(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 March 2004 (04.03.2004)

PCT

(10) International Publication Number
WO 2004/018833 A1

(51) International Patent Classification[7]: E21B 34/06, 34/10, F16K 31/00

(21) International Application Number: PCT/US2002/026724

(22) International Filing Date: 22 August 2002 (22.08.2002)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (*for all designated States except US*): **HALLIBURTON ENERGY SERVICES, INC.** [US/US]; 2601 Beltline Road, Carrollton, TX 75006 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **FRIPP, Michael, L.** [US/US]; 2128 Tiburon Drive, Carrollton, TX 75006 (US). **SIMONDS, Floyd, R.** [US/US]; 645 Wentworth Drive, Richardson, TX 75081 (US). **MICHAEL, Robert, K.** [US/US]; 3316 Hilltop Lane, Plano, TX 75023 (US). **DAGENAIS, Pete, C.** [US/US]; 4009 Heron Cove Lane, The Colony, TX 75056 (US).

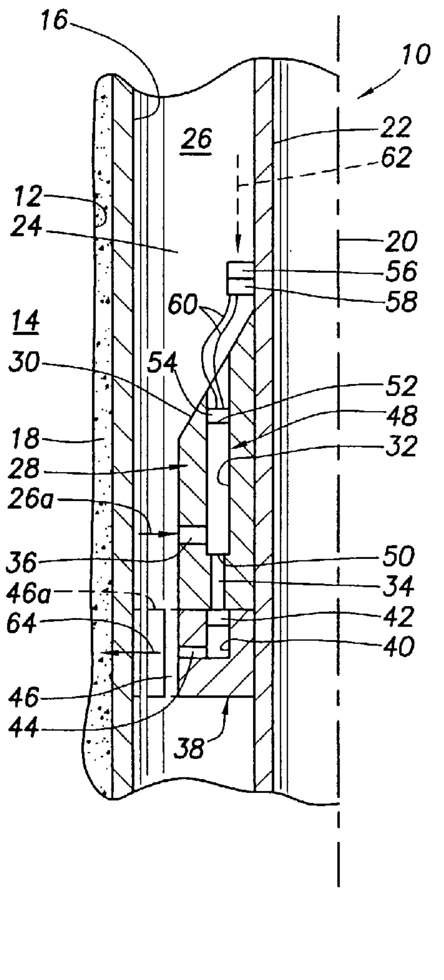
(74) Agent: **KONNEKER, J., Richard**; Konneker & Smith, P.C., 660 North Central Expressway, Suite 230, Plano, TX 75074 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT (utility model), AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ (utility model), CZ, DE (utility model), DE, DK (utility model), DK, DM, DZ, EC, EE (utility model), EE, ES, FI (utility model), FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW),

[Continued on next page]

(54) Title: SHAPE MEMORY ACTUATED VALVE



(57) Abstract: A normally closed shuttle valve operatively installed downhole in a subterranean well completion is selectively opened by applying heat to a shape memory portion of its actuation structure. The shape memory portion includes a pre-tensioned shape memory alloy wire wrapped around a pulley structure in the valve and connected to a latch structure holding a movable valve member in a closed position. When the wire is heated it longitudinally contracts and pulls a portion of the latch structure away from a valve member-holding position thereof, to thereby permit well fluid pressure to drive the movable valve member to its open position.

WO 2004/018833 A1

Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

SHAPE MEMORY ACTUATED VALVE

TECHNICAL FIELD

The present invention relates generally to well tool apparatus and, in an embodiment described herein, more particularly provides a downhole shuttle valve selectively actuatable utilizing a specially designed shape memory material portion.

BACKGROUND

Downhole valves and other well tools operatively disposed in subterranean well completions typically have actuation structures associated therewith which may be selectively operated to change the tool from a first state to a second state - for example, by shifting a valve from a closed state to an open state. Various well-known problems, limitations and disadvantages are typically associated with well tool actuation structures of conventional construction and operation. These problems, limitations and disadvantages include complexity, high cost, less than ideal reliability, undesirably large size, high power requirements, and difficult installation and service requirements. In view of this, a need exists for an improved actuation structure for a well tool such as a valve.

SUMMARY

In carrying out the principles of the present invention, in accordance with an embodiment thereof, a specially designed shape memory actuated well tool, representatively a shuttle valve, is operatively incorporated in a subterranean well. The representatively depicted actuatable well tool comprises a body, an operating member carried by the body, and a drive structure operable to utilize stored energy to move the operating member relative to the body from a first position to a second position in response to actuation of the tool.

The tool is further provided with a specially designed shape memory-based actuation system for selectively actuating the tool. According to features of the invention, the actuation system includes an elongated flexible shape memory member, representatively a wire formed from a shape memory metal alloy selected from the alloy group consisting of Ni-Ti; Ni-Al; Cu-Al-Ni; Cu-Zn-Al; Fe-Mn-Si; Fe-Ni-Co-Ti; Ni-Ti-Hf; and Ni-Ti-Pd. As alternatives to the wire configuration of the shape memory member, it could, for example but not by way of limitation, be formed in the shape of a ribbon (having a rectangular cross-section), a multi-stranded wire, or a spring.

In accordance with other features of the invention, the wire is shortenable in response to heating thereof, and is held in a pre-tensioned condition, with one end of the wire being associated with the operating member, preferably through a latch structure, and the other end of the wire being anchored to the body. Preferably, a central portion of the wire is partially wrapped around a support member, representatively a rotatable pulley, and is disposed in the

body in an elongated, generally U-shaped configuration. A side portion of the wire is guidingly contacted by a second support member, representatively a second rotatable pulley.

