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(54) Title: CAPILLARY ACTUATOR DEVICE

(57) Abstract: A pressure storage device includes a porous material; and a non-wetting fluid having a glass transition temperature above a normal exposure temperature for the device and method.

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CAPILLARY ACTUATOR DEVICE

BACKGROUND

[0001] One of the facts of the hydrocarbon recovery industry is that tools used in the downhole environment are often there for a very long time, in very harsh conditions, and with very important jobs to do. Reliability is key with respect to many aspects of the industry. Some of the conditions that are so difficult on downhole tools relate solely to the temperature, pH, erosional factors due to flowing fluid, and other purely environmental issues. Other things that create problems for the industry relate to complexity of tools and cycle life. Yet other issues relate to the difficulty of actually fitting a tool that has the capability of doing what must be done into a borehole that is quintessentially too small to put much in. And this while the largest possible amount of patency is reserved for produced fluid flow. Because of these difficulties, the art is always in need of alternative arrangements that can reduce the problems associated with production.

SUMMARY

[0002] A pressure storage device includes a porous material; and a non-wetting fluid having a glass transition temperature above a normal exposure temperature for the device.

[0003] A method for storing pressure for later use includes heating a non-wetting fluid above a glass transition or material melting temperature thereof; forcing the fluid into a porous material non-wettable thereby while maintaining the temperature of the fluid above the glass transition or material melting temperature; and reducing a temperature of the fluid to below the glass transition or material melting temperature thereof.

[0004] A downhole actuator device includes a porous material; and a non-wetting intrusion fluid introduced into the porous material under pressure and at a temperature above a glass transition or material melting temperature of the fluid and retained in the porous material at a temperature below the glass transition or material melting temperature of the fluid.

[0005] An actuation system includes a plurality of combinations of porous materials and non-wetting intrusion fluids introduced into the porous materials under pressure and at a temperature above a glass transition or material melting temperature of the fluid and retained in the porous material at a temperature below the glass transition or material melting temperature of the fluid.

[0006] An actuation system includes a plurality of combinations of porous materials and non-wetting intrusion fluids introduced into the porous materials under pressure and at a temperature above a glass transition or material melting temperature of the fluid and retained in the porous material at a temperature below the glass transition or material melting temperature of the fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Referring now to the drawings wherein like elements are numbered alike in the several Figures:

[0008] Figure 1 is a schematic view of a first embodiment of an actuator as disclosed herein;

[0009] Figure 2 is a schematic view of a second embodiment of an actuator as disclosed herein;

[0010] Figure 3 is a schematic view of a third embodiment of an actuator as disclosed herein; and

[0011] Figure 4 is a schematic view of a fourth embodiment of an actuator as disclosed herein.

DETAILED DESCRIPTION

[0012] Capillary action can be used to benefit the hydrocarbon recovery industry when used in conjunction with a non-wetting intrusion fluid. This is because in such circumstances, the fluid, rather than being drawn into the capillary pore, is repelled from it. Forcing the fluid to occupy a space defined by one or more pores through the

application of an externally applied pressure exerted on the fluid can be achieved if the pressure is above a threshold pressure for the particular combination of porous material and non-wetting fluid. Such a fluid is then resident in the pore space of the material until the pressure is removed whereupon the fluid is expelled from the material with substantially the same pressure that was required to force the fluid into the material initially, with some small amount of hysteresis being expected. Such a configuration is useful for a wide variety of spring force operations but is limited in that the external pressure must be maintained for the device to be useable. Incorporated by reference in its' entirety is co-pending and co-filed US Patent Application Serial No. 11/948,369 by Xu and Richard, Attorney Docket Number 284-45836-US/BAO-0195, entitled and filed DOWNHOLE TOOL WITH CAPILLARY BIASING SYSTEM, which includes further information directed to a capillary spring and its use in the downhole environment.

