bosses 14. Accordingly, all fiber bundles 20 which form the domed end portions 13 efficiently contribute to increasing the strength of the pressure vessel 11 in the axial direction.

[0053] (3) The shape correction member 18 has a surface adjacent to the liner 15, the surface being shaped along the surface of the first fiber bundle layer 17a, and arranged to fill in the recess 19 on the surface of the first fiber bundle layer 17a. Since the shape correction member 18 is arranged to fill in the surface of the first fiber bundle layer 17a, the fiber bundles 20 wound outside of the shape correction member 18 are arranged tightly along the surface opposite to the liner.
Thus, the strength of the pressure vessel 11 is increased. During winding of the fiber bundles 20 outside of the shape correction member 18, the inner previously wound fibers of the first fiber bundle layer 17a are tensioned through the shape correction member 18, and voids are prevented from being created in the impregnated resin of the first fiber bundle layer 17a, thus contributing to increasing the strength of the pressure vessel 11.

(0054) The shape correction member 18 has a surface on the side opposite to the liner 15, the surface having a smaller curvature than the outer surface of the dome 15b of the liner 15. In comparison to a structure in which the shape correction member 18 has a surface on the side opposite to the liner 15, the surface having a greater curvature than the outer surface of the dome 15b of the liner 15, it is more appropriate to form (wind the fiber bundles 20) the domed end portions 13 of the pressure vessel 11.

(0055) The shape correction member 18 has a smaller outside diameter than the portion of the first fiber bundle layer 17a on the body 15a of the liner 15. Accordingly, it is easy to wind the fiber bundles 20 outside of the shape correction member 18.

(0056) Using the shape correction member 18 allows an arrangement line of the fiber bundles 20 on the domes 15b to be estimated easily when the fiber bundles 20 are to be further wound outside of the domes 15b that are already wound by the fiber bundles 20. Thus, design will be easier.

(0057) During the manufacture of the pressure vessel 11, filament winding is performed in a state where the liner 15 is fixed to the chucks 32 of the FW apparatus 31 so as to rotate integrally therewith, and the annular shape correction members 18 for shape correction of the fiber bundle layer formed on the domes 15b are previously prepared at saving positions, at which filament winding is not interrupted, between the chucks 32 and the liner 15. In the mid course of winding fiber bundles 20, the shape correction members 18 are prepared at the saving positions and are moved to positions to contact the first fiber bundle layer 17a which has been wound by then. Then, the filament winding is continued. When the filament winding is interrupted and the shape correction members 18 are moved to positions to contact the first fiber bundle layer 17a, the shape correction members 18 may be moved to appropriate positions on the first fiber bundle layer 17a without removing the liner 15 from the chucks 32. Thus, arrangement of the shape correction members 18 and continuation of the filament winding after the arrangement are performed fast.

(0058) Inserting of the shape correction members 18 improves the appearance of the pressure vessel 11. Accordingly, the fiber bundles 20 for improving the appearance are reduced thereby making the pressure vessel 11 light and compact. Thus, fewer fiber bundles 20 are used to reduce manufacturing cost.

(0059) During supporting of the liner 15 by the chucks 32 of the FW apparatus 31, the bosses 14 are not directly supported but rather supported through the rods 38 which are screwed into the threaded holes 14a. Since the length of the bosses 14 is determined as the sum of the length required for winding the fiber bundles 20 which form the domed end portions 13 and the length required for being supported by the chucks 32, the pressure vessel 11 does not require additional processes, such as removing an extra portion after the shell 16 is formed. In addition, the liner 15 may be manufactured with less material.

(0060) The following will describe a second preferred embodiment of the present invention with reference to FIG. 6. The second preferred embodiment differs from the first preferred embodiment in that a plurality of the shape correction members 18 are arranged between the adjacent fiber bundle layers which form the domed end portion 13. The other components are similar to those of the first preferred embodiment. The same reference numerals denote the substantially identical components as those of the first preferred embodiment, and the description is omitted. It is noted that in FIG. 6, to distinctly differentiate the first and second fiber bundle layers 17a, 17b and the shape correction members 18, the cross-section area of the shape correction members 18 is indicated not by hatching but by dotting.