To actuate the well tool, the wire is heated using a heating structure associated with the tool, with the resulting shortening of the wire releasing the latch structure and permitting the drive structure to forcibly move the operating member to its second position.

Representatively, the latch structure includes an annular collet finger array attached to the operating member and held in a locking position, in which the collet fingers are interlocked with a recess in the body, by a holding member which is slidingly restrained within the collet finger array and releasably prevents the collet fingers from being released from the body. In an illustrated valve embodiment of the well tool, the drive structure includes an inlet passage for communicating pressurized fluid from a source thereof with the operating member, representatively a valve shuttle member, and biasing the operating member toward its second position. When the shape memory wire is heat-shortened it pulls the holding member out of the balance of the latch structure, thereby releasing the latch structure and permitting the drive structure to forcibly move the operating member to its second position.

In a representatively depicted application of a valve embodiment of the well tool the valve is supported downhole within a side pocket structure exteriorly mounted on a tubing element extending through the wellbore. Actuation of the valve responsively actuates a second well tool, representatively a packer. Upon receiving a suitable actuation signal which causes the heating structure to heat and shorten its shape memory actuating element, the valve is actuated to thereby permit pressurized well fluid to enter its inlet passage and drive the valve member from a closed position to an open position.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic quarter sectional view through a longitudinal portion of a representative subterranean well completion having incorporated therein a specially designed shape memory actuated valve embodying principles of the present invention;

FIG. 2 is an enlarged upper end view of the valve;

FIG. 3 is a cross-sectional view through the valve, taken along line 3-3 of FIG. 2, with the valve in its closed position;

FIG. 3A is a view similar to that in FIG. 3, but with the valve in its open position; and

FIG. 4 is a reduced scale exploded side elevational view of a lower portion of the valve.

DETAILED DESCRIPTION

Schematically depicted in quarter sectional form in FIG. 1 is a longitudinal portion of a representative subterranean well completion 10 which embodies principles of the present invention. The well completion 10 includes a representatively vertical wellbore 12 extending through the earth 14 and illustratively lined with a tubular metal casing 16 which is cemented-in as at 18. Alternatively, the wellbore 12 could be uncased or uncemented. In the following description of the well completion 10 and other apparatus and methods described herein, directional terms, such as "above", "below", "upper", "lower", etc., are used only for convenience in referring to the accompanying drawings. Additionally, it is to be understood that the various apparatus of the present invention described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from principles of the present invention.

Casing 16 is centered about a vertical axis 20 and generally coaxially receives a smaller diameter tubular structure 22, representatively a production tubing string. Alternatively, the inner tubular structure may be of another type such as, for example but not by way of limitation, completion tubing or a drill string. An annulus 24 is defined between the casing 16 and the tubing string 22 and is representatively filled with well fluid having a pressure which is representatively higher than the pressure within the tubing string and, as later described herein, serves as a stored source of well tool actuation energy.

Mounted on an outer side portion of the tubing 22 is a generally solid side pocket structure 28 having an upper end 30 through which a circular bore 32 downwardly extends. The bottom end of the bore 32 communicates with the top end of a smaller diameter vertical circular bore 34, and an inlet opening 36 horizontally extends rightwardly through the side pocket structure 28 to communicate with a lower end portion of its vertical bore 32.

At the lower end of the side pocket structure 28 is a schematically depicted hydraulically actuatable packer structure 38 having a vertical bore 40 that communicates at its upper end with the lower end of the bore 34 and slidably receives an actuation piston 42. The lower end of the bore 40 communicates with a horizontal bore 44 which, in turn, communicates with an expandable packer seal structure 46. The solid line position of the schematically depicted seal structure 46 shown in FIG. 1 represents its unexpanded, non-sealing position.

Removably, complementarily and sealingly received in the vertical bore 32 of the side pocket structure 28 is a specially designed electrically actuatable shuttle valve 48 which embodies principles of the present invention and which will be subsequently described in detail herein. Valve 48 has a generally tubular configuration, with a lower end 50 positioned upwardly adjacent the upper end of the bore 34, and an upper end 52 which is downwardly inset from the upper side pocket structure end 30 and is covered by a plug member 54 removably threaded into an upper end portion of the bore 32. Exteriorly mounted on the tubing 22 above the side pocket structure 28 is signal receiver structure 56 having an electrical battery portion 58. Battery 58 is operatively connected to an interior actuation portion of the valve 48 via electrical wires 60 that pass through the plug 54 and into an upper interior end portion of the valve 48.

The valve 48 schematically depicted in FIG. 1 is in its closed state in which the valve prevents the communication of the pressurized well fluid 26 with the packer actuating piston 42 via the side pocket bores 34 and 36. However, as later described herein, when a wireless actuation signal 62 is appropriately transmitted to the receiver 56, the receiver responsively causes the battery 58 to transmit electrical actuation power to the valve 48, via the wires 60, to cause the valve 48 to open, thereby communicating the pressurized well fluid 26 with the packer actuating piston 42 via the side pocket structure bores 36 and 34. Such pressurized fluid communication, depicted by the arrow 26a in FIG. 1, downwardly drives the piston 42 from its FIG. 1 position to thereby radially expand the packer seal structure 46, as indicated by the arrow 64 to its dotted line position 46a in which it is forced into sealing engagement with the interior side surface of the well casing 26.

