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(54) Title: RESIDUAL CURVATURE BEFORE STINGER IN S-LAY

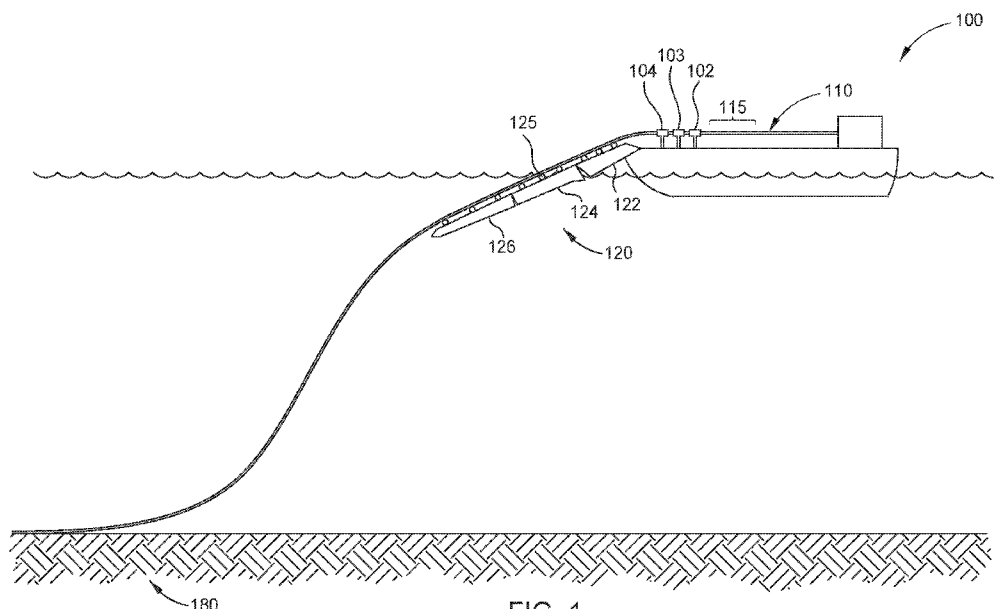


FIG. 1

(57) Abstract: The present disclosure relates to apparatus and methods for introducing residual curvature to sections of pipeline during S-lay, where the residual curvature is introduced on the lay barge (100) before the selected section reaches the stinger (120). By bending a pipeline section before the pipeline section reaches the stinger, the pipeline can be monitored during bending, by the bending apparatus (104) to ensure that the proper curvature is induced. Additionally, introducing the curvature before the stinger allows residual curvature methods to be used on S-lay vessels where the stinger or stinger rollers are not adjustable while the pipeline is in place.



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RESIDUAL CURVATURE BEFORE STINGER IN S-LAY

BACKGROUND

Field

[0001] Embodiments of the disclosure relate to the laying of pipeline onto the seabed.

Description of the Related Art

[0002] The S-lay technique of laying offshore pipelines has been used for many years. In this technique, pipeline is fed near horizontally off the back of a lay barge, often over a stinger, before curving down to and eventually lying on the seabed. The "S"-shaped profile of the pipeline between the lay barge and the seabed gives the technique its name.

[0003] Once in use, the pipeline is subjected to high temperatures and pressures and may significantly expand and contract longitudinally during operation. This expansion and contraction can result in axial compressive forces which may cause undesirable buckling at sections of the pipeline and may ultimately cause failure of the pipeline. One method of preventing or mitigating buckling is known as the residual curvature method, a version of which is described in U.S. Patent No. 6,910,830 for reel-lay vessels. In this method, a plastic bending strain is introduced to selected sections of the pipeline before the pipeline is laid on the seabed. The curved sections with residual stress/strain created by the plastic bending introduce bending imperfection, and thus increase the likelihood of buckling at the bending area compared to other pipeline sections with fewer imperfections. The introduction of residual stress/strain functions similarly to laying pipeline onto a vertical sleeper, but is significantly less expensive because it does not require the vertical sleeper's cost.

[0004] To perform the residual curvature method during S-lay, curvature may be induced in a section of the pipeline by either adjusting the position of the rollers on the stinger or adjusting the configuration of the stinger itself (e.g., from

a shallow water configuration to a deep water configuration and vice versa) while the pipeline is being laid. However, since the selected section of the pipeline is at least partially underwater when bending using a stinger, it is difficult to monitor the section and ensure that the proper amount of strain is being introduced. Additionally, this method is only possible if the stinger or the rollers are capable of being adjusted with the pipeline in place.

[0005] There is a need for improved apparatuses and methods for introducing residual curvature during S-lay.

SUMMARY

[0006] In one embodiment, a vessel for laying a pipeline on a seabed is provided. The vessel includes a bending apparatus disposed on a deck of the vessel for inducing a bending strain in a section of a pipeline. The vessel also includes a stinger coupled to an end of the vessel.

[0007] An apparatus for inducing a bending strain in a section of a pipeline, the bending apparatus comprising: a first support; a first plurality of adjustable rollers coupled to the first support; a second support; a second plurality of adjustable rollers coupled to the second support, the second plurality of adjustable rollers opposing the first plurality of adjustable rollers; and one or more actuators configured to change a radius of curvature of the first plurality of adjustable rollers or the second plurality of adjustable rollers.

[0008] In another embodiment, a method for laying a pipeline on a seabed is provided. The method includes inducing a bending strain in a section of a pipeline using a bending apparatus. The method further includes feeding the section of the pipeline over a stinger, wherein the bending strain is induced in the section of the pipeline before the section of the pipeline reaches the stinger. The method further includes laying the section of the pipeline on a seabed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, and the disclosure may admit to other equally effective embodiments.

[0010] Figure 1 illustrates a vessel laying a pipeline using an S-lay technique, according to an embodiment described herein.

[0011] Figure 2 illustrates a side view of a bending apparatus, according to an embodiment described herein.

[0012] Figure 3 illustrates a vessel laying a pipeline using an S-lay technique, according to an embodiment described herein.

[0013] Figures 4A, 4B, and 4C illustrate side views of a bending apparatus, according to embodiments described herein.

[0014] Figure 5A illustrates a pipeline section with induced residual curvature lying over a depression in the seabed, according to an embodiment described herein.

[0015] Figure 5B illustrates a pipeline section with induced residual curvature lying over a depression in the seabed, according to an embodiment described herein.

[0016] Figure 5C illustrates a pipeline section with induced residual curvature lying over a depression in the seabed, according to an embodiment described herein.

[0017] Figure 6 illustrates a flow diagram of a method for laying a pipeline on a seabed, according to an embodiment described herein.

[0018] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0019] The present disclosure relates to apparatus and methods for introducing residual curvature to sections of pipeline during S-lay, where the residual curvature is introduced on the lay vessel before the selected section reaches the stinger. By bending a pipeline section before the pipeline section reaches the stinger, the pipeline can be monitored during bending to ensure that the proper curvature is induced. Additionally, introducing the curvature before the stinger allows residual curvature methods to be used on S-lay vessels where the stinger or stinger rollers are not adjustable while the pipeline is in place.