[0013] The present inventors have devised a number of configurations in which a capillary spring type device can be configured as a pressure storage medium irrespective of the maintenance of an external applied pressure thereon. More specifically, it has been discovered that where a nonwetting fluid is forced to occupy the pores of a nonwetable porous material at a temperature above the fluid glass transition temperature and the temperature is then brought to below the glass transition temperature, the porous material becomes a pressure storage device. In other words, once the material and fluid are at a temperature below the glass transition temperature of the fluid, the pressure needed to force the fluid into the porous material may be removed without the fluid being expelled from the material. Rather, the pressure is stored in the porous material until the temperature is once again brought above the glass transition temperature of the fluid transforming the fluid from a solid to a liquid (or other fluid). For purposes of this disclosure, and in each of the embodiments exemplified herein, the porous material and intrusion fluid post being forced to intrude into the porous material and brought to a temperature below the glass transition temperature of the intrusion fluid is termed the actuator.

[0014] Materials contemplated for the porous material include silica, silicates, aluminosilicates, lithosilicates, titanosilicates, aluminogermanates and other natural and

synthetic zeolite-like materials, with pore sizes ranging from about 3nm to about 10nm, and, in one particular embodiment, about 5nm. Specifically included in these porous materials are those exhibiting microporosity, which includes those materials whose capillary characteristics are known to vary with temperature and pressure. Fluids include water, organo-liquids, metals and metal alloys, or any liquid exhibiting a high surface tension. As the range of potential fluids available for use may be either morphous or amorphous when in their solid form, a fluids "melting point" and "glass transition temperature" are considered to be synonymous for purposes of this teaching.

[0015] In one embodiment of an actuator, referring to figure 1, a heater 10 is disposed in operable communication with an actuator 12 such that a heat load may be applied to the actuator 12 when desired. Timing of the heat load may be by human surface intervention or may be based upon a controller running a program or even simply a timer whether in the downhole environment or remotely. In this embodiment, a current conductor 14 is also illustrated that suggests current for the heater comes from a remote location. Indeed this is possible but it is also possible that the current to power the heater may be supplied from a local source such as a battery. Depending upon the heat necessary to reach the glass transition temperature of the intrusion fluid, it is also possible that no additional heater will be needed. That is, in some cases, the downhole temperature itself may be sufficient to raise the temperature of the actuator to above the glass transition temperature without additional input. In such an embodiment, simplicity is obtained but at the cost of greater risk since if the downhole tool becomes stuck during running, it is possible that the actuator will actuate at a location other than the desired location.

[0016] Returning more directly to the figure 1 embodiment, a housing 6 is very schematically illustrated for environment. It will be appreciated that the heater 10 and actuator 12 are disposed at the housing and a pressure defeatible member 18 such as a rupture disk as illustrated is positioned to seal off the actuator from other portions of the housing. This arrangement ensures that the pressure stored in the actuator is released suddenly rather than slowly over time. This arrangement is thus for applications that require more of a pressure pulse than a particular threshold pressure for a particular desired end result to occur. The defeatible member is useful in this regard because it is

difficult to heat a solid material to a higher temperature all at the same time. Rather, a temperature gradient is exhibited as heat load interacts with radially outward portions of the solid before it migrates to deeper portions of the solid. Was the member 18 not in place, pressure stored in the actuator would slowly build in the housing 16 until all of the intrusion fluid reached a temperature above the glass transition temperature. With the member 18, pressure builds in a confined area around the actuator as the temperature increases. It will be noted that the temperature increase is also assisted by the increasing pressure in the confined area, thus requiring less eternally applied heat or current or whatever the heat source is. The member 18 is calibrated to hold pressure to a certain number and then to defeat rapidly. Thus, pressure will build until the preset pressure and then all of the available pressure from the actuator will be released to the housing when the member 18 releases. A well defined pressure pulse is the result and can be used for any activity that uses a pressure pulse for some action. Those of skill in the art will be familiar with many downhole tools and actions that are reliant upon pressure pulses. It is to be understood that although the description of figure 1 suggests a relative match between the preset rupture pressure of the member 18 and the pressure storage capability of the actuator, it is not so limited but rather the same actuator could be utilized for dual (or even more) duty by setting the defeatable member 18 to defeat at a pressure that is less than the total pressure stored in the actuator. This results in a pressure pulse while maintaining stored pressure in the actuator. Remaining pressure could be continuously released slowly or could be released in stages pursuant to a program in a controller or pursuant to surface intervention by actuating the heater at selected times to raise the temperature of the actuator in stages thereby releasing the pressure as noted. Figure 2 is directed to an embodiment that is a purely over time release that can be a continual release or a staged release as noted above. The distinction in figure 2 is that the configuration does not include a defeatable member for production of a pressure pulse.

