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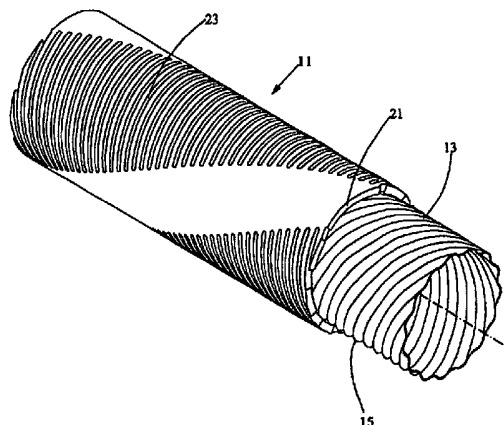
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(54) Title: SUBSEA FLEXIBLE PIPE



(57) Abstract

A flexible pipe (11) for subsea installation has a fluid impervious tube (13) surrounded by a structure pipe (21). The structure pipe (21) is a cylindrical monolithic member. It has at least two rows of slots (23) extending along the length of the wall. The slots (23) are evenly spaced apart, parallel and located on a helix (31). Each of the slots are in a row, which is also located on a helix (25), but extending in a different direction from the slot helix (31). Solid bands (27) extend between the rows of slots (23). Arc members (33) are located between each of the slots, the arc members (33) joining the bands (27). The structure pipe (21) surrounds a fluid impervious tube (13) which is corrugated.

SUBSEA FLEXIBLE PIPE

Technical Field

This invention relates in general to flexible pipes for oil and gas well installations and in particular to those used for subsea oil and gas production.

Background Art

In well production operations, flexible pipes are used for various purposes such as flowlines. A flexible pipe is herein considered to be a pipe having, at least during transportation and installation, sufficient flexibility along its longitudinal axis to accept a minimum radius of curvature around 6.5 times the diameter of the pipe. These flexible pipes must be able to withstand high internal pressures, as much as 5,000 psi. In underwater use for subsea well production, they must be able to withstand crushing due to external pressures as well as tensile loading during installation. In some installations, high temperatures are also encountered. In addition flexing should not affect the strength properties of the pipe.

Available flexible pipes rely on an inner polymeric tube to contain the high pressure fluid. While this works well enough at low temperature, high temperatures combined with pressure may make the polymers permeable to gas. This situation results in varying degrees of loss of transported fluid which accumulates between the inner and outer sheath which could cause the collapse of the inner sheath in case of rapid depressurization. Also this could cause accelerated corrosion of the reinforcing structure in case of hydrocarbon fluid containing corrosive agents such as H₂S, CO₂, etc.... In addition polymeric tubes are generally limited to temperatures less than 100 to 130 degrees C depending of the nature of the polymer.

To withstand high temperature service, a metallic internal liner would be highly desirable. However, it has not been used because of the inherent rigidity of metal incompatible with the requirement of flexibility of a flexible pipe. Some attempts have been made to use a metallic liner with a corrugated wall. Since in these attempts, it was only considered to operate within the yield strength of the material the wall thickness had to be very thin leading to a wave height to wall thickness ratio of the corrugations exceeding 8. This high ratio causes very deep corrugations, which take up a large radial portion of the flexible pipe wall thickness. Also the resulting thin wall thickness limits the pressure capability and offers reduced service life in case of corrosive fluids.

Flexible pipes also have a reinforcing structure surrounding the fluid containing tube. Typical reinforcing structure includes a combination of at least two cross helical tensile armors wrapped around a helical winding of interlocking strips. While workable, this structure has many parts and is expensive to manufacture.

Disclosure of Invention

The flexible pipe of this invention has a monolithic metal structure pipe which surrounds the fluid containing tube. The structure pipe has at least two rows of slots extending along the length of the wall to provide flexibility. Each of the slots extends substantially in a circumferential

1 direction over a fraction of 180 degrees. The space between the rows of slots defines at least two
2 solid bands which extend along the length of the structure pipe and which are free of slots to
3 provide tensile strength.

4 The row of slots and the band extend along helical lines. The arc members between the slots
5 also are on a helix, but inclined in a different direction and at a much larger helical angle with
6 regard to the axis of the flexible pipe. The slots are circumferentially spaced apart from each
7 other and parallel. The solid bands linked by the arc members provide tension capability even
8 without internal pressure.