The wireless signal 62 may be generated in a variety of manners including, for example but not by way of limitation, acoustically, vibrationally, electromagnetically or by pressure. Alternatively, there could be a hard wire direct connection between the receiver and the surface such that the electrical actuation signal could simply be sent from the surface directly via electrical wiring. Similarly, if desired, the battery 58 could be dispensed with, and the electrical actuation power could be transmitted from the surface directly to valve 48 via electrical wiring.

With reference now to FIGS. 2, 3 and 4, the valve 48 has an elongated, generally tubular configuration and includes a body structure in the form of a lower tubular shuttle housing 66, and an upper tubular actuator housing 68. A lower end portion 69 of the housing 68 is downwardly telescoped into an upper end portion of the housing 66 and captively retained therein by a diametrically opposed pair of set screws 70. At the lower end of the shuttle housing 66 are a pair of annular exterior side surface seal grooves 72,74 (see FIG. 4) that respectively receive O-ring seal members 76,78 (see FIG. 3). Just above the seals 76,78 are four circumferentially spaced apart sidewall fluid flow ports 80 (including, as viewed in FIG.

3, the leftwardly facing inlet port 80a) which communicate at their top sides with a circular axial bore 82 extending through the shuttle housing 66. At their bottom sides, the ports 80 communicate with a circular axial bore 84 having a diameter smaller than that of the bore 82. The lower end of the bore 84 communicates with a still smaller diameter circular axial bore 86 that, at its lower end, opens outwardly through the bottom end of the shuttle housing 66 which forms the lower end 50 of the valve 48.

Somewhat above the ports 80 are a pair of annular exterior side surface seal grooves 88,90 formed on the shuttle housing 66 (see FIG. 4) and respectively receiving O-ring seal members 92,94. With the valve 48 operatively installed in the side pocket bore 32 (see FIG. 1), the shuttle housing sidewall port 80a is aligned and communicated with the side pocket inlet opening 36, and the shuttle housing lower end bore 86 is aligned and communicated with the vertical bore 40 in the packer structure 38. The external shuttle housing seals 76,78 form annular seals between the shuttle housing 66 and the interior of the side pocket bore 32 above the side pocket horizontal inlet opening 36, and the external shuttle housing seals 92,94 form annular seals between the shuttle housing 66 and the interior of the side pocket bore 32 below the side pocket horizontal inlet opening 36.

Referring now to FIGS. 3 and 4, the shuttle valve 48 further includes a movable valve member 96, a movable holding member 98, and a resilient restraining O-ring member 100. The movable valve member 96 has a solid cylindrical body portion 102 with a reduced diameter bottom end section 104. Annular side surface seal grooves 106,108 are formed in the bottom end section 104 and respectively receive O-ring seals 110 and 112, and larger diameter annular side surface seal grooves 114,116 are formed in the body portion 102 above the reduced diameter bottom end section 104 and respectively receive O-ring seals 118,120.

Longitudinally extending upwardly from a peripheral portion of a hollow upper end section of 121 of the valve or operating member 96 are a circumferentially spaced series of vertically elongated flexible collet fingers 122 having laterally outwardly enlarged upper ends 124. In a manner subsequently described herein, these collet fingers 122 form with the holding member 98 a latching structure that functions to releasably maintain the movable valve member 96 in a closed position. As will be seen, the collet fingers 122 form a latching portion of this overall latching structure.

The holding member 98 has a generally cylindrical configuration, with an upper end portion 126 from which a reduced diameter portion 128 downwardly extends. An annular side surface groove 130 is formed on a lower end of the holding member portion 128 and receives the restraining O-ring member 100. As cross-sectionally illustrated in FIG. 3, a small diameter axial bore 132 extends downwardly through the upper end of the holding member 98 and meets a larger diameter, internally threaded axial bore 134 extending upwardly through the lower end of the holding member 98. Extending through a juncture area of these vertical bores 132,134 is a transverse circular bore 136.

As cross-sectionally illustrated in FIG. 3, the shuttle valve 48 is in its closed state, with the lower end section 104 of the movable valve member 96 being sealingly received in the reduced diameter shuttle housing bore 84, and the larger diameter body portion 102 of the valve member being sealingly received in the larger diameter shuttle housing bore 82. In this closed position thereof, the valve member 96 prevents well fluid 46a from flowing inwardly through the inlet port 80a and downwardly through the bottom end bore 86 of the shuttle housing 66 into the packer structure bore 40 (see FIG. 1).

The laterally enlarged upper collet finger ends 124 are received in an annular interior side surface depression 138 formed in the shuttle housing 66 somewhat below an annular, upwardly facing interior ledge 140 disposed within the shuttle housing just beneath the lower the actuator housing end portion 69 telescopingly received in the shuttle housing 66. The holding member 98, with the valve 48 in its FIG. 3 closed state, is slidably and telescopingly received in the hollow upper end section 121 of the valve member 96, with the upper end portion 126 of the holding member 98 laterally bearing against the inner sides of the enlarged upper collet finger ends 124 and preventing them from being laterally inwardly deflected out of the annular inner side surface depression 138.

This holding by the member 98 of the collet finger end portions 124 within the annular inner side surface depression 138 of the shuttle housing 66 prevents the valve member 96 from being upwardly shifted away from its FIG. 3 closed position within the shuttle housing 66. The holding member 98 is releasably retained in its FIG. 3 position by means of the positioning of a radially outer portion of its lower end O-ring member 100 below laterally inwardly projecting sidewall projections 142 formed on the collet fingers 122 (see FIG. 3).

