



(51) International Patent Classification:

F17C 1/08 (2006.01)

(21) International Application Number:

PCT/EP2019/086680

(22) International Filing Date:

20 December 2019 (20.12.2019)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

18306827.9 21 December 2018 (21.12.2018) EP

(71) Applicant: SOLETANCHE FREYSSINET [FR/FR];
280, avenue Napoléon Bonaparte, 92500 RUEIL-MAL-
MAISON (FR).

(72) Inventors: LEBON, Jean-Daniel; 41, rue des Panlous,
78100 SAINT-GERMAIN-EN-LAYE (FR). NOVARIN,
Marco; 12 Villa Meyer, 94170 LE PERREUX SUR
MARNE (FR).

(74) Agent: TANTY, François; NONY, 11, rue Saint-Georges,
75009 PARIS (FR).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,

OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

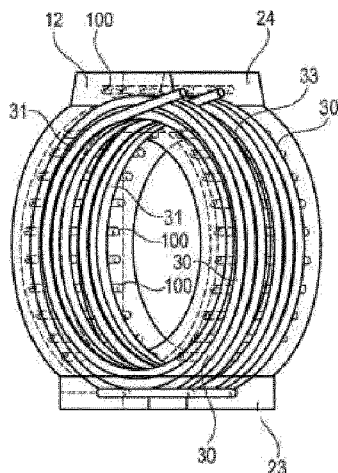
Published:

— with international search report (Art. 21(3))

(54) Title: MODULAR PRESTRESSED CONCRETE PRESSURE TANK

(57) Abstract: A modular compressed gas storage tank comprising a plurality of prestressed preformed ring elements, each ring element comprising a concrete body and at least one tensioning tendon extending circumferentially within the concrete body.

[Fig. 6]



MODULAR PRESTRESSED CONCRETE PRESSURE TANK

The present invention relates to compressed gas energy storage, and more particularly but not exclusively to compressed air energy storage (CAES).

Renewable energies such as wind or solar energies lead to a surplus of energy
5 when power generation exceeds power consumption. Furthermore, as renewable energies are intermittent, power demand may exceed power that is produced.

To overcome these drawbacks, intensive research is made to develop energy storage solutions.

Many solutions rely on batteries, which is not entirely satisfactory as battery
10 production and recycling raise strong environmental issues.

CAES consists in using surplus energy in a compression stage to compress air for storage in a storage reservoir and in using the compressed air at a later stage to drive turbines to produce electrical energy.

Steel tanks have been used as an aerial storage component. However, the cost of
15 such tanks is high as they are made of cumbersome parts costly to transport. As of today, this solution is limited to small capacity storage facilities.

Another solution is to use underground natural cavities as storage components. However, this implies specific geological conditions which are not always met and necessitates long and costly preparation work.

20 Pressure tanks made at least partially of prestressed concrete have been disclosed as an alternative to pressure tanks made entirely out of steel.

CN207316457U teaches a prestressed concrete pressure tank of spherical or cylindrical shape assembled at the site of use.

FR3055942 discloses a cylindrical pressure tank made of a plurality of
25 concentric layers including an innermost concrete internal layer, a steel layer, a concrete layer on which steel wires are wound and an outermost protective layer. The tensioning of the steel wires requires an heavy equipment which renders the operation relatively difficult on site. This technique also limits the annular segment diameter because of the equipment used to wind and tension the wires and also leads to a relatively high loss of prestressing.
30 The monitoring and maintenance of the wires is relatively difficult, if not impossible. The concrete layer internal to the tank raises suffers from a risk of loss of adherence and resistance over time, with potential crack apparition.

US3926134 discloses a tank for cryogenic liquids adapted for placement within a conventional marine transportation vessel. The tank is made up of a series of concrete, modular tank wall sections which are circumferentially prestressed by steel tendons and which have holes therein for through-passage of axial prestressing tendons. The modular wall sections are separated by concrete or steel stiffening disks.

There remains a need for improving solutions for compressed gas energy storage and the present invention aims at satisfying this need.

Exemplary embodiments of the invention thus provide a modular compressed gas storage tank comprising a plurality of prestressed preformed ring elements, each ring element comprising a concrete body and at least one tensioning tendon extending circumferentially within the concrete body.

The prestressed ring elements may be located between end elements.

The invention offers a less expansive solution for energy storage than the solution relying on vessels that are entirely made of steel. Concrete is a relatively inexpensive material that is available everywhere. A storage tank according to the invention can be produced close to the energy storage production site. The use of preformed elements increases reliability of the tank. The storage tank may be easily made to withstand an internal pressure varying in the range 60 to 130 bars during the day.

Furthermore, the gas storing capacity can be easily adjusted by selecting the number of ring elements per tank and the number of tanks.

By “within the concrete body” one should understand that the tendon comprises at least one portion that extends circumferentially between the inner and outer radiuses of the concrete body.

Ends of the at least one tendon are preferably anchored against an external surface of the concrete body.

Preferably, the at least one tendon extends circumferentially over at least two or three turns about a longitudinal axis of the ring element. This enables to space apart the tendon anchoring zones, and have the concrete body withstand the high mechanical loads. Preferably, the at least one tendon extends helically. Each ring element may comprise at least one radially outer tendon extending circumferentially and at least one radially inner tendon extending circumferentially coaxially to the first tendon. In this way the tank is capable of withstanding higher internal pressures. Each ring element may comprise at least two radially

outer tendons separated axially from each other by a gap, at least one end of the at least one radially inner tendon extending through the gap. For example, each ring element comprises at least two radially inner tendons. Each radially inner tendon preferably extends circumferentially, e.g. helically, over at least two or three turns about a longitudinal axis of the ring element.

