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(54) **CHRISTMAS TREE AND METHOD**

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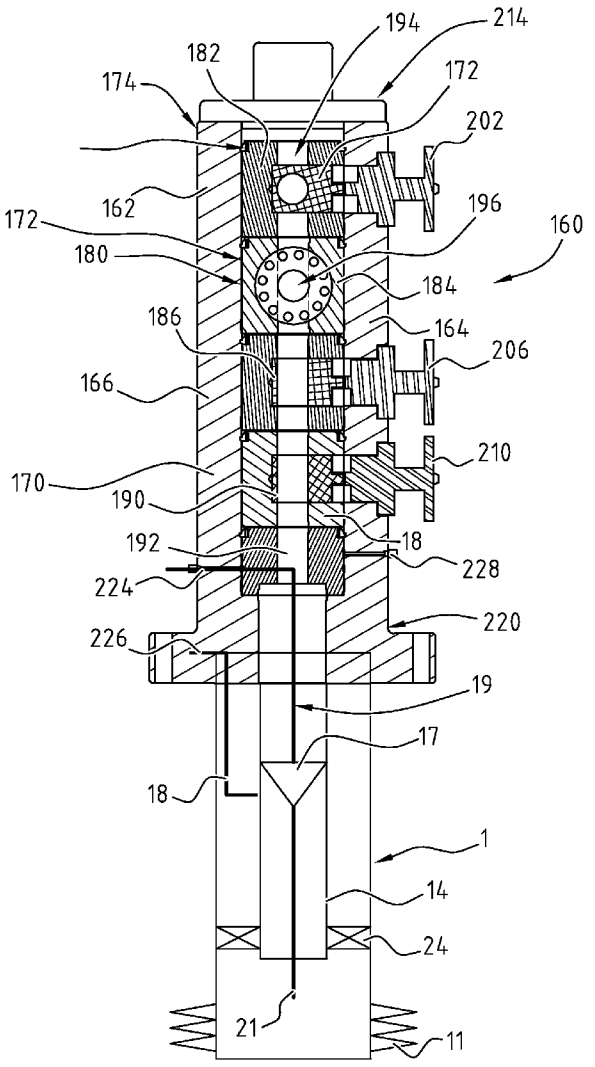
(57) **ABSTRACT**

The invention provides a Christmas tree for a wellbore, comprising a plurality of modules, each module including: at least one module opening, the modules being connected to each other to form a housing, the respective module openings being connected to form a continuous passage though the housing, said continuous passage being adapted to be connected to the wellbore; a retrievable valve insert arranged in the module opening; and control means coupled to the module to control the valve insert between a closed position and an open position.



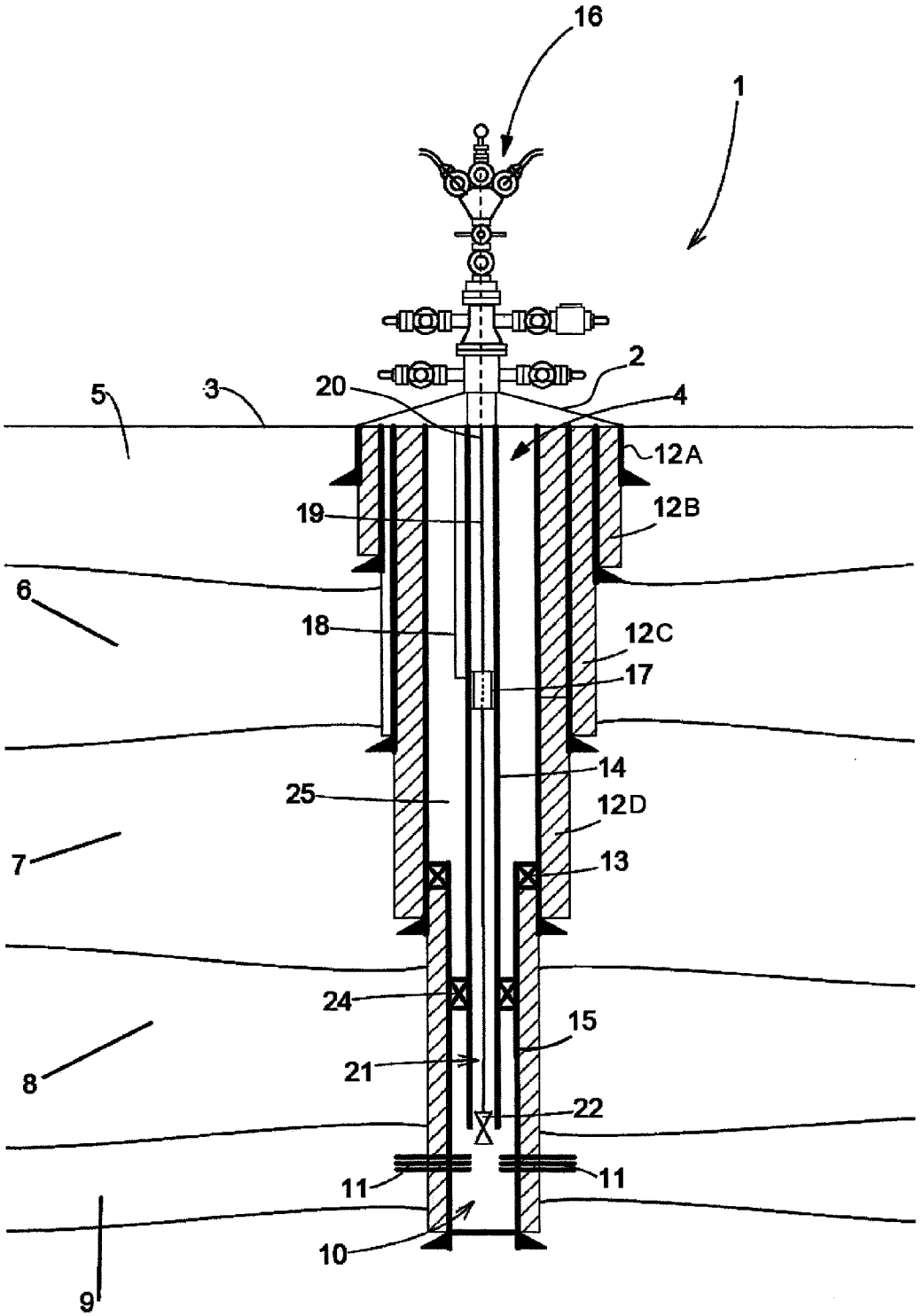

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FIG. 1

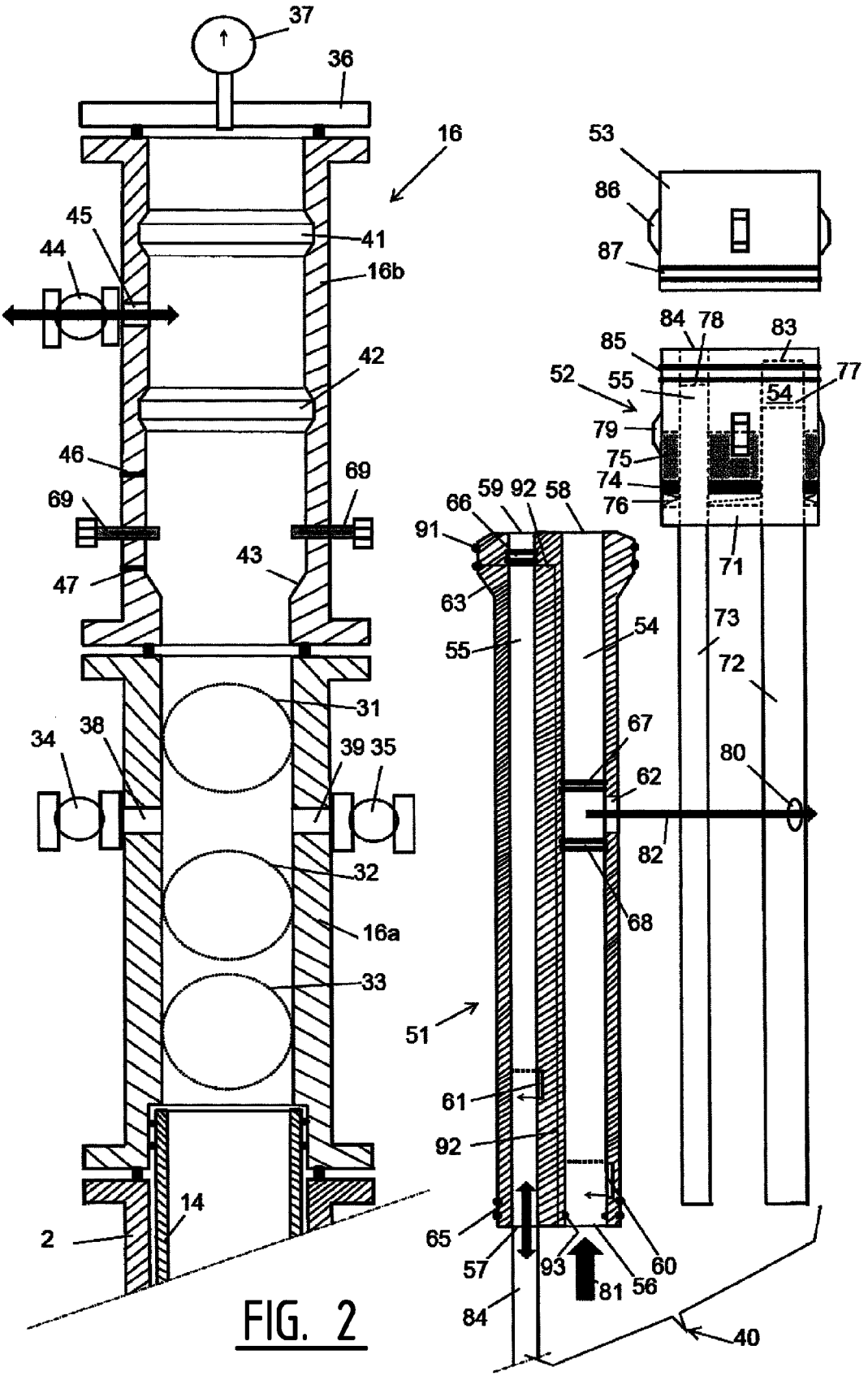
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FIG. 2

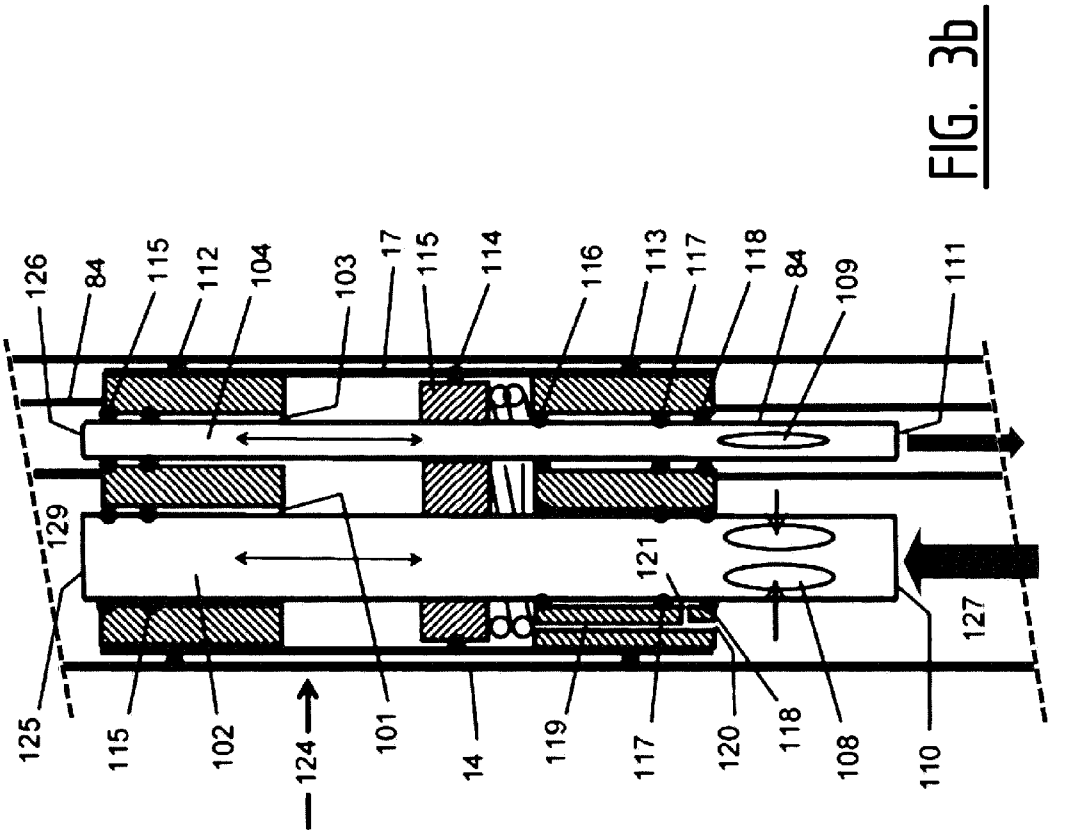
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FIG. 3b