[0020] Figure 1 illustrates a vessel laying a pipeline using an S-lay technique, according to an embodiment described herein. A vessel or lay barge 100 is used to lay a pipeline 110 onto the seabed 180. Any suitable vessel capable of performing an S-lay technique may be used. In one embodiment, the pipeline 110 has a diameter between about 4.5 inches and about 60 inches. The pipeline is passed through a plurality of optional roller apparatuses 102 and 103 and a bending apparatus 104 before passing over the stinger 120, which is coupled to an end of the vessel 100. In some example, the roller apparatuses 102, 103 may include guide rollers for facilitating guiding of the pipeline 110 through the bending apparatus. In some examples, one or both of the roller apparatuses 102, 103 may be replaced with a tensioner. In yet another example, a tensioner is included between roller apparatuses 102, 103 and the bending apparatus 104.

The stinger 120 is divided into sections 122, 124, and 126. A plurality of rollers 125 is disposed along the length of the stinger 120 for feeding the pipeline off the stern of the vessel 100.

[0021] The bending apparatus 104 can be disposed anywhere on a deck of the vessel 100 through which the pipeline 110 passes before reaching the stinger 120, for example the bending apparatus 104 can be placed before, after, or in-between roller apparatuses 102 and 103. In one example, the bending apparatus is placed between a tensioner and the stinger 120. In one embodiment, the bending apparatus 104 is located at a pipeline welding station, or adjacent thereto, on the vessel 100. The bending apparatus 104 is used to induce a bending strain in a section 115 of the pipeline. As shown in Figure 1, the section 115 is approaching the bending apparatus 104 and has yet to have the bending strain induced. In one embodiment, the bending apparatus is configured to induce a plastic bending strain of about 0.2% to about 1%, such as about 0.2% to about 0.6%, or about 0.9% to about 0.5%, in the section 115. In one embodiment, the bending apparatus 104 is a roller apparatus similar to roller apparatuses 102 and 103. However, in such an embodiment, the roller apparatuses 102, 103 are configured as guide rollers (for example, including one or more linear arrangements of rollers) which do not induce bending, while the bending apparatus is configured to induce bending to a section 115 of the pipeline 110.

[0022] Figure 2 illustrates a side view of a bending apparatus 104 according to one embodiment. A plurality of rollers 131, 132, 133, 134, and 135 are disposed in the bending apparatus 104. The rollers may be of any suitable diameter that provides the desired curvature. The rollers may be formed from any suitable material including metals and alloys, which may be coated to improve performance, such as with epoxy or other resinous coatings. In one embodiment, one of these rollers, for example roller 133, is adjustable, meaning that the

position of roller 133 can be altered as desired relative to the remaining rollers. Adjustable rollers, such as roller 133, may be coupled with an actuator 190 that is connected to an onboard computer in order to make adjustments as pipeline laying conditions change. In such an example, one or more sensors (or other data inputs) may be configured to provide data to the onboard computer. In response to the received data, the computer may facilitate movement of the position of one or more rollers. Data received by the onboard computer may include, for example, seabed topography.

[0023] In another embodiment, multiple rollers (such as one or more of rollers 131-135) may be adjustable, and may likewise have positions controlled by a respective actuator 190 and an onboard computer. While five rollers 131 to 135 are shown in Figure 2, it is contemplated that any desirable number of rollers may be used and that any of the rollers 131-135 may be adjustable. Likewise, it is contemplated that one or more actuators 190 may be utilized, such as that rollers 131-135 are adjustable individually or in groups.

[0024] During the laying of the pipeline 110, the pipeline 110 is fed through the rollers 131 to 135. When the pipeline section 115 into which a bending strain is to be induced passes through the rollers 131 to 135, one or more of the rollers 131 to 135 may be repositioned to induce a plastic bending strain into the section 115. For instance, in one embodiment, rollers 131, 132, 134, and 135 are fixed, and roller 133 is moved upward to create a plastic bending strain in the section 115, either while the pipeline 110 is being laid or while the pipeline 110 is static. In another embodiment, the bending apparatus 104 is repositioned relative to the pipeline 110, such as by moving the bending apparatus 104 vertically relative to the deck of the vessel 100 (shown in Figure 1), to induce a plastic bending strain into the section 115. In such an example, one or more rollers 131-135 may remain fixed relative to the bending apparatus, while the bending apparatus is moved relative to the deck of the vessel 100.

[0025] Figure 3 illustrates a vessel laying a pipeline using an S-lay technique, according to an embodiment described herein. After passing through the bending apparatus 104, the section 115 (having a bend therein) passes over the stinger 120 before coming to rest on the seabed 180. The section 115 bends elastically as the section 115 passes over the stinger 120, but no additional plastic bending strain is applied by the stinger 120 or stinger rollers 125. Figure 3 shows the section 115 in between the stinger 120 and the seabed 180, retaining the residual curvature created by the bending strain induced by the bending apparatus 104. In one embodiment, the section 115 has a length between about 10 meters (m) and about 100 m.

[0026] Due to the tension applied to the pipeline 110 at the vessel 100, the strain on the section 115 is reduced before the section 115 comes to lie on the seabed 180. For instance, for a section 115 with an initial plastic bending strain of about 0.5% created by the bending apparatus 104, the section 115 comes to rest on the seabed 180 with a residual bending strain of about 0.1% to about 0.3%, such as about 0.2%.

[0027] Figure 4A illustrates a side view of a bending apparatus 404A according to one embodiment. The bending apparatus 404A is similar to bending apparatus 104, and may be used in place thereof. A plurality of rollers 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, and 156 are disposed in the bending apparatus 404. The top rollers 151-156 are coupled together by a flexible coupling 191, such leaf spring, which is attached to an adjusting arm 157. Similarly, the adjusting arm 157 may be formed from a flexible material, such as a leaf spring, to facilitate adjustment of the positions of the rollers 151-156. The adjusting arm 157 is in turn coupled to a support 159, which is supported on the deck of a vessel 100 (shown in Figure 1). A first actuator 190 is coupled to and extends between the support 159 and the flexible coupling 191 to facilitate relative movement therebetween. Movement of the actuator 190,

which is coupled to a central portion of the flexible coupling 191, induces a desired radius of curvature into the flexible coupling 191 and the rollers 151-156 coupled thereto. One or both of the flexible coupling 191 and the adjusting arm 157 may be flexible to allow a desired radius of curvature to be achieved.

[0028] Similarly, the bottom rollers 141-150 are coupled by a flexible coupling 193. The flexible coupling 193 couples the rollers 141-150 to the adjusting arm 158, which is similar to adjusting arm 157. A second actuator 190 is coupled to and extends between the support 160 and the flexible coupling 193. Movement of the actuator 190 moves the flexible coupling 193 relative to the support 160 to achieve a desired radius of curvature of the flexible coupling 193 and the rollers 141-150 coupled thereto. It is contemplated that suitable actuators included, for example, a stepper motor, a hydraulic actuator, a pneumatic actuator, an electric motor, or magnetic actuator, and/or a mechanical actuator.

[0029] The bottom rollers 141 through 150 and the top rollers 151 through 156 may be arranged in a straight line or in a curved arcuate shape that is either convex or concave relative to the deck of the vessel. The bottom rollers 151 through 156 may have the same or different radius of curvature as formed by the top rollers 151 through 156. For example, the bottom rollers 141 through 150 may be arranged in a curved arcuate shape, while top rollers 151 through 156 are arranged in an opposite curved shape, or in a straight line. In such an example, the radius of curvature of the shape formed by the bottom rollers 141 through 150 may be the same or different than the radius of curvature formed by the top rollers 151 through 156. In some embodiments, the bottom rollers have a convex shape and the top rollers a concave shape.