(0061) As shown in FIG. 6, the domed end portions 13 of the pressure vessel 11 each include three-layer fiber bundle layers 17a, three shape correction members 18 and an outer second fiber bundle layer 17b. Each shape correction member 18 is made thinner than the shape correction member 18 of the first preferred embodiment. The total thickness of the first and second fiber bundle layers 17a, 17b depends upon the thickness of the used fiber bundle 20, strength of the fiber, pressure resistance required for the pressure vessel 11 and the like. If the total thickness of the first and second fiber bundle layers 17a, 17b for ensuring pressure resistance required for the pressure vessel 11 does not need to be so thick, the single shape correction member 18 as well as the first preferred embodiment may be enough.

(0062) However, if the total thickness of the first and second fiber bundle layers 17a, 17b needs to be thick, using the single shape correction member 18 results in an excessive amount of fibers on the portion adjacent to the bosses 14, even if the shape of the winding of the fiber bundles 20 is corrected in such a manner that the winding of the fiber bundles 20 is interrupted in the mid course of the filament winding and the shape correction member 18 is arranged to contact the first fiber bundle layer 17a. As a result, the fiber bundles 20 contribute little to increasing the strength of the pressure vessel 11 in the axial direction in the same amount of winding, so that the amount of fiber bundles 20 for ensuring pressure resistance required for the pressure vessel 11 increases and the appearance of the domed end portions 13 worsens. However, in this embodiment, a plurality of the shape correction members 18 are used, so that the fiber bundles 20 may be wound for effectively contributing to the strength of the pressure vessel 11 in the axial direction. Thus, the appearance of the domed end portions 13 gets better and the amount of fiber bundles 20 needed is reduced.

(0063) According to the second preferred embodiment, in addition to the above mentioned advantages, (1) through (10) of the first preferred embodiment, the following advantage is obtained.

(0064) A plurality of the shape correction members 18 are arranged between the first and second fiber bundle layers
which form the domed end portions 13. Accordingly, the domed end portions 13 may easily be formed in a desired shape. Thus, design of the pressure vessel 11 will be easier and the appearance thereof will also be better. Furthermore, when the total thickness of the first and second fiber bundle layers 17a, 17b which form the domed end portions 13 is made thicker for enhancing the strength of the pressure vessel 11, it permits easy adjustment of the thickness.

The present invention is not limited to the embodiments described above but may be modified into the following alternative embodiments.

In an alternative embodiment, the shape of a surface of the shape correction member 18 adjacent to the liner 15 is not limited to a smooth shape. For example, as shown in FIG. 7, a groove (recess) 18a may be formed to extend radially. In this case, during the manufacture of the pressure vessel 11, the shape correction members 18 are prepared at positions in contact with the surface of the first fiber bundle layer 17a. Then, during winding of the fiber bundles 20 on the shape correction members 18, resin liquid exuded from the first fiber bundle layer 17a may easily be guided to the periphery of each shape correction member 18, and, therefore, the shape correction members 18 easily closely contact the surface of the first fiber bundle layer 17a.

In an alternative embodiment, as shown in FIG. 7, the shape correction members 18 each have a through hole 18b. With the through holes 18b, during the manufacture of the pressure vessel 11, after the shape correction members 18 are prepared at positions in contact with the surface of the first fiber bundle layer 17a, during winding of the fiber bundles 20 on the shape correction members 18, resin liquid exuded from the first fiber bundle layer 17a may easily be drained outside from the shape correction members 18 through the through holes 18b. Thus, the shape correction members 18 easily closely contact the first fiber bundle layer 17a. As shown in FIG. 7, the shape correction members 18 each may have a groove 18a and a through hole 18b.

In an alternative embodiment, the shape correction members 18 each need not have a surface adjacent to the liner 15 along the surface of the first fiber bundle layer 17a. Even if the shape correction members 18 each have a shape that is partially spaced apart from the first fiber bundle layer 17a without any restriction, they are applicable when they are deformable so as to closely contact the surface of the first fiber bundle layer 17a due to the tension of the fiber bundles 20 wound outside of the shape correction members 18.

In an alternative embodiment, the shape correction members 18 are not limited to having a rounded surface on the side opposite to the liner 15, the curvature of the rounded surface being smaller than that of the outer surface of the dome 15b of the liner 15. The rounded surface may have a greater curvature than the outer surface of the dome 15b. However, the rounded surface having a smaller curvature than the outer surface of the dome 15b improves the appearance of the domed end portions 13 and tends to cause appropriate tension to act on the fiber bundles 20 during winding of the fiber bundles 20.