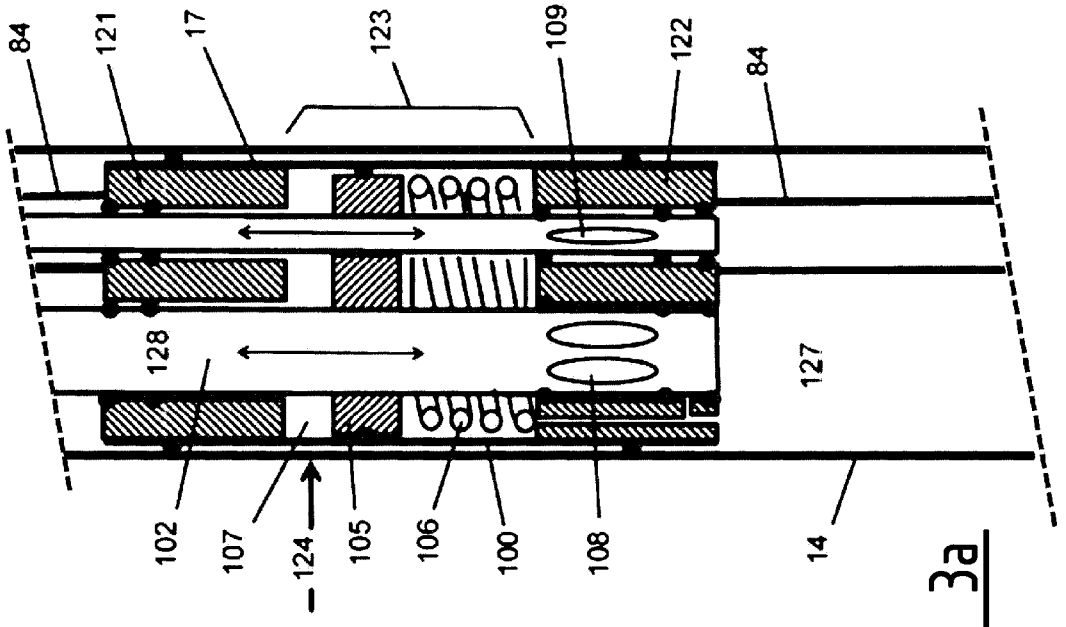
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FIG. 3a

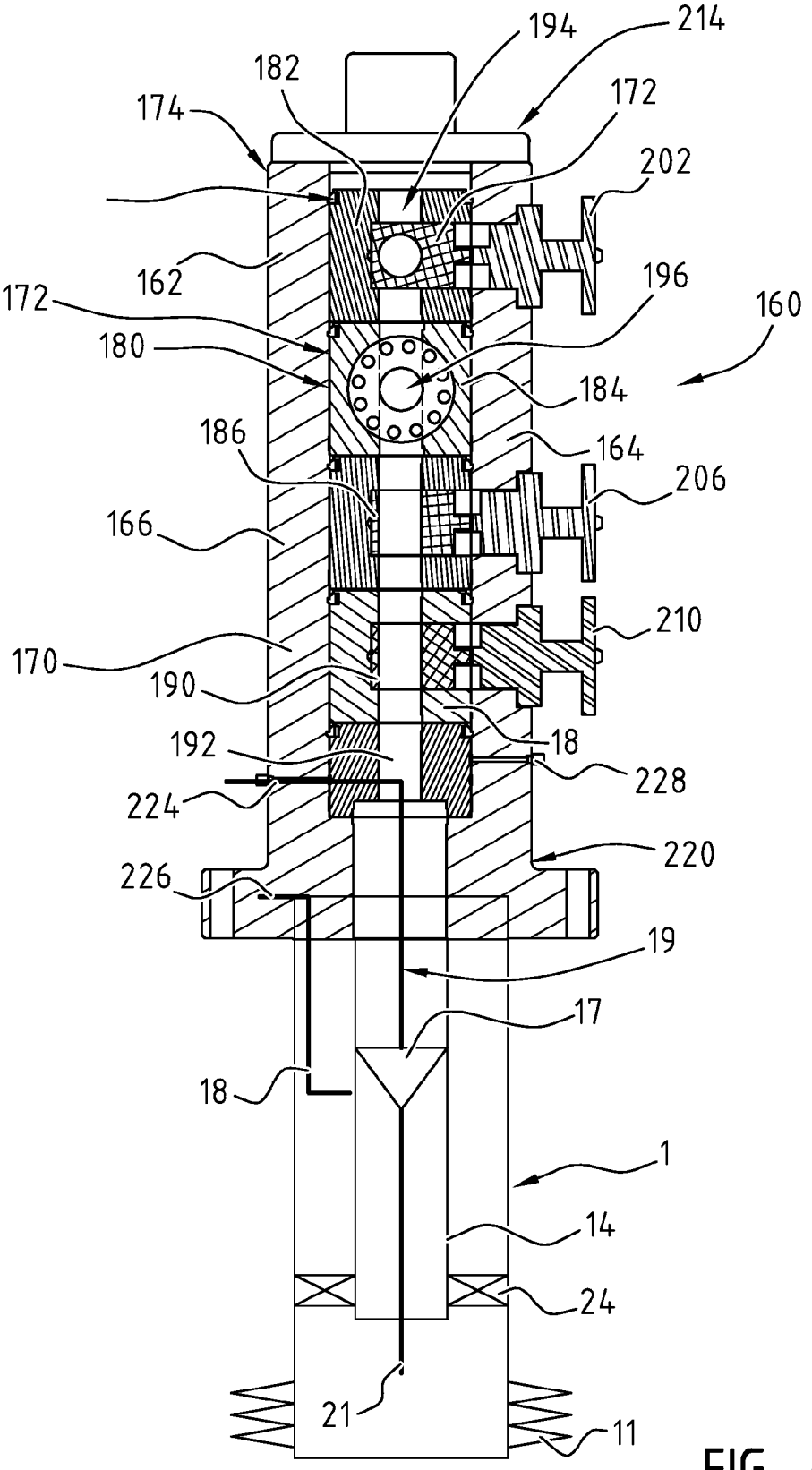
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FIG. 4

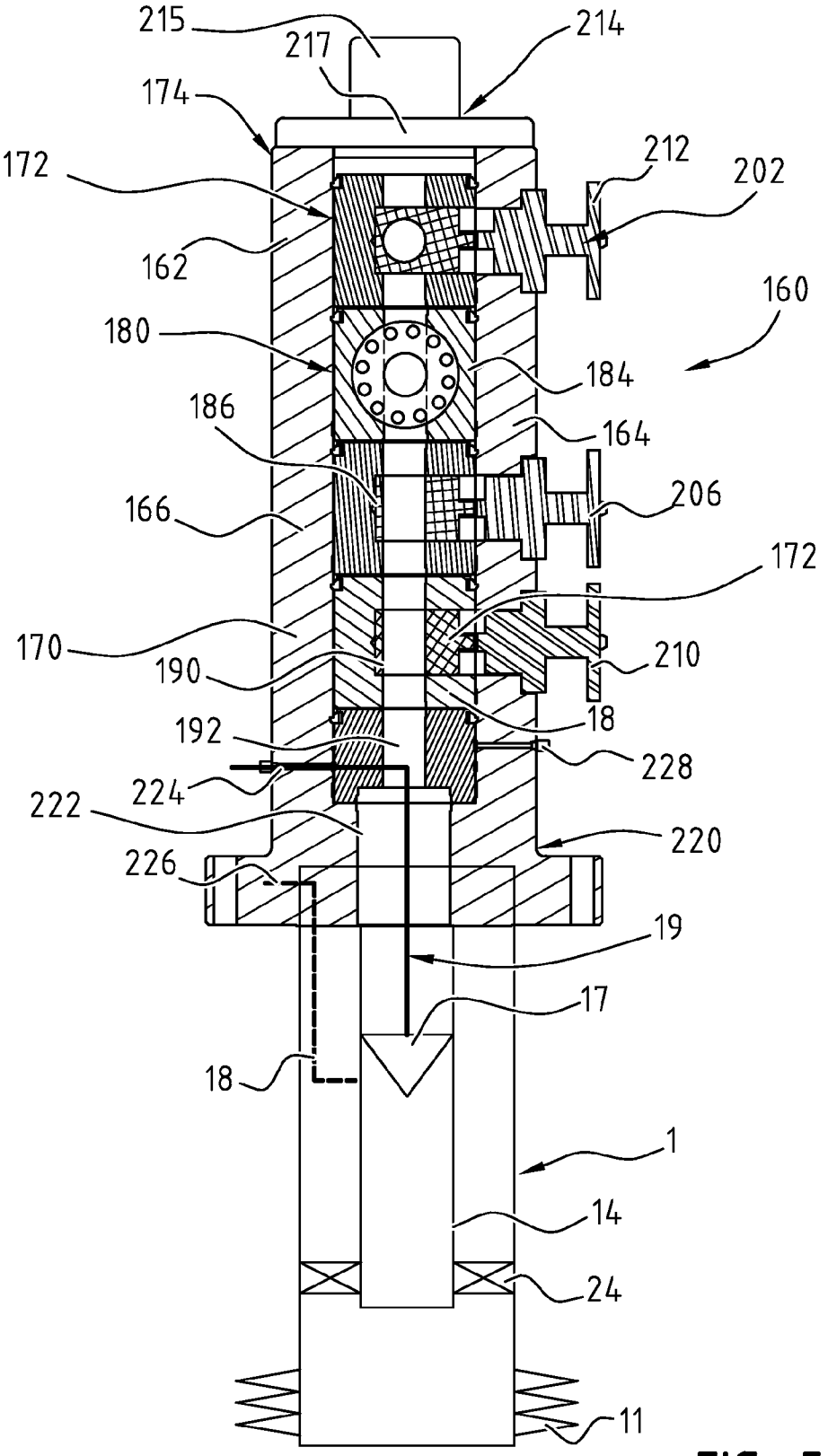
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FIG. 5

