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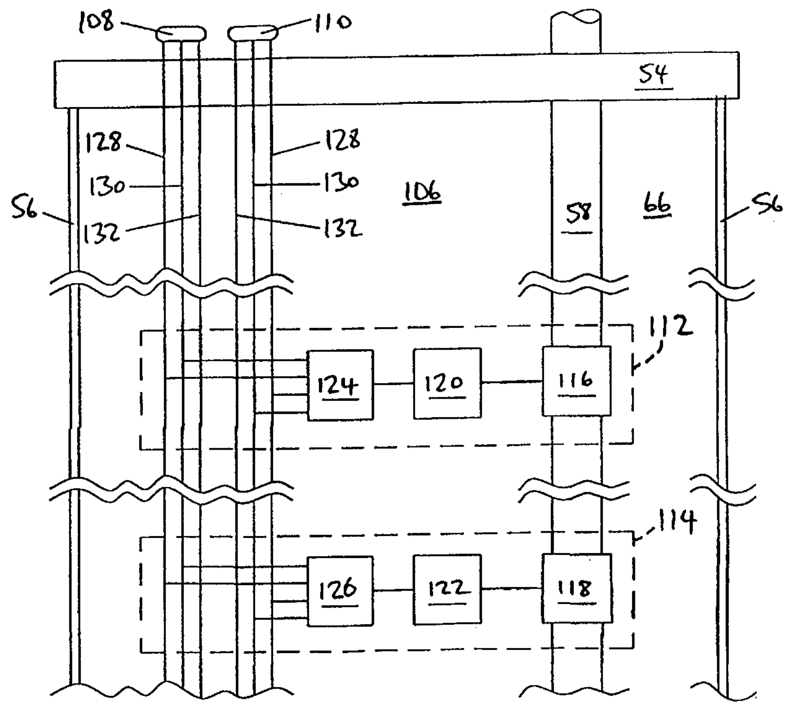
(57) Abstract

A control system (106) is provided for controlling the flow of hydrocarbons out of a production well. The control system has hydraulic decoders which operate a plurality of chokes (116 and 118). The hydraulic decoders (124 and 126) provide actuation signals on receiving hydraulic control pressures within predetermined ranges. The actuation signals operate a hydraulic actuator (120 and 122) to open or close a particular choke. In this way chokes can be operated independently.



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WELL CONTROL

This invention relates to controlling the flow of fluids in a well. It is particularly, but not exclusively, related to controlling the flow of hydrocarbons.

An oil or gas well, hereinafter referred to as a well, is typically constructed by drilling a borehole and then lining it with a steel casing which is cemented into position. A conduit for carrying hydrocarbons from a lower region of the well to the surface, referred to as production tubing, is inserted into the casing and extends from the surface to the lower region from where hydrocarbons are extracted. The space created between the casing and the production tubing is referred to as an annulus. A location which is in the well is referred to as downhole.

Intake of hydrocarbons into the production tubing is either through an open lower end, one or more regions provided with ports along its length or both. Devices referred to as packers are provided between the production tubing and the casing to prevent flow up the annulus rather than up the production tubing.

It should be noted that material other than hydrocarbons, whether in liquid or gaseous form, can flow along the production tubing. It may convey debris remaining from drilling, released interstitial water, sand or particles of rock. The term hydrocarbons is used purely for convenience, although it should be understood that these other materials may be present. Furthermore, materials may be conveyed from the surface to the lower region, such as chemicals, including water, which are provided to assist in the extraction of hydrocarbons.

In view of the high cost of extracting hydrocarbons from wells it is desirable to recover as high a proportion of hydrocarbons as is possible from in-place reserves.

It has been recognised that the amount of hydrocarbons which is extracted from a well can be increased if flow control means are provided downhole to control the flow of hydrocarbons. An example is an annular isolation valve. Such flow control means are generally referred to as chokes. To locate chokes downhole, it is convenient to provide them on the production tubing to control the flow of hydrocarbons from the exterior of the tubing into its interior. To improve operation of the well further, it has been proposed to make downhole measurements of flow rate of hydrocarbons in the production tubing and temperature and pressure of hydrocarbons and to use this information to control the chokes.

A simple version of a choke comprises a body provided with a set of holes carrying a moveable sleeve. Movement of the sleeve relative to the body exposes or covers the holes. In another embodiment the body is provided with a first set of holes and the sleeve is provided with a second set of holes. Relative movement of the body and sleeve allows the first and second series of holes to move in to and out of registration with each other, thus enabling and disabling flow of hydrocarbons through the choke. The relative movement can be parallel to the axis of the production tubing or about it. Such chokes have two positions and so are on/off devices. An alternative embodiment of a choke has a number of intermediate positions definable between the open and closed configurations. These positions allow a variable choking effect on the fluid flow, thus enabling a variable pressure drop to be applied.

An example of a known choke-controlled well 10 is shown in Figure 1. The well 10 has a wellhead 12 controlling a main bore 14 which extends down into a hydrocarbon bearing zone 16. Although the zone 16 may not be very thick (for example 10 to 100m) it may have a considerable lateral extent (for example several kilometres). There is another hydrocarbon bearing zone 18 which is in the form of an isolated pocket. The zone 16 is large enough to justify the cost of drilling the well 10. In order to maximise extraction of the hydrocarbons, on entering the zone 16, the well extends in the form of a horizontal leg 20 to extract hydrocarbons from a significant extent of the zone 16. However, hydrocarbon bearing zones are rarely uniform and it is common for water to break into a long horizontal well at some point along its horizontal length before extraction of hydrocarbons is complete along its entirety. Therefore, the leg 20 is provided with a number of chokes 22 in respective sealed regions 24 which control the intake of hydrocarbons into the leg 20. Although an attempt is made to seal the regions from each other to some degree, they are not necessarily hermetically sealed because the zone comprises porous material. Should water break into any region, its choke can be activated so as to prevent fluid extraction from that region. The zone 18 is not large enough to justify the cost of drilling a separate well and so the well is provided with a branch or lateral 26 to extract hydrocarbons from the zone 18. Flow of hydrocarbons from the lateral 26 into the main bore 14 is controlled by a choke 28.

It should be noted that the horizontal leg 20 may extend for many kilometres. The longer the leg is, the more uneven is fluid flow along it. Therefore, rather than having a long horizontal leg, a similar length of horizontal well can be provided by two shorter horizontal legs branching off into the zone 16 in opposite directions from a common junction point. The shape of the well is similar to an inverted T. The common junction point may be controlled by a choke.