In an alternative embodiment, the material of the shape correction member 18 is not limited to epoxy resin. For example, the shape correction member 18 may be made of resin other than epoxy resin, such as fiber reinforced plastic, metal or ceramics. However, resin is preferable for reducing weight in comparison to metal and ceramics.

In an alternative embodiment, the shape correction members 18 each do not have the same hardness as a whole, but may have a portion on the side adjacent to the liner 15 which is softer than the other side thereof. For example, the shape correction members 18 each may have a two layer structure which includes a first portion on the side opposite to the liner 15 and a second portion on the side adjacent to the liner 15, the first portion and the second portion being made of materials having different hardness. For example, the shape correction member 18 may have an elastomer layer on the side adjacent to the liner 15. In this case, during the manufacture of the pressure vessel 11, in winding of the fiber bundles 20 on the shape correction member 18 on the side opposite to the liner 15, the shape correction member 18 easily closely contacts the first fiber bundle layer 17a, and voids between the shape correction member 18 and the first fiber bundle layer 17a are more difficult to create. As a result, the strength of the pressure vessel 11 is improved.

In an alternative embodiment, when the shape correction member 18 is made of a heat curing resin such as epoxy resin, the hardness of the shape correction member 18 may be different between the portion on the side adjacent to the liner 15 and the portion on the side opposite to the liner 15 until the heat curing resin, which is impregnated in the fiber bundles 20, is heated and cured after the filament winding. In one example, the portion of the shape correction member 18 on the side opposite to the liner 15 is made of completely cured heat curing resin, while the portion on the side adjacent to the liner 15 is made of the same heat curing resin which is half cured. In this case, during the winding of the fiber bundles 20 on the portion of the shape correction member 18 on the side opposite to the liner 15, the shape correction member 18 easily closely contacts the first fiber bundle layer 17a on the side adjacent to the liner 15, and voids between the shape correction member 18 and the first fiber bundle layer 17a are difficult to create.

In an alternative embodiment, the shape correction member 18 is not limited to one having a smaller diameter than a portion of the first fiber bundle layer 17a on the body 15a of the liner 15, but may have a greater diameter than the above portion. However, the shape correction member 18 having a smaller diameter than the above portion is preferable.

In an alternative embodiment, the shape correction member 18 may be formed of a plurality of rings (annular members) having different diameters.

In an alternative embodiment, the shape correction member 18 may be formed so that a plurality of members are combined to be annular. In this case, during filament winding, even if the shape correction members 18 are not predeceently prepared at the saving positions between the chucks 32 of the FW apparatus 31 and the liner 15, they may easily be arranged at the positions to contact the surface of the first fiber bundle layer 17a.

In an alternative embodiment, the two and second fiber bundle layer 17a, 17b which form the domed end portions 13 are not limited to being formed only by helical winding but may be the combination of fiber bundle layer
formed by helical winding and fiber bundle layer formed by in-plane winding, or may be formed only by in-plane winding. When the fiber bundles 20 are wound at the domed end portions 13 so as to come in contact with the bosses 14, as the ratio of the outside diameter of the body 15a of the liner to the outside diameter of the boss 14 increases, the fiber bundle layer adjacent to the bosses 14 becomes thicker than the other portion. Accordingly, depending on the ratio of the outside diameter of the body 15a to the outside diameter of the boss 14 and pressure resistance required for the pressure vessel 11, winding is appropriately determined for the fiber bundles 20 which form the domed end portions 13.

[0077] In the above preferred embodiments, in the first fiber bundle layer 17a which forms the domed end portions 13, helical winding layer is first formed, then hoop winding layer is formed, and finally helical winding is formed again, while the second fiber bundle layer 17b is formed by helical winding. However, it is not limited to this structure. The order of windings may be changed, another winding layer may be formed, and one helical winding layer of the first fiber bundle layer 17a may be omitted. It is applicable that the winding layer of the fiber bundles 20 which pass on the bosses 14 is contained in the fiber bundle layer adjacent to the shape correction member 18 on the side adjacent to the liner 15.