[0017] Referring now to figure 3, a sequential pulse system is illustrated. It is to be understood that although three actuators and defeatable members are illustrated, the concept is not limited to such. Any number of devices may be utilized in this manner limited only by practicality and space. In the illustration of figure 3, a sequence of three pressure pulses are available at will or based upon a program, as desired.

[0018] A system 100 in figure 3 includes a housing 116 and a manifold 130. The manifold as illustrated has four runners 132, 134, 136 and 138. Each of runners 134, 136, and 138 further includes a check valve 140, 142 and 144, respectively. Runner 132 is an outlet runner that is intended to direct pressure to a piston 150 deflectably or slidably disposed in the housing 116. The runner 132 is the only conduit for pressure delivery from the system of figure 3 to the area 152 in contact with the piston 150 due to a plug 154 located within housing 116 that does not move at least at the pressures contemplated for use in the system of figure 3. Pressure from each of the storage actuators is released similarly to that of the device illustrated in figure 1, all of the alternate methods of operation of which also being applicable. Following exposure to the description of figure 1, components 110a-c, 112a-c and 118a-c will be recognized. Each of these devices operates as did figure 1 as noted. The difference in this embodiment is that the actuators materials (intrusion fluid and possibly porous material too, since the porous material must be non-wettable to the selected fluid) has a distinct glass transition temperature. This means that each of the actuators 112a-c will release pressure at different temperatures. In one embodiment, actuator 112a will transition at 200 degrees; actuator 112b will transition at 225 degrees and actuator 112c will transition at 250 degrees. It is to be appreciated that these temperatures are merely used by way of example and indicate no limitation on the concept of the invention. By employing different temperatures in the three actuators, three pressure events are ensured (though it is to be understood that the multiple events for each actuator discussed with reference to figure 1 are applicable here too). In the event that the system is configured with defeatable members 118a-c as illustrated, three pulse events are possible. While temperature alone can be the differentiator for the actuators as discussed, it is also possible to vary the pressure amount that are released by configuring the defeatable members to defeat at distinct pressures from one another. In one exemplary embodiment, the members 118a-c are configured to defeat at 5000psi, 7500 psi and 10000 psi, respectively. Any pressures can of course be selected.

[0019] Each of the pressure devices feed into a chamber 160a-c, respectively, that is fluidly connected to runners 134, 136 and 138, respectively, through the associate check valve 140, 142 and 144. Thereby, when pressure is applied to any of the chambers 160a-

c, that pressure is directed through runner 132 to area 152 and will have the desired effect when so doing. Activities can include but are not limited to opening sleeves, opening chemical injection lines, closing sleeves, etc.