These collet finger projections 142 prevent the holding member 98 from being upwardly removed from the interior of the hollow valve member upper end section 121 unless a sufficient upward force is exerted on the holding member 98 to radially compress its lower end O-ring 100 and allow it to move upwardly past the collet finger projections 142. Due to the diameter difference between the lower valve member seals 110,112 and the upper valve member seals 118,120 the pressurized well fluid 26 at the valve port 80a exerts a net upward biasing force on the valve member 96. However, as long as the holding member 98 is in place within the colleted upper end of the valve member 96 as shown in FIG. 3, the valve member 96 is releasably locked in its closed position.

To permit the valve member 96 to be driven upwardly to its FIG. 3A open position by the pressurized well fluid 26, a specially designed actuation system 143, which representatively embodies principles of the present invention, is provided as shown in FIGS. 3 and 3A. As will now be described with reference to FIGS. 3 and 3A, when the actuation system 143 is operated, the holding member 98 is upwardly pulled out of the hollow colleted upper end of the valve member 96, thereby permitting the upper collet finger ends 124 to be laterally deflected inwardly out of their locking engagement with the associated annular shuttle housing depression 138. Thus, after the holding member 98 is pulled upwardly from its FIG. 3 position as subsequently described herein, the upwardly directed fluid biasing force on the valve member 96 causes the inward freeing deflection of the collet fingers 122 to thereby permit this fluid force to upwardly drive the valve member 96 to its FIG. 3A open state, thereby also upwardly shifting the released holding member 98 to its FIG. 3A position as well. The opening of the valve 48 permits pressurized well fluid 26a to enter the valve port 80a (via the side pocket inlet opening 36 shown in FIG. 1) and be discharged through its lower end bore 86 into the packer structure bore 40 (see FIG. 1) to set the packer seal structure 46 as previously described.

The lower actuator housing portion 69 has a vertical opening 144 extending therethrough, with a laterally enlarged bottom part of the opening 144 being configured to receive the holding member 98 and the upper colleted end of the valve member 96 (see FIG. 3A) when the valve member 96 is shifted upwardly to its open position. As can be seen in FIGS. 2 and 3, an upper longitudinal section of the actuator housing has an open configuration, being bounded on opposite sides thereof by parallel side walls 146,148 joined at their upper ends by a circular end wall 150 having a central circular opening 152 therein. The upper side of the end wall 150 forms the upper end 52 of the valve 48.

The specially designed actuation system 143 representatively includes first and second support structures 154 and 156, an anchoring member 158, and an elongated flexible shape memory member 160.

The first support member 154 is a rotatable pulley supported between the actuator housing walls 146,150 just above the lower portion 69 of the actuator housing 68 and horizontally offset toward the left edges of the housing side walls 146,148 as viewed in FIG. 3. The second support member 156 is a larger diameter rotatable pulley centrally positioned between the side walls 146,148 just beneath the upper housing end wall 150 as viewed in FIG. 3.

The anchoring member 158 is secured between the side walls 146,148 at right edge portions thereof and is vertically disposed somewhat higher than the pulley 154. A horizontal, internally threaded circular bore 162 extends through the anchoring member 158 and communicates with two opposing vertical bores 164,166 near the horizontally inner end of the anchoring member 158.

The elongated flexible member 160 is formed from a shape memory material, and is preferably a thin wire formed from a shape memory metal alloy having the usual shape memory material characteristic that when heated to a temperature within the transition range of the material the member will change its shape from a deformed shape toward a pre-deformed original shape. The shape memory material wire 160 shown in FIGS. 3 and 3A has a deformed shape in which the wire is lengthened, and a shorter pre-deformed original shape. Accordingly, when the wire 160 is heated to a temperature within the transition range of its shape memory material it will shorten with respect to its deformed length prior to such heating.

As will now be described, the wire 160 is used to selectively exert an upwardly pulling force on the holding member 98 to upwardly move it relative to the collet fingers 122 and thereby release the closed valve member 96 for fluid-driven upward opening movement thereof.

A first end of the wire 160 extends downwardly through the holding member bore 132, and outwardly through one of the transverse bores 136 of the holding member 98, and is clamped in place within the holding member 98 (thereby operatively associating the first end of the wire 160 with the valve operating member 96 via the holding member 98 and the valve member collet fingers 122) by means of a set screw member 168 (see FIG. 3) upwardly threaded into the holding member bore 134. From this clamped securement point the wire 160 extends upwardly through the vertical bottom end opening 144 of the actuator housing 68, engages a side surface portion of the lower pulley 154, and is then looped around the upper pulley 156 so that the remaining portion of the wire 160 extends downwardly toward the anchoring member 158. The second end of the wire 160 is extended downwardly through the anchoring member transverse bores 164,166 and is clamped in place within the anchoring member 158 by means of a set screw 170 threaded into the anchoring member bore 162.

Preferably, to increase the minimum temperature of the transition temperature range of the wire 160 the wire 160 in its FIG. 3 pre-actuation state is held in a pre-stressed (i.e., pre-tensioned) condition. Representatively, the shape memory wire 160 is of a Ni-Ti shape memory alloy, has a diameter of 0.010", and is pre-tensioned with a two pound tensioning force. The upward force which needs to be exerted on the holding member 98 to upwardly move it out of its collet finger-blocking FIG. 3 position and permit the opening of the valve 48 is representatively about four pounds.