In controlling a multi-zone well, typically several hydrocarbon layers separated from one another by intermediate impermeable layers, generally it is not efficient to extract hydrocarbons in one continuous operation from one zone until it is exhausted and then extract in other continuous operations from each of the zones until they are all exhausted. It is usually more efficient to switch extraction operations a number of times between the zones. Once a first extraction operation from a first zone has occurred, the zone is left to recover whilst a second extraction operation from a second zone takes place. Following the second extraction operation, third and subsequent extraction operations are carried out on third and subsequent zones. When the first zone has recovered it can undergo another extraction operation. Proportionally more in-place hydrocarbon reserves can be extracted if the zones are allowed to recover. Furthermore, a greater proportion of extracted hydrocarbons is extracted earlier in the lifetime of the well. Remotely controlled chokes can be used in switching extraction operations.

Clearly, in certain circumstances it is desirable to have a number of chokes located downhole. However, there is little space available between the casing and the production tubing and it is for this reason that electrohydraulic systems have been proposed to operate a number of chokes. In such a system actuators of the chokes receive a common hydraulic supply which is switched to operate particular chokes by electrical switching means. Since any electrical supply required occupies little space and only one hydraulic supply is necessary such a system is suitable for a multi-choke arrangement. However, in the harsh downhole environment, there is general concern that such relatively complicated systems may not be reliable enough. The reliability of downhole devices is of considerable commercial importance. Firstly, the production lifetime of a well can be in the region of decades and so downhole devices can be in place for a long period of time. Secondly, any repair or replacement operation can affect the operation of the well and can, in most cases, require the well to be shut down whilst a part of or the whole of the production tubing is removed. Intervention costs for a well can cost in the region of $1 million per day. Clearly, it is desirable for a well to be shut down as infrequently as possible during its lifetime.

According to a first aspect of the invention there is provided a control system for controlling flow of fluid in a well comprising a downhole device and a control unit for controlling the downhole device the control unit producing a first actuation signal in response to a hydraulic control signal having a pressure within a first predetermined range the first actuation signal operating the downhole device into a first state and a second actuation signal in response to a hydraulic control signal having a pressure within a second predetermined range the second actuation signal operating the downhole device into a second state the first and second predetermined ranges being arranged so that both the first actuation signal and the second actuation signal cannot be produced at the same time.

According to a second aspect of the present invention there is provided a control system for controlling flow of fluid in a well comprising a plurality of hydraulic control units and a plurality of downhole devices the hydraulic control units operating the plurality of downhole devices at least two of the downhole devices operating on receiving hydraulic control signals at different hydraulic pressures in which a hydraulic control unit operated by a hydraulic control signal at a particular pressure can be operated independently of a hydraulic control unit operated by a hydraulic control signal at a lower pressure.

Preferably the hydraulic control units receive hydraulic control signals along hydraulic lines extending down the well.

There may be two, three, four, five or six downhole devices. There may be more than six. Preferably at least one of the downhole devices is a choke. Most preferably all are chokes. Alternatively the plurality of downhole devices are a plurality of sub-assemblies in a single main downhole unit.

Preferably the hydraulic control units includes a hydraulic actuator for operating a downhole device. Preferably the hydraulic control unit includes a hydraulic addressing unit which produces an actuation signal to actuate the hydraulic actuator. Preferably the hydraulic control units comprise the downhole devices.

According to a third aspect of the invention there is provided a control unit for operating a downhole device the control unit producing a first actuation signal in response to a hydraulic control signal having a pressure within a predetermined range the first actuation signal operating the downhole device into a first state and a second actuation signal in response to a hydraulic control signal having a pressure within a second predetermined range the second actuation signal operating the downhole device into a second state the first and second predetermined ranges being arranged so that both the first actuation signal and the second actuation signal cannot be produced at the same time.

Preferably the control unit comprises an actuator which operates the downhole device in response to the actuation signals. Preferably the control unit is configured to produce actuation signals of short duration to switch the downhole device between different configurations.

Preferably the downhole device is a choke. It may be a downhole safety valve, or an isolator sleeve such as a sliding sleeve. It may be a packer, a gaslift control valve, a polished-bore-receiver release tool, or a fluid loss control valve. Where a plurality of downhole devices are provided they may be of the same type or they may be of different types.

According to a fourth aspect of the invention there is provided a well comprising a control system in accordance with the first aspect of the invention.

Preferably the well is a production well. It may be for producing oil, gas or both. Alternatively it may be an injection well.

An embodiment of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 shows a schematic illustration of a production well;

Figure 2 shows a schematic illustration of a control system;

Figure 3 shows a diagrammatic representation of a production well;

Figure 4 shows a cross section of a flat pack control cable;

Figure 5 shows downhole details of the control system of Figure 2;

Figure 6 shows a hydraulic decoder; and

Figure 7 shows an alternative embodiment of a hydraulic decoder.

In the following description, the invention is described in relation to subsea use. In such an application a part of the control system is located downhole and a part of the control system is located on the seabed and a final part which supplies power and control signals is located on a platform or land based installation. However, the invention also applies to a wholly autonomous intelligent well in which processing means are provided downhole to analyse operating parameters of the well and control its operation accordingly with little or no intervention from outside of the well.

Figure 2 shows a schematic illustration of a control system 30 providing control of a well 32 from a platform 34. In this specific embodiment of the invention, the platform is an oil rig. Located on the platform 34 is a hydraulic supply unit 36 and a sensor control unit 38. Outputs from these units are routed to a junction box 40 at which they are combined and packaged into an umbilical 42 which passes from the platform 34 to the seabed 44. The umbilical 42 terminates on a tree 46, also known as a christmas tree, which is located on a wellhead 48 at the seabed 44. There is also provided a chemical injection unit 50 on the platform which supplies chemicals to be pumped into the well 32 to assist in extraction of hydrocarbons. Actuators on the tree 46 open and close valves which control the flow of chemicals and hydrocarbons through the tree. The sensor control unit 38 monitors and/or interrogates a number of sensors located on the tree and downhole. The sensors are operated either electrically or optically. The hydraulic power unit 36 controls and operates several downhole devices located in the well one of which is shown and indicated by the numeral 52. It can also control and operate tree located devices.