[0020] Referring now to figure 4, a wave release of pressure is contemplated. A housing 216 is similar to the foregoing housings but contains a number of actuator devices specially configured to produce a complex pressure change profile. In this embodiment, a first actuator device comprises an actuator 212a, a heater 210a and a defeatable member 218a so that a pressure pulse is created by this first device. In one example, the actuator releases pressure at 200 degrees and the pulse is at 2500 psi when the member 218 is defeated. In this example, a sleeve is opened by this pulse, which allows for a operation to begin such as, for example, an acidizing operation. After this initial pressure event, the sleeve being now open, a wave of pressure is desirable. This is obtained by positioning and configuring 212b-f and 210b-d as illustrated. Actuator 212b is configured to release at 250 degrees and a member 218b is in place to ensure this event occurs as a pulse. There is a dedicated heater 210b to heat 212b for this purpose. This initial wave pulse is in this example 5000psi. Upon conclusion of this pulse, heater 210c is activated thereby heating both actuator 212b and 212c. This configuration does not include another defeatable member and thus allows pressure to "wash" out of the actuators 212c and 212d. The two actuators are, however, different in that 212c is set to release at 225 degrees and release 3000psi while the actuator 212d is set to release at 250 degrees and 5000psi. As was introduced above, such an arrangement causes selective release that can be "streamed" if desired by continuing heating through both threshold temperature levels. A single heater is provided for actuators 212c and 212d. Moving to actuators 212e and 212f, it will be appreciated that the identical situation to that of actuators 212c and 212d is repeated for another wave of 3000psi and then 5000psi. One possible benefit of this arrangement is that distribution of acid in the formation is enhanced by the wave effect. This is, of course, but one example while many other uses of the configuration disclosed are possible. Finally, in this exemplary acidizing embodiment, the acidizing sleeve (not shown) must be closed. In order to accomplish this, another pressure event is created by adding another dedicated heater 210e in operable communication with actuator 212g. This actuator is configured to release the intrusion fluid at 300 degrees, a comfortable

margin from the temperatures of the other actuators in this embodiment to prevent an early and unintended closure of the sleeve. Further, this last actuator is configured to release 10,000psi in a pulse and so includes a defeatable member 218c that is defeatable, at 10,000psi. This last pulse causes the sleeve to close and concludes the operation. It is important to recognize that the above-discussed specific example of a complex pressure profile is but one example in a vast field of possible examples. How specific actuators are configured is limited only by practicality and available space.

[0021] Finally, due to the use of heaters in many of the foregoing embodiments, it is possible to increase the pressure that is available from the porous material. While in the described embodiments heating occurs until the intrusion fluid is brought to just above the glass transition temperature of the intrusion fluid, it is not necessary to shut down the heaters at that point. Rather, the heating may be continued. In such condition, the higher temperature of the fluid will increase its pressure, as is always the case with fluids raised to a higher temperature. The total pressure available from the device then is increased over that of the initial intrusion pressure.

[0022] While the foregoing embodiments utilize heaters to bring the solid phase intrusion fluid above the glass transition temperature or the melting temperature, heaters per se are not the only way to achieve the result. Rather, any source that is capable of causing the threshold temperature to be exceeded, thereby releasing the stored pressure is contemplated for use with the teaching hereof. In one alternate embodiment, the heat source can be the ambient temperature downhole. One possible alternate is to employ an insulator that insulates the capillary spring from the ambient temperature of the wellbore until a selected time when the insulator is defeated by moving the same, or dissolving the same (whether by the addition of a specific chemical or simply by time in the wellbore, etc.).

[0023] While preferred embodiments have been shown and described, modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustrations and not limitation.

CLAIMS

- Claim 1. A pressure storage device comprising:
- a porous material; and
- a non-wetting fluid having a glass transition or material melting temperature above a normal exposure temperature for the device.
- Claim 2. The device as claimed in claim 1 wherein the porous material is silica-based.
- Claim 3. The device as claimed in claim 1 wherein the fluid is water, organo-liquid, metal or metal-alloy.
- Claim 4. A method for storing pressure for later use comprising:
- heating a non-wetting fluid above a glass transition or material melting temperature thereof;
- forcing the fluid into a porous material non-wettable thereby while maintaining the temperature of the fluid above the glass transition or material melting temperature; and
- reducing a temperature of the fluid to below the glass transition or material melting temperature thereof.
- Claim 5. The method as claimed in claim 4 wherein the forcing is pressurizing the non-wetting fluid above a threshold intrusion pressure for the porous material.
- Claim 6. The method as claimed in claim 4 wherein the method further comprises heating the fluid to above the glass transition or material melting temperature to release pressure stored.