[0078] In an alternative embodiment, the fiber bundles 20 wound at the domed end portions 13 are not limited to one all on the line passing the bosses 14. The fiber bundles 20 wound at the domed end portions 13 may partially include low latitude winding which does not pass on the bosses 14.

[0079] The shape correction members 18 are arranged between all three fiber bundle layers in the second preferred embodiment but they are not limited to this arrangement. In an alternative embodiment, at least one shape correction member 18 is arranged between the fiber bundle layers.

[0080] In an alternative embodiment, four or more fiber bundle layers may be formed. In this case, the shape correction members 18 need not be arranged between every adjacent fiber bundle layers. It is applicable that at least one shape correction member 18 is arranged between the fiber bundle layers.

[0081] In an alternative embodiment, the pressure vessel 11 has a heat exchanger inside the liner 15. When gas is filled in the pressure vessel 11 with high pressure, the gas needs to be cooled to fill therein for a short time due to heat resulting from compression. Particularly, when the pressure vessel 11 is used as a hydrogen storage tank and hydrogen storage material such as hydrogen storing alloy is filled inside, the inside of the pressure vessel 11 needs to be cooled. In this case, the heat exchanger is preferably mounted inside the liner 15. As shown in FIG. 8 showing the heat exchanger mounted inside the liner 15, a cover 21 may be provided as the dome 15b of the liner 15. For example, the liner 15, separable on one end (which is shown in FIG. 8), includes an opening 23, instead of the dome 15b of the preferred embodiment, and a cover 21. The opening 23 has a larger diameter than the outside diameter of the heat exchanger 22. The cover 21 covers the opening 23 and is integrally formed with the heat exchanger 22. The cover 21 is fixed to the body 15a by screws 24. The heat exchanger 22 has a heat medium conduit 25, an end plate 26, a heat transfer fin 27 and a cylindrical filter 28, and a hydrogen storing alloy (not shown) is filled between the end plate 26 and the heat transfer fins 27.

[0082] In an alternative embodiment, when the pressure vessel 11 has a heat exchanger inside the liner 15, the liner 15 need not be separable. For example, a heat exchanger is fixed to one dome 15b, and the other end is formed by a drawing operation. After that, the shell 16 is formed by filament winding and heat curing.

[0083] In an alternative embodiment, the material of the liner 15 is not limited to aluminum alloy but may be another metal such as stainless steel or copper or may be airtight resin instead of metal. When the liner 15 is made of resin, the boss 14 made of metal is fixed to the center of the dome 15b. A liner made of resin contributes to light weight in comparison to the liner 15 made of metal.

[0084] In an alternative embodiment, when the liner 15 is directly supported by the chucks 32 of the FW apparatus 31, the boss 14 is elongated to make a winding position for the fiber bundles 20 wound on the dome 15b instead of supporting the pressure vessel 11 through the rod 38. Then, the liner 15 is supported by the chucks 32 at the bosses 14, and an extra portion is cut off or removed after winding of the fiber bundles 20 and curing of the resin.

[0085] In an alternative embodiment, the matrix resin of FRP which forms the shell 16 is not limited to epoxy resin but may be heat curing resin such as polyimide resin or thermoplastic resin having a high elastic modulus in bending such as polyetheretherketone may be used in conformity with performance required for the pressure vessel. Another resin such as vinyl ester resin and phenolic resin may be used. In this case, the cost of these resins is lower than that of epoxy resin, so that manufacturing cost is reduced.

[0086] In an alternative embodiment, prepreg fiber in which carbon fibers are precedent impregnated is used. In this case, no resin impregnating apparatus is needed, so that work time may be reduced and installation space of the entire apparatus may be reduced by the space of resin impregnating apparatus.

[0087] In an alternative embodiment, the material of the fiber bundles 20 is not limited to carbon fiber. Another inorganic fiber such as glass fiber or organic fiber having a high strength and a high elasticity such as polyaramide is used in conformity with performance required for the pressure vessel.

[0088] In an alternative embodiment, the body 15a of the liner 15 is not limited to a cylindrical shape but may be elliptical in cross section or a polygonal in shape. It is noted that the fiber bundles 20 should be formed to be continuously wound on the body 15a and the substantially hemispherical domes 15b.