9 The fluid containing tube is a metallic pipe having a corrugated wall with undulations. The
10 apparent pitch, or the width of each undulation, is selected to allow the pipe to be bent on a radius
11 that is around 6.5 times the diameter of the pipe with acceptable plastic strain according to the
12 material used. The corrugated tube has an initial outer diameter less than the inner diameter of the
13 structure pipe. For assembly, the corrugated tube slides easily into the structure pipe, due to the
14 annular clearance given. During the manufacturing acceptance pressure test, the fluid pressure
15 plastically deforms the corrugated tube outward into tight contact with the structure pipe.

16 Brief Description of Drawings

17 Figure 1 is an isometric view illustrating a portion of a flexible pipe constructed in accordance
18 with this invention.

19 Figure 2 is an isometric view illustrating the structure pipe for the flexible pipe of Figure 1.

20 Figure 3 is a sectional view of the structure pipe of Figure 2, taking along a plane indicated by
21 the numerals III-III of Figure 2.

22 Figure 4 is an enlarged sectional view of a portion of the corrugated tube of the flexible pipe
23 of Figure 1.

24 Figure 5 is a side view of the structure pipe with an end fitting of the flexible pipe of Figure 1.

25 Figure 6 is a sectional view of a flexible pipe jumper assembly constructed in accordance with
26 this invention.

27 Best Mode for Carrying Out Invention

28 Referring to Figure 1, flexible pipe 11 has a fluid containing tube 13 which is a solid metal
29 cylinder, impermeable to fluid and having a corrugated wall with undulations 15. Undulations 15
30 can be perpendicular to the liner axis as shown in Figure 6 or helicoidal as shown in Figure 1.
31 Undulations 15, referring to Figure 4, have a selected apparent pitch D, wall thickness WT for
32 each liner diameter to allow flexibility during installation, yet be able to withstand up to 5,000 psi
33 internal service pressure. The table below gives the desired dimensions for a suitable corrugated
34 tube in millimeters for 316L stainless steel, with ID and OD referring to inner and outer diameters
35 with a crest to crest distance D of 16 mm.

36	ID	OD	WT
37	104	117	1

1	173	186	1.5
2	216	231	2
3	266	282	2.5
4	310	326	3

5 Note that the wave height, which is the difference between the ID and OD divided by 2, is less
6 than seven times the wall thickness WT. A structure pipe 21 surrounds the corrugated tube 13.
7 Structure pipe 21, shown in Figure 2, is a monolithic or single piece metal pipe. Structure pipe 21
8 is cylindrical and has rows of parallel slots 23. In the embodiment shown, there are two rows of
9 slots 23, spaced opposite each other. Each slot 23 has a circumferential length defined by a first
10 end 23a and an opposite end 23b. This length is substantially less than 180 degrees.

11 For a structure pipe 21 having an inner diameter in the 4 to 12 inch range, the wall thickness is
12 from 0.4 to 0.8 inch, and the width of each slot is from 0.080 to 0.160 inch. A centerpoint 23c is
13 equidistant to the ends 23a, 23b and is located on a row helix 25. Helix 25 is at the same helix
14 angle or pitch for both rows of slots 23. The length of each of the slots 23 is preferably the same
15 within a central portion of support tube 21, and preferably the length of slots 23 in one row is the
16 same as the slots 23 in the other row. As shown in Figure 3, the centerpoints 23c are 180 degrees
17 apart from each other when two rows of slots 23 are employed.

18 The two rows of slots 23 define two bands 27 between them which are solid and free of slots
19 23. Bands 27 are also located on helices 29, which are parallel to the helices 25 for the rows of
20 slots 23. Helix 29 is within a range of 10 to 30 degrees relative to axis 30. The width of each
21 band 27 is uniform and constant throughout the central portion of support tube 21. The widths of
22 bands 27 are not necessarily the widths of the rows of slots 23, however. In the preferred
23 embodiment, the sum of the widths of bands 27 will cover 25 to 45 percent of the circumference,
24 with the widths of the slots 23 covering the remaining circumference.

25 Slots 23 are parallel to each other and inclined relative to axis 30 of wall 21 on a helix angle
26 that is other than 90 degrees, and preferably 65 to 85 degrees. An arc member 33 is defined
27 between each slot 23, joining the bands 27. Each arc member 33 is substantially located on a
28 helix 31 which inclines opposite to the helices 25, 29 and at a much higher helical angle, or
29 smaller pitch. Each arc member 33 is substantially perpendicular to helix 29 at the point of
30 intersection. The helix angle for helices 31 is preferably 65 to 85 degrees relative to axis 30.

