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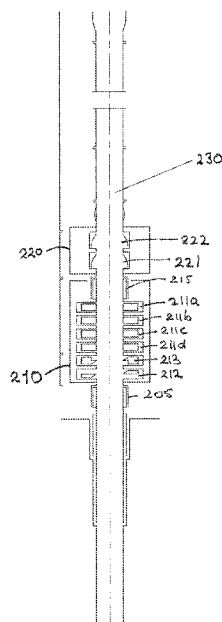


FIG. 3

(57) Abstract: The present invention relates to a subsea blowout preventer (BOP) stack system for ensuring pressure control of a wellbore up to a pressure A, which BOP stack system is connectable to an offshore rig by a drilling riser that provides a continuous pathway for a drill string and drilling fluids emanating from the wellbore. The subsea BOP stack system comprises a first blind shear ram (BSR) housing with pressure rating A, comprising at least two BSRs having a pressure rating A, designed to shear the drill pipe in the well and seal the wellbore simultaneously. The subsea BOP stack system further comprises one or more pipe rams, designed to close around a drill pipe. At least one pipe ram has a pressure rating B, wherein B is lower than A.



MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
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Subsea drilling rig blowout preventer (BOP) stack system and use of such a system
in drilling subsea wells

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The present invention relates to a subsea blowout preventer (BOP) stack system for ensuring pressure control of a wellbore, which BOP stack system is connectable to an offshore rig by a drilling riser that provides a continuous pathway for a drill string and drilling fluids emanating from the wellbore.

10

The invention further relates to the use of such a subsea drilling rig BOP stack system in drilling subsea wells.

A blowout preventer (BOP) is a large, specialized valve or similar mechanical device, used
15 to seal, control and monitor oil and gas wells to prevent blowout: the uncontrolled release of crude oil and/or natural gas from a wellbore (reservoir of oil and gas). Blowout preventers are developed to cope with extreme erratic pressures and uncontrolled flow emanating from a well reservoir during drilling. They are usually installed redundantly.

20 In a BOP housing, one or more BOPs can be provided. A BOP stack system can comprise one BOP housing or multiple BOP housings stacked on top of each other. Subsea BOP stack systems are secured to the top of the wellbore, known as the wellhead.

In drilling a subsea well, subsea BOP stack systems are connected to an offshore rig above
25 by a drilling riser that provides a continuous pathway for the drill string of drill pipes and drilling fluids emanating from the wellbore. Without the drilling riser, the drilling fluids, including mud, would simply spill out of the top of the BOP stack system onto the seafloor.

The column of drilling mud exerts a downward hydrostatic pressure to counter opposing
30 pressure from the formation being drilled.

A kick is a well control problem in which the pressure found within the drilled rock is higher than the mud hydrostatic pressure acting on the borehole or rock face. When this occurs, the greater formation pressure has a tendency to force formation fluids into the wellbore.
35 This forced fluid flow is called a kick. If the flow is successfully controlled, the kick is considered to have been killed. An uncontrolled kick that increases in severity may result in what is known as a "blowout."

As the well is drilled, drilling fluid, "mud", is fed through the drill string down to the drill bit, and returns up the wellbore in the ring-shaped void, annulus, between the outside of the drill pipe and the casing (piping that lines the wellbore). Interconnected drill pipes are referred to
5 as a drill string.

BOPs come in two basic types, *ram* and *annular*. Both are often used together in drilling rig BOP stack systems, typically with at least one annular BOP capping a stack of several ram BOPs. Furthermore, BOPs come in a variety of styles, sizes and pressure ratings. Several
10 individual BOPs serving various functions are combined to compose a blowout preventer stack system.

Common types of ram BOPs are:

- pipe rams close around a drill pipe, restricting flow in the annulus (ring-shaped space
15 between concentric objects) between the outside of the drill pipe and the wellbore, but do not obstruct flow within the drill pipe. Variable-bore pipe rams can accommodate tubing in a wider range of outside diameters than standard pipe rams, but typically they have limited pressure holding and pipe hang off capability;
- blind rams (also known as sealing rams), which have no openings for tubing, can
20 close off the well when the well does not contain a drill string or other tubing, and seal it;
- shear rams are designed to shear the pipe in the well;
- blind shear rams (also known as shear seal rams, or sealing shear rams) are
25 intended to seal a wellbore, even when the bore is occupied by a drill string, by cutting through the drill string as the rams close off the well.