Preferably, each ring element comprises passages for longitudinal tensioning tendons extending from one end element to the other end element.

The tendons anchors of each ring element may abut against shoulders that may be defined by at least one protruding rib section.

This rib section may be oriented downwardly and connect a foundation.

Preferably, the shoulders are defined by more than one protruding rib section. For example, the shoulders are defined by two opposite protruding ribs or by more than two protruding rib sections regularly spaced along the circumference of the ring element. The number of ribs may depend on the number of concentric tendons. The presence of multiple ribs allows to space apart the anchoring zones and makes it easier for the tendons of layers of different depths to cross and reach their respective anchoring zone.

The tank may comprise more than two concentric layers of tendons extending circumferentially within the concrete body. The number of concentric layers of tendons may depend on the internal pressure the tank is to withstand.

Ends of each tendon may be anchored on shoulders defined by a respective rib section.

Preferably, each tendon extends within a corresponding duct (also called “sheath”).

Preferably, the tank comprises longitudinal tensioning tendons for applying an axial load to the ring elements.

The end elements may each comprise a preformed concrete wall. Each end element may comprise an internal cover, which may be a lining, impermeable to the gas.

Each ring element may comprise an internal liner section impermeable to the gas.

The internal liner section of each ring may comprise end flanges extending radially inwardly. These flanges are used to make a seal between two consecutive ring elements.

The internal layer section and internal cover may comprise a metal layer, such as steel for example. The flanges may be soldered together.

The tank may comprise studs fixed to the surface of the internal liner section and anchored in the concrete body. These studs may be metal studs soldered to the liner section.

5 Two consecutive ring elements may be provided with complementary shear keys on facing surfaces. These shear keys may be match casted. The tank may not comprise any stiffening disk between two consecutive ring elements. The interface between two consecutive ring elements may be filled with a polymeric binder such as an epoxy-based resin.

10 Preferably, at least one of the end elements comprises a pipe opening out in the inside of the tank, such as an air intake pipe.

A further object of the invention is a method of making a tank as defined above, the method comprising:

- positioning at least two preformed ring elements in a succession,
- 15 - applying an axial compression load on the ring elements.

The method may be performed close to the energy production site where the tank is to be used.

The method may comprise introducing a polymer binder at an interface between two the consecutive ring elements. This binder is for example an epoxy-based resin.

20 The method may comprise installing the ring elements one after the other, with provisional tensioning bars being introduced through the ring elements to apply a provisional axial load on them during curing of the polymer binder. The provisional tensioning bars may be replaced by tendons after all ring elements are in place.

25 Each ring element preferably comprising an internal liner section as mentioned above, the method may comprise soldering the internal liner sections in succession. This soldering is preferably performed in automated manner by a robot. The seal is also preferably checked in an automated manner.

30 The method may comprise assembling the internal cover to the adjacent internal liner section prior to assembling the concrete wall of the end element to the adjacent ring element. The soldering of the cover to the internal liner section may be performed from the outside.

The method may comprise filling a recess situated behind the cover on the inside of the concrete wall with a cement grout after a provisional load is applied between the wall and the adjacent ring element.

The ring elements may be match casted.

5 Further embodiments of the invention relate to a prestressed concrete ring element for a tank as defined above, comprising a concrete body, at least one radially inner tensioning tendon extending circumferentially within the concrete body and at least one radially outer tendon extending circumferentially in concentric manner with the radially inner tendon, ends of each tendon being anchored against an external surface of the concrete
10 body, preferably against shoulders provided on said external surface.

This ring element may comprise some or all of the features defined above in relation to the tank.

A further object of the invention is a method for producing a ring element as defined above, the tendons extending in corresponding ducts, the method comprising
15 winding the tendons and the ducts around a removable forming tool, positioning ducts and tendons according to their position in the concrete body and preferably forming a reinforcement cage around the ducts.

The circular or circumferential tendons of the ring element are preferably present within the ducts during casting of the concrete. The tendons are preferably pre-threaded in
20 the ducts before the reinforcement cage is installed around the ducts and concrete casted. The tendons are preferably individually sheathed with plastic material such as HDPE and lubricated (greased) within each individual sheath to insure a low friction coefficient. The friction coefficients μ and k are preferably less than 0,06 and 0,015 respectively.

The method may comprise injecting a cement grout inside the ducts prior to
25 tensioning the tendons.

The ring element preferably comprising a liner section, the method may comprise casting the concrete directly in contact with a surface of the liner.

The ring element may be match casted with an adjacent ring element previously made.

30 A further object of the invention relates to a method of temporary storing of energy, comprising compressing a gas and storing the compressed gas in a tank in accordance with the invention, as defined above.

A further object of the invention is an energy storage system, comprising at least one tank as defined above, at least one compression train for compressing a gas to be stored under pressure in the tank and at least one turbine for producing energy by expansion of the compressed gas.