A diagrammatic representation of a known well 10 is shown in Figure 3. This shows a bore 54 lined with a casing 56 which contains production tubing 58. The casing extends from the surface 60 until the end or toe 62 of the bore 54. It should be understood that in this described embodiment the surface 60 is the seabed. The casing 56 supports a tubing hanger 64 which in turn supports the production tubing 58. The casing 56 and production tubing 58 define between them an annulus 66. The annulus serves a number of purposes. It can be used to detect fluid leakage from the production tubing 58. When extracting viscous liquid hydrocarbons pressurised gas can be introduced down the annulus and introduced into the production tubing through one-way valves along its length so as to provide a gas lift and assist extraction.

The tubing hanger 54 accommodates a bore for the production tubing 58, a bore to allow access to the annulus 66 and one or more bores to allow passage of lines for downhole control and sensing operations. Therefore in plan area much of the tubing hanger is occupied.

At about 300m from the surface 60 the production tubing 58 has a SCSSV (surface controlled subsurface safety valve) 68. This is an emergency shut-off valve which can be closed to provide a barrier to the uncontrolled flow of hydrocarbons. The barrier is intentionally located below the wellhead to protect the aquatic environment in the event of a failure of the tree or wellhead.

Along its length the casing 56 passes through a number of hydrocarbon bearing zones 70 and 72 from which hydrocarbons such as oil and gas are extracted. Within each zone a part or region of the casing 56 is open such that hydrocarbons can flow into its interior. Within zone 70 the wall of the casing 56 is perforated. Within zone 72 the casing has an open end 74. The production tubing 58 is likewise provided with ports which correspond to those present in the casing 56. Therefore the production tubing 58 has ports in zones 70 and 72.

In known wells the production tubing may be provided with a motor driven electrical submersible pump (ESP) at the well toe to pump hydrocarbons from the lower region of the well. This is convenient if the hydrocarbon bearing zone being abstracted is at low pressure. It is important to monitor the temperature of the motor to check that it is not overheating. This is because in the event of the ESP failing a workover of the well is required.

It is important to isolate the hydrocarbon bearing zones 70 and 72 from non-hydrocarbon bearing zones 75 and 76. If these zones contain aquifer layers from which water is extracted, allowing communication between the aquifer layers and the zones 70 and 72 can cause their contamination. Therefore the annulus 66 is divided into compartments 78, 80 and 82 by packers 84, 86 and 88 which prevent transfer of material between hydrocarbon bearing zones 70 and 72 and non-hydrocarbon bearing zones 75 and 76 occurring along the annulus 66.

Hydrocarbons present in the zones 70 and 72 may be at different pressures. If the pressures are considerably different, hydrocarbons could flow from one zone to another rather than up the production tubing 58 if there is unrestricted communication between the zones. For this reason variable chokes 90 and 92 are provided to restrict flow from zones 70 and 72 into the production tubing 58. Two chokes are needed to control extraction of hydrocarbons from two zones. Generally, n chokes are used to control n zones.

In order to control the flow of hydrocarbons, sensors are provided to measure temperature and pressure in the production tubing 58 at each of the producing zones.

A flat pack is used to supply hydraulic power to downhole devices and electrical conductors to allow monitoring of downhole sensors. A cross-section of a flat pack is shown in Figure 4 and designated by the numeral 94. The flat-pack contains a hydraulic power line 96, a hydraulic control line 98 and an electrical communications line 100 containing a twisted pair 102 and 104. It may also contain one or more optical fibres for downhole optical sensors. All of the lines 96, 98 and 100 comprise steel jackets or tubes. Due to space constraints within the tubing hanger 54, and in the annulus 66, the flat pack has a maximum size. Therefore there is a limitation on the number of lines and the outer diameter of their steel tubes (which is typically less than 1cm).

Figure 5 shows downhole details of the control system of Figure 2. The part of the control system shown, indicated by numeral 106, is being used to control a production well. The control system 106 has two flat packs 108 and 110 which extend down the annulus 66. The use of two flat packs provides redundancy within the system. With two flat packs there are, in total, two hydraulic power lines, two hydraulic control lines and two electrical communication lines extending down the well. Each flat pack extends down the annulus 66 as far as the most distant choke. In a practical embodiment of the system the flat packs 108 and 110 are strapped to the outside of the production tubing 58 on opposite sides. In this way a damaging impact to one side of the production tubing is less likely to damage both flat packs. Of course, to provide a simpler system a single flat pack containing two hydraulic lines may be provided or even two separate flat packs or cables each containing a single line.

The flat packs enable control of downhole control modules 112 and 114 incorporating, respectively, chokes 116 and 118, hydraulic actuators 120 and 122 and hydraulic decoders 124 and 126. The downhole control modules 112 and 114 are integrated into the production tubing 58 as individual sections to be connected in-line allowing through-flow of hydrocarbons. The chokes 116 and 118 are operated, or actuated, by hydraulic actuators 120 and 122 which are controlled by respective hydraulic decoders 124 and 126. The actuators may each simply comprise a hydraulic driven piston or a hydraulic ram. They are each coupled to the moving section of the chokes 116 and 118.

The flat packs 108 and 110 each have a hydraulic control line 128, a hydraulic power line 130 and a communications line 132. Each flat pack terminates at the top of each downhole control module and then extends onward from its bottom. The lines 128, 130 and 132 extend through the control module which can extract appropriate hydraulic power, control and communications.

The control system has a hydraulic control circuit comprising hydraulic control lines 128, the hydraulic power lines 130, one of the hydraulic decoders 124 or 126 and one of the hydraulic actuators 120 or 122.

Hydraulic operation of the choke 116 by the hydraulic decoder 124 is described in relation to Figure 6. The hydraulic control lines 128 are consolidated by a shuttle valve 134 into a single hydraulic control supply 136. This is fed into respective pairs of valves 138 and 140 and 142 and 144. The hydraulic control supply 136 provides a variable hydraulic supply which is used to control the valves 138, 140, 142 and 144. The valves permit or prevent supply of hydraulic power to the hydraulic actuator 120 so as to be actuated either to open or close its associated choke 116. The hydraulic power lines 130 are consolidated by a shuttle valve 146 into a single hydraulic power supply 148. This is switchable through the valves 138, 140, 142 and 144 to actuate the hydraulic actuator 120 and open or close the choke 116. Referring now to valves 138 and 140, they are configured so that, in the absence of the variable hydraulic control supply 136, valve 138 is closed (that is it does not transmit the hydraulic power supply 148) and valve 140 is open (that is it does transmit the hydraulic power supply 148). Valve 138 is configured to energise at 1000psi and valve 140 is configured to energise at 1200psi. If the pressure of the hydraulic control supply 136 is increased to be between 1000 and 1200psi, valve 138 energises into an open state. Since valve 140 is already open, the hydraulic power supply 148 is transmitted through the decoder 124 and actuates the actuator 120 and opens the choke 116. Once the variable hydraulic supply exceeds 1200psi, valve 140 energises into a closed state which prevents transmission of the hydraulic power supply 148 to the actuator 120. The functionality provided by the pairs of valves 138 and 140 and 142 and 144 could be incorporated into a single valve assembly for each pair.