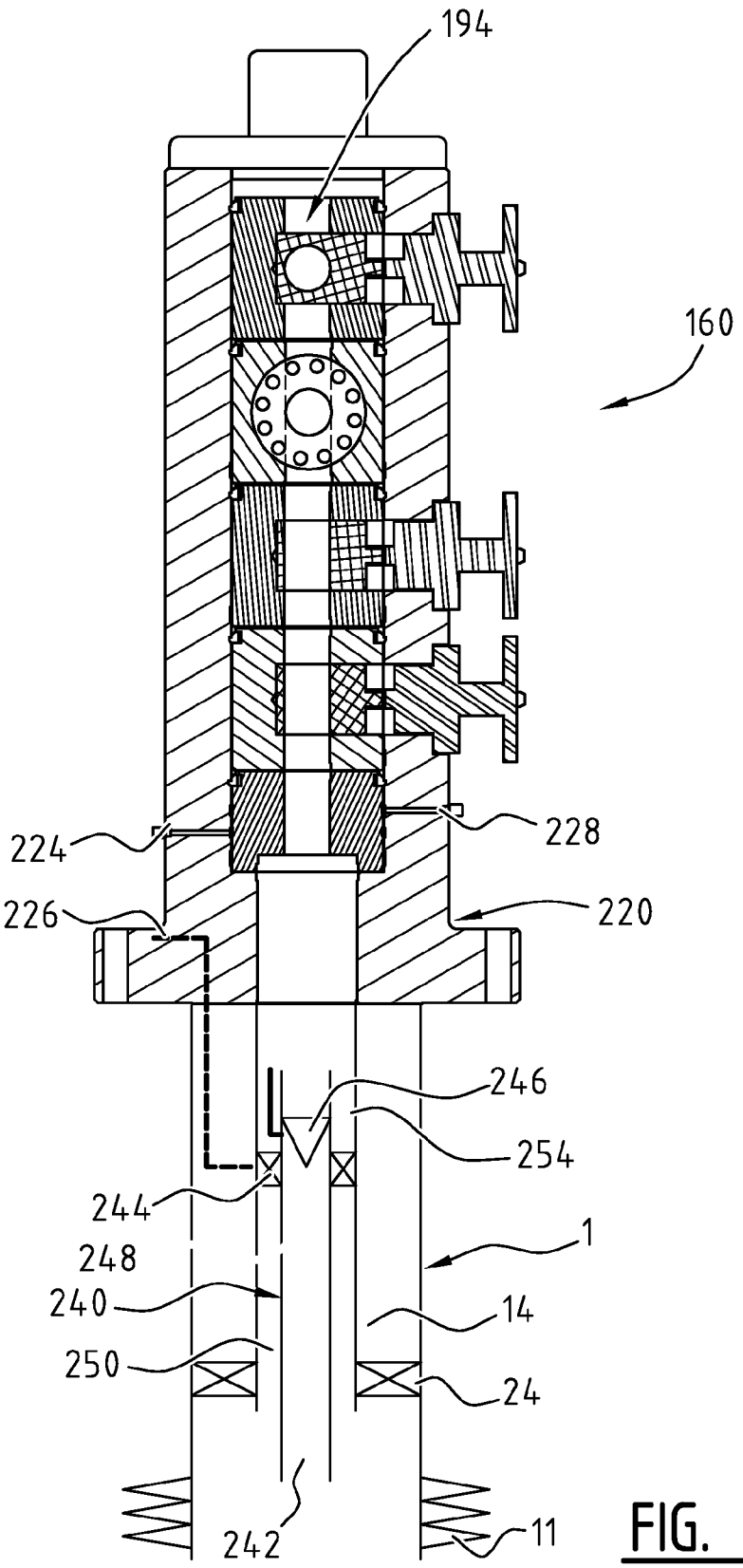

FIG. 6

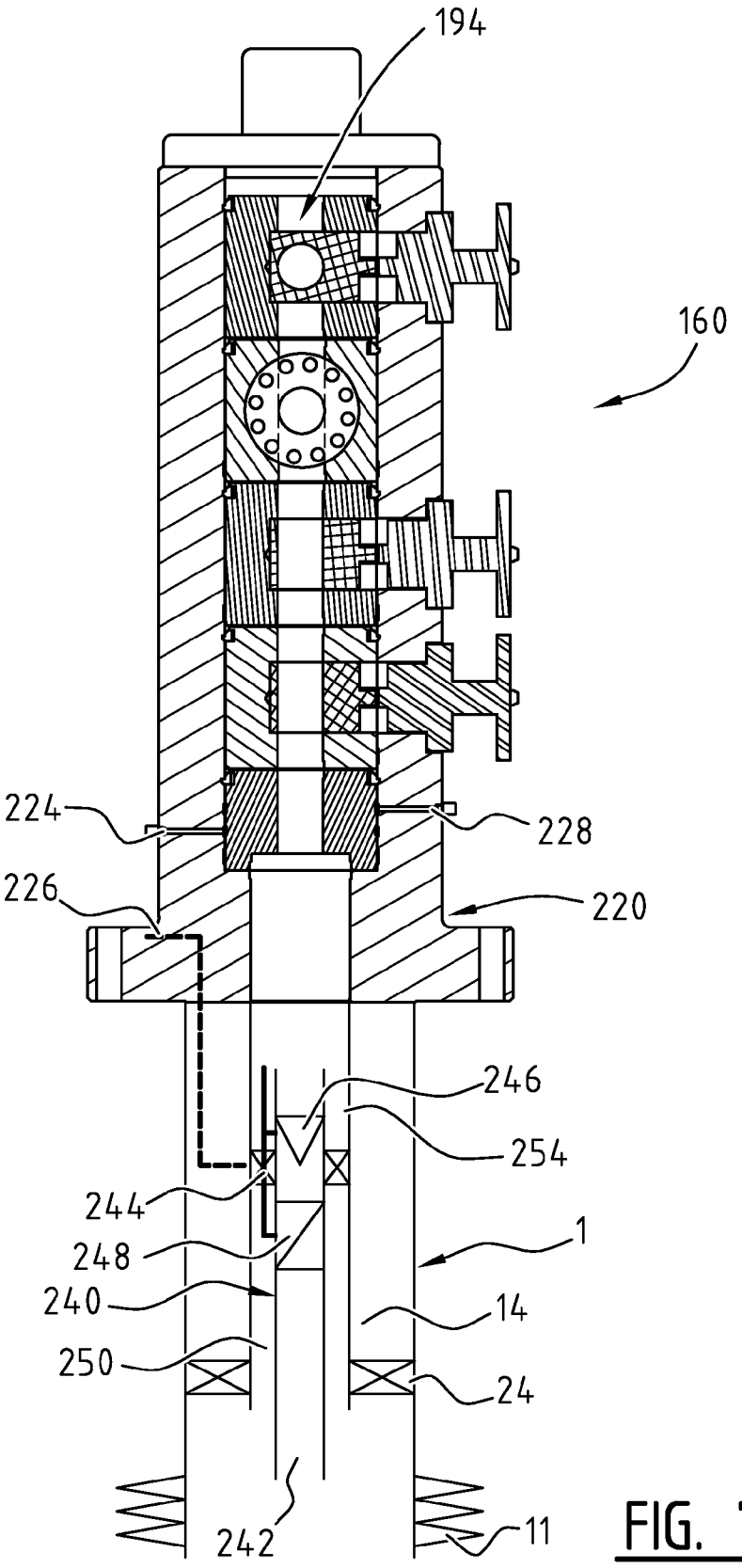

FIG. 7

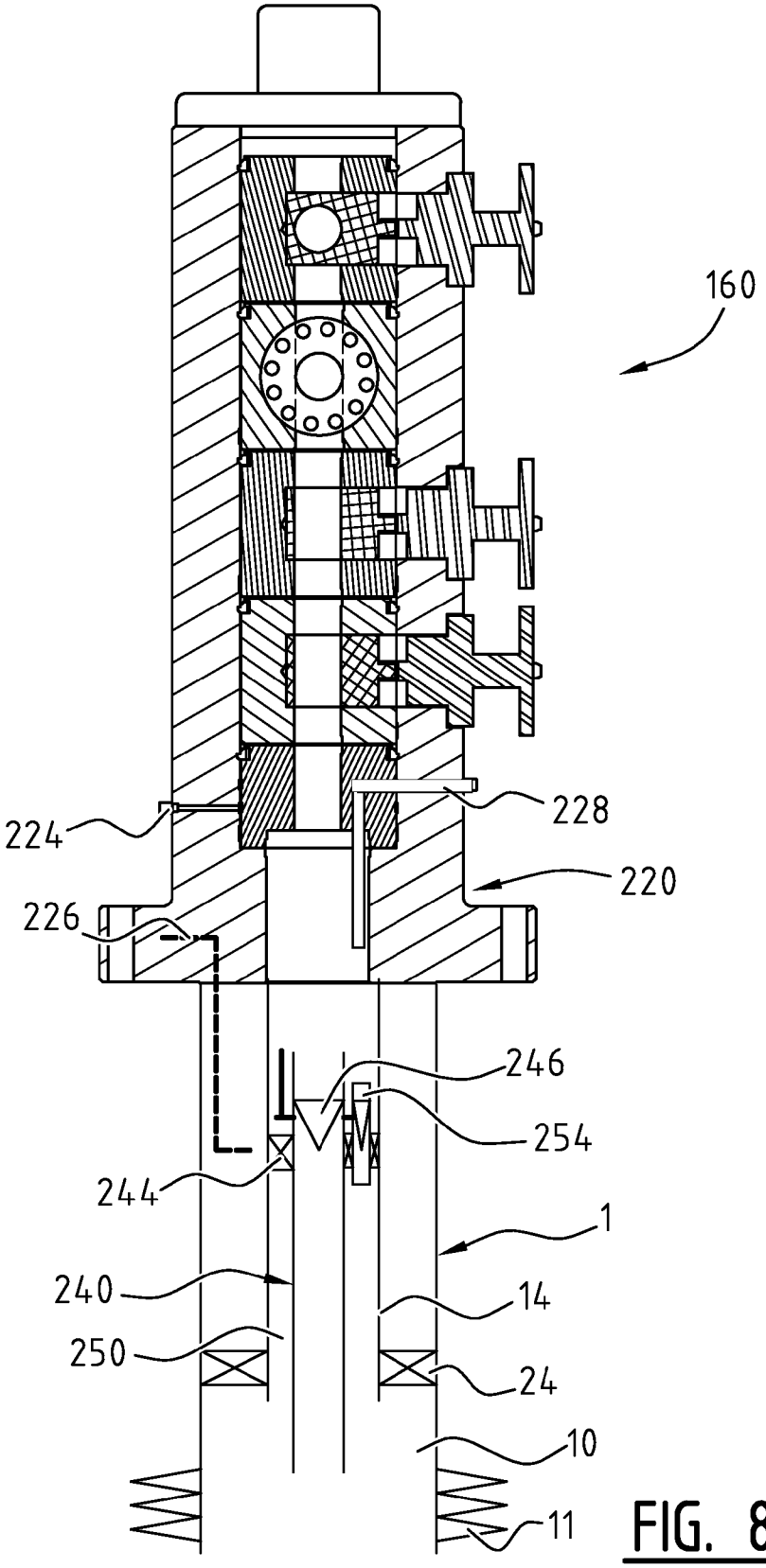

FIG. 8

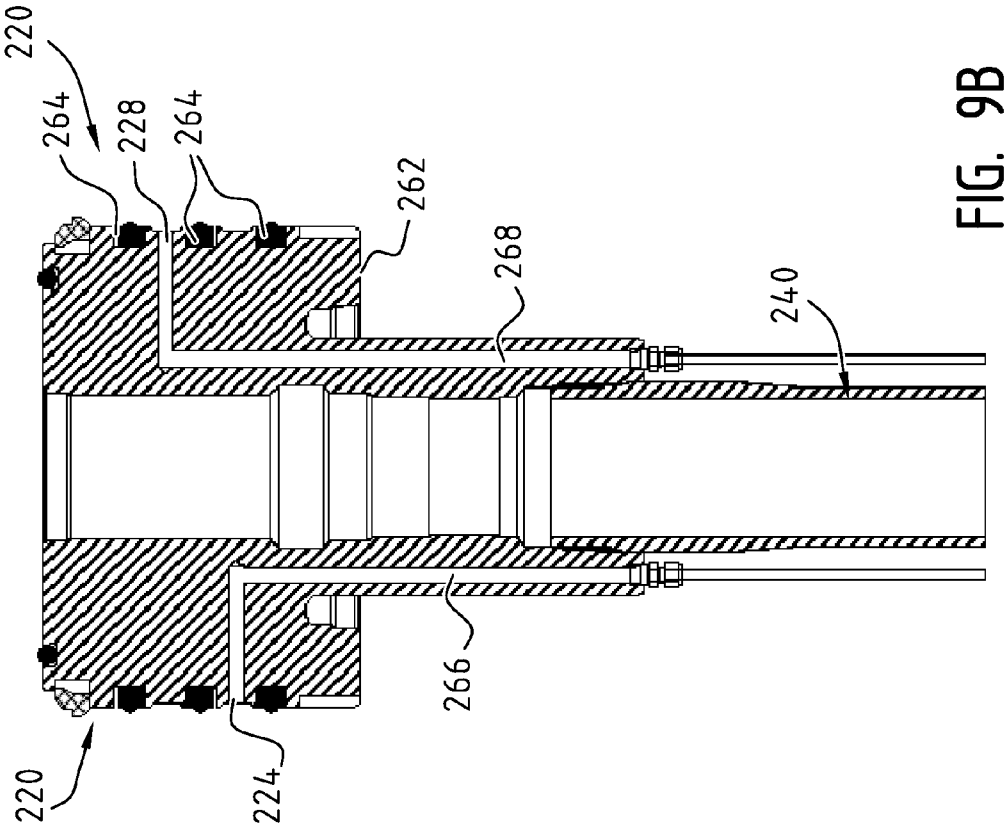
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FIG. 9B