5 The drawings illustrate exemplary and non-limiting embodiments of the present invention.

In the Drawings:

- Figure 1 is a schematic view of an energy storage system in accordance with the invention,
- 10 - Figure 2 is a perspective view of an exemplary embodiment of the reservoir of the system of figure 1,
 - Figure 3 illustrates the assembling of a tank,
 - Figure 4 shows in cross section the tank and supporting structure,
 - Figure 5 is a front view of a ring element showing in transparency the tendon
 - 15 ducts and the passages for axial tendons,
 - Figure 6 is a perspective view of the ring element of Figure 5,
 - Figure 7 is a side view of the ring element of Figure 5,
 - Figure 8 is a partial and schematic view illustrating the anchoring of a tendon extending within a ring element,
 - 20 - Figure 9 is a partial cross section of the concrete body of a ring element showing rebar of the reinforcement cage,
 - Figure 10 is a partial cross section of a liner section showing anchorage studs extending within the concrete body,
 - Figure 11 is an axial section showing an end element and adjacent ring
 - 25 elements,
 - Figure 12 shows detail XII of Figure 11,
 - Figure 13 is a partial and schematic axial section of an end element showing an intake pipe,
 - Figure 14 shows detail XIV of Figure 11,
 - 30 - Figure 15 is a partial and schematic axial section of two adjacent ring elements of the tank showing an example of interlocking shapes (such as match-cast shapes) between the elements, and

- Figures 16 and 17 are schematic front views of variant embodiments of a ring element, showing different rib sections distributions.

The energy storage system 1 shown in Figure 1 comprises a compressed air reservoir 2 and one or more compressor trains 3 for compressing intake air and feeding the reservoir 2 with compressed air and one or more turbines 4 for producing electricity by expansion of the compressed air.

The reservoir 2 is made of one or a plurality of compressed air tanks 10 as shown in Figure 2.

The tanks 10 may be connected in parallel and/or in series. Each tank 10 may be associated with a respective compressor train and/or turbine. In a variant, a compressor train and/or turbine is associated with more than one tank 10.

Each tank 10 is of modular construction and comprises two opposite end elements 11 and a plurality of intermediate ring elements 12 made at least partially out of prestressed concrete. The system may comprise one or more heat exchangers (not shown) and/or a thermal insulation so that the temperature of the air inside the tank does not expose the concrete to more than 100°C.

The number of tanks 10 and the number of intermediate ring elements 12 per tank 10 depend on the storage capacity that is sought. Each tank 10 may comprise between 1 and 50 ring elements, preferably between 2 and 50, more preferably between 10 and 30.

The number of tanks may range from 1 to 50

The overall storage capacity of a tank 10 may range from 50 to 3000m³

The internal volume available for compressed air storage brought by each additional ring element 12 may range from 3m³ to 150m³, and preferably between 15m³ and 60m³

In the described embodiment, each tank 10 extends along a straight longitudinal axis and horizontally but the invention is not limited to a specific orientation of the longitudinal axis. In a variant (not shown) the tank is a torus, for example with a median diameter of between 30 to 100 m, a ring element inner diameter of 2 to 4 m, each ring element having a length of 1,5 to 4,5 m and a bevel angle of about 5°.

The maximum nominal internal pressure of a tank filled with compressed air may range between 60 and 180 bars, preferably between 100 and 150 bars.

As can be seen in Figures 2 and 4 for example, each tank 10 may comprise a lower rib 20 extending longitudinally along the entire length of the tank.

The rib 20 protrudes downwardly and may rest on a foundation slab 13 supported by the ground. A backfilled excavation 14 supports the lower part of the tank 10 on either
5 side of the rib 20. The embankment provides more mechanical stability and may reduce the risk of having the ground extending below the tank 10 freeze in winter. The foundation slab 13 may be replaced by a foundation extending more deeply into the ground.

The end elements 11 and ring elements 12 each comprise a rib section 23 so that these sections 23 when aligned form the longitudinal rib 20. Preferably, the rib 20 is
10 continuous along the entire length of the tank 10.

In the example shown in Figures 2 to 4, the tank 10 comprises only one longitudinal rib 20. In preferred embodiments, the tank comprises more than one rib protruding on its external surface, as will be detailed below.

Each ring element 12 is preformed and comprises prestressed concrete. End
15 elements 11 are also pre-formed.

Figures 5 to 7 show a ring element 12 according to an exemplary embodiment of the invention.

The ring element 12 shown in these figures has two diametrically opposite rib sections 23 and 24. The lower rib section 23 may be oriented downwardly and rest on the
20 above cited foundation slab 13.

The ring element 12 comprises a concrete body 25 which is preferably made of high performance concrete (HPC). The concrete used for making the concrete body 25 has a compressive strength of better than 30 MPa, preferably better than 60 MPa, and more preferably of 90 MPa or better.

The ring element 12 comprises tensioning tendons that extend circumferentially within the concrete body 25 in corresponding ducts 30 and 31.

These tendons extend in concentric paths within the concrete body 25. In the example shown, ducts 30 receive radially outer tendons and ducts 31 receive radially inner tendons.

As can be seen in Figures 6 and 7, the ring element 12 is provided with two
30 radially outer ducts 30 each helically wound around the longitudinal axis of the tank 10.

These coils made of ducts 30 are spaced apart in order to define between them an annular gap 33. Each coil may comprise at least two turns and preferably three turns as shown.

Opposite ends of each duct 30 opens out on a respective shoulder 34 or 35 defined by the lower rib section 23, as best seen in figure 5.

5 Opposite ends of each duct 31 opens out on a respective shoulder 36 or 37 defined by the upper rib section 24.

To reach the shoulder 36 or 37, the ends of a duct 31 extend through the gap 33, as one can see in Figure 6.

10 The presence of two rib sections 23 and 24 provides enough spacing to the anchors of the corresponding tendons for the concrete body to bear the load.