A typical BOP stack system might consist of one to eight ram-type preventers and, optionally, one or two annular-type preventers. A typical stack system configuration has the ram preventers on the bottom and the annular preventers at the top. Practical configurations
30 are known wherein the pipe rams are provided below the blind rams. Also, alternative practical configurations are known wherein the pipe rams are provided above the blind rams. The configuration of the stack preventers is optimized to provide maximum pressure integrity, safety and flexibility in the event of a well control incident.

35 For example, in a multiple ram configuration, one set of rams might be fitted to close on 5-in. (12,7 cm) diameter drillpipe, another set configured for 4 1/2-in. (114 cm) drillpipe, a third fitted with blind rams to close on the openhole and a fourth fitted with a shear ram that can

cut the drillpipe as a last resort, preferably having a diameter of 18-3/4 (476 cm) inch. It is common to have an annular preventer or two on the top of the stack since annulars can be closed over a wide range of tubular sizes and the openhole, but are typically not rated for pressures as high as ram preventers. The BOP stack system also includes various spools, adapters and piping outlets to permit the circulation of wellbore fluids under pressure in the event of a well control incident.

In US2012/1217019 examples of existing configurations of BOP stacks are presented. Such known configurations comprise e.g. spools, single rams and annular preventers. Such a known BOP stack has, depending on the bore dimension, a rated working pressure of e.g. 5 (345 bar), 10 (689 bar) or 15 kpsi (1035 bar; 103,5 MPa).

WO99/49179 discloses a BOP stack system having a body with a first and second set of ram members. US2003/000693 discloses a BOP stack system with a number of valve means including pipe rams and shear blind rams.

As reservoir pressures increase and the pressure at the wellhead rises beyond the capability of conventional BOP equipment, costs to develop and manufacture new equipment increase significantly the costs for drilling subsea wells.

There is a desire to develop technologies to be able to drill, complete, produce, and intervene in deepwater reservoirs that have pressures in excess of 15 kpsi (1035 bar; 103,5 MPa), in particular up to 20 kpsi (1379 bar; 137,9 MPa). The equipment preferably withstands reservoir temperatures over 150°C, in particular up to 200°C.

With the subsea well pressures increasing beyond 15 kpsi, the weight, costs and dimensions of equipment to full shut off wellhead pressure renders some oil and gas reserves un-economic to develop.

It is an object of the present invention to provide an improved subsea blowout preventer stack system for pressure control of a wellbore having in pressure in excess of 15 kpsi.

This object is achieved in that a subsea drilling rig BOP stack system is provided, for ensuring pressure control of a wellbore up to a pressure A, which BOP stack system is connectable to an offshore rig by a drilling riser that provides a continuous pathway for a drill string and drilling fluids emanating from the wellbore, comprising:

- a blind shear ram (BSR) housing with pressure rating A, comprising at least two BSRs having a pressure rating A, designed to shear the drill pipe in the well and seal the wellbore simultaneously;
- one or more pipe rams, designed to close around a drill pipe, wherein at least one pipe ram has a pressure rating B, wherein B is lower than A.

An advantage of such a subsea BOP stack system for ensuring pressure control of a wellbore up to a pressure A, with components having a pressure rating B, is that the costs and dimensions are relatively low compared to a blowout preventer stack wherein all rams have a pressure rating A, while still being able to control the pressure of a wellbore up to a pressure A.

It is possible to provide a BOP stack system with pipe rams having a pressure rating B, wherein B is lower than A, because the column of drilling mud, provided above the BOP stack system, exerts a downward hydrostatic pressure Δ , at the level of the BOP (just above the wellhead), to counter opposing pressure from the formation being drilled. Hence, a safe pressure control is achieved with a pressure rating B that is equal to or exceeds the difference between pressure rating A and hydrostatic pressure Δ . In a formula: $B \geq A - \Delta$. Or in other words, the hydrostatic pressure Δ should at least compensate for the difference between pressure rating A and B. In a formula: $\Delta \geq A - B$. Or in other words $B + \Delta \geq A$.