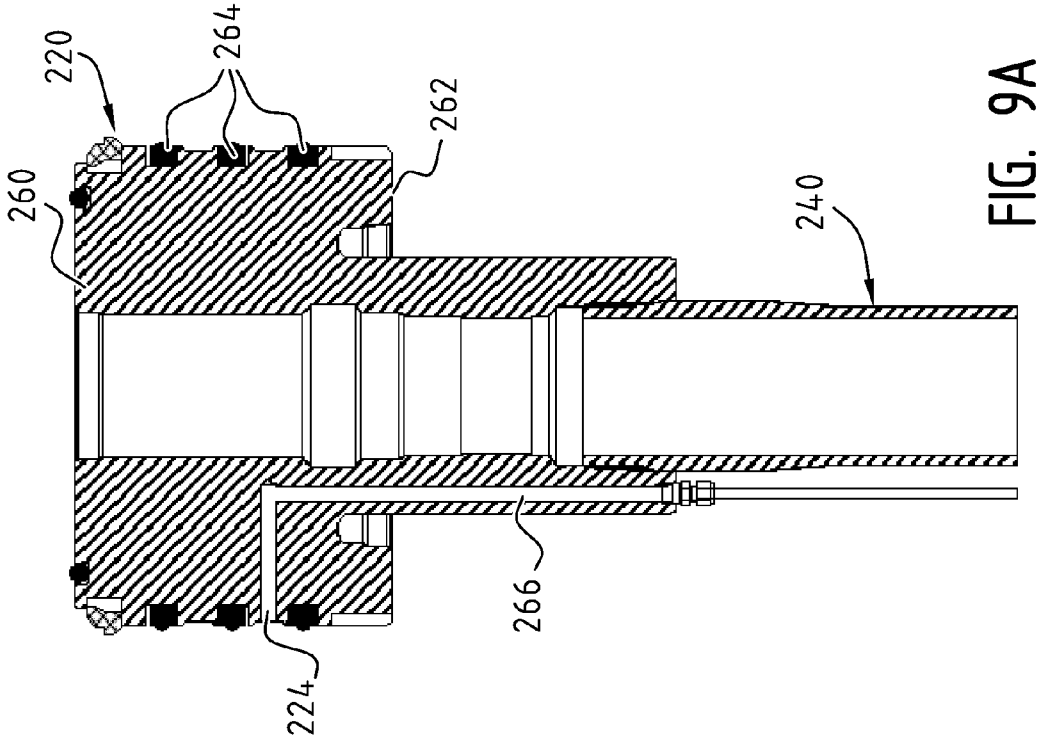
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FIG. 9A

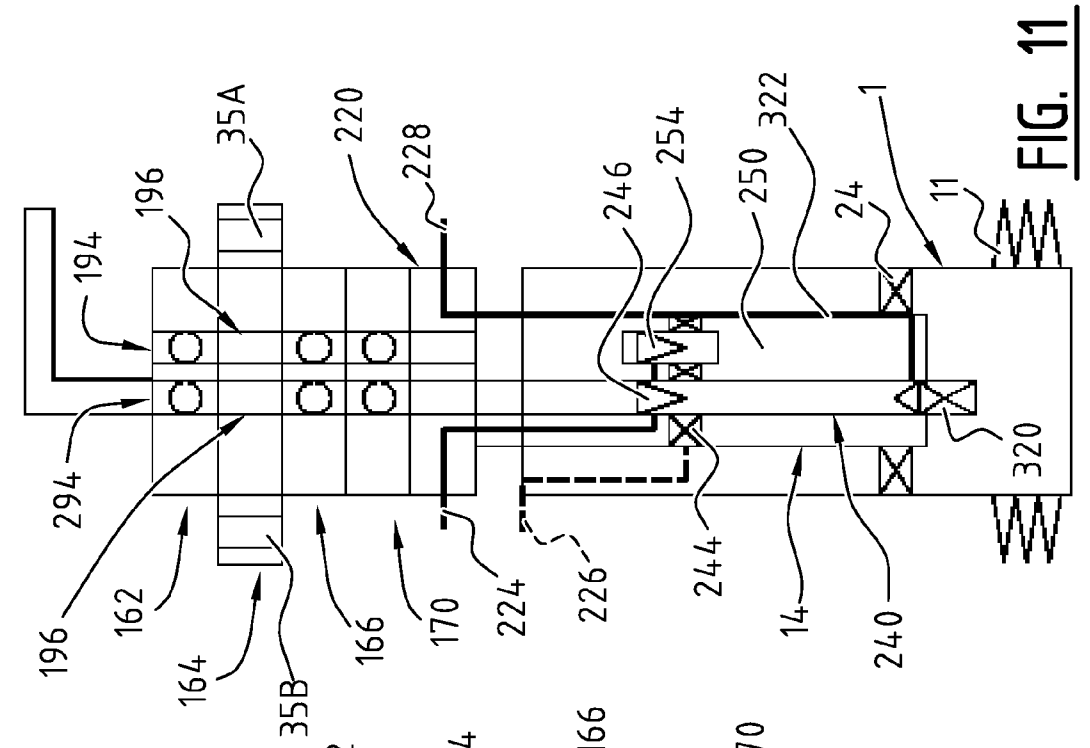
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FIG. 11

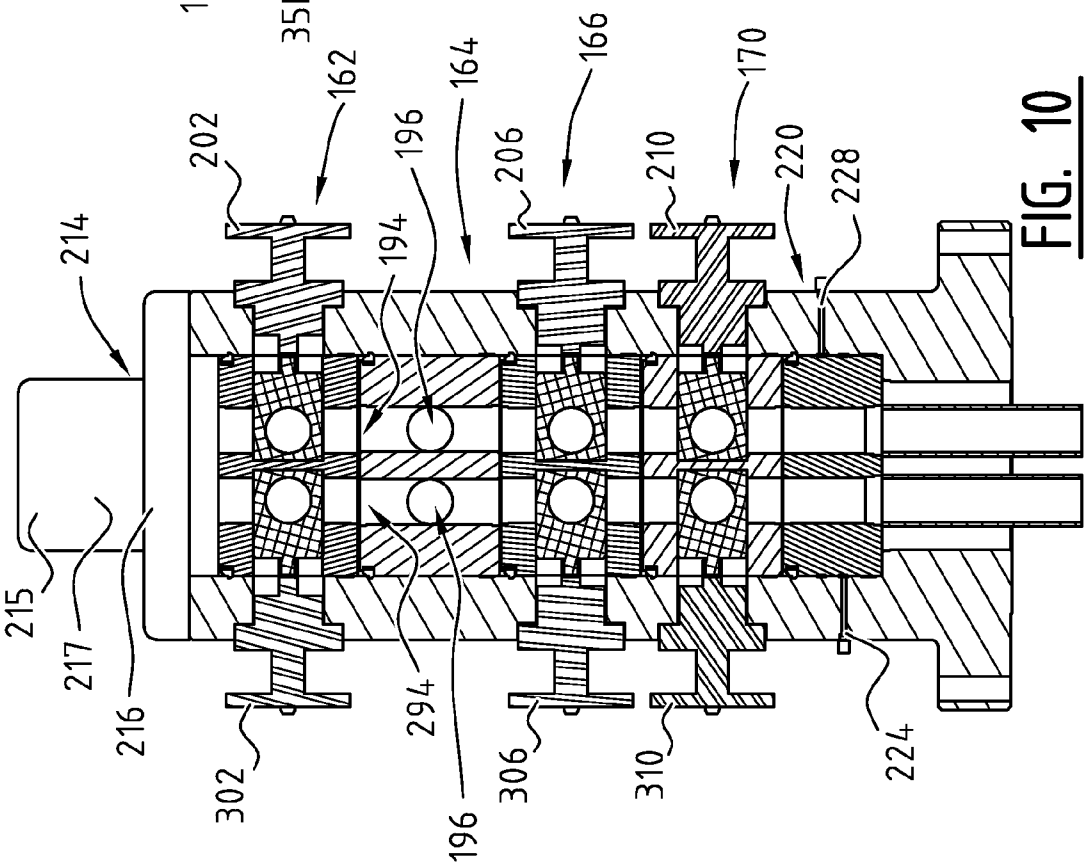
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FIG. 10