[0089] In an alternative embodiment, ultraviolet curing resin is used as matrix resin instead of heat curing resin.

[0090] Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive. The invention is not to be limited to the embodiments described herein. It is to be understood that other similar embodiments may be used or modifications and additions may be made to the described embodiments for performing the same function. Therefore, the claimed invention should not be limited.
to any single embodiment, but rather should be construed in breadth and scope in accordance with the appended claims.

What is claimed is:

1. A pressure vessel comprising:
   an airtight liner; and
   a shell made of fiber reinforced plastic and formed by curing resin impregnated fiber bundles wound outside of the liner, wherein the pressure vessel has a cylindrical portion, a domed end portion on each end of the cylindrical portion and a boss provided at the center of each domed end portion, wherein the shell includes at least two fiber bundle layers which are formed by the resin impregnating fiber bundles and at least one shape correction member arranged between the fiber bundle layers at each domed end portion.

2. The pressure vessel according to claim 1, wherein the surface correction member has a smaller outside diameter than a portion of the fiber bundle layer on a body portion of the liner.

3. The pressure vessel according to claim 1, wherein the shape correction member has a surface adjacent to the liner, the surface being shaped along a surface of the fiber bundle layer adjacent to the liner, and wherein the shape correction member is arranged so as to fill in a recess of the surface of the fiber bundle layer adjacent to the liner in a cross-section of the pressure vessel taken along an axis of the pressure vessel.

4. The pressure vessel according to claim 3, wherein the shape correction member has a rounded surface on a side opposite to the liner, the rounded surface having a smaller curvature than an outer surface of a dome of the liner.

5. The pressure vessel according to claim 1, wherein a plurality of the shape correction members are arranged between the fiber bundle layers.

6. The pressure vessel according to claim 1, wherein the shape correction member has a smaller side adjacent to the liner than a side opposite to the liner.

7. The pressure vessel according to claim 1, wherein the fiber bundle layer which forms the domed end portion is formed only by fiber bundles which are wound in contact with the boss.

8. The pressure vessel according to claim 1, wherein the fiber bundle layer wound at the domed end portion is formed only by fiber bundles which are wound by helical winding in contact with the boss.

9. The pressure vessel according to claim 1, wherein the fiber bundle layer wound at the domed end portion is formed by helical winding and/or in-plane winding.

10. The pressure vessel according to claim 1, wherein the shape correction member has a surface adjacent to the liner, the surface having a recess which extends radially.

11. The pressure vessel according to claim 1, wherein the shape correction member has a through hole.

12. The pressure vessel according to claim 1, wherein the shape correction member is made of resin.

13. The pressure vessel according to claim 12, wherein the shape correction member is made of epoxy resin.

14. The pressure vessel according to claim 12, wherein the shape correction member is made of metal or ceramics.

15. A hydrogen storage tank comprising the components of claim 1.

17. A method for manufacturing a pressure vessel having a cylindrical portion, a domed end portion on each end of the cylindrical portion and a boss provided at the center of the domed end portion, wherein resin impregnated fiber bundles are wound outside of an airtight liner by filament winding, comprising the steps of:

   fixing the liner at a rotation support portion of a filament winding apparatus so as to rotate integrally therewith;
   performing the filament winding while an annular shape correction member for adjusting a shape of a fiber bundle layer formed at the domed end portion is prepared at a saving position, which does not interfere the filament winding, between the rotation support portion and the liner;
   moving the shape correction member prepared at the saving position to contact the fiber bundle layer wound by then in the mid course of winding the fiber bundles; and
   continuing the filament winding.

18. A method for manufacturing a pressure vessel having a cylindrical portion, a domed end portion on each end of the cylindrical portion and a boss provided at the center of the domed end portion, wherein resin impregnated fiber bundles are wound outside of an airtight liner by filament winding, comprising the steps of:

   performing filament winding in a state where the liner is fixed at a rotation support portion of a filament winding apparatus so as to rotate integrally therewith;
   arranging a shape correction member on the outside of the fiber bundle layer wound by then when an outline of the fiber bundle layer formed by fiber bundles wound at the domed end portion becomes a shape by which pressing force from the fiber bundles wound outside of the fiber bundle layer is less than a predetermined value; and
   forming the fiber bundle layer by winding the fiber bundles on the shape correction member.