In practical embodiments, the pressure rating A of the housings and the BSRs can be in excess of 15 kpsi (1035 bar; 103,5 MPa), in particular up to 20 kpsi (1379 bar; 137,9 MPa). The hydrostatic pressure Δ depends amongst others on the water depth and mud density, and may vary between 1 kpsi (69 bar; 6,9 MPa), and 10 kpsi (689 bar; 68,9 MPa), in particular between 1 kpsi and 5 kpsi (345 bar; 34,5 MPa). Accordingly, the pressure rating B of the pipe rams and possibly other BOPs and equipment may be as low as 5 – 15 kpsi.

By closing the pipe rams, the wellbore pressure is countered by the combination of the pipe rams and the column of drilling mud. It is noted that in case of a gas blowout, filling the drill string with gas instead of mud (a so-called gas-evacuated riser), there is no longer a downward hydrostatic pressure Δ and hence the blind shear rams are activated to seal the wellbore.

It is common to consider a BOP stack system maximum rated well pressure equal to the lowest rated ram BOP pressure. According to this definition, the BOP stack system of the present invention has a maximum rated well pressure B. Nonetheless, with the BOP stack

system configuration of the invention, due to the above insight, the BOP stack system is safe to withstand a wellbore pressure A.

The inner and top faces of the rams are fitted with packers, i.e. elastomeric seals, that press against each other, against the wellbore, and around tubing running through the wellbore. It is in particular difficult to provide such seals having an increased pressure rating.

Amongst the known functions of a blowout preventer system are:

- control (regulate and monitor) the downhole (occurring in the drilled hole) pressure and the flow of well fluid (oil and gas);
- provide means to add fluid to the wellbore;
- allow controlled volumes of fluid to be withdrawn from the wellbore;
- prevent tubing (e.g. drill pipe and well casing), tools and drilling fluid from being blown out of the wellbore (also known as bore hole, the hole leading to the reservoir) when a blowout threatens;
- center and hang off the drill string in the wellbore;
- shut in the well (e.g. seal the void, annulus, between drillpipe and casing);
- "kill" the well (prevent the flow of formation fluid, influx, from the reservoir into the wellbore) ;
- seal the wellhead (close off the wellbore);
- sever the casing or drill pipe (in case of emergencies).

Dependent on the function, a subsea deepwater blowout BOP system further includes auxiliary components, such as electrical and hydraulic line connectors, control pods, hydraulic accumulators, test valve, kill and choke line connectors and valves, riser joint and hydraulic connectors, etc. etc..

Another advantage of the BOP stack system of the invention is that with the pipe rams having a pressure rating B, lower than A, other equipment such as the choke and kill lines can also have a pressure rating B instead of A.

In embodiments, the two or more blind shear rams have an acoustic control system allowing operation of the blind shear rams upon an acoustic signal. Such a system is advantageous as no control and signal lines are required.

In embodiments, the BOP stack system comprises at least 7 ram BOPs in total, with two blind shear rams having a pressure rating A and the other rams having a pressure rating B.

In embodiments, the BOP stack system further comprises an upper BOP housing with pressure rating B, connected to or connectable to an upper side (downstream of) the BSR housing. One or more further BOP housings with pressure rating B can be connected or
5 connectable to this upper BOP housing. Alternatively, or in addition thereto, the BOP stack system further comprises a lower BOP housing with pressure rating A, connected to or connectable to a lower side (upstream of) the BSR housing.

In embodiments, a pipe ram having a pressure rating B is provided in the BSR housing,
10 together with the BSRs. If present, the upper BOP housing comprises one or more further ram BOPs having a pressure rating B.

Yet alternatively, a pipe ram having a pressure rating B is provided in the upper BOP housing. Possibly, the upper BOP housing comprises one or more further ram BOPs having
15 a pressure rating B.

In a BOP housing one or more BOPs can be housed. For example, two BSRs in the BSR housing and two pipe rams in the upper BOP housing, and 3 other ram BOPs in a third housing, connected to this upper BOP housing, e.g. comprising a variable bore ram. In this configuration, the pipe rams and other ram BOPs can all have a pressure rating B.
20

In embodiments, all ram BOPs and further equipment above (downstream of) the blind shear rams have a pressure rating B.