The valves 142 and 144 are in a similar "one open, one closed" configuration in the absence of the hydraulic control supply 136. Valves 142 and 144 are configured to actuate at 1500psi and 1700psi respectively. Therefore, when the pressure of the hydraulic control supply is between 1500psi and 1700psi, the hydraulic power supply 148 is transmitted through the combination of the valves 142 and 144 and actuates the actuator 120 and closes the choke 116. Opening and closing of the choke is a wholly hydraulic operation. It is preferred to have a control module which opens and closes the choke in response to separate positive signals. In this way if the downhole control module fails the choke fails in an "as is" condition.

It can be seen that were one of the flat packs 108 or 110 to fail, and hydraulic control and power in it fail also, the shuttle valves would switch to isolate the failed supplies and cause the hydraulic control and power supplies to be supplied by the other flat pack.

An alternative embodiment of a hydraulic control system is shown in Figure 7. This is similar to the system of Figure 6 and has features and methods of operation in common. Rather than having a single hydraulic decoder, the system of Figure 7 has a pair, hydraulic decoders 124 and 150. Each decoder receives a hydraulic control supply and a hydraulic power supply from one of the flat packs. The decoders are operated in the same way as the decoder described in relation to Figure 6. However, rather than receiving a consolidated input, the outputs of the decoders are consolidated by shuttle valves 152 and 154. That is, hydraulic power transmitted through the valves 138 and 140 to actuate the actuator and open the choke are consolidated in shuttle valve 152 to provide supply 156 and hydraulic power transmitted through the valves 142 and 144 to actuate the actuator and close the choke are consolidated in shuttle valve 154 to provide supply 158. In this way, the system of Figure 7 has greater redundancy over the system of Figure 6 since two independent hydraulic control circuits are provided. In the event of failure of either a single flat pack or a single decoder, the system would still be able to operate.

A significant feature of the present invention is that the actuator is actuated by separate signals, that is distinct control pressures. In this way it can be seen that when the choke or other downhole device is moved into a particular configuration, hydraulic pressure does not have to be continuously applied to maintain it in that configuration. In other words, for downhole devices which do not have to be fail-safe, having a system which is fail-as-is is more convenient, requires less power over time and does not expose hydraulic lines to sustained hydraulic load.

It should be understood that hydraulic operation of the downhole valves and actuators does not occur instantaneously on sending a command from above. There can be a delay of minutes between sending a hydraulic command and the stabilised hydraulic pressure being achieved at the control module. Therefore it is preferred to send a command to the hydraulic decoders to set the valves into a desired configuration and then waiting until that configuration is likely to be present before applying the hydraulic power through the lines 130 to operate the actuator 120 or 122. In this way one can be reasonably certain that the correct configuration of valves is present and that the correct operation will occur.

The hydraulic decoders in each downhole control module are activated at different pressures applied by the variable hydraulic supply. Therefore a number of downhole control modules can be selectively operated by applying an appropriate hydraulic control supply pressure along lines 128.

It should be noted that a number of actuators are connected to the same hydraulic line. In this way the number of lines required to operate a number of downholes devices is kept to a minimum.

The control system may be provided with means to detect failure. Detecting loss of hydraulic power in one of the lines may indicate a break. A position sensor connected to a moveable part of the choke such as the sliding sleeve may indicate that it is not moving in response to instructions to do so. Sensors in the production tubing may indicate that there is no change in pressure or flow rate or both in response to a command being given for the choke to change its configuration.

Associated with the choke assembly is a series of sensors. Typically these would monitor the following physical parameters:

(i) configuration of the choke (open or closed);

(ii) pressure and temperature inside the choke (in the production tubing);

(iii) pressure and temperature in the annulus; and

(iv) flow rate of hydrocarbons in the production tubing.

The sensors are monitored and/or interrogated locally by the downhole control module and information derived used to operate the choke or they are monitored and/or interrogated remotely from the wellhead or the platform. Such remote interrogation would be appropriate for sensors which are optical in nature and relay an optical signal by one or more optical fibres. Other downhole devices can be operated (that is controlled, monitored or both) by the control system such as flow meters, remotely set production packers and gas lift valves. Although a position sensor is also provided to detect the configuration (open or closed) of the choke, if pressure is measured both inside and outside of the production tubing, the configuration of the choke can be confirmed independently.

Although the embodiments of the invention described have a plurality of downhole control modules and a plurality of chokes, in an alternative embodiment only a single downhole control module and a single downhole device may be provided. This may be particularly suitable for controlling a downhole device having a number of states or configurations it can occupy. For example the downhole device may comprise a number of sub-assemblies such as a plurality of valves each of which is switchable between two states or one or more sub-assemblies switchable between more than two states.

The invention has been described applied to a production well. It may equally apply to an injection well in which water or another fluid is pumped into a region of a production zone distant from a region where extraction is occurring in order to maintain pressure in the production zone and to flush out the zone. Although the invention has been described in relation to subsea wells and installations, it is not limited to such use. It may, with appropriate modifications, be used in a well which is land based or offshore, for example a platform well.

CLAIMS

1. A control system for controlling flow of fluid in a well comprising a downhole device and a control unit for controlling the downhole device the control unit producing a first actuation signal in response to a hydraulic control signal having a pressure within a first predetermined range, the first actuation signal operating the downhole device into a first state and a second actuation signal in response to a hydraulic control signal having a pressure within a second predetermined range the second actuation signal operating the downhole device into a second state the first and second predetermined ranges being arranged so that both the first actuation signal and the second actuation signal cannot be produced at the same time.

2. A control system according to claim 1 characterised in that the control unit comprises a hydraulic actuator for operating the downhole device.

3. A control system according to any preceding claim characterised in that the downhole device is a choke.

4. A control system according to any preceding claim which comprises a plurality of control units.

5. A control system according to any preceding claim which comprises a plurality of downhole devices.

6. A control system according to any preceding claim characterised in that the well is a production well.

7. A control system according to any one of claims 1 to 6 characterised in that the well is an injection well.

8. A control system for controlling flow of fluid in a well comprising a plurality of hydraulic control units and a plurality of downhole devices the hydraulic control units operating the plurality of downhole devices at least two of the downhole devices operating on receiving hydraulic control signals at different hydraulic pressures in which a hydraulic control unit operated by a hydraulic control signal at a particular pressure can be operated independently of a hydraulic control unit operated by a hydraulic control signal at a lower pressure.