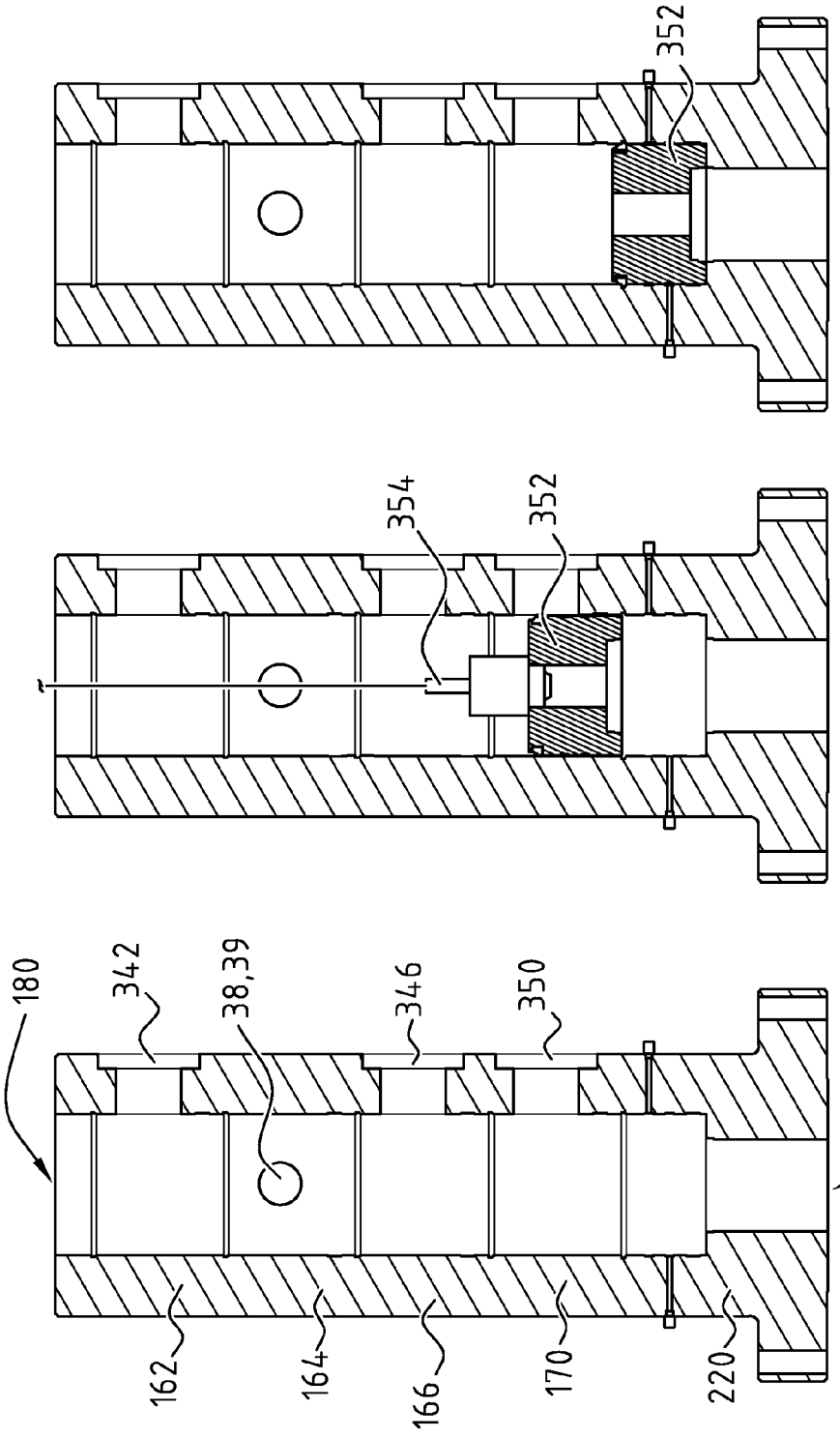

FIG. 12C

FIG. 12B

FIG. 12A

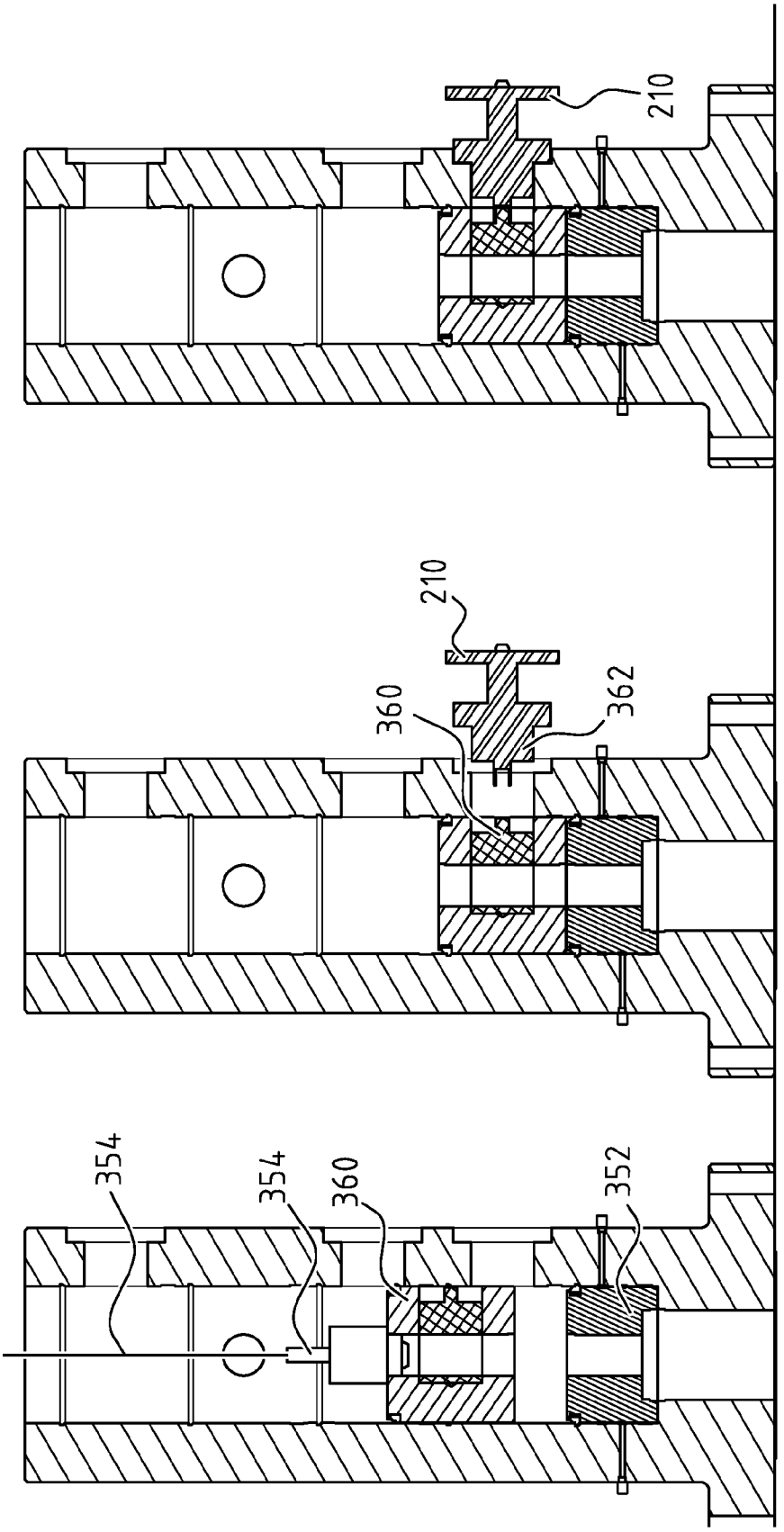

FIG. 12F

FIG. 12E

FIG. 12D

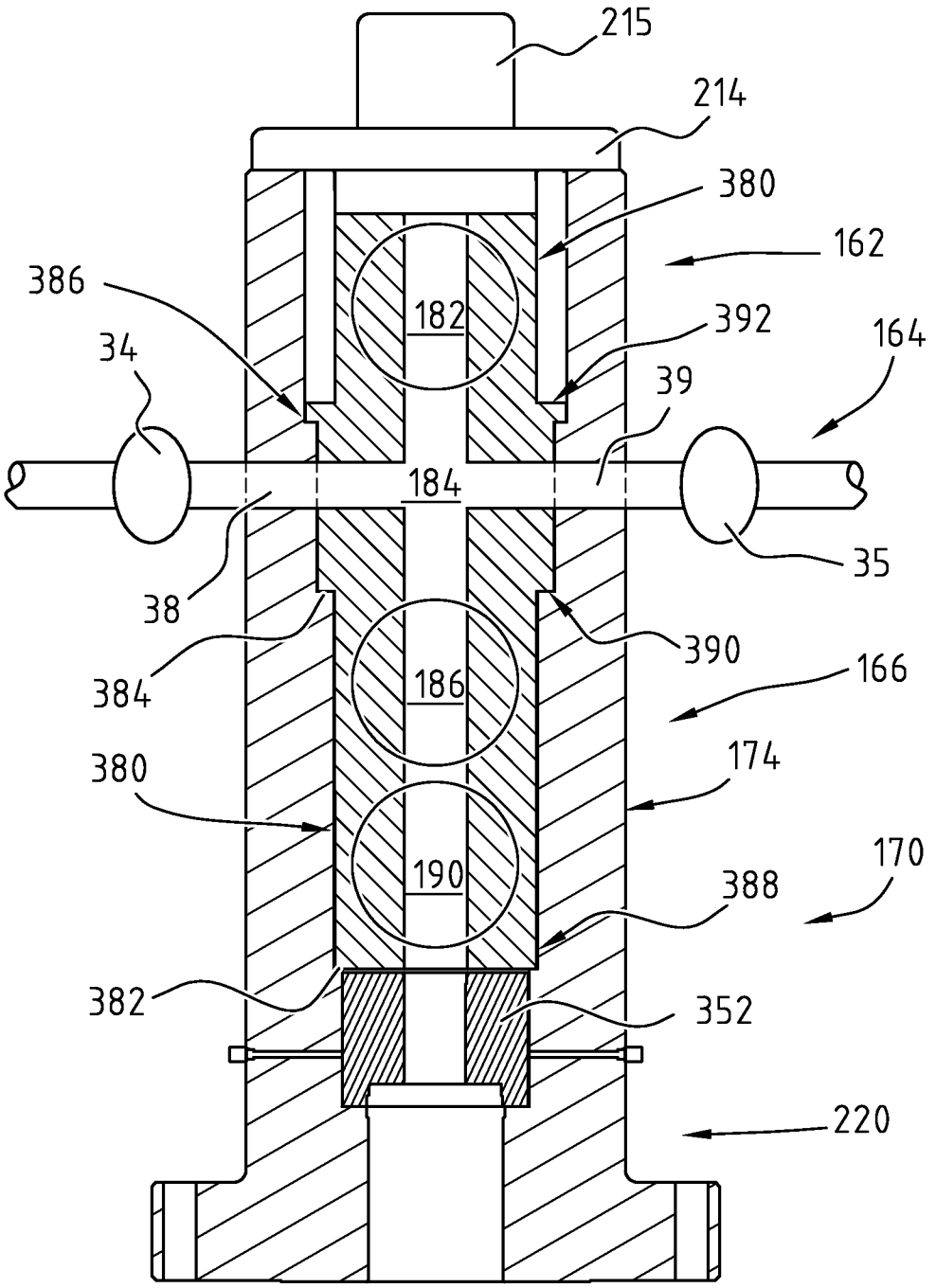
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FIG. 13

CHRISTMAS TREE AND METHOD

[0001] The invention relates to Christmas tree for a wellbore and to a method of retro-fitting a Christmas tree with safety valves.

[0002] Hydrocarbon wellbores are typically provided with a so-called Christmas tree at surface. Said Christmas tree may contain one or more valves to close a fluid channel in the event of emergency or for other reasons like maintenance or repair. The Christmas tree is typically arranged on a wellhead. In general the Christmas tree is arranged above ground level. Off-shore, the tree would be at the sea bottom and on shore on land. The Christmas tree may conventionally comprise a housing consisting of a solid block of material, wherein a predetermined number of valves and fluid connections is included, such as gate valves having a slide slidable transverse to a bore. Said slide may be manually, hydraulically or pneumatically operated.

[0003] Safety valves arranged below the wellhead are usually arranged at a depth of 100-150 meters below ground level. These safety valves are in the field frequently indicated as sub surface safety valves (SSSV). Known sub surface safety valves are provided as an elongate tubular component which is inserted in the production tubing as tubing retrievable or wire retrievable. In case of tubing retrievable, the component is provided at its upper end and lower end with connection means, like screw thread, for attachment to an upper and lower part, respectively, of the production tubing so that the lower production tubing part, tubular component and upper production tubing part form a continuous string. In order to retrieve a tubing retrievable component, the whole tubing has to be withdrawn from the wellbore up to the component surfaces. Components may be retrievable by wireline, wherein the tubular component is inserted as a plug into the production tubing, and fixed to the inner wall of the production tubing. Fixing may include a landing nipple provided inside the production tubing and a lock mandrel having keys provided on the outside of the tubular component. For retrieving a wireline retrievable component, a wire provided with a so called jar is lowered into the production tubing, the wire or jar is coupled to the component, the component is disengaged from the production tubing and subsequently retrieved by withdrawing the wire together with the connected component from the production tubing.

[0004] During the lifetime of the well, it may be desirable to change the setup of the wellbore as described above. For instance, additional tubing may be introduced in the wellbore to enable the injection of a treatment fluid or a velocity string to limit the diameter of the production tubing. The treatment fluid can for example be a soap-like substance to lower the surface tension of water in the well to limit liquid loading.

[0005] In practice, changing the setup of a producing wellbore is quite complicated, as the additional tubing has to be introduced through the Christmas tree, which has to be removed. The additional tubing has to be very flexible to allow insertion into the wellbore and to allow passage through the sub surface safety valve. Passage of the surface safety valve is in general achieved by introducing the additional tubing at a level lower than the surface safety valve or by first temporarily removing the surface safety valve, introducing the additional tubing, connecting the additional tubing to a side port below the surface safety valve and replacing the temporarily removed surface safety valve. This is all quite complicated and time consuming.

[0006] The invention aims to improve the flexibility of a producing wellbore.

[0007] According to a first aspect, the invention provides a Christmas tree for a wellbore, comprising a plurality of modules, each module including:

[0008] at least one module opening;

[0009] a retrievable valve insert arranged in the module opening, the retrievable valve insert being provided with at least one fluid passage; an

[0010] control means coupled to the module to control the valve insert between a closed position and an open position of the at least one fluid passage;

[0011] the modules being connected to each other to form a housing, the respective module openings being connected to form a continuous conduit though the housing, the respective fluid passages of the valve inserts being connected to form at least one continuous fluid passage, said continuous fluid passage being adapted to be connected to the wellbore.