Figure 8 shows the end of a tendon 62 extending within a duct 31. This end is provided with an anchor 68 of known structure and that is shown schematically. A metal (for instance steel) plate 67 may be inserted between the anchor 68 and the shoulder 36 to better distribute the load to the concrete body 25. The plate may be replaced otherwise by a trumpet
15 shaped metal element (steel, cast iron or other) to better distribute the load behind the anchor. Depending on the tensile strength of the concrete used to cast the body of the ring elements, an anti-bursting specific reinforcement element (several frames or helicoidal) can be arranged behind each anchor element and around the duct.

Each ring element 12 is also provided with substantially axially oriented
20 passages 100 for tensioning tendons 60 (only one of them is shown in dashed lines in Figure 7) extending from one end element 11 to the other through the ring elements 12.

These passages 100 may be provided as shown between the ducts 30 and 31 and also in the upper rib sections 24. The passages 100 may be spaced uniformly around the longitudinal axis of the ring element 12 between the inner and outer duct layers, as shown in
25 Figure 5.

Each ring element 12 is provided with a reinforcement cage 70 embedded in the concrete as shown schematically in Figure 9.

Each ring element 12 is also provided with an internal liner section 50 as shown in Figures 10-12, defining the internal surface 51 of the ring element in contact with the
30 compressed air and impervious to the latter.

The internal liner 50 is preferably made of a steel sheet, for example stainless steel, provided at its axial ends with flanges 52 extending radially inward, as can be seen in Figure 12.

For better mechanical connection of the liner section 50 with the concrete body 25, the liner 50 is preferably provided with studs 53 extending radially within the concrete body 25, as shown in Figure 10.

Each end element 11 may comprise as shown in Figure 11 a concrete wall 14 which may be reinforced with a cage (not shown) and an internal cover 80 which may be a lining.

The internal cover 80 is made of a material impervious to compressed air and preferably of the same material as the internal liner sections 50 of the ring elements 12, e.g. steel.

At least one end element 11 may be provided as shown in Figure 13 with at least one intake pipe 90 for supplying compressed air to the tank 10 during a compression stage. The same pipe or another pipe may be used for taking away compressed air from the tank to power a turbine during an expansion stage. A corresponding recess 91 may be provided in the concrete wall 14 for the passage of the pipe 90.

The tank 10 may be provided with various pressure, strain or temperature sensors and with thermal insulation or heat exchange system (not shown).

Each end element 11 is provided with a recess 86 behind the cover 80, that is filled with a hard filler 85, so that the force exerted by the compressed air on the cover is transmitted to the wall 14.

The flange 52 of the internal liner section 50 of the ring element 12 adjacent to the end element 11 is provided with an end collar 55 configured for overlapping a corresponding end collar 88 of the cover 80. The two collars may be fixed together by soldering or welding.

The ring elements 12 are preformed and may be produced at a distant location. Their size is preferably compatible with transportation by conventional trucks. Alternately, the ring elements 12 are produced on site or nearby to reduce or avoid the cost of transportation. The same is true for the end elements 11.

The internal liner sections 50 may be produced at a distant location and brought to the site where the ring elements 12 are made, with their final shape. They may also be

made in separate parts assembled after transportation. Each internal liner section 50 may thus be an integral piece or produced by assembling sub-sections. In case sub-sections are assembled, these sub-sections are preferably made of sectors assembled along longitudinal welding lines.

5 Before casting the concrete of each ring element 12, the corresponding ducts and tendons are cut to the required length and the tendons are threaded in the ducts.

Then, the ducts and tendons are shaped using a removable forming tool so that they extend circumferentially with the desired curvature and the duct ends are positioned in accordance with the outline of the concrete body.

10 The rebars of the reinforcement cage 70 are positioned in the formwork. Duct segments are positioned to form the passages 100 for the longitudinal tendons 60.

After positioning of the ducts and rebars, the shaping tool may be removed. The internal liner section 50 serves as the internal wall of the formwork.

15 The bottom of the formwork used to cast a ring element 12 may be horizontal and be constituted by the top face another ring element 12 previously casted. In this way the ring elements 12 are match casted, which allows to easily obtain interlocking shapes at the interface of adjacent ring elements. Facing surfaces of two adjacent ring elements may thus be provided with female and male complementary shear keys 101 and 102 as shown in Figure 15, that contribute to properly position one ring element in contact with the adjacent
20 one during the assembly operation, and also increases shear resistance of each joint.

Concrete is then poured in the formwork and left to set.

25 The ducts 30 and 31 are provided before casting with their corresponding tendons. The tendons are possibly greased and plastic (with HDPE for example) individually sheathed with low friction coefficient. Before post-tensioning the tendons, a cement grout is injected in the ducts. The friction coefficient applying to this type of tendons may be given as coefficients μ (rad^{-1}) and k (rad.m^{-1}) as per NF EN 1992-1-1 where the tension (prestressing) force is given by $P(x)=P_0 \exp(-\mu \cdot (\theta + k \cdot x))$ as a function of x position and cumulative angular variation θ along cable layout. For such type of tendons (lubricated with grease and HDPE sheathed), typical values of μ and k are respectively $0,05 \text{ rad}^{-1}$ and
30 0.012 rad.m^{-1} . These values are preferably respectively below $0,06 \text{ rad}^{-1}$ and 0.015 rad.m^{-1} .