[0030] In some embodiments, the supports 159 and 160 may be vertically adjustable in relation to the deck of the vessel, for example, by actuators 194. For example, as supports 159 and 160 are lowered the rollers may be adjusted

to form an arc in which the center of curvature is vertically above the rollers, and, alternatively, when the supports are raised the rollers may be adjusted to form an arc in which the center of curvature is vertically below the rollers. Additionally, the supports may be individually adjustable, for example, support 159 may be raised or lowered at a different rate than support 160, and support 159 may move in a direction opposite to that of 160. Actuation of the supports 159 and 160 may not only facilitate adjustment of curvature, but may also influence the force applied to section 115 of the pipeline 110.

[0031] In one embodiment, bottom rollers 141 through 150 and/or top rollers 151 through 156 are individually adjustable in order to provide a desired curve or radius of bending. In another embodiment, any of the rollers within bending apparatus 404 are dependently adjustable, meaning that a position of one or more rollers is dependent upon (and moves in response to) the position or changes of position of another roller. In such an example, the adjusting arms 157 and 158 may allow for a curve of a certain radius to be formed.

[0032] In other embodiments, the rollers are not adjustable, and the radius of the arc formed by the rollers is set. In such an example, actuation may be limited to the supports 159, 160. In such an example, which may be combined with other examples, the supports 159, 160 may be raised or lowered to produce bending.

[0033] While the configuration of ten rollers 141-150 on bottom and six rollers 151-156 on top is shown in FIG 4A, it is contemplated that any desirable number of rollers may be used. It is also contemplated that the rollers may all be stationary in relation to each other or that one or more of the rollers may be adjustable. Furthermore, while the configuration of an arc is shown for rollers 141 to 150 in FIG. 4A, it is contemplated that the arc formed may have the opposite curvature, or no curvature. Furthermore, rollers on the top (151 through 156) may

also form an arc with the center of curvature vertically above or below the rollers (e.g., the direction of curvature may be downward or upward).

[0034] During operation the pipeline 110 is fed through the rollers 141 to 156. When the pipeline section 115 into which a bending strain is to be induced passes through the rollers 141 to 156, one or more of the rollers 141 to 156 may be repositioned to induce a plastic bending strain into the section 115. For instance, in one embodiment, rollers 141 through 156 are simultaneously raised upward to create a plastic bending strain of about 0.6% or less in the section 115. A plastic bending strain of about 1% or less, such as about 0.8% or less, about 0.6% or less, about 0.5% or less, about 0.4% or less, or such as about 0.2% to about 0.8%, or about 0.4% to about 0.6% may provide sufficient bending without causing overbending or buckling.

[0035] Figure 4B illustrates a side view of a bending apparatus 404B according to one embodiment. The bending apparatus 404B is similar to bending apparatus 104, and may be used in place thereof. In the bending apparatus 404B, the support 159 and upper rollers 151-156 coupled thereto are offset relative to the support 160 and the lower rollers 141-150. As illustrates, none of the rollers 151-156 vertically overlap with the rollers 141-150. It is contemplated, however, that one or more of the rollers 151-156 may overlap with one or more of the rollers 141-150. Additionally, it is contemplated that either of the rollers 151-156 or the rollers 141-150 may be positioned closer to the stinger in the offset configuration of bending apparatus 404B.

[0036] In addition, the rollers 141-156 of the bending apparatus 404B are individually coupled to actuators 190 that allow for individual adjustment and positioning of the rollers 141-156. In such an example, the arms 157, 158 may be rigid and/or linear to facilitate accurate positioning of the rollers 141-156. It is to be noted, however, that the rollers 141-156 of the bending apparatus 404A may

be individually actuated as shown in Figure 4B. Likewise, bending apparatus 404B may be actuated in a manner as discussed with respect to Figure 4A.

[0037] Figure 4C is similar to figure 4A, but in bending apparatus 404C the upper rollers 151 through 156 form a curved arcuate shape. The upper rollers 151-156 define a radius of curvature greater than a radius of curvature of the lower rollers 141-150 (e.g., the lower rollers 141-150 have a greater degree of curvature than the upper rollers 151-156).

[0038] The bending apparatus discussed herein, such as bending apparatuses 104, 404A, and 404B, may also be used to compensate for irregular topology on the seabed. Figure 5A illustrates a pipeline section 115 with induced residual curvature lying over a depression 185 in the seabed 180, according to an embodiment described herein. The pipeline section 115 of the pipeline 110 has two residually curved subsections 115A and 115B induced by a bending apparatus as shown in Figure 4A or Figure 4B. The subsections 115A and 115B, which have a center of curvature that is below the pipeline and an arc that is concave downward relative to the seabed 180, rest on the edges of the depression 185, allowing the section 115 to rest across the span with reduced stress as compared to an unbent pipeline.

[0039] Figure 5B illustrates a pipeline section 115 with induced residual curvature lying over a depression 185 in the seabed 180, according to an embodiment described herein. The pipeline section 115 of the pipeline 110 has a residually curved subsection 115C induced by a bending apparatus as shown in Figure 4. The subsection 115C, which has a center of curvature that is above the pipeline and an arc that is concave upward relative to the seabed 180, rests across the span of the depression 185, allowing the section 115 to rest across the span with reduced stress as compared to an unbent pipeline.

[0040] Figure 5C illustrates a pipeline section 115 with induced residual curvature lying over a depression 185 in the seabed 180, according to an embodiment described herein. The pipeline section 115 of the pipeline 110 has residually curved subsections 115A, 115B, and 115C induced by a bending apparatus as shown in Figure 4. The subsections 115A and 115B, which have a center of curvature that is below the pipeline rest on the edges of the depression 185, and the subsection 115C, which has a center of curvature that is above the pipeline and an arc that is concave upward relative to the seabed 180, rests across the span of the depression 185, allowing the section 115 to rest across the span with reduced stress as compared to an unbent pipeline.

[0041] Figure 6 illustrates a flow diagram 600 of a method for laying a pipeline on a seabed, according to an embodiment described herein. At operation 601, a bending strain is induced in a section of a pipeline, as described with respect to Figures 1, 2, and 3 above. In one embodiment, the bending strain is about 0.5%.

[0042] In one embodiment, which can be combined with other embodiments, the inducing a bending strain is sequentially repeated, such that a plurality of selected sections of the pipeline each have a bending strain introduced therein. In another embodiment, the section of the pipeline is monitored while the bending strain is being induced. The bending apparatus is adjusted to maintain the bending strain such that a desired curvature is achieved in the section of the pipeline. In one embodiment, a second bending strain is induced in a subsequent section of the pipeline in a direction opposite to the direction of the first bending strain.

[0043] At operation 602, the section of the pipeline is fed over a stinger. The bending strain is induced in the section of the pipeline before the section of the pipeline reaches the stinger. In one embodiment, the stinger is maintained in a fixed configuration while the section of the pipeline is fed over the stinger. At

operation 603, the section of the pipeline is laid on a seabed. In one embodiment, the section of the pipeline is laid on the seabed with a residual strain of about 0.2%.