[0012] The Christmas tree of the invention having retrievable valve inserts simplifies making changes to the wellbore setup. With a conventional tree, the entire tree would have to be removed and safety measures for well control must be established before tubing in the well can be introduced or replaced. The Christmas tree of the invention allows to replace valve inserts to repair broken valves, allows to remove valve inserts and to insert tubing in or remove tubing from the wellbore. Tubing or replacement valve inserts may for instance be introduced via a lock mechanism which may be arranged on top of the Christmas tree. Time required to maintain or update the wellbore setup will be significantly reduced.

[0013] In an embodiment, the continuous conduit is a straight cylindrical channel. Also, the continuous fluid passage may be a straight cylindrical passage.

[0014] In another embodiment, the valve inserts of each module may include at least two parallel fluid passages, the at least two fluid passages of the subsequent modules constituting at least two parallel continuous fluid passages though the continuous conduit of the housing. Herein, each module may comprise at least two control means coupled to the module, each control means enabling the control of the valve insert between a closed position and an open position of one of the at least two fluid passages.

[0015] In an embodiment, the control means are releasably coupled to the valve insert of the respective module.

[0016] The valve inserts may be retrievable by wireline.

[0017] According to another aspect, the invention provides a method of building a Christmas tree for a wellbore, comprising the steps of:

[0018] providing a plurality of modules, each module including at least one module opening;

[0019] connecting the modules to each other to form a housing, the respective module openings forming a continuous conduit though the housing;

[0020] arranging a retrievable valve insert in the module opening of the modules, each retrievable valve insert being provided with at least one fluid passage, the respective fluid passages of the valve inserts being connected to form at least one continuous fluid passage, said continuous fluid passage being adapted to be connected to the wellbore; and

[0021] coupling control means to each module to control the valve insert in the respective module between a closed position and an open position of the at least one fluid passage.

[0022] The term "wellbore", as used in the present application, may imply for instance "wellbore for the production of hydrocarbons", but also "injection wellbore for pressurizing a sub-surface formation in order to force hydrocarbons to surface" and "storage wellbore for sub-surface storage of hydrocarbons". The term "valve" may imply a valve arranged in the path of a fluid flow to enable interruption of said flow.

[0023] The invention will now be explained by way of example with reference to the accompanying drawings, wherein:

[0024] FIG. **1** shows a cross-section of an exemplary hydrocarbon wellbore, provided with a system for injecting a treatment fluid and a Christmas tree;

[0025] FIG. **2** shows a cross-section of an embodiment of a Christmas tree according to the invention;

[0026] FIG. **3***a* shows a cross-section of a safety valve assembly for use in combination with the Christmas tree of the invention, in blocked position;

[0027] FIG. **3***b* shows a cross-section of a safety valve assembly for use in combination with the Christmas tree of the invention, in flow position;

[0028] FIG. **4** shows a cross-section of a wellbore provided with an embodiment of a Christmas tree of the invention;

[0029] FIG. **5** shows a cross-section of a wellbore provided with another embodiment of a Christmas tree of the invention;

[0030] FIG. **6** shows a cross-section of a wellbore provided with an embodiment of a Christmas tree of the invention;

[0031] FIG. **7** shows a cross-section of a wellbore provided with an embodiment of a Christmas tree of the invention;

[0032] FIG. **8** shows a cross-section of a wellbore provided with an embodiment of a Christmas tree of the invention;

[0033] FIGS. **9**A-**9**B show cross-sections of embodiments of a velocity string insert for a hanger module of the Christmas tree of the invention;

[0034] FIG. **10** shows a cross-section of another embodiment of a Christmas tree of the invention;

[0035] FIG. **11** shows a cross-section of a wellbore provided with the Christmas tree of FIG. **10**;

[0036] FIGS. **12**A-**12**F show exemplary steps of a method to provide a Christmas tree according to the invention; and

[0037] FIG. **13** shows a cross section of yet another embodiment of a Christmas tree of the invention.

[0038] FIG. **1** shows a wellbore **1**, comprising borehole **4** which has been drilled from surface **3** through a number of earth formation layers **5**, **6**, **7**, **8** to a reservoir layer **9**. The reservoir layer **9** comprises hydrocarbons, for example oil and/or gas. The wellbore **4** is lined with one or more casings **12**A-**12**D and a liner **15** which is suspended from the casing **12**C by means of a liner hanger **13**. Casing **12**A may also be referred to as conductor. Casing **12**D may also be referred to as production casing. The liner **15** extends to the reservoir layer **9** and is provided with perforations **11** to allow fluid communication from the reservoir layer **9** to a production zone **10** of the wellbore **1**.

[0039] A production tubing **14** is arranged within casing **12**D and liner **15**. The production tubing **14** typically extends from a wellhead **2** of the wellbore **1** to the production zone **10**. Hydrocarbons may be conveyed to the wellhead **2** through the interior of the production tubing **14**. A Christmas tree **16** is installed on the wellhead **2** to control fluid flow in and out of the wellbore.

[0040] A sub-surface safety valve assembly **17** (also called downhole safety valve **17**) may be installed in the production tubing **14**. The sub-surface safety valve **17** may be surface-controlled. The safety valve **17** may be located at a depth exceeding 50 m, for example at approximately 100 m. The safety valve **17** may close the production tubing **14**, for instance in the event of an emergency. The safety valve **17** may be designed to be fail-safe, i.e. to automatically close the wellbore **4** in the event of failure or damage to the control equipment at surface. An annular space **25** is defined between the outer surface of the production tubing **14** and the casing **12**D. A hydraulic control line **18** extends from surface **3** within the annular space **25** to the safety valve **17** to control the safety valve.

[0041] A packer member **24** may be arranged between the production tubing **14** and the liner **15** to substantially isolate the annular space **25** from the interior of the production tubing **14**. The packer member **24** may comprise means for securing the packer member **24** against the wall of the liner **15**, such as a slip arrangement, and means for establishing a reliable hydraulic seal to isolate the annular space **25**. Said isolation means may for instance include an expandable elastomeric element or an inflatable packer. The portion of the production tubing **14** below the packer member **24** may be referred to as the tail.

[0042] The wellbore **1** may comprise a system for injecting a treatment fluid into the production zone **10**, comprising a treatment fluid injection tubing **19** having an uphole supply end **20** and a downhole discharge end **21**. The supply end **20** may be installed in or coupled to the Christmas tree **16**.

[0043] The treatment fluid injection tubing **19** is arranged in the interior of the upper part of the production tubing **14**, which upper part extends from the Christmas tree **16** to the safety valve **17**. The treatment fluid injection tubing **19** passes the safety valve **17** and runs further downhole through the interior of the lower part of the production tubing **14** up to the discharge end **21** in the production zone **10**. Thus, the treatment fluid injection tubing **19** extends below the safety valve **17** and below the packer member **24**. The treatment fluid injection tubing **19** may be several kilometers long.

[0044] The inner diameter of the pipes may be less than 1 cm, preferably less than 0.5 cm. The inner diameter of the tubing **19** may be much larger than 1 cm as well, for example 2.5 cm or larger. The additional tubing **19** can be stiff or rigid. The lower end of the treatment fluid injection tubing **19** might comprise a treatment fluid injection valve **22**.

[0045] The additional tubing **19** is described as a system for injecting a treatment fluid into the production zone **10**. This is just an example of additional tubing which can be useful in a wellbore. Additional tubing **19** for other purposes is also conceivable. Tubing **19** might also serve as a guide to insert a measurement device, a tool, an inspection means (like a camera), or any other object to any level between the wellhead **2** and the production zone. Further, additional tubing might serve the purpose of taking a sample from any level between the wellhead and the production zone.

[0046] As shown in FIG. **2**, an embodiment of a Christmas tree **16** may comprise an original tree **16***a* and an additional spool module **16***b* on top of the original tree **16***a*. The additional spool module **16***b* is part of a retro fit assembly comprising this spool module **16***b* and a valve assembly **40**. The

spool module **16***b* enables to mount the valve assembly **40** in the tree part **16***a* by hanging off constriction **43**.

[0047] The term 'original tree' may imply a Christmas tree of an existing wellbore. The tree **16***a* may comprise a swab valve **31**, a lower master valve **32** and an upper master valve **33**. Controls (not shown) of the respective valves may include hand-controlled wheels extending to sides of the tree. In addition, the tree may comprise a kill wing valve **34** mounted on a kill wing port **38** and a flow wing valve **35** mounted on the flow wing port **39** for discharging production flow. The lower end of the original tree **16***a* may be mounted on the wellhead **2**. The production tubing **14** may hang off a lower end of the tree or the wellhead **2**.

[0048] The spool **16***b* may be mounted on the upper end of the tree **16***a*. The upper end of the spool **16***b* may be closed by a cap **36** provided with a pressure gauge **37**. The cap **36** with pressure gauge **37** may previously have been mounted on top of the tree **16***a*.

[0049] The spool module **16***b* is provided with hanger nipples, for instance upper hanger nipple **41** and lower hanger nipple **42**. The hanger nipples may include circumferential recesses formed in the inner wall of the spool module **16***b*. An internal surface of lower end of the spool module **16***b* may be provided with a constriction or seat surface **43**.

[0050] The spool module **16***b* may be provided with a side port **45** and valve **44** to allow fluid flow to exit or enter the spool module **16***b*. Hydraulic ports **46**, **47** provide a fluid passage for hydraulic fluid to allow control of a hydraulically operated device inside the spool module.

[0051] The valve assembly **40**, shown in FIG. **2**, may comprise an insert assembly comprising three parts: a lower insert part **51**, an upper insert part **52** and a bull plug **53**. In the drawing, parts **51**, **52** and **53** are shown, in disassembled state, on the same vertical level with respect to the spool module **16***b* and tree **16***a* as they will have when mounted in the spool module and tree. The locking dogs **79** will engage in the landing nipple **42**. The locking dogs **79** and landing nipple **42** will preferably lie on the same horizontal line.

[0052] The lower insert part **51** comprises for instance a massive body of steel having two longitudinal fluid passages. A first passage **54** may have a large diameter and a second passage **55** may have a smaller diameter. Both passages **54** and **55** have an open lower end **56**, **57** and open upper end **58**, **59**. A spring biased flapper valve **60**, **61** may be provided in one passage or in both passages. The flapper valves **60**, **61** are shown in open position. In closed position the flapper valves **60**, **61** will shut off the passages **54** and **55** completely to prevent fluid flow through the passages **54** and **55**. A radial bore **62** provides a side port in the first passage **54**.

[0053] The lower insert part **51** is optionally provided with hydraulic line **92**. When mounted into the spool **16***a*, **16***b*, the hydraulic line **92** will be connected with hydraulic port **47**. Hydraulic line **92** can be used for operation of a wide range of devices, for example to operate one of the flapper valves **60**, **61**. The line **92** may also be used to operate a device arranged below the first insert part **51** inside the tubing **14**. A hydraulically operated device may for instance be arranged near the downhole end of the wellbore.

[0054] To provide sealing, the lower insert part **51** may be provided with seals selected from the group of: one or more outer seals **65** extending all around the circumference of the lower end of the insert part; one or more outer seals **91** extending around the circumference of the upper end of the lower insert part; one or more inner seals **66** provided in the second passage; one or more inner seals **67** provided in the first passage above the bore **62**; one or more inner seals **68** provided in the first passage below the bore; and one or more inner seals **93** provided in the first passage at the lower end of the first passage.

[0055] To mount the lower insert part **51** in the tree **16**, the cap **36** may be removed and the lower insert is lowered into the spool module **16***b* until the downward facing support surface **63** engages the corresponding seat surface **43**. Tie down bolts **69** may fix the lower insert part **51** in the spool module **16***b*. When the support surface **63** engages the mating seat surface **43**, the lower end of the lower insert part **51** projects into the upper end of the production tubing. The lower end of the lower insert part **51** fits like a plug in the upper end of the production tubing **14**. The outer seal **65** seals circumferentially against the inner side of the production tubing **14** to prevent fluid from bypassing between the outside of the insert assembly and the inside of the production tubing. A further tubing **84** might be connected to the lower port **57** of the second passage **55**.