When it is desired to open the valve 48, the actuation signal 62 (see FIG. 1) is transmitted to the receiver 56 which responsively flows electrical power from the battery 58 through the wires 60. Wires 60 extend inwardly through the upper end opening 152 of the actuator housing 68 and are conductively associated with the wire 160 in a suitable manner such that the electrical current flow through the wires 160 heats the shape memory wire 160 to a point within its transition range, thereby shortening the wire 160 (as indicated by the arrowheads on the wire 160 in FIG. 3A), and causing the heated wire 160 to pull the holding member 98 vertically out of the collet portion 122 of the valve member 96 and permit, as previously described herein, the valve member 96 to be fluid driven upwardly to its FIG. 3A open position from its FIG. 3 closed position. An essentially straight upward pull on the holding member 98 by the heated wire 160 is facilitated by the engagement of the wire with the lower pulley 154 which serves as a guide structure that maintains the end portion of the wire 160 adjacent the holding member 98 in an essentially vertical orientation.

The pre-tensioning of the wire 160 which elevates the minimum transition range temperature of the wire advantageously permits the actuation system 143 to be used in higher temperature well environments without the ambient well temperature causing the triggering of the actuation system prior to a desired opening of the valve 48. In the particular wire 160 illustrated herein, this pre-tensioning elevates the minimum transition range temperature of the shape memory wire by approximately 30 to 50 degrees Centigrade. After the setting of the packer seal element 46 (see FIG. 1) the packer can be unset in a variety of suitable manners well known to those of ordinary skill in this particular art. Upon retrieval of the opened valve 48 its actuation system 143 can be easily and quickly re-set to prepare the valve 48 for subsequent downhole use.

While the well tool representatively illustrated herein as incorporating the specially designed shape memory actuation system is a shuttle valve, it will be readily appreciated by those of ordinary skill in this art that the actuation system could be alternatively utilized in a wide variety of other types of well tools such as, for example but not by way of limitation, a safety valve, a sliding sleeve valve, a non-hydraulically set packer structure, or a perforating gun. Additionally, while the illustrated shape memory wire 160 is illustratively formed from a Ni-Ti shape memory alloy, a variety of other types of shape memory materials, such as alloys of Ni-Al, Cu-Al-Ni, Cu-Zn-Al, Fe-Mn-Si, Fe-Ni-Co-Ti, Ni-Ti-Hf, and Ni-Ti-Pd, could alternatively be utilized if desired.

Further, while a pre-tensioned shape memory wire is preferably utilized as the primary actuation member in the illustrated well tool 48, and is shortenable to release the overall latch structure and permit the well tool 48 to be shifted from a first state to a second state, it will be readily appreciated by those of reasonable skill in this particular art that a differently configured shape memory actuation member could be alternatively utilized to lengthen upon heating to release the latch structure, for example by pushing on a portion thereof, if desired.

Although electrical current has been representatively illustrated as being utilized to heat the shape memory actuation member, it will also be readily be appreciated by those of ordinary skill in this particular art that a variety of alternative heating means, such as the use of an exothermic material, or a high downhole well temperature, could be employed to heat-reconfigure the shape memory actuation member from its deformed configuration toward its pre-deformed shape.

As previously described herein, the inlet porting of the valve 48, and the varied diameter configuration of the valve member 96, provide a drive structure for utilizing stored energy (i.e., the pressure in the well fluid 26) to upwardly bias the valve member 96 toward its closed position, and drive the valve member thereto when the latch structure is released. However, it will be readily appreciated by those of ordinary skill in this particular art that a variety of other types of drive structures could be provided to utilized stored energy to shift the valve member 96 from its closed state to its open state if desired. Such alternate drive structures could, for example, be mechanical structures such as springs.

As also previously described herein, the holding member O-ring 100 is used to releasably retain the holding member 98 within the collet finger section 122 of the valve member 96 and restrain its removal therefrom to release the valve member latch structure in addition to maintaining a desired pre-tensioning force on the wire 160. A variety of other types of releasable restraining structures could alternatively be employed if desired and include, by way of example and not of limitation, leaf spring, shear pin, spring/ball detent, axial spring, hydraulic rupture disk, snap ring/groove, drag block and additional shape memory material structures. Further, with respect to the representative collet finger-based latching structure, a variety of alternatively configured latching structures, such as tooth and groove structures, friction blocks, or spring-loaded dogs, could be employed if desired without departing from principles of the present invention.

The foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the present invention being limited solely by the appended claims.

WHAT IS CLAIMED IS:

1. An actuatable well tool comprising:

a body;

an operating member carried by the body;

a drive structure operable to utilize stored energy to move the operating member relative to the body from a first position to a second position in response to actuation of the tool; and

an actuation system for selectively actuating the tool, the actuation system including an elongated flexible shape memory member held in a tensioned condition, with a first end being operatively associated with the operating member, and a second end being anchored to the body, the shape memory member being shortenable in response to heating thereof.

2. The actuatable well tool of Claim 1 wherein:

the shape memory member is a wire formed from a shape memory metal alloy.

3. The actuatable well tool of Claim 2 wherein the alloy is selected from the alloy group consisting of:

Ni-Ti; Ni-Al; Cu-Al-Ni; Cu-Zn-Al; Fe-Mn-Si; Fe-Ni-Co-Ti; Ni-Ti-Hf; and Ni-Ti-Pd.

4. The actuatable well tool of Claim 1 wherein:

the actuation system further includes a first support member carried by the body in a spaced apart relationship with the operating member, and

a longitudinally intermediate portion of the shape memory member is partially wrapped around the first support member.

5. The actuatable well tool of Claim 4 wherein:

the first support member is a rotatable pulley.