9. A control system according to claim 11 characterised in that the hydraulic control units comprise hydraulic actuators.

10. A control system substantially as described herein with reference to Figures 4, 5, 6 and 7 of the accompanying drawings.

11. A well comprising a control system in accordance with any preceding claim.

12. A well substantially as described herein with reference to Figures 4, 5, 6 and 7 of the accompanying drawings.

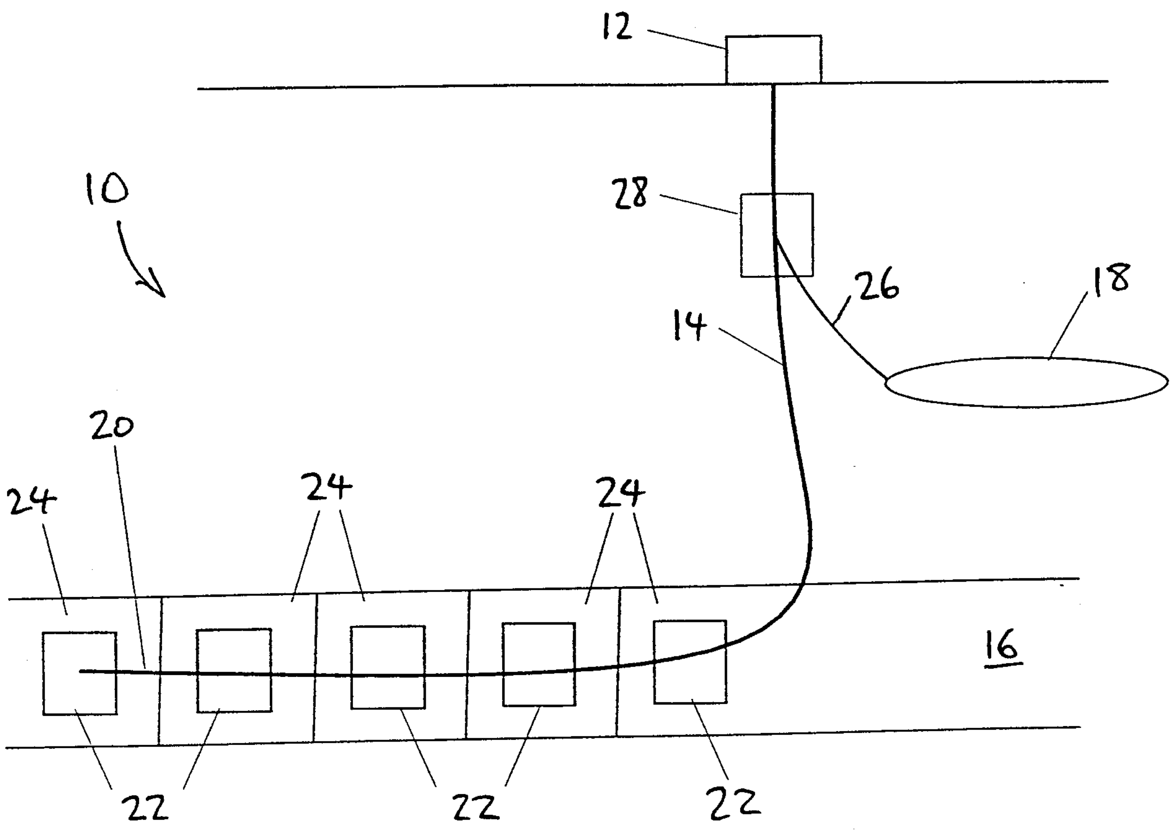

FIG. 1.