31 Slots 23 provide flexibility, allowing pipe 11 to bend for transportation and installation far
32 beyond metallic material limitations. The arc members 33 are free to flex in the plane of the pipe
33 wall allowing shear motion of the tension bands 27 which in turn lowers greatly the moment
34 required to bend the pipe 11. Tension bands 27 linked by arc members 33 provide the tension
35 capability of structure pipe 21 when no internal pressure is present. Bending of the arc members
36 33 in a plane perpendicular to the pipe 11 keeps the tension bands 27 apart from each other,
37 preventing collapse of the pipe under tension without internal pressure. To achieve high tension

1 capability without pressure, a minimum ratio must be maintained between the wall thickness of
2 structure pipe 21 and the lengths of arc members 33. The lengths of arc members 33 can be
3 reduced and consequently the wall thickness by increasing the number of bands 27 to more than
4 the two shown. Hoop strength is provided by the small pitch helical arc members 33 linking the
5 sides of the two bands 27. The continuous helixes 31 of the arc members 33 balance torsion as
6 these helixes are opposite in direction to the helixes 25, 29.

7 When manufacturing pipe 11, the outer diameter (OD in Fig. 4) of corrugated tube 13 is sized
8 slightly smaller than the inner diameter of structure pipe 21. This difference provide the necessary
9 clearance to slide the corrugated tube 13 into the structure pipe 21. The diametrical clearance is
10 preferably about one percent of the inner diameter of structure pipe 21. For example, for an inner
11 diameter of structure pipe 21 of 4 inches, the clearance on a diameter is approximately 0.040 inch.

12 A more complete assembly for flexible pipe 11 is shown in Figures 5 and 6. A conventional
13 outer protection layer 35 will be placed over the structure pipe 21. The structure pipe 21 has a
14 transition zone 43 joining each central portion near each end of support tube 21. In transition
15 zone 43, slots 45 gradually decrease in circumferential length, while slots 23 in the central portion
16 of support tube 21 between the transition zones 43 are of the same length. This results in
17 increased width bands 46 within transition zone 43. Transition zone 43 joins a rigid pipe section
18 47 which has no slots. Rigid section 47 is a final end portion which joins a connecting flange 49,
19 and which couples to rigid subsea production equipment 50 (Fig. 6).

20 In Figure 6, details of structure pipe 21 are not clearly shown. However, both ends will have
21 a transition zone 43 and a rigid pipe section 47. A connector 53 is located on the opposite end
22 from flange 49 for connecting to a rigid pipe 55. In Figure 6, a flexible pipe jumper 11 is used to
23 connect rigid pipe 55 to rigid production equipment 50.

24 After assembling the corrugated tube 13 inside the structure pipe 21, an acceptance test
25 pressure will be applied to the flexible pipe 11 and will be sufficient to plastically and permanently
26 deform the corrugated tube 13 radially outward into contact with the inner diameter of structure
27 pipe 21. The material and dimensions of corrugated tube 13 are selected to exceed yield and
28 undergo permanent deformation as corrugated tube 13 expands radially into contact with
29 structural pipe 21. Structure pipe 21 will not undergo any plastic expansion in diameter while test
30 pressure is applied. After the test pressure is bled-off, the zero clearance between the outer
31 diameter of corrugated tube 13 with the inner diameter of structure pipe 21 provides adequate
32 strength for corrugated tube 13 to resist normal pressures expected to be encountered during use.

33 During installation, when undergoing curvature, the axial dimension or widths of the slots 23
34 will change. On the outer portion of the bend, the widths of slots 23 will increase, while on the
35 inner part of the bend, the widths of slots 23 may close entirely at its center 23c, with arc
36 members 33 touching each other. This will occur only at the minimum radius of curvature of
37 flexible pipe 11 and will create minimum localized plastic deformation

1 As long as the radius of curvature is above 6.5 times the diameter of flexible pipe 11 and
2 corrugated tube 13 will bend within acceptable plastic deformation. This is acceptable because
3 only one or possibly two bending to minimum radius and straightening cycles are applied during
4 the lifetime of the flexible pipe 11.

5 The invention has significant improvements. The structure pipe is of a single piece and
6 replaces a carcass and armors having several lengths of components. The monolithic structure
7 pipe is less expensive to manufacture than numerous parts prior art types, yet provides pressure,
8 tension and compression capabilities. The metallic corrugated tube permits substantial short
9 radius of curvature during installation yet is able to withstand high temperature and high pressure
10 during service life.