[0044] The apparatus and methods described herein are believed to offer several advantages. First, because the pipeline is bent and the curvature introduced while the pipeline is still on the vessel, the pipeline can be monitored as the pipeline passes through the bending apparatus. If the amount of strain induced in a section of the pipeline is too high, the pipeline may buckle during bending. If the amount of strain induced is too low, the section may have insufficient residual curvature when the section is laid on the seabed. By monitoring the pipeline during bending, the amount of strain can be adjusted so that a desired curvature is achieved.

[0045] Additionally, because neither the stinger nor the stinger rollers require adjustment to induce the bending strain, the methods and apparatus described herein can be utilized on S-lay vessels which are incapable of adjusting the stinger rollers or stinger configuration while the pipeline is in place.

[0046] Furthermore, the use of a bending apparatus capable of bending in a vertical direction relative to a deck of the vessel enables the inducing of opposite residual curvatures in a section of the pipe, as shown, for instance, in Figure 5C. Inducement of opposite residual curvatures is normally difficult to achieve during S-lay. The ability to induce opposite residual curvatures allows for greater control of pipeline geometry in response to seabed topography, further reducing the possibility of undesirable buckling or pipeline failure.

[0047] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised

without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A vessel for laying a pipeline on a seabed, comprising:
a vessel;
a bending apparatus disposed on a deck of the vessel for inducing a bending strain in a section of a pipeline;
a stinger coupled to an end of the vessel.
2. The vessel of claim 1, wherein the bending apparatus comprises one or more adjustable rollers.
3. The vessel of claim 2, wherein the bending apparatus is configured to induce a bending strain by adjusting the height of the one or more adjustable rollers in a vertical direction relative to the deck of the vessel.
4. The vessel of claim 2, wherein the bending apparatus further comprises one or more actuators connected to the one or more adjustable rollers.
5. The vessel of claim 2, wherein the one or more rollers comprises a plurality of bottom rollers with a curved arcuate shape that is convex relative to a deck of the vessel.
6. The vessel of claim 1, wherein the bending apparatus comprises a plurality of fixed rollers attached to an adjustable support connected to one or more actuators.
7. The vessel of claim 1, wherein the bending apparatus comprises a plurality of rollers and a plurality of actuators, and wherein each actuator of the plurality of actuators is coupled to a respective roller of the plurality of rollers.
8. An apparatus for inducing a bending strain in a section of a pipeline, the bending apparatus comprising:

a first support;
a first plurality of adjustable rollers coupled to the first support;
a second support;
a second plurality of adjustable rollers coupled to the second support, the second plurality of adjustable rollers opposing the first plurality of adjustable rollers;
and
one or more actuators configured to change a radius of curvature of the first plurality of adjustable rollers or the second plurality of adjustable rollers.

9. The apparatus of claim 8, further comprising one or more actuators configured to adjust a vertical position of the first support and the second support.

10. The apparatus of claim 9, further comprising a first flexible coupling that connects each roller of the first plurality of rollers.

11. The apparatus of claim 10, further comprising a second flexible coupling that connects each roller of the second plurality of rollers.

12. The apparatus of claim 8, wherein the radius of curvature of one of the first plurality of rollers or the second plurality of rollers is fixed.

13. The apparatus of claim 12, wherein the first plurality of rollers is coupled to the support by a flexible arm.

14. The apparatus of claim 12, wherein the one or more actuators is centrally located with respect to the first plurality of adjustable rollers.

15. A method for laying a pipeline on a seabed, comprising:
inducing a first bending strain in a section of a pipeline using a bending apparatus;

feeding the section of the pipeline over a stinger, wherein the bending strain is induced in the section of the pipeline before the section of the pipeline reaches the stinger;

laying the section of the pipeline on a seabed.

16. The method of claim 15, further comprising:
sequentially repeating the inducing a bending strain for a plurality of sections of the pipeline.

17. The method of claim 15, further comprising:
monitoring the pipeline during the inducing a bending strain; and
adjusting the bending apparatus to maintain the bending strain.

18. The method of claim 15, wherein the inducing a bending strain comprises creating a bending strain of about 0.6% or less in the section of the pipeline.

19. The method of claim 15, wherein the section of the pipeline is laid on the seabed with a residual strain of about 0.3% or less.

20. The method of claim 16, further comprising:
inducing a second bending strain in a subsequent section of the pipeline using the bending apparatus in a direction opposite to the direction of the first bending strain.

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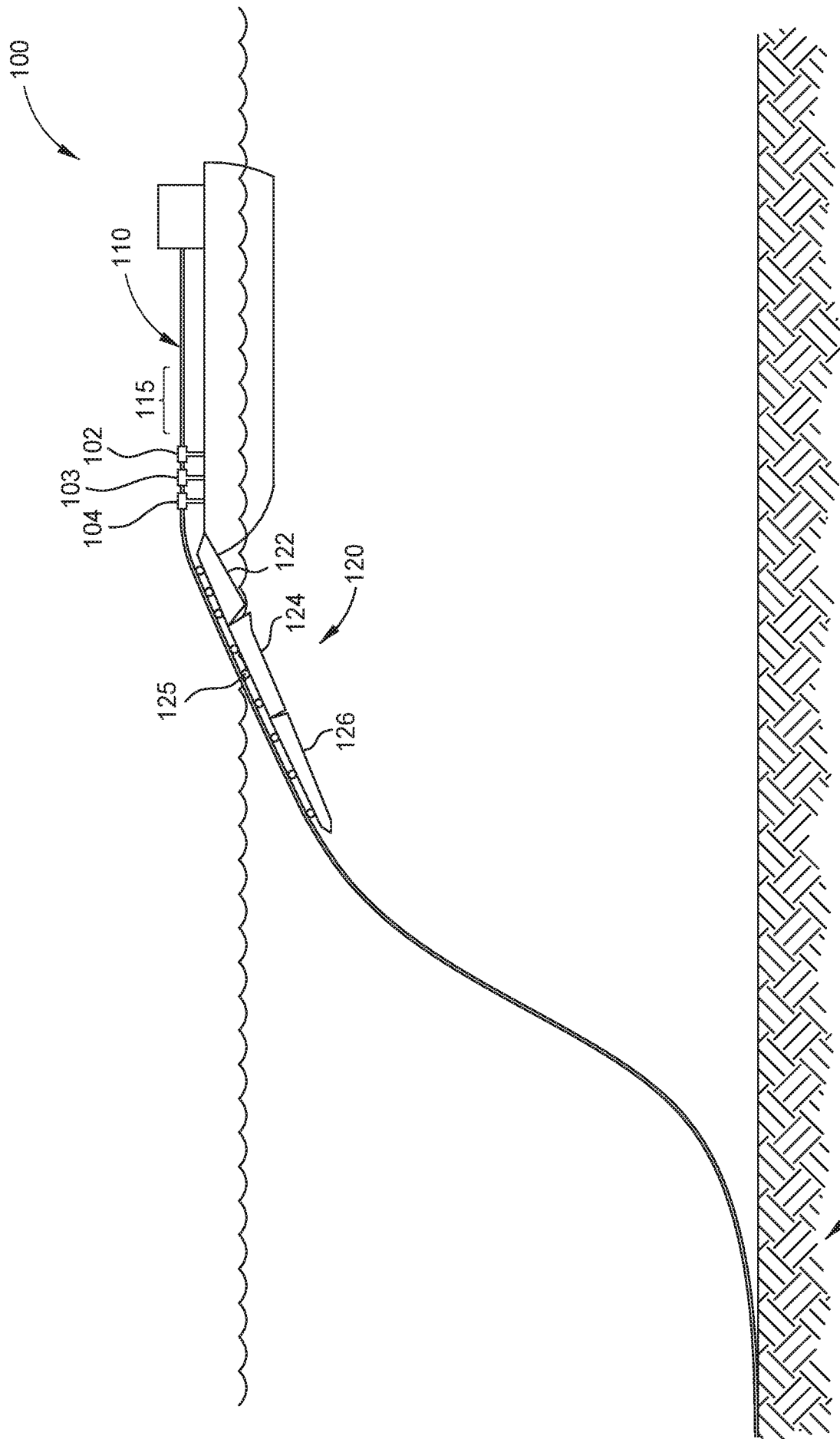