[0056] The upper insert part **52** may comprise a body part **71** supporting a first tube **72** and a second tube **73**. To accommodate the first and second tube in slidable manner in the upper insert part, the upper insert part is provided with passages corresponding to the passages in the lower insert part. The diameter of the first tube **72** is smaller than or about equal to the diameter of the first passage **54** so that the first tube can slide vertically within the first passage. Correspondingly, the diameter of the second tube **73** is less than or about equal to the diameter of the second passage **55** so that the second tube can slide within the second passage **55**. Both tubes **72** and **73** are connected to a common piston member **74**. The first tube **72** has an upper end **77** and the second tube **73** has an upper end **78**. The lower ends of both tubes **72**, **73** are open. The piston member **74** is immovable with respect to the tubes **72** and **73**. A spring **76** may bias the piston member **74** in upward direction, the blocking direction. In order to be able to push the tubes **72** and **73** downward against the action of the spring **76**, a hydraulic pressure chamber **75** may be provided adjacent to the piston member **74**. Hydraulic medium can be introduced in or removed from the hydraulic pressure chamber via hydraulic port **46**.

[0057] To mount the upper insert part **52** in the tree **16**, the cap **36** may be removed and the upper insert is lowered into the spool **16***b* until the locking dogs **79** are radially aligned with the lower hanger nipple **42**. The locking dogs **79** may be spring biased so that they automatically engage in the lower hanger nipple. In order to prevent disengaging of the locking dogs **79** from the lower hanger nipple, the locking dogs may be fixated to prevent them from withdrawing in radial inward direction. When the locking dogs engage in the lower hanger nipple, the first tube **72** projects into the first passage **54** and the second tube **73** projects into the second passage **55**. The inner seal **66** seals circumferentially against the outer side of the second tube **73** and the inner seals **67** and **68** seal circumferentially against the first tube **72** to prevent fluid from bypassing between the inner side of the respective passage and the outer side of the respective tube.

[0058] During mounting of the upper insert part **52** in the tree **16**, the second tube **73** will push the flapper valve **61** in the open position. The flapper valve **60** will however not be opened by the first tube as the flapper valve **60** is arranged lower. In case the flapper valve **60** would be arranged higher and/or in case the first tube would be longer, also the flapper

valve **60** would be opened when mounting the upper insert part **52** in the tree. Similarly, opening of the flapper valve **61** would not occur during mounting of the upper insert part in the tree, in case the flapper valve **61** would have been arranged lower and/or in case the second tube would be longer. In mounted condition, an outer seal **85** prevents bypass between the spool wall and the outside of the upper insert part **52**.

[0059] FIG. **2** shows the tubes **72** and **73** pushed downwards in a flow position. Herein, the first tube **72** has pushed the flapper valve **60** open. In case the flapper valve **61** would have been arranged lower and/or the second tube would have been longer, also the flapper valve **61** would have been opened by the second tube **73**. When the tubes are in the flow position, the radial aperture **80** in the first tube **72** is radially aligned with the bore **62** and the side port **39**.

[0060] When the tubes are in the so called flow position, production fluid can, as indicated with arrows **81** and **82**, flow from the production tubing into the lower end of the first passage, into the lower end of the first tube, through the first tube **72**, through the radial aperture **80**, through the bore **62** into the side port **39** of the original tree **16***a*. The first passage **54** in the upper insert part **52** has a closed upper end, whilst the first tube **72** is preferably open at its upper end. Alternatively, the upper end **77** of the first tube might be closed, in which case the upper end **83** of the first passage **54** in the upper insert part **52** has preferably a venting opening.

[0061] Upon relieving the pressure in the pressure chamber **75**, the piston member **74** and tubes **72**, **73** will be pushed upwards by the spring **76** to the blocking position. In this blocking position, the flapper valve **60** will be closed and the radial aperture **80** will be lie opposite a closed inner wall of the first passage **54** so that no flow is possible.

[0062] A secondary fluid flow through the second passage **55** and second tube is possible both in the blocking position and in the flow position of the tubes **72**, **73**. This is due to the fact that in this configuration the flapper valve **61** is always open, that the second tube is open at both ends, and that the second passage is open at both ends **57** and **84**. This secondary flow can leave or enter the tree via the side port **45** and may be controlled by a control valve **44**. Taking into account that the second tube **73** and second passage **55** always allow flow, it is also possible to use these for introducing—for example by means of a wireline—an instrument, tool, sensor or other device into the wellbore.

[0063] In order to prevent leakage of any fluid through the upper end of the spool **16***b*, a bull plug **53** may be provided. This bull plug **53** has locking dogs **86** for locking engagement in upper landing nipple **41** and an outer seal **87**.

[0064] FIG. **3***a* shows the assembly in blocking position (the valves being closed) and FIG. **3***b* shows the assembly in flow position (the valves being opened). The safety valve assembly **17** of FIGS. **3**A, **3**B may be used as a safety valve assembly, either as a sub-surface safety valve or as a surface safety valve. A surface safety valve, including valve assembly **17**, may be included in the Christmas tree of the present invention.

[0065] The safety valve assembly **17** may be configured as one unit, which may be installed in the production tubing **14** and/or in the Christmas tree **16**. The safety valve **17** may be installed or retrieved by wireline. The safety valve **17** may be fixed inside the production tubing or Christmas tree using, for instance, a landing nipple formed in the internal surface of the production tubing or Christmas tree and locking dogs provided on the outer surface of the safety valve assembly **17**.

[0066] The safety valve assembly **17** may comprise an insert assembly arranged in a cylindrical housing **100** which is except for passages to be described closed at its upper side **121** and lower side **122**. The cylindrical housing **100** is provided with two passages, a first passage **101** and a second passage **103**. Both passages extend from the lower end face of the housing **100** up to the upper end face of the housing **100**. A tube is arranged in each passage. First tube **102** is arranged in the first passage **101** and second tube **103** is arranged in second passage **104**.

[0067] A control compartment **123** is provided inside the housing **100**. This control compartment comprises a spring **106**, a piston member **105** and a hydraulic pressure chamber **107**. The first and second tube **102** and **104** are both fixed to and immovable with respect to the piston member **105**. The spring **106** pre-biases the piston member **105** in upward direction. The hydraulic pressure chamber **107** exerts a downward force onto the piston member **105** when it is filled with a hydraulic fluid—indicated by arrow **124**—under a pressure sufficient to overcome the force of the pre-biased spring **106**. In order to prevent leakage of hydraulic medium from the pressure chamber to the spring **106**, a seal **114** may be mounted to the piston member **105** for sealing engagement with the inner wall of the control compartment **123**.

[0068] The tubes **102** and **104** may be provided with one or more radial apertures **108** and **109**, respectively. The lower ends **110** and **111** of both tubes are preferably closed. The upper ends **125** and **126** of both tubes (see FIG. **3***b*) are both open to allow passage of fluid.

[0069] A pressure equalizing line **119** may be provided in the lower part of the housing. The pressure equalizing line **119** debouches with its lower end into the internal **127** of the production tubing. In order to prevent pressure build up in the compartment containing the spring upon compression of the spring **106**, the pressure equalizing line may debouch in the compartment containing the spring **106**. Due to the lower end **110** of the first tube being closed, the first tube might experience large upward forces if the pressure in the internal space **127** of the production tubing increases. Correspondingly large hydraulic pressure in the pressure chamber **107** may be required to push the tubes downward. The hydraulic power required to push the piston member **105** and tubes **102**, **104** downward may be reduced by providing the pressure equalizing line **119** with an equalizing port **121** debouching into the passage **101** at a location below the radial passage **108** when the first tube is in its blocking position. Above and below the equalizing port **121**, a circumferential seal **117** and circumferential seal **118** are provided to define a pressure equalizing space around the first tube **102**. When the first tube **102** is pushed downwards, the equalizing line **119** provides fluid communication between the internal **127** of the production tubing and the internal of the first tube **102** as soon as the radial aperture **108** passes the upper seal **117**. As a result, the upward pressure acting on the closed lower end **110** of the first tube is compensated for.

[0070] Outer seals **112** and **113** are provided on the outside of the housing **100**. The seals extend around the housing **100** and seal against the inner wall of the production tubing **14** to prevent bypass of hydrocarbon fluid (gas and/or liquid) around the insert assembly **17**. To prevent bypass around the tubes **102** and **104** through the passages **101** and **103**, respectively, several inner seals **115**, **116**, **117** and **118** may be provided.

[0071] The first passage **101** communicates at both ends with the inner space **127**, **129** of the production tubing **14**. The second passage **103** is at both ends sealingly connected to a further tubing **84**, which extends through the production tubing. The diameter of the second tube **104** will consequently be smaller than the diameter of the additional tubing **84**. It is noted that depending on circumstances, the second tube **104** can also be absent or might have an open bottom end. Absence of the second tube **104** or an open bottom end of tube **104**, allows the additional tubing to be used easier as guide channel for an instrument, sensor, tool or other device to be brought deep into the wellbore. Note however, that, although less easy due to the radial passage **109**, this guide function can also be provided in presence of the second tube **104** having closed lower end **111**.

[0072] The safety valve assembly **17** functions as follows. FIG. **3**A shows the blocked position, in which there is no flow communication between the upper end and the lower end of the insert assembly. In the blocked condition, the spring exerts a pre-tension force directed in upward direction in order to keep the piston member and tubes in blocked position. Starting from the blocked position, hydraulic fluid is supplied (indicated by arrow **124**) to the hydraulic pressure chamber **107**. The fluid forces the piston member **105** and tubes **102** and **104** downward to the flow position, shown in FIG. **3**B.

[0073] In the flow position, hydrocarbons (gas and/or liquid) can flow through radial apertures **108** into the first tube **102**, flow upward through the first tube **102** and leave the first tube **102** to enter the production tubing **14** at a location above the insert assembly **100**. Similarly, a treatment fluid or other fluid can be passed in the opposite direction through the insert assembly when the piston member **105** and tubes **102** and **104** are in flow position. Treatment fluid may arrive through additional tubing **84** at the upper end of the insert assembly **100**. The fluid enters the second tube **104** through its open upper end **126**, passes through the second tube **104** downwards and leaves the second tube **104** through the radial aperture(s) **109** to continue downwards through the part of the additional tubing **84** extending below the insert assembly **100**. To keep the insert assembly **100** in the flow position, the increased pressure in the pressure chamber **107** is to be maintained. To close the safety valve assembly **17**, the hydraulic pressure in the pressure chamber is released (reduced) and the spring **106** will push the piston member **105** and tubes **102**, **104** to the blocked position shown in FIG. **3**A. This functions as a fail-safe mechanism.

[0074] As shown in FIGS. **4** and **5**, a Christmas **160** according to the invention may comprise a number of modules **162**, **164**, **166**, **170**. Each module is provided with a module opening **172**. The modules are connected to each other to form a housing **174**. The module openings **172** together form a continuous conduit **180**. Preferably, the continuous conduit **180** is a straight, cylindrical opening.

[0075] One or more retrievable inserts **182**, **184**, **186**, **190** may be arranged in the module openings of the respective modules. The retrievable inserts are provided with at least one fluid passage **192**. The respective fluid passages **192** of the subsequent inserts are connected to each other, forming a continuous fluid passage **194**. Retrievable inserts **182**, **186** and **190** as shown in FIG. **4** are valve inserts. Retrievable insert **184** can be regarded as a junction insert, providing for instance one or two fluid passages **196** extending sideways and connecting to the kill wing port **38** and/or the flow wing port **39** respectively (See FIG. **2**). The kill wing port and the flow wing port may be connected to corresponding fluid conduits. The ports **38**, **39** may be closed or opened using kill wing valve **34** and flow wing valve **35** respectively. Said valves may be located outside of the housing **174**, as shown in FIG. **2**.

[0076] Control means **202**, **206**, **210** are coupled to the modules to control the valve insert in the respective module between a closed position and an open position of the at least one fluid passage. In the closed position of the valve insert the fluid passage is blocked, whereas in the open position fluid may pass through the fluid passage of the valve insert. The control means may be releasably coupled to the valve inserts. In one embodiment, the control means couple to the inserts comparable to a key would couple to and control a lock. When an insert has to be replaced, the control means are released from the corresponding inserts to allow replacement of one or more inserts. Afterwards, the control means can be re-coupled to the respective insert.