- Claim 7. The method as claimed in claim 6 wherein the method further comprises further heating the fluid after achieving the glass transition or material melting temperature to increase pressure of the fluid.
- Claim 8. A downhole actuator device comprising:
- a porous material; and
- a non-wetting intrusion fluid introduced into the porous material under pressure and at a temperature above a glass transition or material melting temperature of the fluid and retained in the porous material at a temperature below the glass transition or material melting temperature of the fluid.
- Claim 9. The downhole actuator device as claimed in claim 8 further comprising a heater in operable communication with the porous material.
- Claim 10. The downhole actuator device as claimed in claim 8 further comprising a defeatable member having a pre-selected defeat pressure.
- Claim 11. The downhole actuator device as claimed in claim 10 wherein the defeatable member is a rupture member.
- Claim 12. The downhole actuator device as claimed in claim 10, wherein the defeatable member is positioned to retain pressure released from the porous material upon heating to above the glass transition or material melting temperature of the fluid disposed therein, until the pressure reaches the pre-selected defeat pressure.
- Claim 13. The downhole actuator device as claimed in claim 10 wherein the defeatable member enables a pressure pulse action from the actuator device.
- Claim 14. The downhole actuator device as claimed in claim 9 wherein the heater is actuatable selectively.
- Claim 15. The downhole actuator device as claimed in claim 9 wherein the heater is electrically activated.

Claim 16. An actuation system comprising:

a plurality of combinations of porous materials and non-wetting intrusion fluids introduced into the porous materials under pressure and at a temperature above a glass transition or material melting temperature of the fluid and retained in the porous material at a temperature below the glass transition or material melting temperature of the fluid.

Claim 17. The actuation system as claimed in claim 16 wherein each combination of material and fluid is configured for a selected glass transition or material melting temperature.

Claim 18. The actuation system as claimed in claim 17 wherein the temperature selected is different for at least one combination than at least one other combination.

Claim 19. The actuation system as claimed in claim 17 wherein the temperature is selected among the plurality of combinations to enable sequential release of stored pressure.

Claim 20. The actuation system as claimed in claim 16 wherein at least one of the combinations further includes a defeatable member to resist pressure release until a threshold pressure is achieved.

Claim 21. The actuation system as claimed in claim 16 wherein the combinations create a wave effect in pressure profile released.

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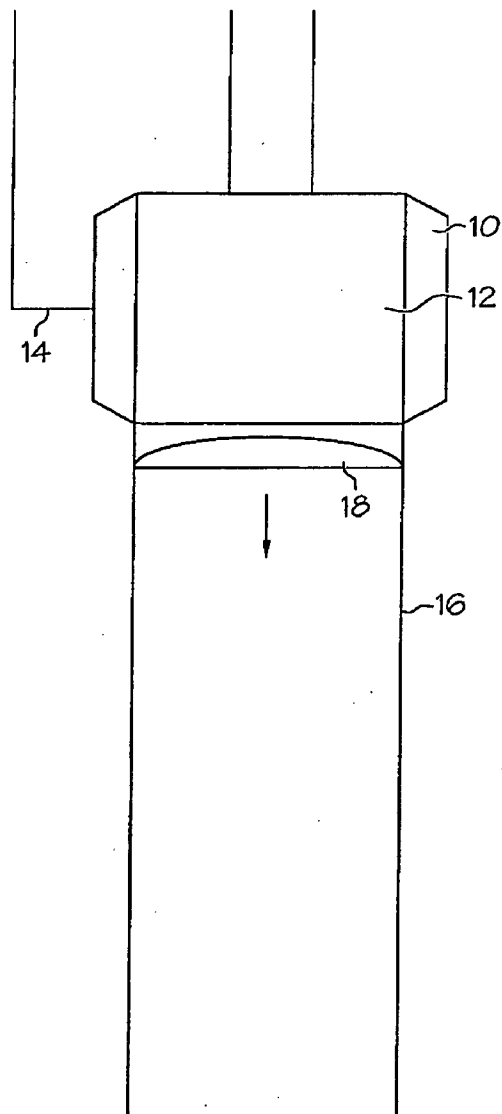