FIG. 1

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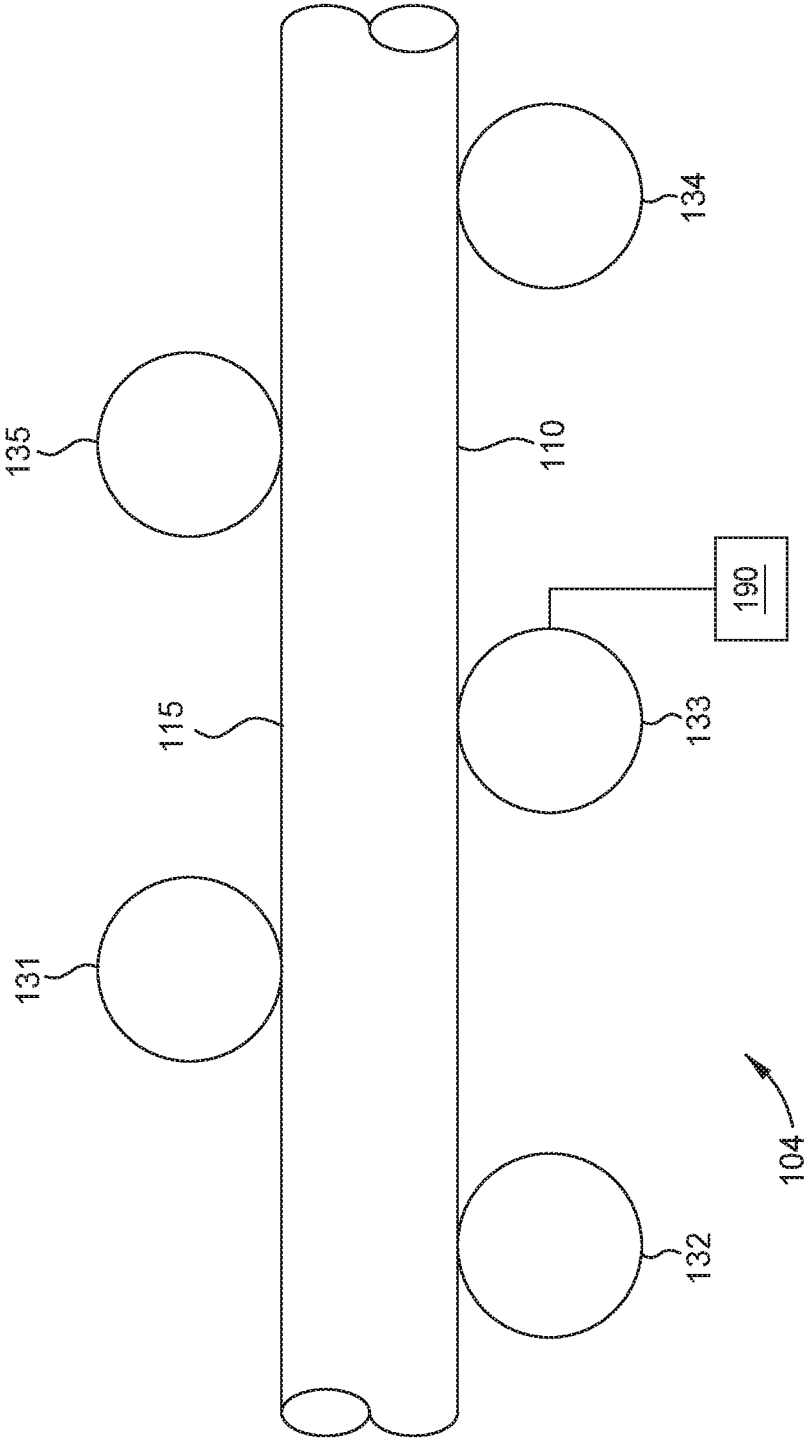


FIG. 2

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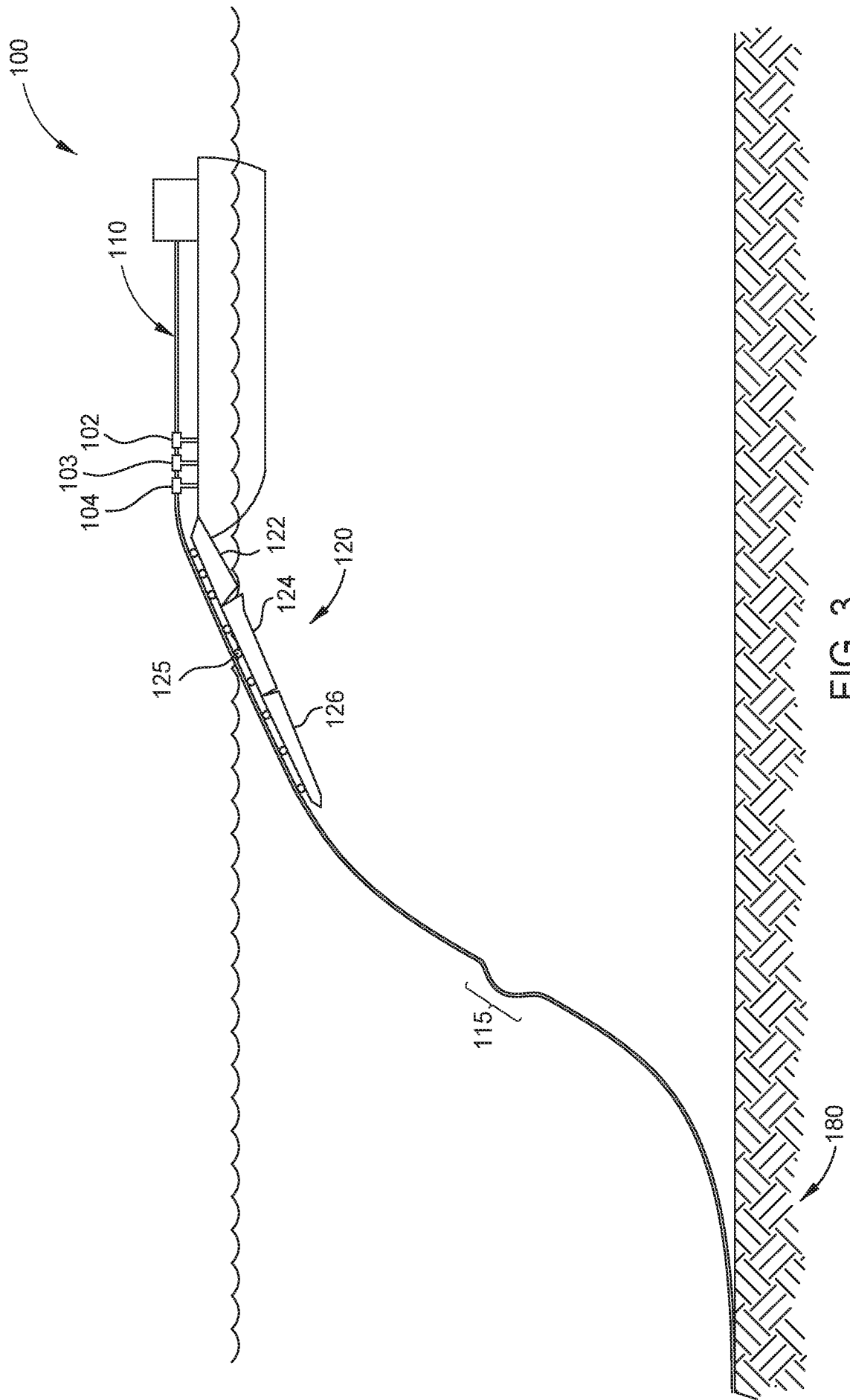