6. The actuatable well tool of Claim 4 wherein:

the shape memory member is supported in an elongated, generally U-shaped configuration.

7. The actuatable well tool of Claim 4 wherein:

the actuation system further includes a second support member spaced apart from the first support member and guidingly engaging a longitudinal portion of the shape memory member.

8. The actuatable well tool of Claim 7 wherein:

the second support member is a rotatable pulley.

9. The actuatable well tool of Claim 1 wherein:

the well tool is a valve, and the operating member is a valve member movable between open and closed positions.

10. The actuatable well tool of Claim 1 wherein:

the drive structure includes a passage for communicating pressurized fluid from a source thereof with the operating member.

11. The actuatable well tool of Claim 1 further comprising:

a heating structure operable to selectively heat the shape memory member.

12. The actuatable well tool of Claim 11 wherein:

the heating structure includes electrical wiring through which electrical power from a source thereof may be transmitted to the shape memory member to heat it.

13. An actuatable well tool comprising:

a body;

an operating member carried by the body;

a drive structure operable to utilize stored energy to move the operating member relative to the body from a first position to a second position in response to actuation of the tool; and

an actuation system for selectively actuating the tool, the actuation system including:

a first support member carried by the body in a spaced apart relationship with the operating member, and

an elongated flexible shape memory member having a first end operatively associated with the operating member, a longitudinally intermediate portion partially wrapped around the first support member, and a second end anchored to the body in a spaced apart relationship with the support member, the shape memory member being heat-deformable.

14. The actuatable well tool of Claim 13 wherein:

the shape memory member is a wire formed from a shape memory metal alloy.

15. The actuatable well tool of Claim 14 wherein the alloy is selected from the alloy group consisting of:

Ni-Ti; Ni-Al; Cu-Al-Ni; Cu-Zn-Al; Fe-Mn-Si; Fe-Ni-Co-Ti; Ni-Ti-Hf; and Ni-Ti-Pd.

16. The actuatable well tool of Claim 13 wherein:

the first support member is a rotatable pulley.

17. The actuatable well tool of Claim 13 wherein:

the shape memory member is supported in an elongated, generally U-shaped configuration.

18. The actuatable well tool of Claim 13 wherein:

the actuation system further includes a second support member spaced apart from the first support member and guidingly engaging a longitudinal portion of the shape memory member.

19. The actuatable well tool of Claim 18 wherein:

the second support member is a rotatable pulley.

20. The actuatable well tool of Claim 13 wherein:

the well tool is a valve, and the operating member is a valve member movable between open and closed positions.

21. The actuatable well tool of Claim 13 wherein:

the drive structure includes a passage for communicating pressurized fluid from a source thereof with the operating member.

22. The actuatable well tool of Claim 13 further comprising:

a heating structure operable to selectively heat the shape memory member.

23. The actuatable well tool of Claim 22 wherein:

the heating structure includes electrical wiring through which electrical power from a source thereof may be transmitted to the shape memory member to heat it.

24. An actuatable well tool comprising:

a body;

an operating member carried by the body in a first position corresponding to a first state of the tool, the operating member being movable relative to the body to a second position corresponding to a second state of the tool;

a drive structure operable to utilize stored energy to bias the operating member toward its second position;

a latch structure including:

a latch portion, and

a holding portion releasably engaging the latch portion and holding it in a locked position in which the latch portion prevents movement of the operating member to its second position, the holding member being movable in a release direction relative to the latch portion to permit the latch portion to allow movement of the operating member to its second position; and

an actuation system operable to initiate movement of the operating member to its second position, the actuation system including:

a shape memory member connected to the holding portion and being heat-deformable to move the holding portion in its release direction relative to the latch portion.

25. The actuatable well tool of Claim 24 wherein:

the actuatable well tool is a valve.

26. The actuatable well tool of Claim 24 wherein:

the latch portion includes an annular array of collet fingers releasably locked to the body, and

the holding member is releasably restrained within the interior of the collet finger array.

27. The actuatable well tool of Claim 26 wherein:

the holding member has an external annular projection thereon, and

the collet fingers have side wall protrusions thereon which releasably block movement of the holding member projection past the collet finger protrusions to thereby releasably restrain the holding member within the collet finger array.

28. The actuatable well tool of Claim 24 wherein:

the shape memory member is a wire formed from a shape memory metal alloy and having a first end anchored to the holding member and a second end anchored to the body.

29. The actuatable well tool of Claim 28 wherein:

the wire is held in tension.

30. The actuatable well tool of Claim 28 wherein:

the actuation system further includes a support member, and

the wire is held in a generally U-shaped configuration.

31. A subterranean well completion having incorporated therein an actuatable well tool comprising:

a body;

an operating member carried by the body;

a drive structure operable to utilize stored energy to move the operating member relative to the body from a first position to a second position in response to actuation of the tool; and

an actuation system for selectively actuating the tool, the actuation system including an elongated shape memory material wire held in a tensioned condition, with a first end being operatively associated with the operating member, and a second end being anchored to the body, the shape memory material wire being shortenable in response to heating thereof.

32. The subterranean well completion of Claim 31 wherein:

the actuation system further includes a first support member carried by the body in a spaced apart relationship with the operating member, and

a longitudinally intermediate portion of the wire is partially wrapped around the first support member.

33. The subterranean well completion of Claim 32 wherein:

the first support member is a rotatable pulley.

34. The subterranean well completion of Claim 32 wherein:

the wire is supported in an elongated, generally U-shaped configuration.