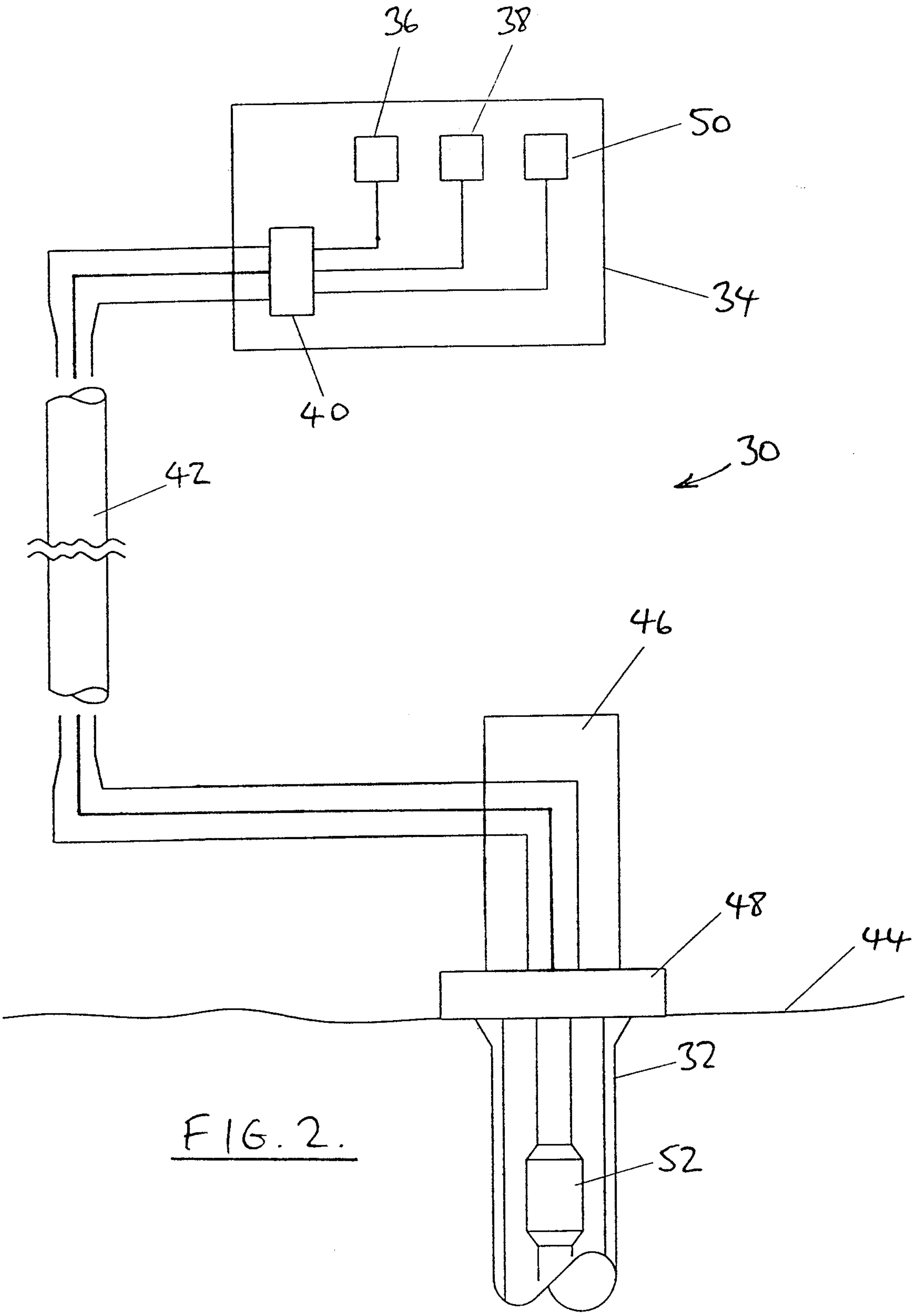

FIG. 2.

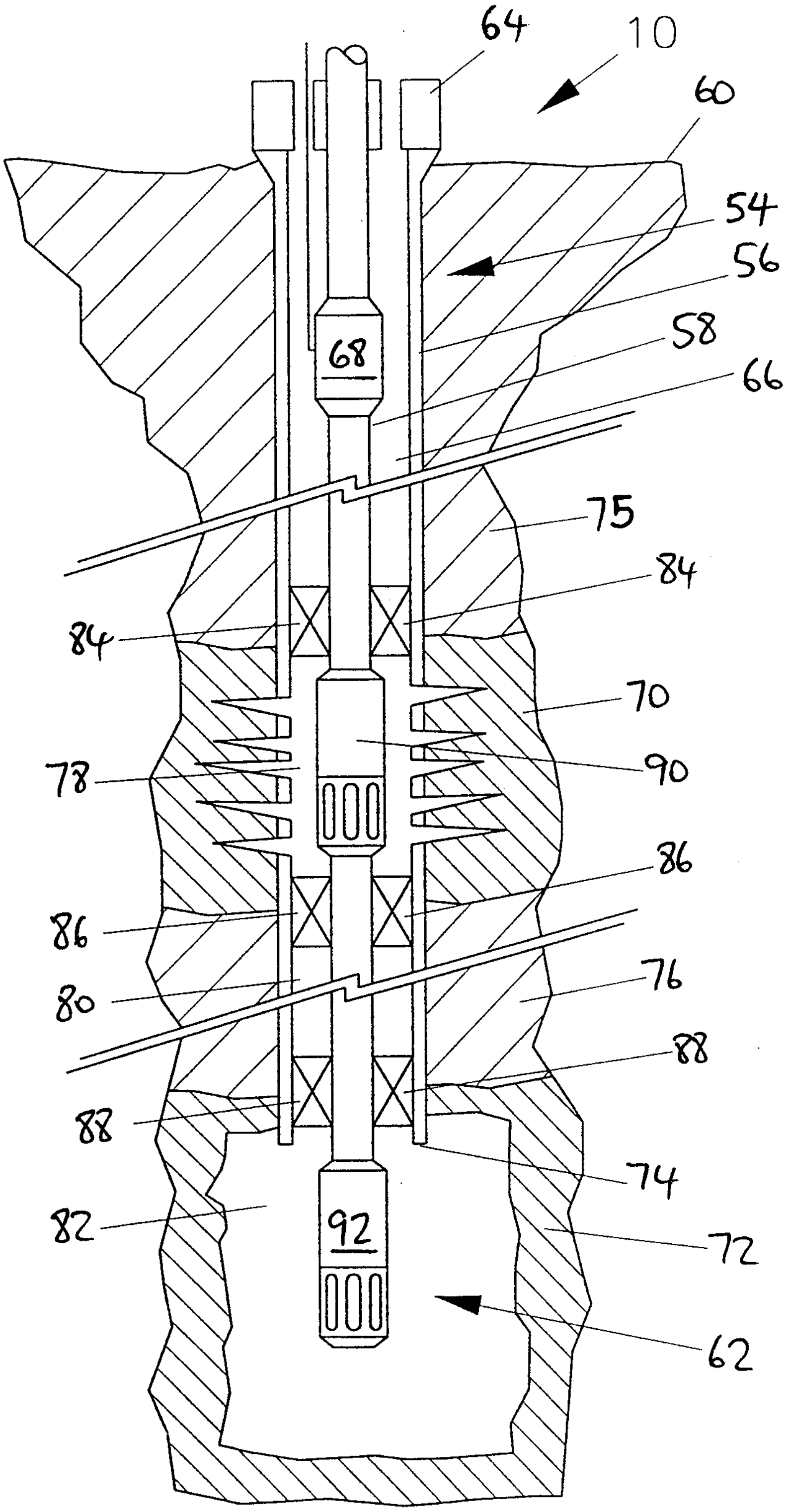
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FIG. 3.