In embodiments, the BOP stack system further comprises one or more annular preventers,
25 commonly having a pressure rating significantly lower than B.

It is conceivable that the lower BOP housing comprises one or more further ram BOPs having a pressure rating A or B.

30 The invention is further elucidated in the drawings, in which:

Fig. 1 represents a 20kpsi subsea BOP stack system according to the prior art;

Fig. 2 represents a an alternative known well control system;

Fig. 3 represents a 20kpsi subsea BOP stack system according to the invention;

Fig. 4 represents an alternative 20kpsi subsea BOP stack system according to the invention.
35

Figs. 1-4 show different configurations of a well control system of a 20kspi well. The configurations of figs. 1 and 2 are known in the prior art. The configurations of figs. 3 and 4

are according to the present invention. The configurations of figs. 1, 3 and 4 involve the use of a subsea drilling rig blowout preventer stack system. The configuration of fig. 2 is structurally different in that well control is achieved by, a.o., a surface BOP stack.

5 In fig. 1 an exemplary 20kpsi subsea BOP stack system 10, 20 according to the prior art is shown, for ensuring pressure control of wellbore 1. A drilling riser 30, also referred to as riser string, extends from the BOP stack system 10, 20 to the surface, e.g. to an offshore rig. The rig is preferably provided with a riser tensioning system. Possibly, a telescopic joint is provided at the termination point of the drilling riser 30.

10

The BOP stack system 10, 20 comprises a lower BOP housing 10, connected via a connector 15 to upper BOP housing 20. Lower BOP housing 10 is connected via a connector 5 to the top of the wellbore, known as the wellbore head.

15 The lower BOP housing 10 here comprises a stack of 6 types of BOPS. The lower four BOPS 11a, 11b, 11c, 11d are of the 'pipe ram' type, possibly one or more of the particular type 'variable bore ram'. On top thereof, in the same BOP housing 10, are provided two rams 12, 13 of the 'blind shear ram' type. Possibly, the shear ram 12 is a casing shear ram. The capacity of the lower BOP housing 10 and all its rams is 20kpsi.

20

The upper BOP housing 20 comprises two annular BOP's 21, 22. This upper BOP housing 20 is also referred to as a Lower Marine Riser Package (LMRP). The capacity of these annular BOP's 21, 22 is e.g. 10kpsi.

25 Because of this configuration of the BOP stack system 10, 20, a low-pressure marine riser 30 can be applied.

In fig. 2 an alternative known well control system is shown, comprising a subsea BOP housing 110, a high-pressure drilling riser 130 and a surface BOP housing 120. The
30 capacity of the subsea BOP housing 110, also referred to as subsea isolation device, is 20kpsi. It here comprises blind shear rams 112, 113.

The surface BOP housing 120 comprises a stack with on top an annular BOP 121, and therebelow a stack of 4 BOPS 111a, 111b, 111c, 111d of the pipe ram type, possibly one or
35 more of the particular type 'variable bore ram'.

The capacity of the surface BOP housing 120 and that of the high-pressure drilling riser 130 is both 15 kpsi.

5 The subsea drilling rig blowout preventer stack system 210, 220 of fig. 3 comprises a lower blind shear ram (BSR) BOP housing 210, connected via a connector 215 to upper BOP housing 220. Lower BSR-BOP housing 210 is connected via a connector 205 to the top of the wellbore.

10 The lower BSR- BOP housing 210 here comprises a stack of 6 types of BOPS. The lower two are respectively blind shear rams 212, 213. The blind shear ram 212 is possibly a casing shear ram. The capacity of the lower BSR-BOP housing 210 and these lower rams 212, 213 is 20kpsi. In other words, the BSR-BOP housing and the BSR's 212, 213 have a pressure rating of 20 kpsi, designed to shear the drill pipe in the well and seal the wellbore simultaneously.