35. The subterranean well completion of Claim 31 wherein:

the well tool is a valve, and the operating member is a valve member movable between open and closed positions.

36. The subterranean well completion of Claim 31 wherein:

the drive structure includes a passage for communicating pressurized fluid from a source thereof with the operating member.

37. The subterranean well completion of Claim 31 further comprising:

a heating structure operable to selectively heat the wire.

38. The subterranean well completion of Claim 36 wherein:

the well completion further comprises a wellbore through which a tubular structure extends, the wellbore forming an annular space around the tubular structure, the tubular structure having an external side pocket structure thereon within which the well tool is operatively disposed, the passage communicating with the annular space.

39. A subterranean well completion having incorporated therein an actuatable well tool comprising:

a body;

an operating member carried by the body;

a drive structure operable to utilize stored energy to move the operating member relative to the body from a first position to a second position in response to actuation of the tool; and

an actuation system for selectively actuating the tool, the actuation system including:

a first support member carried by the body in a spaced apart relationship with the operating member, and

an elongated shape memory metal alloy wire having a first end operatively associated with the operating member, a longitudinally intermediate portion partially wrapped around the first support member, and a second end anchored to the body in a spaced apart relationship with the support member, the wire being heat-deformable.

40. The subterranean well completion of Claim 39 wherein:

the first support member is a rotatable pulley.

41. The subterranean well completion of Claim 39 wherein:

the wire is supported in an elongated, generally U-shaped configuration.

42. The subterranean well completion of Claim 39 wherein:

the actuation system further includes a second support member spaced apart from the first support member and guidingly engaging a longitudinal portion of the wire.

43. The subterranean well completion of Claim 39 wherein:

the well tool is a valve, and the operating member is a valve member movable between open and closed positions.

44. The subterranean well completion of Claim 39 wherein:

the drive structure includes a passage for communicating pressurized fluid from a source thereof with the operating member.

45. The subterranean well completion of Claim 39 further comprising:

a heating structure operable to selectively heat the wire.

46. The subterranean well completion of Claim 44 wherein:

the well completion further comprises a wellbore through which a tubular structure extends, the wellbore forming an annular space around the tubular structure, the tubular structure having an external side pocket structure thereon within which the well tool is operatively disposed, the passage communicating with the annular space.

47. A subterranean well completion having incorporated therein an actuatable well tool comprising:

a body;

an operating member carried by the body in a first position corresponding to a first state of the tool, the operating member being movable relative to the body to a second position corresponding to a second state of the tool;

a drive structure operable to utilize stored energy to bias the operating member toward its second position;

a latch structure including:

a latch portion, and

a holding portion releasably engaging the latch portion and holding it in a locked position in which the latch portion prevents movement of the operating member to its second position, the holding member being movable in a release direction relative to the latch portion to permit the latch portion to allow movement of the operating member to its second position; and

an actuation system operable to initiate movement of the operating member to its second position, the actuation system including:

a shape memory member connected to the holding portion and being heat-deformable to move the holding portion in its release direction relative to the latch portion.

48. The subterranean well completion of Claim 47 wherein:

the actuatable well tool is a valve.

49. The subterranean well completion of Claim 47 wherein:

the latch portion includes an annular array of collet fingers releasably locked to the body, and

the holding member is releasably restrained within the interior of the collet finger array.

50. The subterranean well completion of Claim 49 wherein:

the holding member has an external annular projection thereon, and

the collet fingers have side wall protrusions thereon which releasably block movement of the holding member projection past the collet finger protrusions to thereby releasably restrain the holding member within the collet finger array.

51. The subterranean well completion of Claim 47 wherein:

the shape memory member is a wire formed from a shape memory metal alloy and having a first end anchored to the holding member and a second end anchored to the body.

52. The subterranean well completion of Claim 51 wherein:

the wire is held in tension.

53. The subterranean well completion of Claim 51 wherein:

the actuation system further includes a support member, and

the wire is held in a generally U-shaped configuration.

54. The subterranean well completion of Claim 47 wherein:

the drive structure includes a passage for communicating pressurized fluid from a source thereof with the operating member, and

the well completion further comprises a wellbore through which a tubular structure extends, the wellbore forming an annular space around the tubular structure, the tubular structure having an external side pocket structure thereon within which the well tool is operatively disposed, the passage communicating with the annular space.

55. The subterranean well completion of Claim 54 wherein:

the actuatable well tool is a first actuatable well tool, and

the subterranean well completion further comprises a second actuatable well tool which is activated in response to activation of the first well tool.

56. The subterranean well completion of Claim 55 wherein:

the first actuatable well tool is a valve, and

the second actuatable well tool is a packer.