FIG. 1

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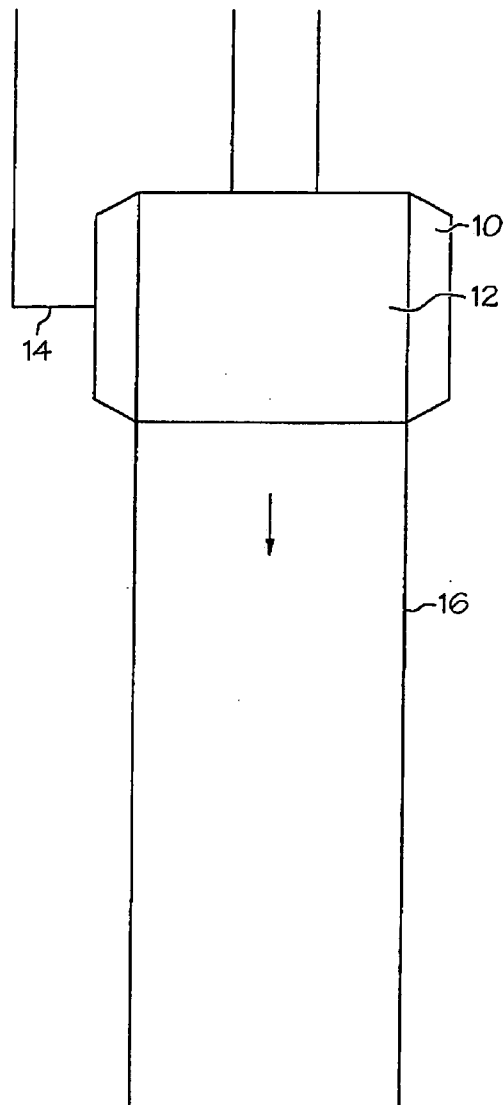
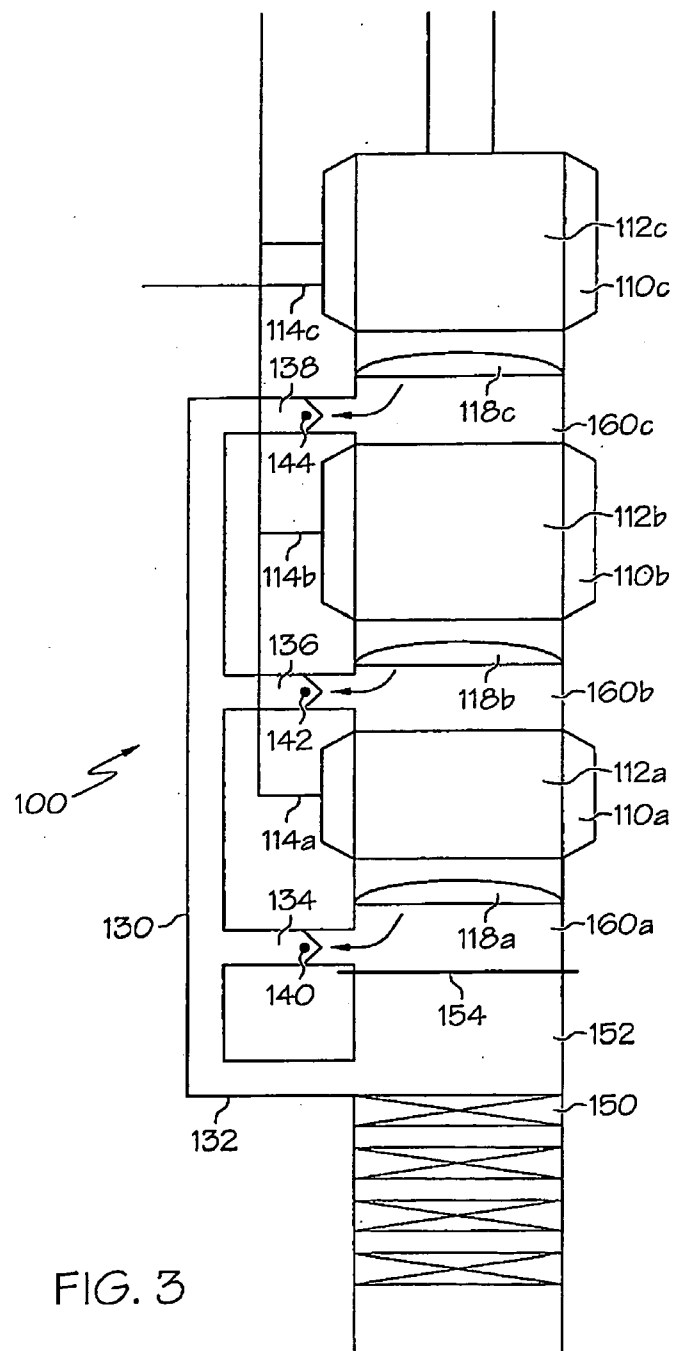