15

On top thereof, in the same BSR-BOP housing 210, are provided four BOPS 211a, 211b, 211c, 211d of the 'pipe ram' type, possibly one or more of the particular type 'variable bore ram' . These pipe rams have, according to the present invention, a capacity of 15 kpsi, wherein 15 kpsi is lower than 20 kpsi.

20

Similar to the configuration of fig. 1, the upper BOP housing 220 comprises two annular BOP's 221, 222. This upper BOP housing 220 is also referred to as a Lower Marine Riser Package (LMRP). The capacity of these annular BOP's 21, 22 is e.g. 10kpsi.

25 Because of this configuration of the BOP stack system 210, 220, a low-pressure marine riser 230 can be applied.

30 The configuration of the subsea drilling rig blowout preventer stack system 310, 320, 330 of fig. 4 differs from that of fig. 3 only in that the two lowermost blind shear rams 312, 313, are provided together in a lower blind shear ram (BSR) BOP housing 310, while the four BOPS 311a, 311b, 311c, 3211d of the 'pipe ram' type thereabove are provided together in a middle BOP housing 320. Between the lower BOP housing 310 and middle BOP housing 320 a connector 315 is provided, and between middle BOP housing 320 and upper BOP housing 330 a connector 325.

35

The capacity of the lower BSR-BOP housing 310 and the lower blind shear rams 212, 213 is 20kpsi. The capacity of the middle BOP housing 320 and that of the pipe rams 311a -

311d is according to the present invention lower than that of the BSR-BOP housing 310, i.e. 20 kpsi, hence e.g. 15 kpsi. The capacity of upper housing 330 with annular BOP's 321, 322 may be 10 kpsi.

- 5 Because of this configuration of the BOP stack system 310, 320, 330 a low-pressure marine riser 340 can be applied.

10
CLAIMS

1. Subsea blowout preventer (BOP) stack system (210, 220) for ensuring pressure control of a wellbore up to a pressure A, which BOP stack system is connectable to an offshore rig by a drilling riser (30) that provides a continuous pathway for a drill string and drilling fluids emanating from the wellbore; the subsea BOP stack system comprising:
- 5 - a blind shear ram (BSR) housing (210) with pressure rating A, comprising at least two BSRs (212, 213) having a pressure rating A, designed to shear the drill pipe in the well and seal the wellbore simultaneously;
- one or more pipe rams (211a, 211b, 211c, 211d), designed to close around a drill pipe,
- 10 characterized in that at least one pipe ram has a pressure rating B, wherein B is lower than A.
2. Subsea drilling rig blowout preventer (BOP) stack system according to claim 1, wherein the one or more blind shear rams have an acoustic control system allowing
- 15 operation of the blind shear rams upon an acoustic signal.
3. Subsea drilling rig blowout preventer (BOP) stack system according to claim 1, wherein at least one pipe ram having a pressure rating B is provided in the BSR housing.
- 20 4. Subsea drilling rig blowout preventer (BOP) stack system according to any of the preceding claims, wherein the BOP stack system further comprises an upper BOP housing (220) with pressure rating B, connected to or connectable to an upper side (downstream of) the BSR housing, wherein preferably the upper BOP housing comprises one or more further ram BOPs having a pressure rating B.
- 25 5. Subsea drilling rig blowout preventer (BOP) stack system according to claim 4, wherein at least one pipe ram having a pressure rating B is provided in the upper BOP housing.
- 30 6. Subsea drilling rig blowout preventer (BOP) stack system according to any of the preceding claims, wherein the BOP stack system further comprises a lower BOP housing with pressure rating A, connected to or connectable to a lower side (upstream of) the BSR housing.

7. Subsea drilling rig blowout preventer (BOP) stack system according to any of the preceding claims, wherein all rams and further equipment above (downstream of) the blind shear rams have a pressure rating B.

5 8. Subsea drilling rig blowout preventer (BOP) stack system according to any of the preceding claims, further comprising one or more annular preventers.

9. Use of a subsea drilling rig BOP stack system according to one or more of the preceding claims in drilling subsea wells.