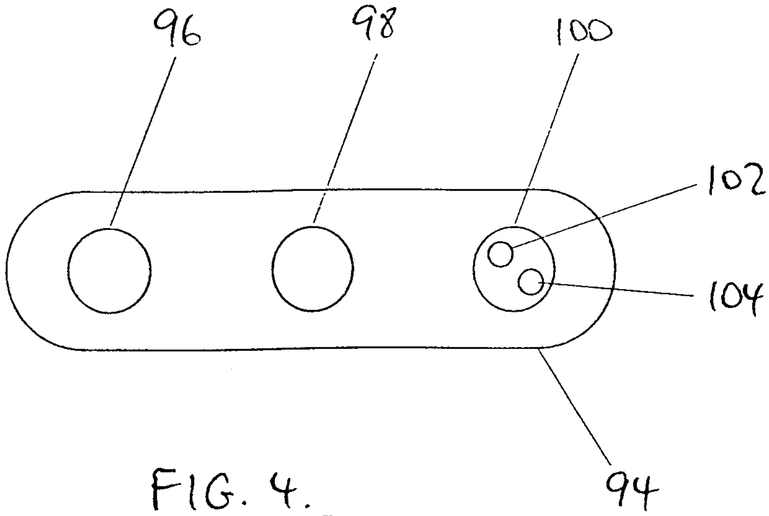
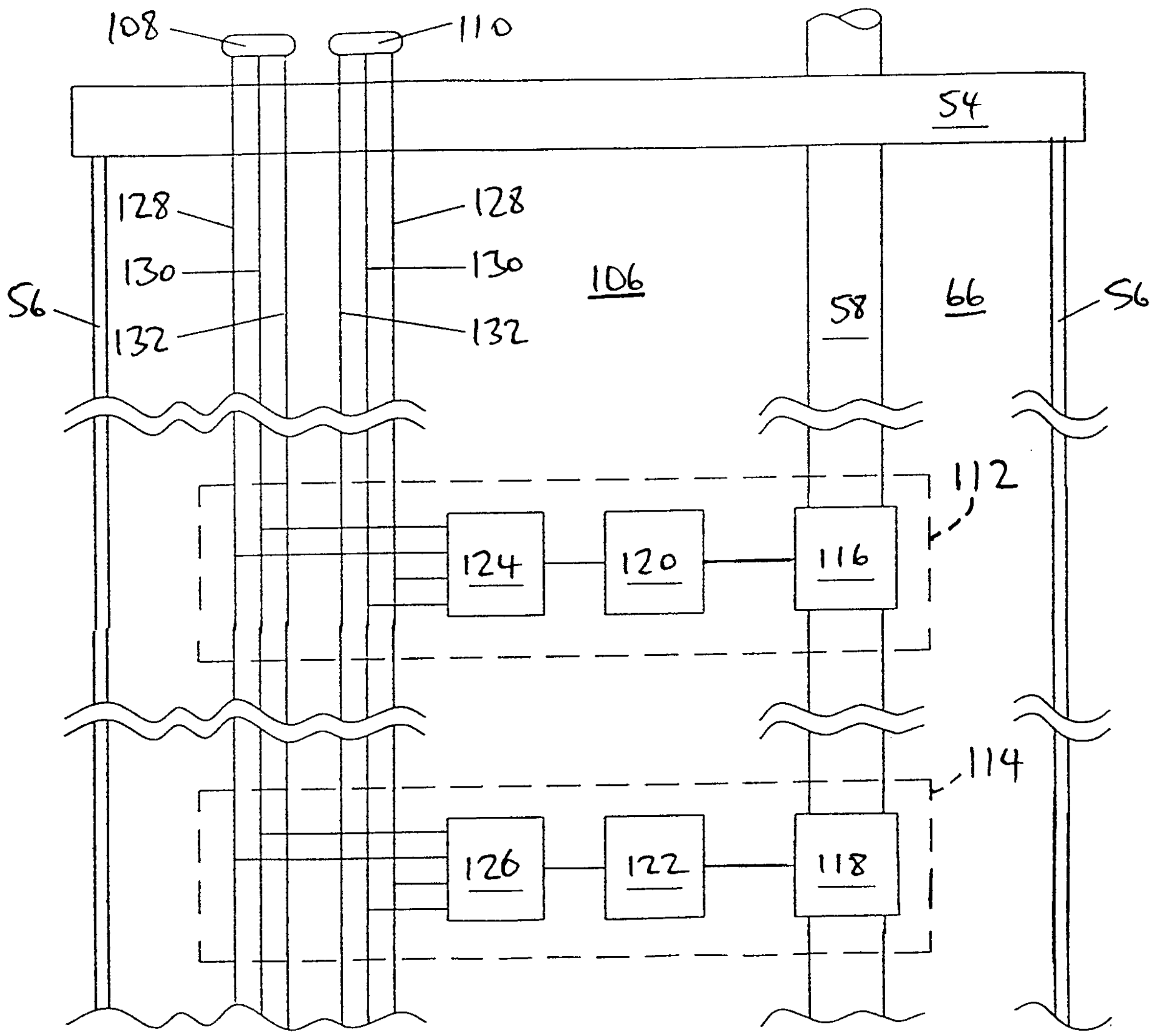

96
98
100
102
104
94

FIG. 4.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110
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128
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56
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106
58
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112
124
120
116
114
126
122
118

FIG. 5.