11 While the invention has been shown in only two of its forms, it should be apparent to those
12 skilled in the art that it is not so limited, but is susceptible to various changes without departing
13 from the scope of the invention.

Claims

1. A flexible pipe (11) having an axis (30), a cylindrical structure pipe (21) and means to contain the transporting fluid inside the structure pipe (21), the improvement characterized by the structure pipe (21) having at least two rows of slots (23), each of the slots extending circumferentially less than 180 degrees, defining at least two bands (27) extending helically along the length of the structure pipe (21) which is free of slots to provide tensile strength.
2. The flexible pipe (11) according to claim 1, wherein the slots (23) of one of the rows define arc members (33) between them which are substantially located on a helix (31) being inclined opposite to and having a much higher helical angle than the helixes (25, 29) formed by the rows of slots (23) and the two bands (27).
3. The flexible pipe (11) according to claim 1, wherein the structure pipe (21) has a transition zone (43) near at least one end of the structure pipe (21) in which the lengths of the slots (23) gradually decrease toward said end.
4. The flexible pipe (11) according to claim 1, wherein the means to contain the transporting fluid is a fluid impervious tube (13).
5. The flexible pipe (11) according to claim 4, wherein the tube (13) comprises a cylindrical conduit having corrugated undulations (15) to enhance flexibility.
6. The flexible pipe (11) according to claim 4, wherein the tube (13) comprises a cylindrical conduit having corrugated undulations (15) to enhance flexibility, the tube having an outer diameter which during assembling is less than an inner diameter of the structure pipe (21), and which is plastically deformed into contact with the inner diameter of the structure tube with internal pressure.



7. The flexible pipe (11) according to claim 4, wherein the tube (13) has an axis (30), the slots (23) are evenly spaced apart from each other to define arc members (33) between each of the slots, each of the slots having a length determined by two ends (23a, 23b) which are circumferentially apart from each other, the arc members being parallel to each other and oriented relative to the axis (30) on an arc member helix (31), each of the slots having a centerpoint (23c) equidistant between its ends, the centerpoints within the same row being located on a row helix (25) which is in the opposite direction to arc member helix (31) and substantially transverse to the lengths of the slot, the row helix of each of the rows being at a row helix angle which is the same as the other rows, and each of the bands (27) joins the arc members and has a centerline which is on a band helix (29) which is at a band helix angle that is the same as the row helix angle.

8. The flexible pipe (11) according to claim 7, wherein at least a central portion of the slots (23) within each of the rows has the same length as the slots within the other of the rows.

9. The flexible pipe (11) according to claim 7, wherein at least a central portion of the slots (23) within each of the rows has the same length as the slots within the other of the rows, and wherein the structure pipe (21) has a transition zone (43) joining the central portion near at least one end of the support tube in which the lengths of the slots gradually decrease toward said end.

10. The flexible pipe (11) according to claim 7, wherein the arc member helix (31) is at a much larger helix angle than the row helix (25) angle and the band helix (29) angle and inclines in an opposite direction.