The tendons are high tensile strength steel cables made of individual units called strands. The tendons used for prestressing the ring elements 12 may be of the type T15.7

strands with $f_{GUTS}=1860\text{MPa}$, with a 150mm^2 section area that is a 279 kN f_{GUTS} (guaranteed ultimate tensile strength)

Once concrete has set, the tendons present in the ducts 30 and 31 may be post-tensioned to the required load. Usually, this type of tendons (also called “strands”) may be tensioned up to 80% of f_{GUTS} , that is up to 1490 MPa.

The ring elements 12 may be stored after the post-tensioning of the tendons until they are assembled to for the tank 10.

To make the tank 10, the ring elements 12 are first assembled successively, one after the other, along the longitudinal axis of the tank, as illustrated in Figure 3. Two ring elements 12 to be assembled are coated on their contact faces with a polymer binder 105 such as an epoxy-based resin, which also acts as a lubricant while unset, as shown in Figure 15.

Provisional tensioning bars (not shown) are introduced into some passages 100 to apply a provisional load forcing the ring elements 12 one against the other until the polymer binder 105 has set.

These bars may have threaded ends to enable to couple bars one in line with the others to accommodate for the increase of length when the number of assembled ring elements become higher.

Once the desired number of ring elements 12 has been assembled, longitudinal tendons 60 may be installed in the free remaining passages 100 and post-tensioned. These tendons may be of the type T15.7 strands with $f_{GUTS}=1860\text{MPa}$, with a 150mm^2 section area that is a 279 kN f_{GUTS} (guaranteed ultimate tensile strength)

After a sufficient number of tendons 60 has been installed and tensioned, the provisional tensioning bars may be removed and additional tendons 60 may be installed in the remaining passages 100 previously occupied by the bars.

Adjacent flanges 52 of the internal liner sections 50 are soldered or welded at their periphery 59 as shown in Figure 12, to provide a sealed connection between two consecutive liner sections. The soldering or welding is preferably performed automatically by a robot.

The cover 80 of each end element 11 is also welded at its edge 89 to the internal liner section 50 of the adjacent ring element 12, as shown in Figure 14, to achieve a sealed connection between the liner 50 and the cover 80.

Once the cover 80 is assembled to the adjacent internal liner section 50, the concrete wall 14 is assembled against the ring element 12 using a polymer binder in a same way as adjacent ring elements 12 are assembled.

After the provisional load is applied to press the concrete wall 14 to the adjacent
5 ring element 12, the recess 86 may be filled with a cement grout 85.

The final tensioning of the tank 10 may take place only after this grout has set.

In a variant embodiment, each ring element 12 is provided with three concentric layers of tendons, i.e. at least one radially inner tendon layer, at least one intermediate tendon layer and at least one radially outer tendon layer. All tendons of each layer are wound
10 helically. A given layer of tendons may comprise coils of same radius that are axially spaced to form annular gaps for the through-passage of tendons of the one or more layers that are situated radially inside this given layer.

The concrete body 25 may be provided with three rib sections 110, as shown in Figure 16, for anchoring these tendons. Each rib section 110 defines two opposite shoulders
15 111 that serve to anchor respective ends of a corresponding tendon.

In the variant embodiment of Figure 17, there are four rib sections 110 to anchor at least four concentric layers of tendons.

The invention is not limited to the disclosed embodiments.

For example, the internal liner sections may be made of a non-metallic material
20 impervious to air such as PVC or any hard airproof plastic for example. The outline of the cross section of a ring element is preferably circular as disclosed above, but other shapes are possible, for example polygonal.

CLAIMS

1. A modular compressed gas storage tank (10) comprising a plurality of prestressed preformed ring elements (12), each ring element (12) comprising a concrete body (25) and at least one tensioning tendon extending circumferentially within the concrete body.
2. The storage tank of claim 1, the at least one tendon extending circumferentially over at least two turns, and preferably three turns about a longitudinal axis of the ring element, the at least one tendon extending preferably helically, the tendons being preferably individually sheathed with plastic material such as HDPE and lubricated within each individual sheath to insure a low friction coefficient.
3. The storage tank of claim 1 or 2, each ring element (12) comprising at least one radially outer tendon extending circumferentially and at least one radially inner tendon extending circumferentially coaxially to the first tendon.
4. The tank of claim 3, each ring element (12) comprising at least two radially outer tendons separated axially from each other by an annular gap (33), at least one end of the at least one radially inner tendon extending through the gap, each ring element (12) comprising preferably at least two radially inner tendons, each radially inner tendon extending circumferentially preferably over at least two turns and preferably three turns about a longitudinal axis of the ring element (12).
5. The tank of any one of claims 1 to 4, comprising end elements (11), the ring elements extending between the end elements (11), each ring element (12) comprising passages (100) for longitudinal tensioning tendons (60) extending from one end element (11) to the other end element (11).
6. The tank of any one of claims 1 to 5, ends of tendons anchors abutting against shoulders defined by at least one protruding rib section (23; 23,24; 110), at least one rib section (23) preferably being oriented downwardly.
7. The tank of any one of claims 1 to 6, comprising shoulders defined by more than one protruding rib sections (23, 24; 110), the shoulders being defined preferably by two opposite protruding ribs (23, 24) or by more than two protruding rib sections (110) regularly spaced along the circumference of the ring element.

8. The tank of any one of claims 1 to 7, comprising more than two concentric layers of tendons extending circumferentially within the concrete body (25), ends of each tendon being anchored on shoulders defined by a respective rib section.

9. The tank of any one of claims 1 to 8, each tendon extending within a corresponding duct (30; 31).

10. The tank according to any one of claims 1 to 10, comprising end elements (11), the end elements (11) each comprising a preformed concrete wall (14) and an internal cover (80) impermeable to the gas.