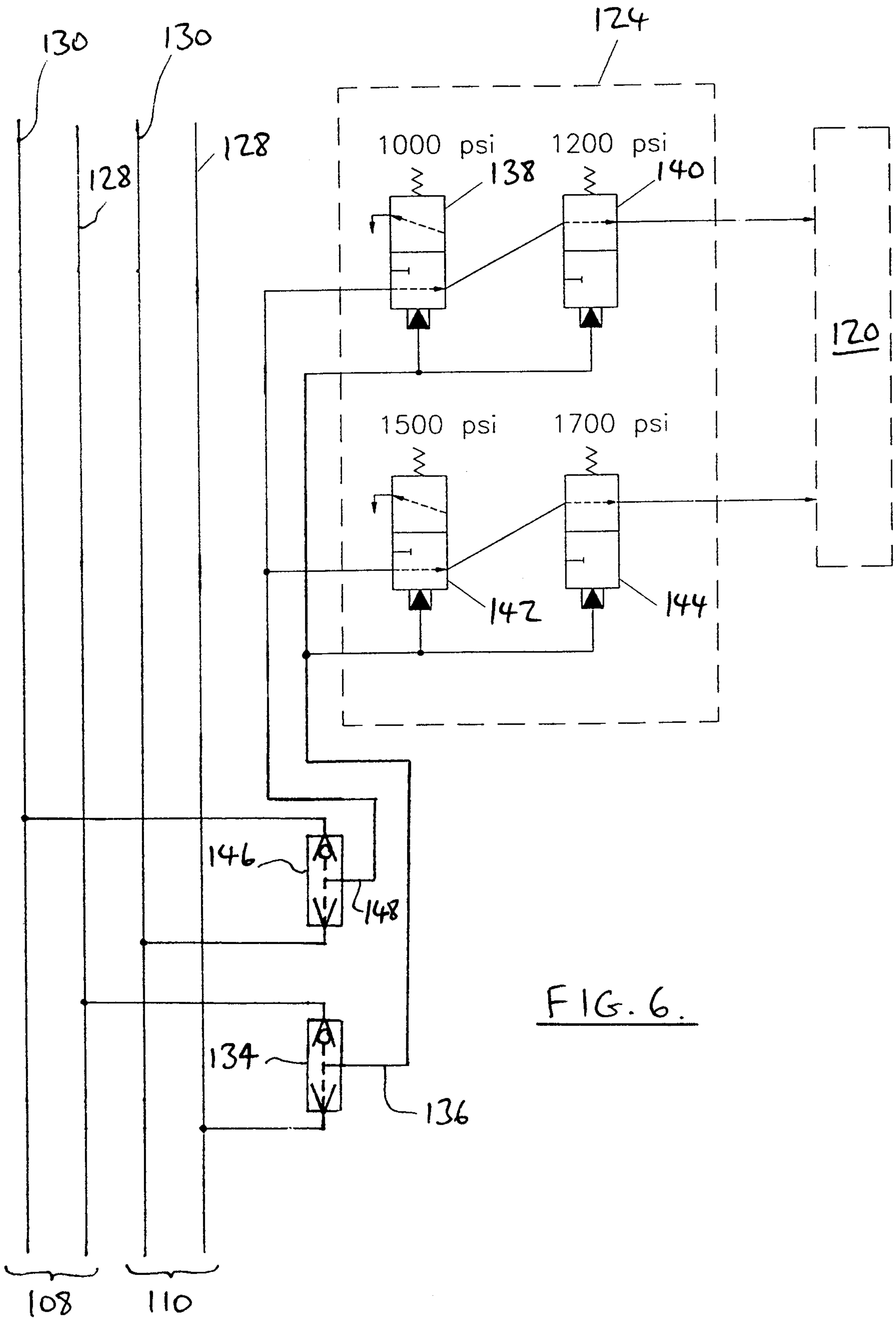
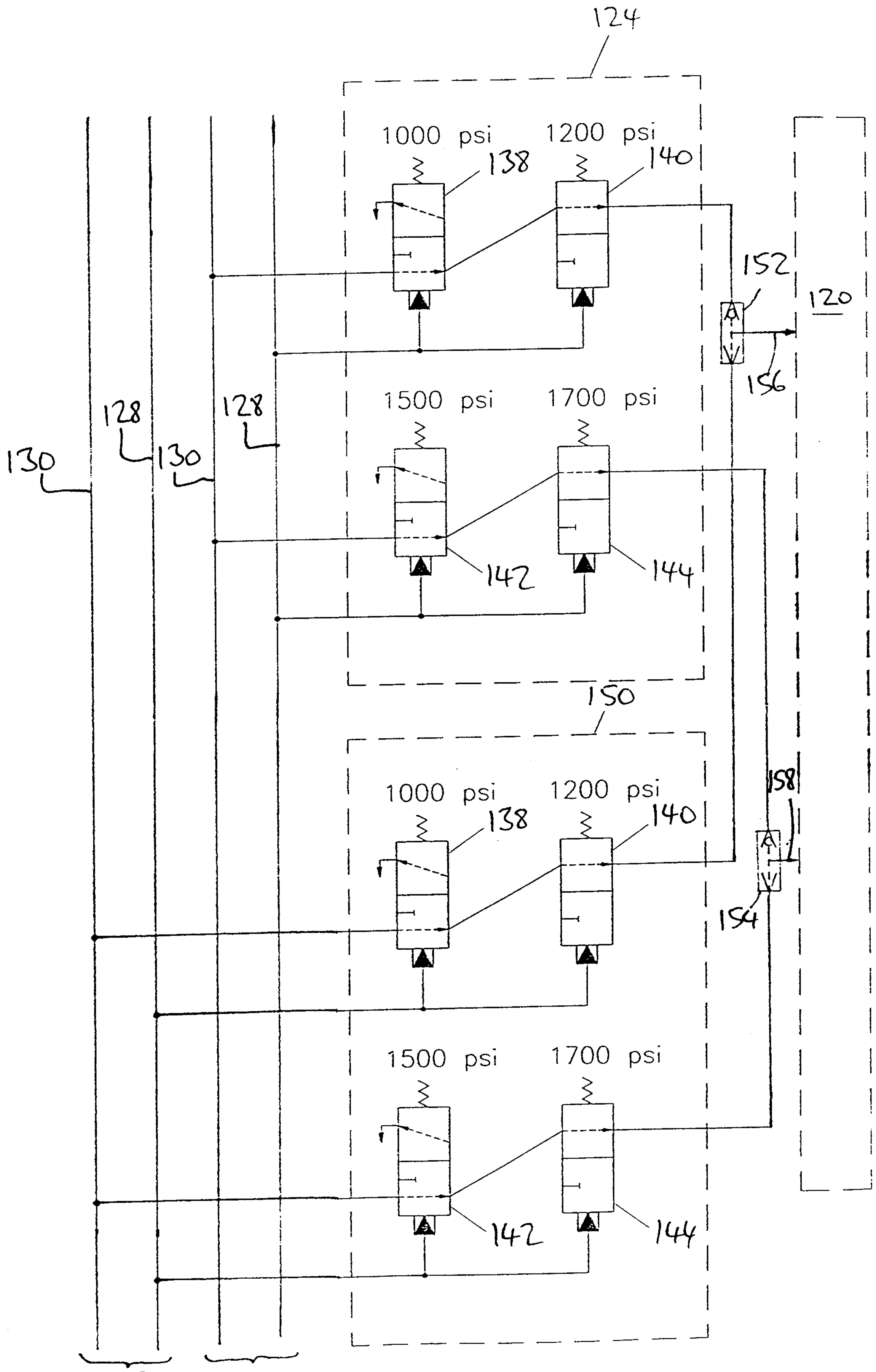

124
130
130
128
128
1000 psi
1200 psi
138
140
120
1500 psi
1700 psi
142
144
146
148
134
136
108
110

FIG. 6.


124
1000 psi
1200 psi
138
140
152
120
156
1500 psi
1700 psi
128
128
130
130
142
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150
1000 psi
1200 psi
138
140
158
154
1500 psi
1700 psi
142
144
108
110

FIG. 7.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 99/00735

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B34/10

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)
IPC 6 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 practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 47852 A (PES INC) 18 December 1997 see page 4, line 11 - page 8, line 9; figures	1,2
X	US 3 986 554 A (NUTTER BENJAMIN P) 19 October 1976 see column 1, line 31 - line 58; figures	8
A	US 3 993 100 A (POLLARD TERRY W ET AL) 23 November 1976 see column 2, line 40 - column 3, line 3; figures see column 4, line 44 - column 5, line 51	1,8
A	US 4 549 578 A (HIBBS DAVID A ET AL) 29 October 1985 see abstract; figures	1,8

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 July 1999	09/07/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Weiand, T

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 99/00735

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