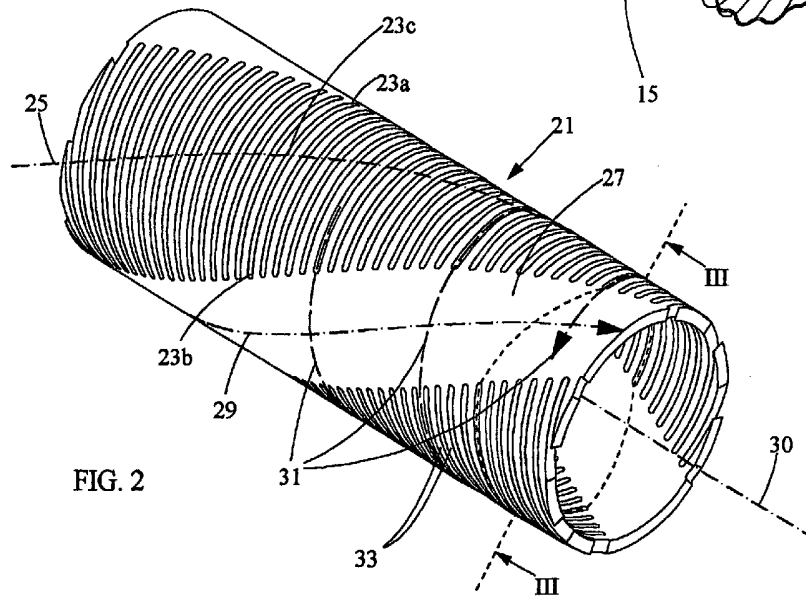
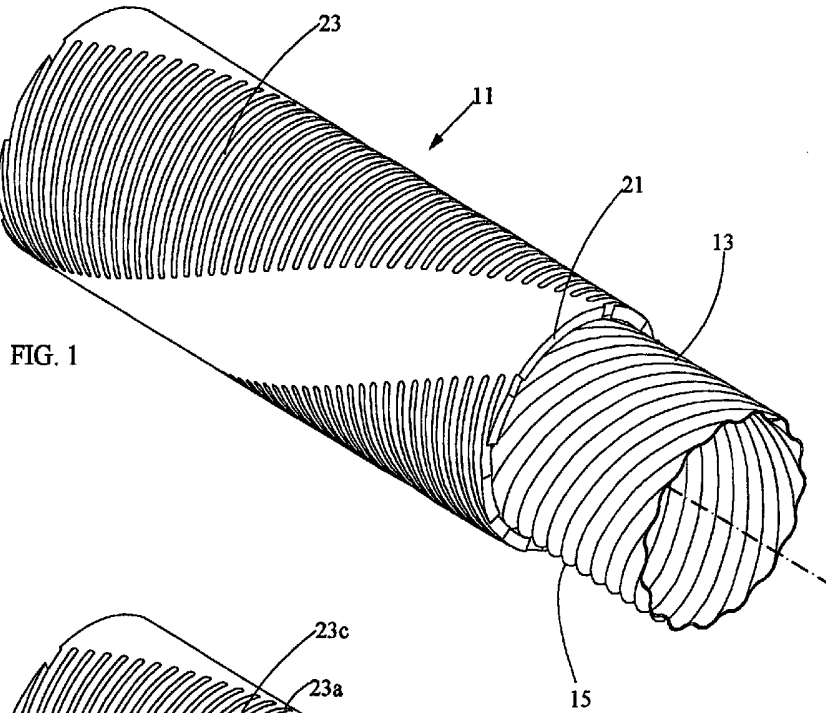
11. The flexible pipe (11) according to claim 7, wherein the tube (13) comprises a cylindrical conduit having corrugated undulations (15) to enhance flexibility.
- 5 12. The flexible pipe (11) according to claim 7, wherein the tube (13) comprises a cylindrical conduit having corrugated undulations (15) to enhance flexibility, the tube having an outer diameter which during assembling of the flexible pipe is less than an inner diameter of the structure pipe (21), and which is plastically deformed into contact with the inner diameter of the structure pipe with internal fluid pressure.
- 10 13. The flexible pipe (11) according to claim 1, wherein the structure pipe (21) is of a monolithic single piece construction.
- 15 14. The flexible pipe (11) according to claim 1, wherein the slots (23) enhance elastic flexing beyond the elastic flexing of the same size and material solid pipe, and wherein the sealing means is a fluid impervious tube (13) having corrugated undulations (15) to enhance elastic flexibility beyond the elastic flexing of the non corrugated tube with the same wall thickness and material.
- 20 15. The flexible pipe (11) according to claim 14, wherein the structure pipe (21) is of a monolithic single piece construction and the fluid impervious tube (13) is inserted within the structure pipe (21).
- 25 16. The flexible pipe (11) according to claim 14 wherein the inner fluid impervious tube (13) has an outer diameter which during installation is less than an inner diameter of the structure pipe (21) by an amount sufficient to provide an annular clearance between the fluid impervious tube (13) and the structure pipe (21), and which is expanded into contact with the inner diameter of the structure pipe (21) with internal fluid pressure.
- 30 35



17. A method of manufacturing a flexible pipe (11), comprising :
- providing a metal monolithic construction fluid pervious structure pipe (21) made flexible by placing at least two rows of slots (23) in the structure pipe, extending helically along the structure pipe (21), which has an inner diameter,
 - providing a metal fluid impervious tube (13) which has an outer diameter that is a selected amount less than the inner diameter of the structure pipe (21), then
 - inserting the metal fluid tube (13) into the structure pipe (21), then
 - applying an internal fluid pressure to the inner fluid tube (13) at a sufficient level to permanently expand the outer diameter of the fluid tube (13) into zero clearance with the inner diameter of the structure pipe (21)
18. The method according to claim 17, wherein the metal impervious tube (13) has corrugations (15).