[0077] The valve inserts **182**, **186**, **190** may include a ball valve. A ball valve includes a spherical disc disposed in the fluid channel to control the flow through the valve. The sphere has a hole, or port, through the middle so that when the port is in line with the fluid passage of the valve, flow is enabled. When the valve is closed, the hole is perpendicular to the fluid passage of the valve, and flow is blocked. The control means may include a wheel **212**, handle or lever to control the valve's position. Alternatively, the valve insert may include a butterfly valve, plug valve, or similar quarter turn valves.

[0078] The control means may be manually operable. For the manual control, the control means may comprise a wheel **212** (FIG. **5**). Alternatively, the control means may include a motor, which may be remotely operated and/or automatically operated by a control computer (not shown).

[0079] In a practical embodiment, the modules may replace the valves of a conventional Christmas tree as follows:

[0080] module **162**: Swab valve;

[0081] module **164**: Flow wing valve and Kill wing valve;

[0082] module **166**: Upper master valve;

[0083] module **170**: Lower master valve.

[0084] At an upper end, the fluid passage **194** of the Christmas tree **160** may be covered by a cover **214**. Preferably, the cover is a lock or floodgate, to allow the passage of material such as tools, tubing, and valve inserts into and out of the wellbore, while enabling to shut in the wellbore to maintain control of the well. The cover may include upper and lower closures **215** and **217**.

[0085] At a lower end, which may be connected to the wellbore **1**, the Christmas tree **160** may include a hanger module **220**. The hanger module includes a hanger opening **222** for hanging off tubing, such as the production tubing **14**. The hanger opening **222** is aligned with the continuous fluid passage **194** of the valve inserts.

[0086] Preferably, the hanger module is provided with one or more control connections **224**, **226**, **228**, to allow control of downhole equipment.

[0087] In a practical embodiment, shown in FIG. **4**, control connection **224** may allow the introduction of foam in the wellbore **1** via the treatment fluid injection tubing **19**. Control connection **226** may enable the hydraulic control of the downhole safety valve **17**. Control connection **228** is closed.

[0088] In another practical embodiment, shown in FIG. **5**, the control of the downhole safety valve **17** via the connection

226 may have failed. The hanger module of the invention enables to change the control of the safety valve 17 and re-establish control of the safety valve 17 using control connection 224, for instance using hydraulics. Control connection 228 is closed.

[0089] In yet another practical embodiment, shown in FIG. 6, a velocity string 240 has been introduced in the production tubing 14. The inner diameter of the velocity string is smaller than the inner diameter of the production tubing, and serves as a remedial treatment to resolve liquid-loading problems. As the reservoir pressure in a gas well depletes, there may be insufficient velocity to transport all liquids up the wellbore. In time these liquids accumulate and impair production. Installing a velocity string reduces the flow area and increases the flow velocity to enable liquids to be carried from the wellbore. Velocity strings are commonly run using coiled tubing as a velocity string conduit.

[0090] The Christmas tree of the invention may allow to insert the velocity string 240 via the conduit 180 or via fluid passage 194. I.e., the velocity string may be inserted in the wellbore through the Christmas tree 160. An upper end of the velocity string may hang off a hanger nipple or similar device in the hanger module 220. Alternatively, the velocity string may be connected to a string insert, which may be inserted in the tree 160 instead of the lower insert 352 (FIG. 12C). An outer surface of the velocity string may be provided with a packer element 244. A fluid channel 242 inside of the velocity string may be provided with a surface controlled safety valve 246. The packer element 244 may be hydraulically inflated and controlled via the connection 226. The safety valve 246 may be hydraulically controlled via connection 224.

[0091] In an improved embodiment, shown in FIG. 7, the velocity string may be provided with a controllable valve 248 to allow opening and closing a fluid passage between the internal fluid channel 242 of the velocity string and an annular space 250 between the velocity string and the production tubing 14. Thus, the reduction of the flow area of the production tubing may be continuously controlled between the area of the production tubing and the area of the velocity string. The controllable valve 248 may include a slidable sleeve door (SSD). The valve 248 may be controlled via hydraulics, for instance via control 226.

[0092] In another improved embodiment, shown in FIG. 8, the packer element 244 includes a valve 254. The valve 254 opens or closes a fluid passage between the section of the annulus 250 above and below the packer 244. The valve 254 may be a gas lift valve, allowing the injection of gas via the control opening 228 into the annulus 250 and into the production zone 10 of the wellbore 1. The injected gas provides a gas-lift system, providing production energy by injecting gas into the production fluid column, thereby reducing the hydrostatic pressure and enabling improved reservoir production.

[0093] FIGS. 9A, 9B show respective embodiments of an upper end of the velocity string 240. Said upper end is for instance provided with a cylindrical head 260 and a support shoulder 262. The support shoulder 262 functions to hang the velocity string in the hanger module 220. An outer surface of the head 260 may be provided with one or more seal rings 264. Also, the head 260 may be provided with fluid passages 266, 268 to connect to control openings 224, 228 of the hanger module respectively.

[0094] As shown in FIGS. 10 and 11, the inserts of the modules 162-170 may be provided with multiple fluid passages, to form for instance two parallel continuous fluid passages 194, 294. Each module may be provided with multiple control means, one control means for each fluid passage. The primary fluid passage 194 may include the control means as described above. In addition secondary control means 302, 306, 310 may control the secondary fluid passage 294.

[0095] In a practical embodiment, the primary fluid passage 194 may be connected to the annulus 250 (FIG. 11). The secondary fluid passage 294 may be connected to the velocity string 240. Downhole valves 246, 254 can be controlled via, for instance, control line 224. A downhole end of the velocity string 240 may be provided with a downhole pump 320. The pump 320 may be powered and controlled, for instance using hydraulics or electricity, via power line 322 which may be connected to the control opening 228 of the hanger module 220. The pump 320 may be replaced using wireline. Gas may be produced via the annulus 250 and the primary fluid passage 194. Hydrocarbon fluids may be produced via the velocity string 240 and the secondary fluid passage 294. The gas may leave the Christmas tree via primary flow wing valve 35A. The fluids may leave the Christmas tree via the secondary flow wing valve 35B.

[0096] The Christmas tree of the invention may be constructed as shown in FIGS. 12A to 12F.

[0097] In a first step (FIG. 12A), modules 162 to 170 are connected. The modules may be connected to hanger module 220. Herein, the respective openings of the modules together form continuous conduit 180. The modules 162, 166, 170 are provide with lateral control openings 342, 346, 350 respectively to allow the connection of control means. The module 164 may be provided with kill wing port 38 and/or flow wing port 39.

[0098] For initial production, an insert 352 having a fluid passage 192 is introduced by wireline 354 (FIGS. 12B, 12C). Said insert 352 may later be retrieved, for instance by wireline, and replaced with another insert carrying a velocity string, as described above with reference to, for instance, FIG. 6.

[0099] Subsequently, a second insert 356 is introduced by wireline 354 (FIG. 12D). Said second inert 356 may be a valve insert, suitable for lower master valve module 170.

[0100] In a next step, corresponding control means 210 may be connected to the module 170 (FIGS. 12E, 12F). The module may be provided with a notch 360 to receive the control means. An end of the control means is provided with an extension 362, which fits into the notch 360 of the valve insert for the control thereof between an open and a closed position.

[0101] The other modules of the Christmas tree may be assembled in a similar way. Also, the tree may be disassembled in reverse order.

[0102] In an embodiment, two or more of the retrievable inserts of respective modules may be combined to form an integral insert. The respective inserts of the integral retrievable insert may be inserted and retrieved in the housing 174 together.

[0103] FIG. 13 shows an embodiment wherein the valve inserts 182, 186 and 190 and the junction insert 184 are combined to form a single insert 380. The integral insert 380 may be inserted or retrieved from the housing, allowing to replace the valve inserts 182, 186, 190 all at once.

[0104] An internal surface of the housing 174 may be provided with placement means to arrange the insert in a predetermined position. The placement means may comprise

grooves, landing nipples, one or more shoulders **382**, **384**, **386**, or a combination thereof. The insert **380** may be provided with ridges or insert shoulders **388**, **390**, **392**, having a shape corresponding to the respective housing shoulder.

[0105] The Christmas tree element **160**, described above with reference to FIGS. **4** to **13**, may be combined with the Christmas tree element **16** as described with reference to FIGS. **2** and **3**.

[0106] For instance, the Christmas tree element **160** may be connected to the top side of one of the Christmas tree elements **16***a* and **16***b*, providing in effect two Christmas trees. Alternatively, element **16***a* may be similar to the Christmas tree element **160** as described above. The element **16***b* may be connected to the topside of the Christmas tree element **160**. When required, the retrievable valve element **51** or the entire valve assembly **40** may be inserted in the Christmas tree at some stage during the lifetime of the well to create multiple fluid lines through the tree, for instance for foam injection.

[0107] The description above describes exemplary embodiments of the present invention. Many modifications therein are conceivable within the scope of the appended claims. Features of respective embodiments may for instance be combined.

1. A Christmas tree for a wellbore, comprising a plurality of modules, each module including:
- at least one module opening;
- a retrievable valve insert arranged in the module opening, the retrievable valve insert being provided with at least one fluid passage; and
- control means coupled to the module to control the valve insert between a closed position and an open position of the at least one fluid passage;
- the modules being connected to each other to form a housing, the respective module openings being connected to form a continuous conduit though the housing, the respective fluid passages of the valve inserts being connected to form at least one continuous fluid passage, said continuous fluid passage being adapted to be connected to the wellbore.

2. The Christmas tree of claim **1**, wherein the continuous conduit is a straight cylindrical channel.

3. The Christmas tree of claim **1**, wherein the continuous fluid passage is a straight cylindrical passage.

4. The Christmas tree of claim **1**, wherein the valve inserts of each module include at least two parallel fluid passages, the at least two fluid passages of the subsequent modules constituting at least two parallel continuous fluid passages though the continuous conduit of the housing.

5. The Christmas tree of claim **4**, each module comprising at least two control means coupled to the module, each control means enabling the control of the valve insert between a closed position and an open position of one of the at least two fluid passages.

6. The Christmas tree of claim **1**, wherein the control means are releasably coupled to the valve insert of the respective module.

7. The Christmas tree of any of claim **1**, comprising a hanger module for hanging tubing into the wellbore.

8. The Christmas tree of claim **7**, wherein the hanger module is provided with at least one hydraulic connection, adapted to be connected to hydraulic activating means.

9. The Christmas tree of claim **8**, wherein one hydraulic connection is connected to hydraulic activating means to control a downhole valve.

10. The Christmas tree of claim **1**, wherein the valve insert of a respective module is retrievable by wireline.

11. The Christmas tree of claim **1**, comprising a junction module, the junction module comprising a kill wing port and/or a flow wing port being provided with corresponding kill wing valve and/or flow wing valve respectively, and a retrievable junction insert.

12. The Christmas tree of claim **11**, wherein the retrievable junction insert is connected to at least one valve insert of a valve module to form an integral retrievable insert.

13. A method of building a Christmas tree for a wellbore, comprising the steps of:
- providing a plurality of modules, each module including at least one module opening;
- connecting the modules to each other to form a housing, the respective module openings forming a continuous conduit though the housing;
- arranging a retrievable valve insert in the module opening of the modules, each retrievable valve insert being provided with at least one fluid passage, the respective fluid passages of the valve inserts being connected to form at least one continuous fluid passage, said continuous fluid passage being adapted to be connected to the wellbore; and
- coupling control means to each module to control the valve insert in the respective module between a closed position and an open position of the at least one fluid passage.

14. The method of claim **13**, wherein the continuous conduit is a straight cylindrical channel.

15. The method of claim **13**, wherein the control means are releasably coupled to the valve insert of the respective module.

16. The method of claim **13**, comprising the steps of:
- connecting a hanger module to the housing for hanging tubing into the wellbore.

17. The method of claim **16**, including:
- hanging tubing off the hanger module into the wellbore; and
- connecting hydraulic activating means to a hydraulic connection of the hanger module to control a downhole valve.

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