10

10. Method for ensuring pressure control of a wellbore up to a pressure A, wherein use is made of a subsea blowout preventer (BOP) stack system (210, 220) comprising:

- a blind shear ram (BSR) housing (210) with pressure rating A, comprising at least two BSRs (212, 213) having a pressure rating A, designed to shear the drill pipe in the
- 15 well and seal the wellbore simultaneously;
- a pipe ram (211a, 211b, 211c, 211d), designed to close around a drill pipe, wherein at least one pipe ram has a pressure rating B, wherein B is lower than A;

the method comprising the step of connecting the BOP stack system to an offshore rig by a drilling riser (30) that provides a continuous pathway for a drill string and drilling fluids

20 emanating from the wellbore.

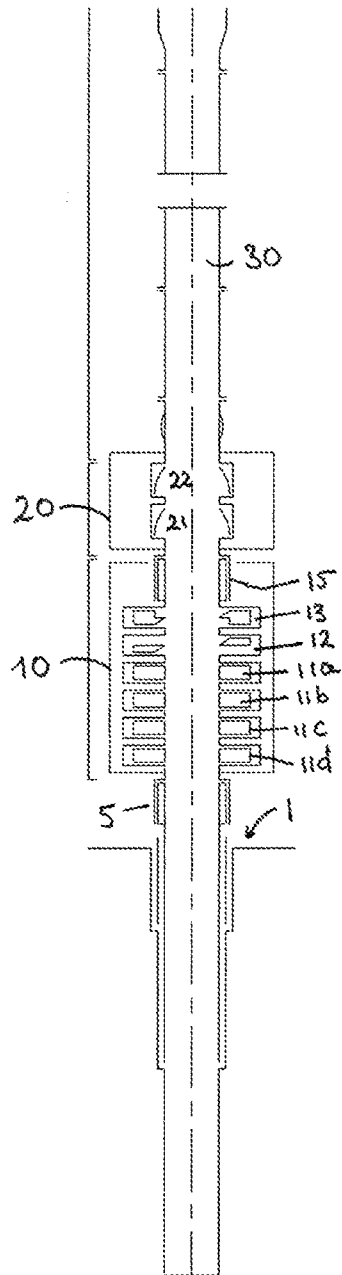


FIG. 1

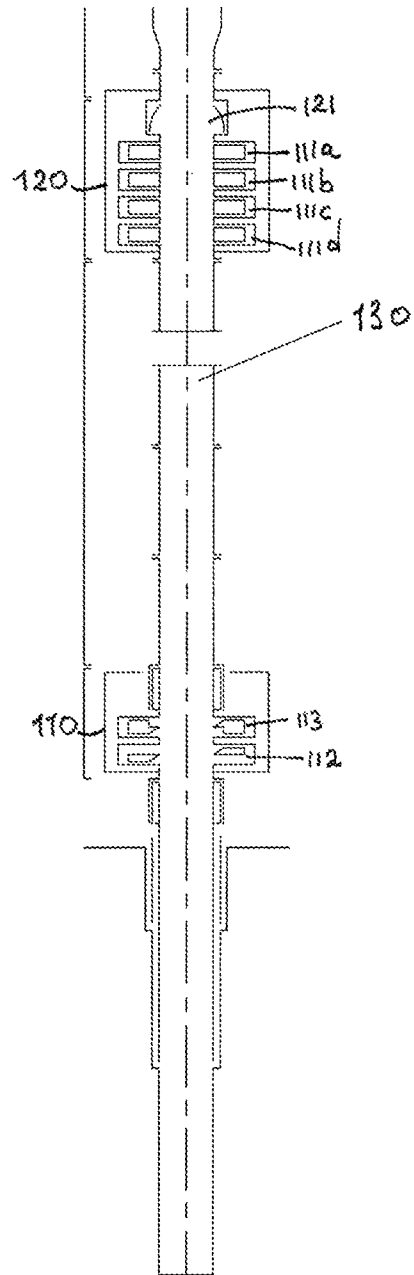


FIG. 2

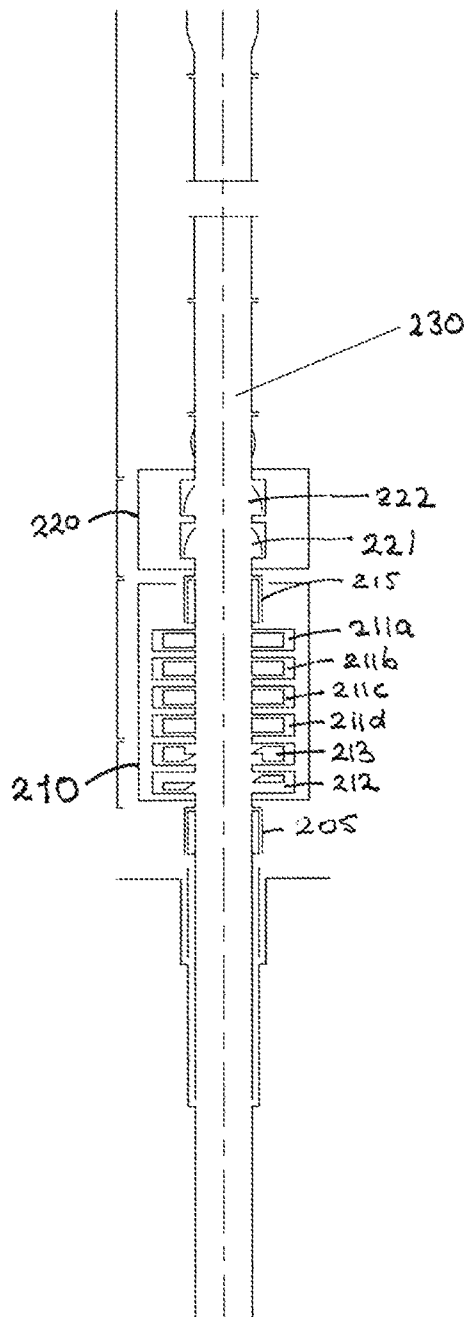


FIG. 3

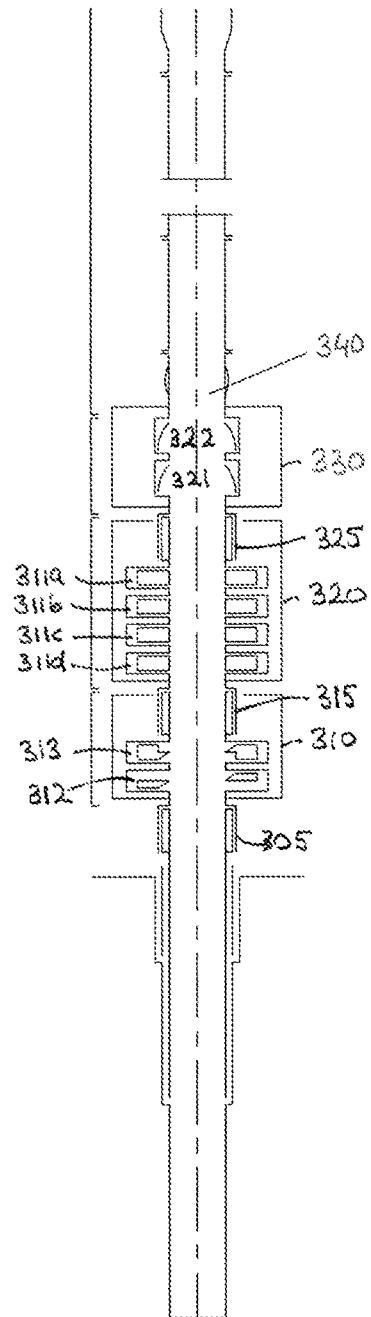


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2018/050472

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B33/06 E21B33/064
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)
E21B

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

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Y	paragraphs [0016], [0017]; figure 8	2-8
Y	----- WO 99/49179 A1 (HYDRIL CO [US]) 30 September 1999 (1999-09-30) page 8, lines 8-29; figure 9	3
Y	----- US 2003/000693 A1 (COUREN PATRICE PAUL LOUIS [FR] ET AL) 2 January 2003 (2003-01-02) paragraph [0089] paragraph [0043]	2,4-8
X	----- US 2015/034384 A1 (LEUCHTENBERG CHRISTIAN [SG]) 5 February 2015 (2015-02-05) paragraphs [0059], [0068] ----- -/-	1,4,7-9



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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"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

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2018/050472

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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