FIG. 3

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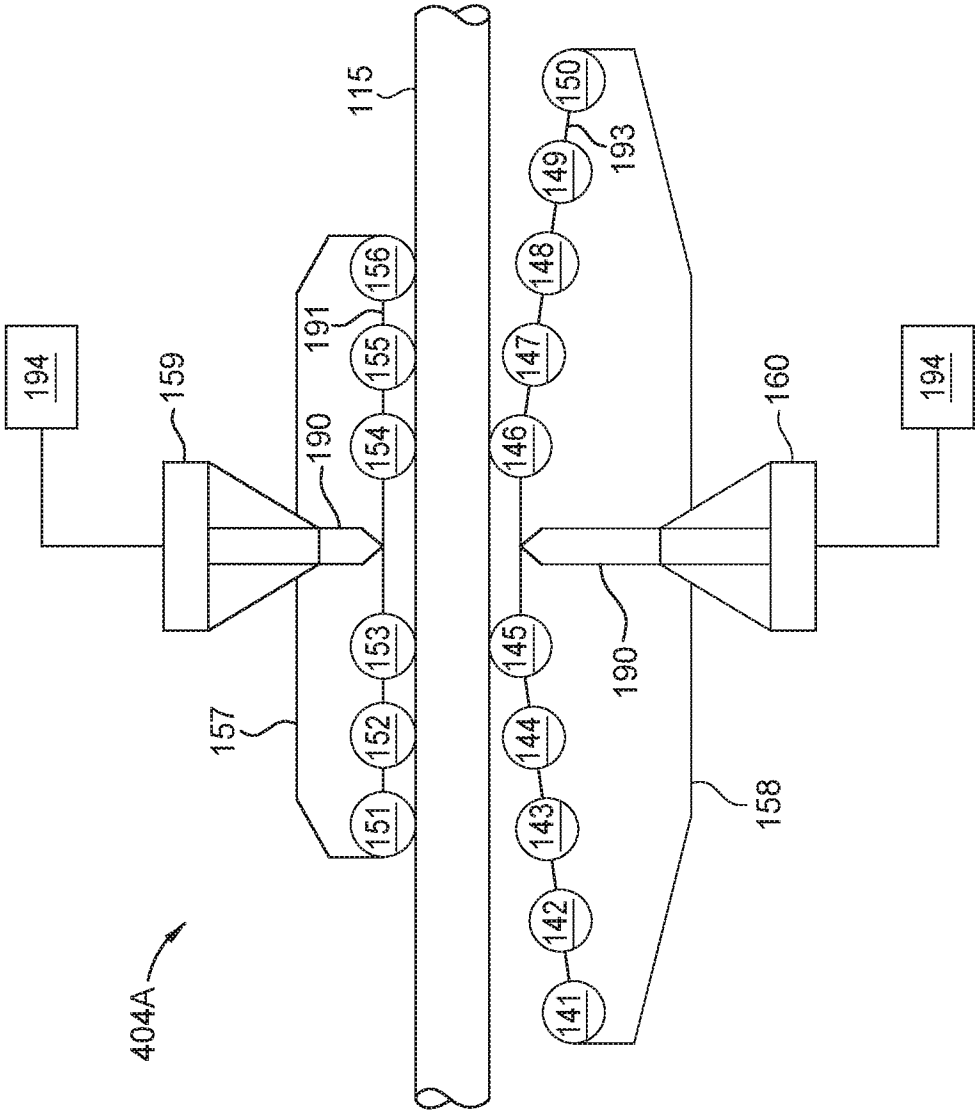


FIG. 4A

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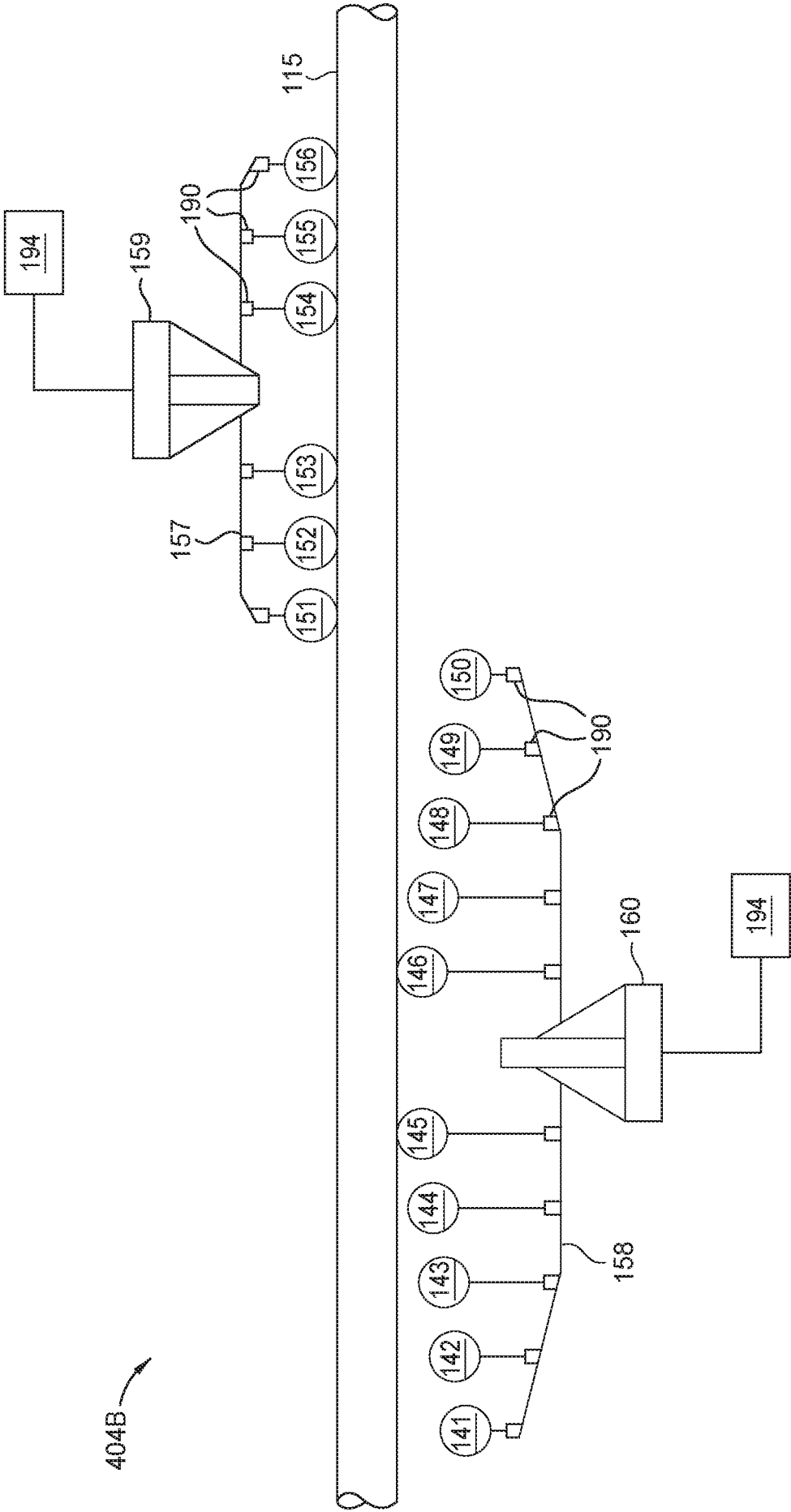