11. The tank of anyone of claims 1 to 10, each ring element (12) comprising an internal liner section (52) impermeable to the gas, the internal liner section (50) of each ring element (12) comprising end flanges (52) extending radially inwardly.

12. The tank of any one of claims 1 to 11, two consecutive ring elements (12) being provided with complementary shear keys (101, 102) on facing surfaces.

13. A method of making a tank (10) as defined in any one of the preceding claims, comprising:

- positioning at least two preformed ring elements (12) in a succession,
- applying an axial compression load on the ring elements (12).

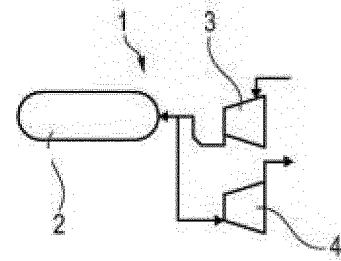
14. A prestressed concrete ring element (12) for a tank (10) as defined in any one of claims 1 to 12, comprising a concrete body (25), at least one radially inner tensioning tendon extending circumferentially within the concrete body and at least one radially outer tendon extending circumferentially in concentric manner with the radially inner tendon, ends of each tendon being anchored against an external surface of the concrete body, preferably against shoulders provided on said external surface.

15. A method for producing a ring element (12) as defined in the preceding claim, the tendons extending in corresponding ducts (30, 31), the method comprising winding the tendons and the ducts around a removable forming tool, positioning ducts and tendons according to their position in the concrete body (25) and preferably forming a reinforcement cage (70) around the ducts, the tendons being preferably pre-threaded in the ducts before the reinforcement cage is installed around the ducts and concrete casted, the ducts being preferably injected with grout prior to tensioning the tendons, the tendons being preferably individually sheathed with plastic material such as HDPE and lubricated within each individual sheath to insure a low friction

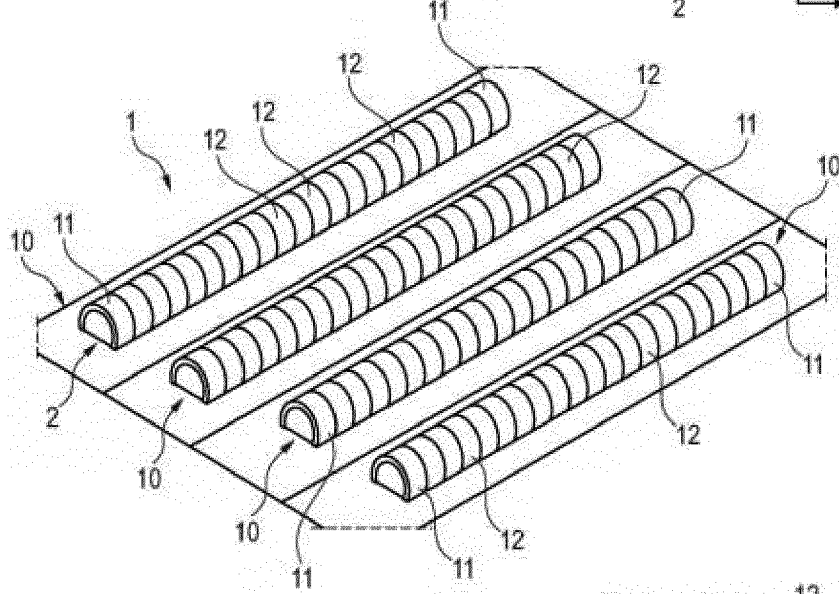
coefficient, the friction coefficients μ and k being preferably less than 0,06 and 0,015 respectively.

1/4

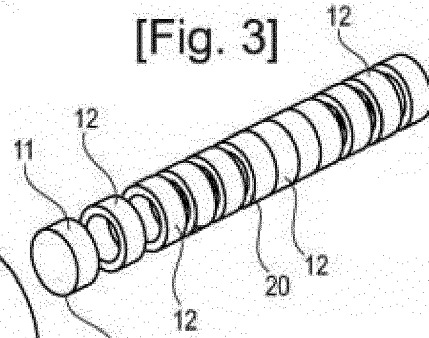
[Fig. 1]



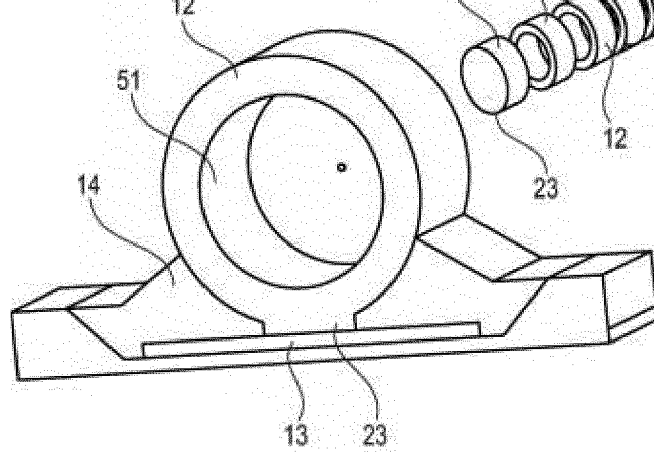
[Fig. 2]