FIG. 2

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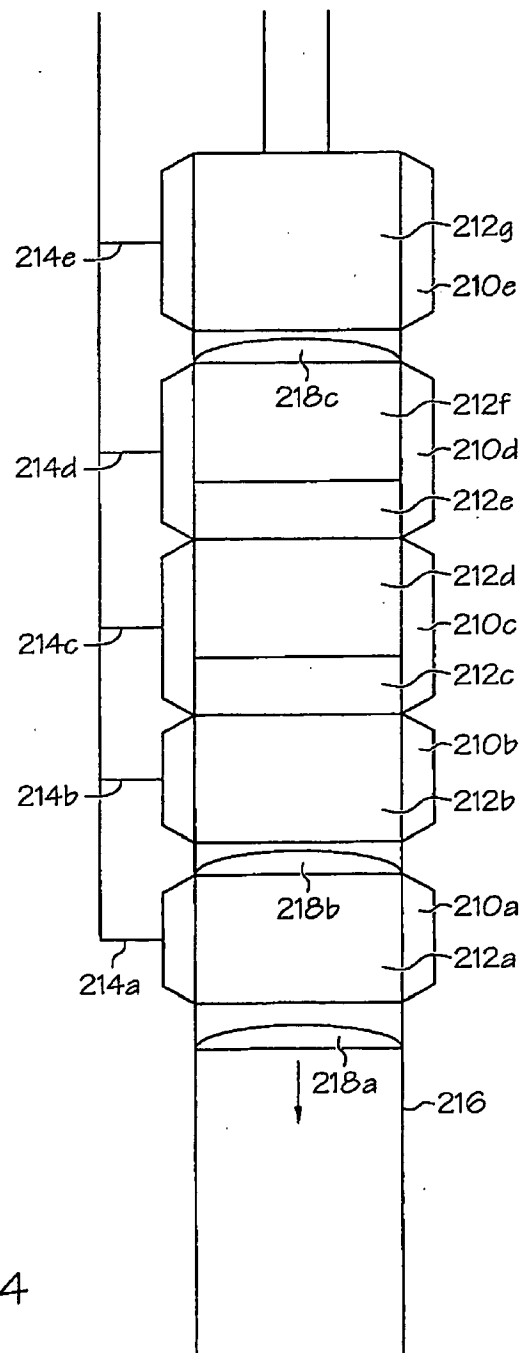


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2008/084925

A. CLASSIFICATION OF SUBJECT MATTER
INV. G05D23/19 F03G7/00

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)
G05D F03G

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 118 071 A (HUELLE ZBIGNIEW R [DE]) 2 June 1992 (1992-06-02) abstract column 7, line 11 - line 25; figures 11,12	1,4,8,16
A	US 5 567 284 A (BAUER HELMUT [DE] ET AL) 22 October 1996 (1996-10-22) abstract column 2, line 34 - line 58; figure 1	1,4,8,16

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

☒ See patent family annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
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- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- *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.
- *Z* document member of the same patent family

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2008/084925

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5118071	A	02-06-1992	NONE	
US 5567284	A	22-10-1996	AT 139007 T	15-06-1996
			CA 2149533 A1	30-03-1995
			DE 4331763 C1	10-11-1994
			WO 9508709 A1	30-03-1995
			EP 0670963 A1	13-09-1995
			JP 2651747 B2	10-09-1997
			JP 8501858 T	27-02-1996
			NO 951016 A	30-03-1995