FIG. 4B

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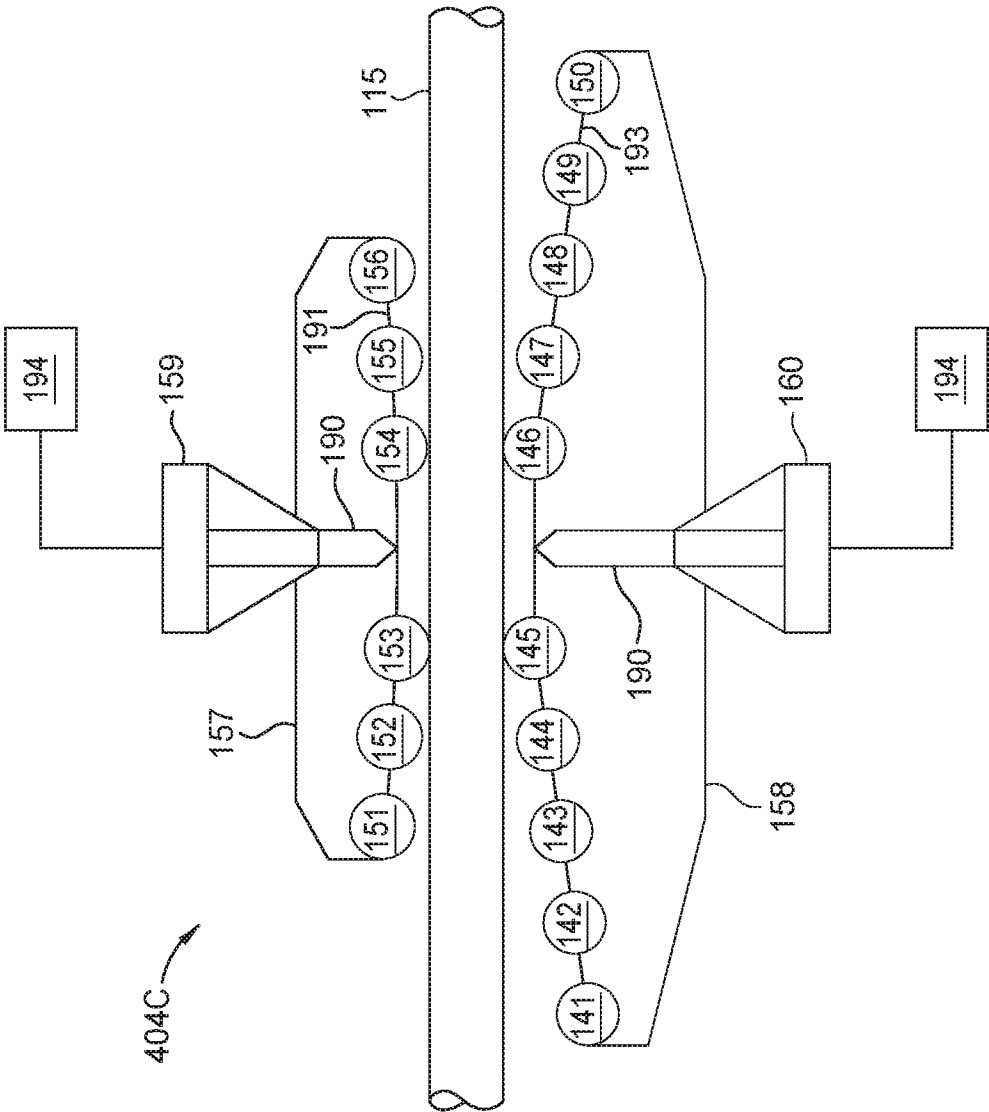