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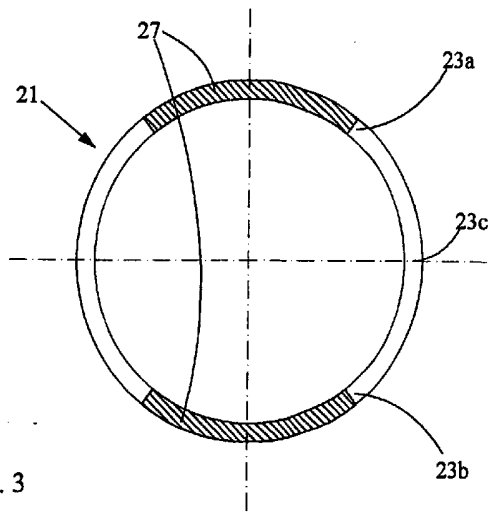


FIG. 3

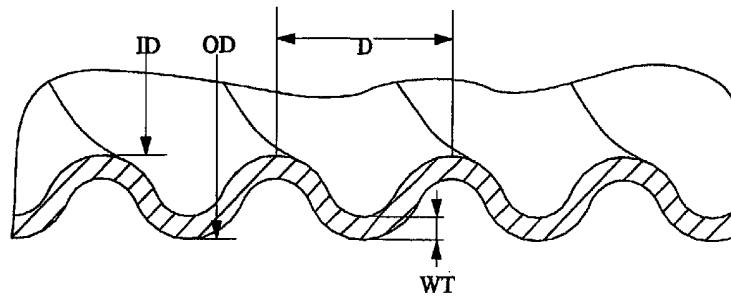


FIG. 4

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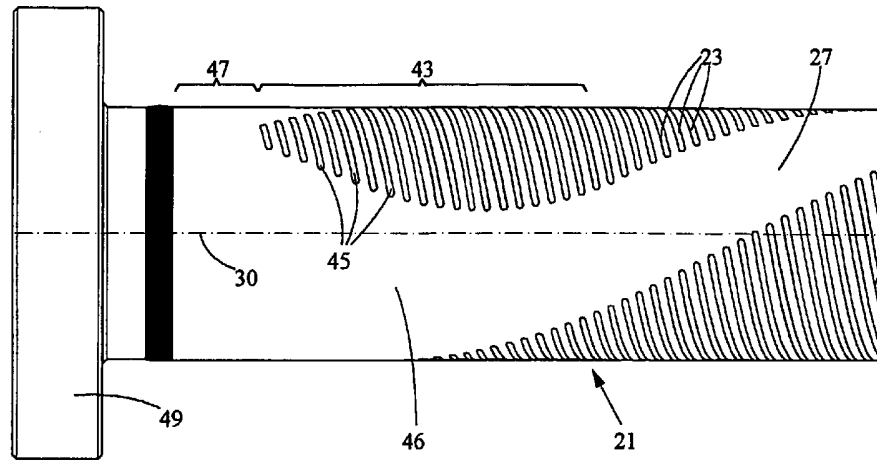


FIG. 5

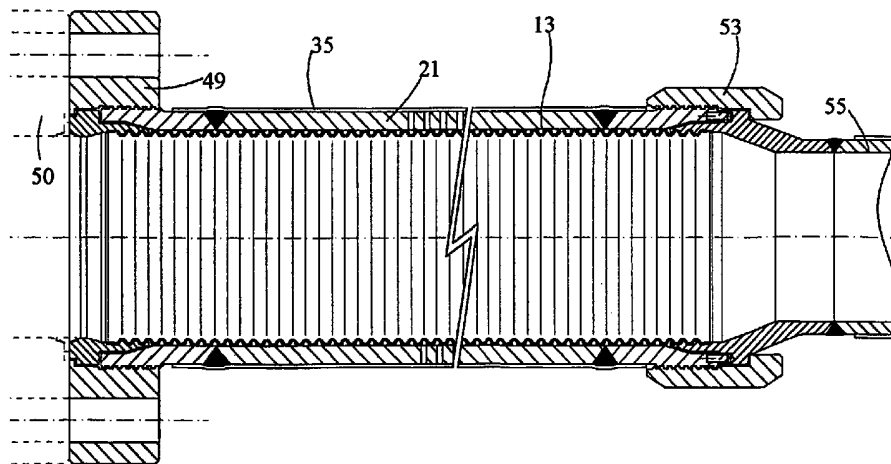


FIG. 6