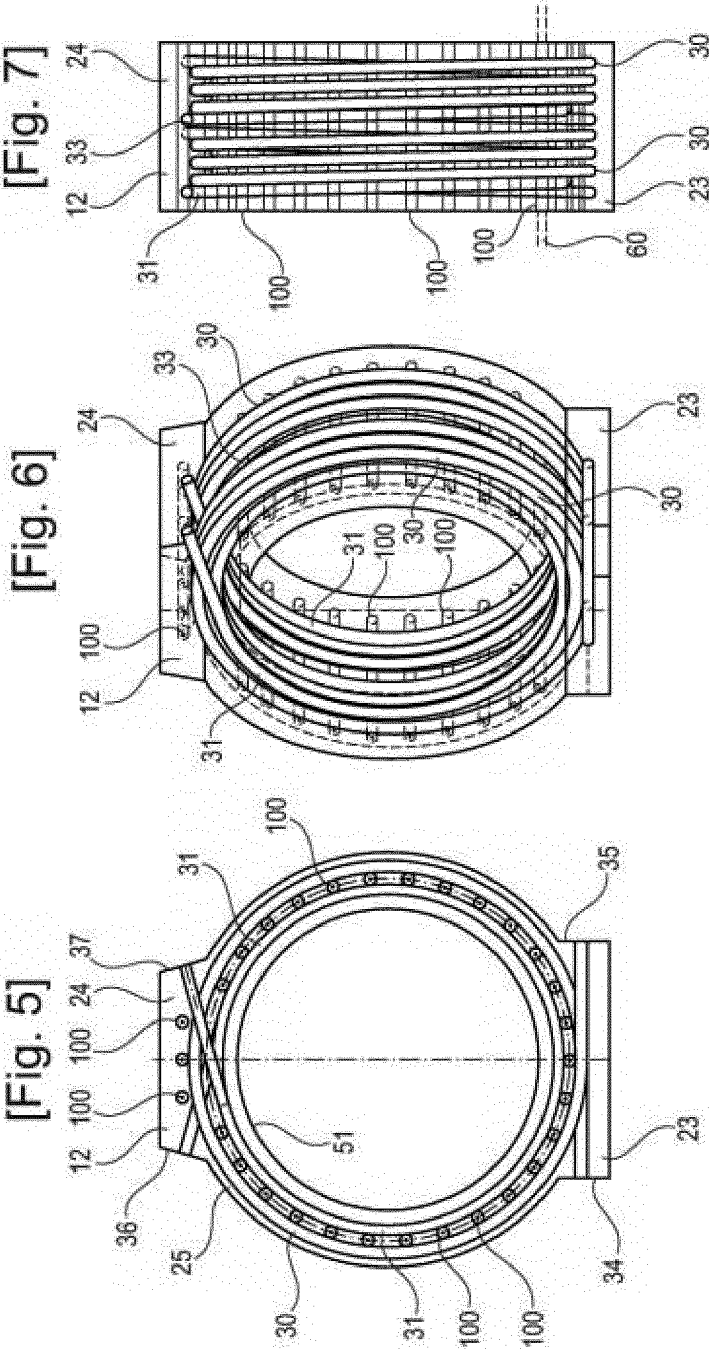


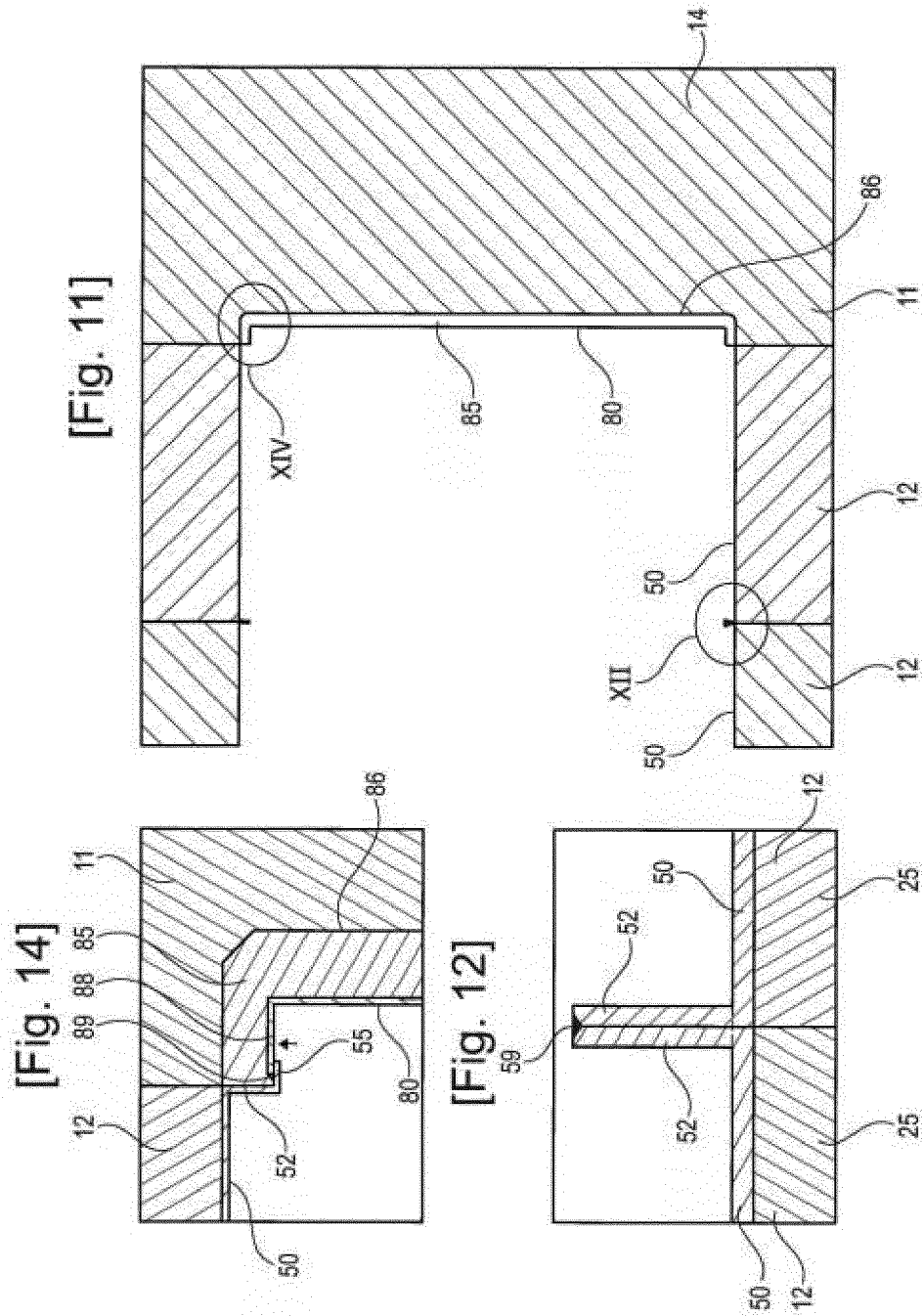
[Fig. 3]