FIG. 4C

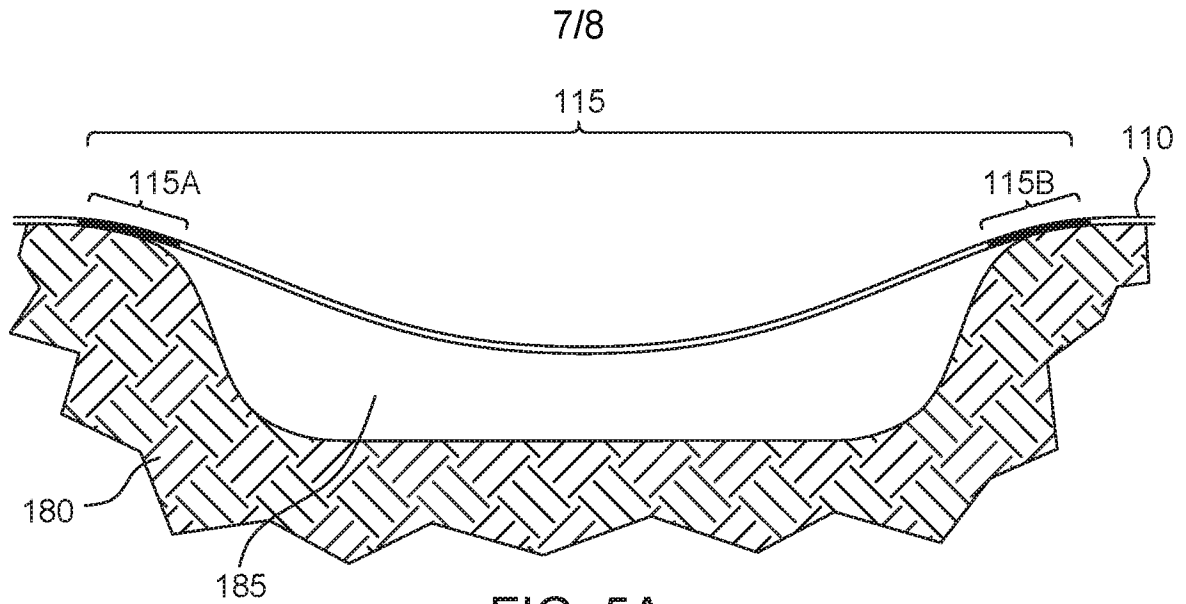


FIG. 5A

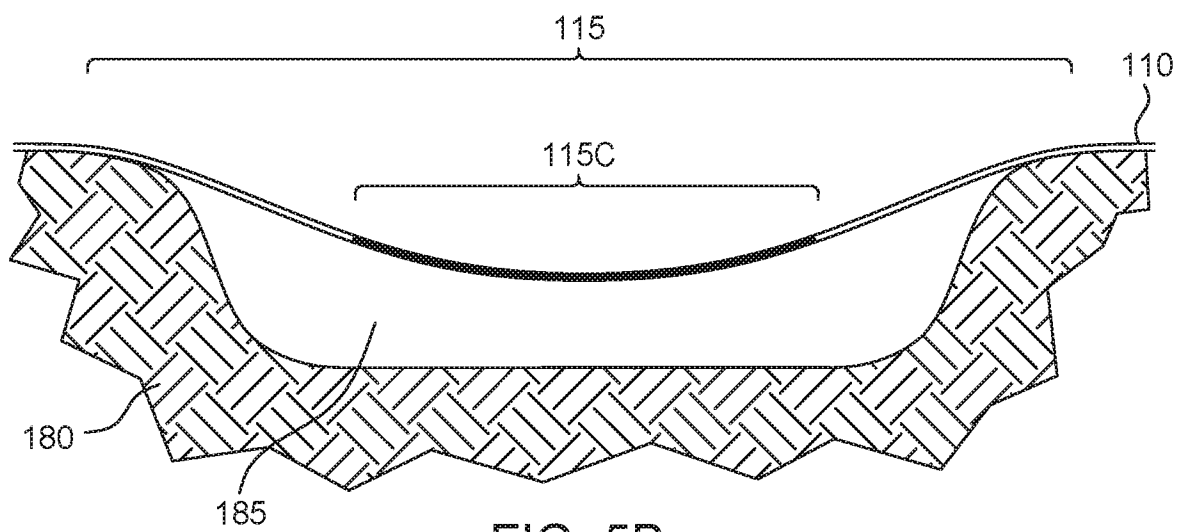


FIG. 5B

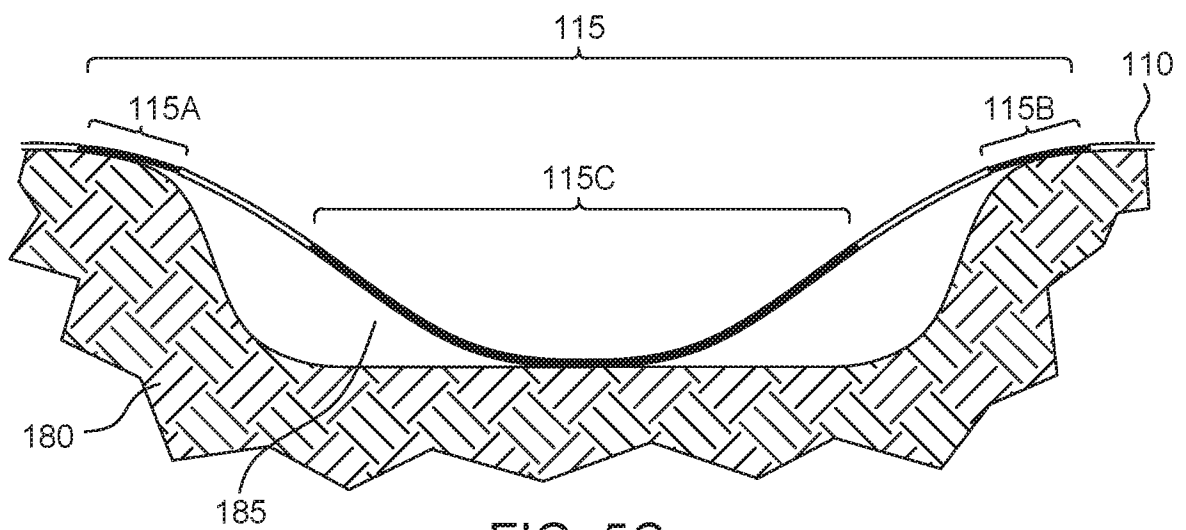


FIG. 5C

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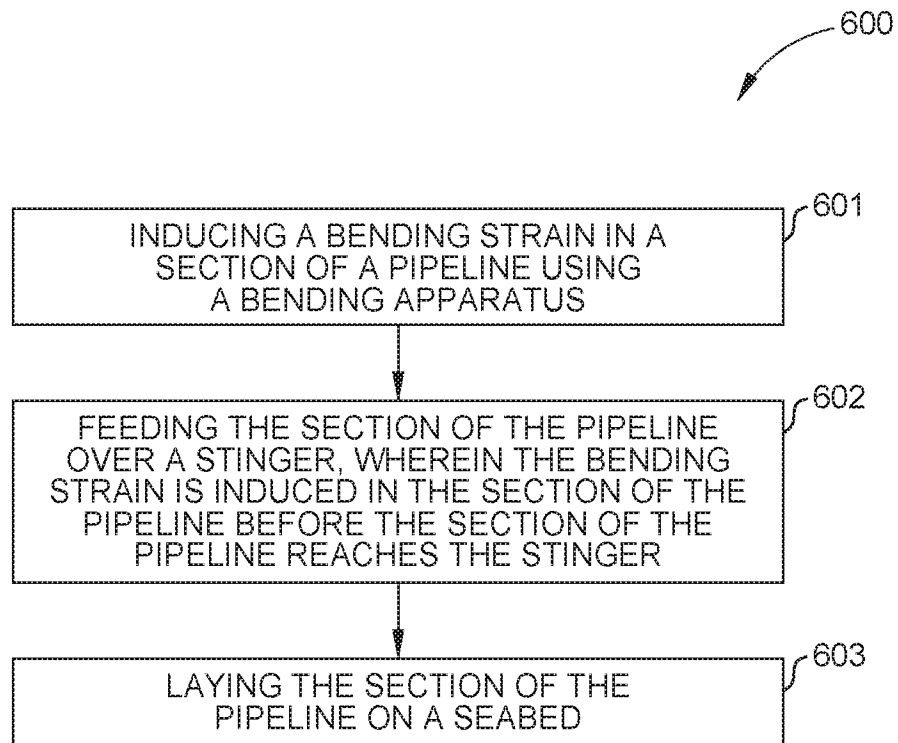


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/030629

A. CLASSIFICATION OF SUBJECT MATTER		
INV. F16L1/18	F16L1/20	F16L1/225 F16L1/235 F16L1/16
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) 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.
X	US 3 872 680 A (NICHOLSON WILLIAM B ET AL) 25 March 1975 (1975-03-25)	1-4,8
Y	column 2, lines 46-61 column 3, line 24 - column 7, line 16 figures	5-7
X	US 4 157 023 A (NICHOLSON WILLIAM B [US] ET AL) 5 June 1979 (1979-06-05) column 3, lines 18-44 figures	8-14
Y	US 3 822 559 A (MATTHEWS J ET AL) 9 July 1974 (1974-07-09) column 2, line 58 - column 6, line 14 figures	15-20
	----- -/--	
☒ 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 31 July 2019		Date of mailing of the international search report 12/08/2019
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 Durrenberger, Xavier

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2019/030629

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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X	US 4 243 345 A (CHA JOHN H ET AL) 6 January 1981 (1981-01-06)	8-14
Y	column 3, line 46 - column 10, line 2 figures -----	5-7, 15-20

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