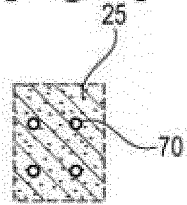
[Fig. 4]



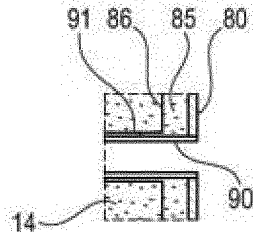




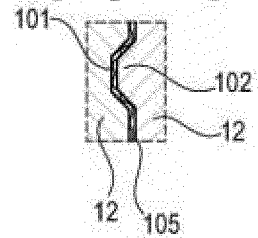
[Fig. 9]



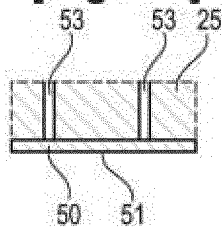
[Fig. 13]



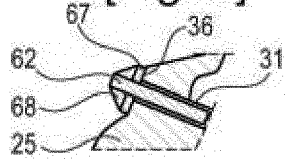
[Fig. 15]



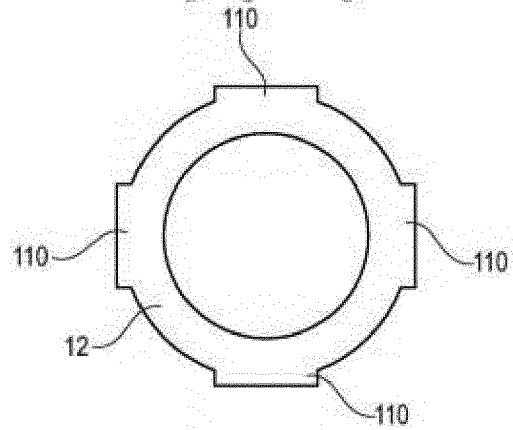
[Fig. 10]



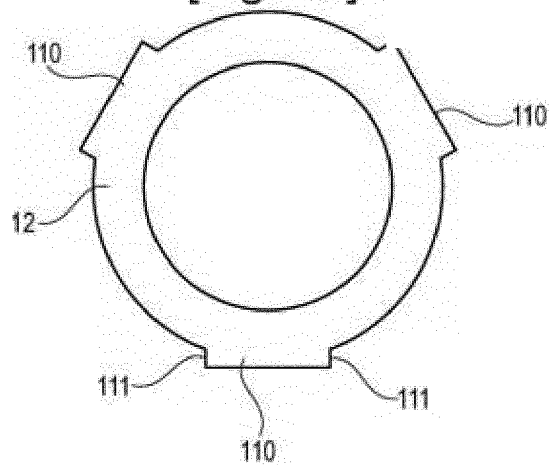
[Fig. 8]



[Fig. 17]



[Fig. 16]



INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2019/086680

A. CLASSIFICATION OF SUBJECT MATTER
INV. F17C1/08
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F17C F16L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN 207 316 457 U (HE SHUYAN) 4 May 2018 (2018-05-04) cited in the application	6,7,14
A	figures 1,2	1-4,9, 13,15
X	----- FR 3 055 942 A1 (IFP ENERGIES NOW [FR]) 16 March 2018 (2018-03-16) cited in the application	1-3,8-14
Y	page 3, line 20 - page 4, line 11; figures	5-7,14
A	1,2 page 10, line 12 - page 10, line 17; figures 1,2	4,15
Y	----- US 3 926 134 A (CLOSNER JOHN J ET AL) 16 December 1975 (1975-12-16) cited in the application	5
A	the whole document ----- -/-	1-4,6-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

3 March 2020

Date of mailing of the international search report

11/03/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Forsberg, Peter

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2019/086680

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 1 518 156 A (GKN BUILDING SUPPLIES & SERV L) 19 July 1978 (1978-07-19) the whole document -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/086680

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
CN 207316457	U	04-05-2018	NONE	

FR 3055942	A1	16-03-2018	CN 109690168 A	26-04-2019
			EP 3513113 A1	24-07-2019
			FR 3055942 A1	16-03-2018
			WO 2018050455 A1	22-03-2018

US 3926134	A	16-12-1975	NONE	

GB 1518156	A	19-07-1978	NONE	