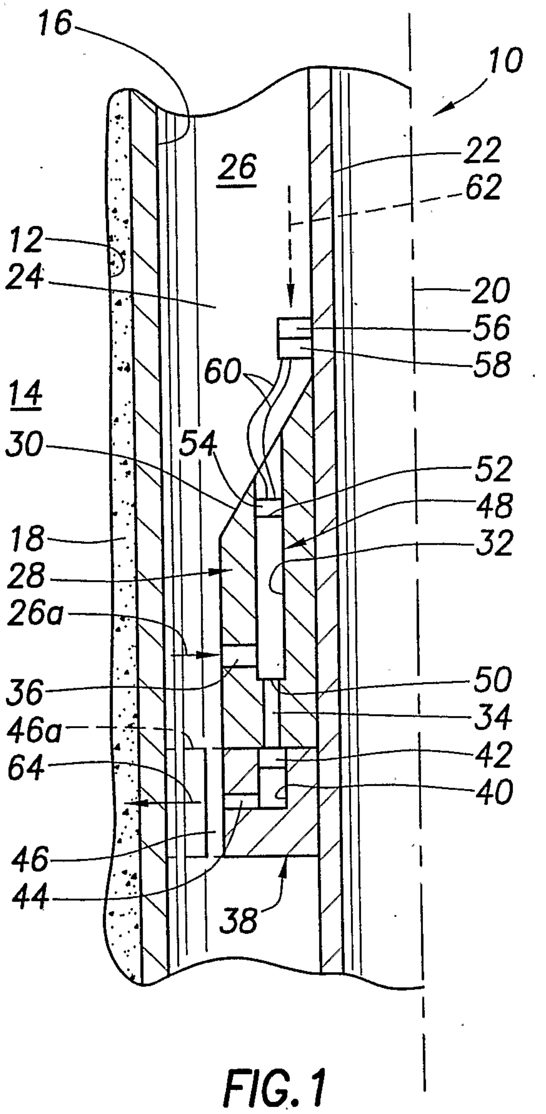


FIG.1

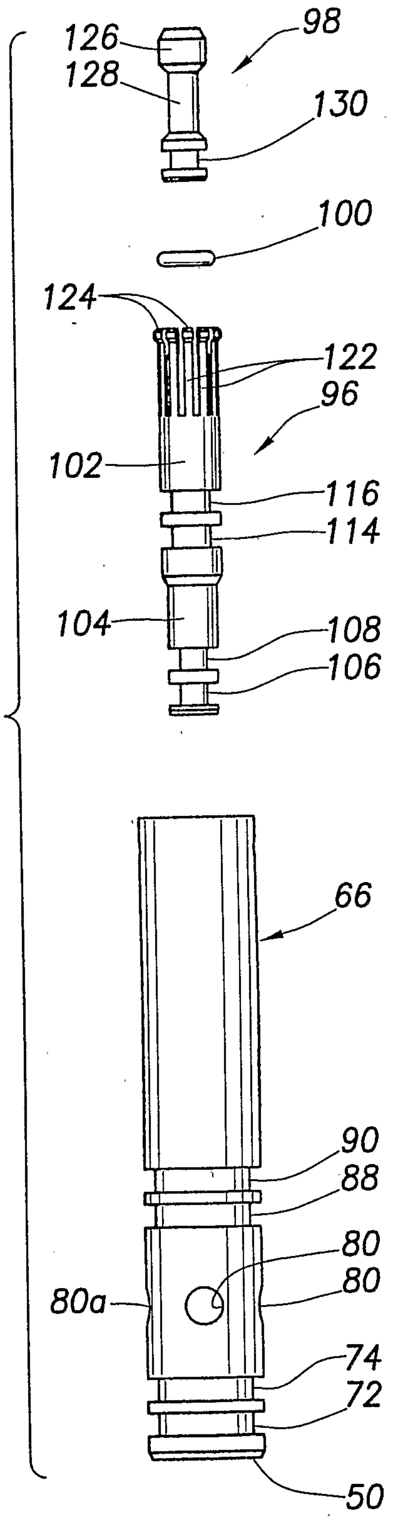


FIG.4

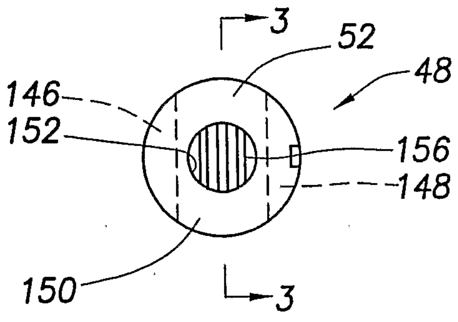


FIG.2

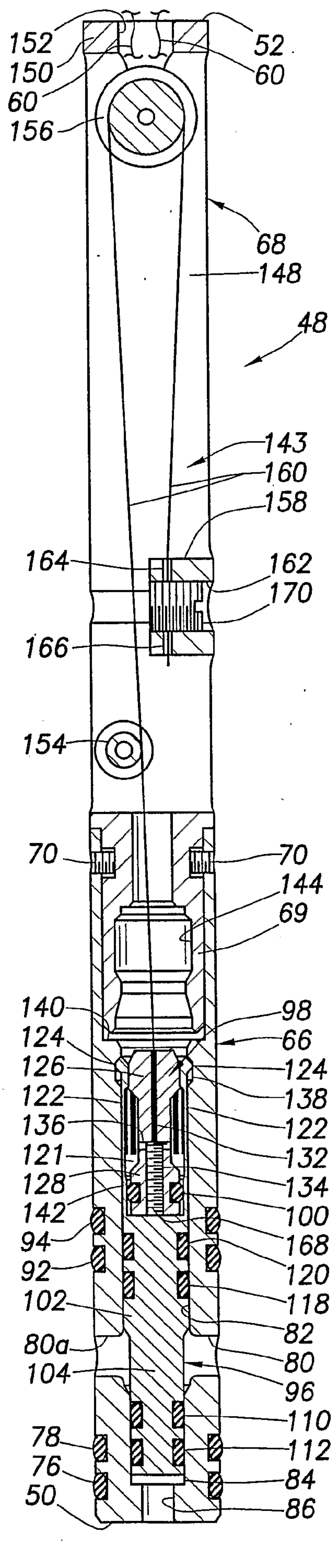
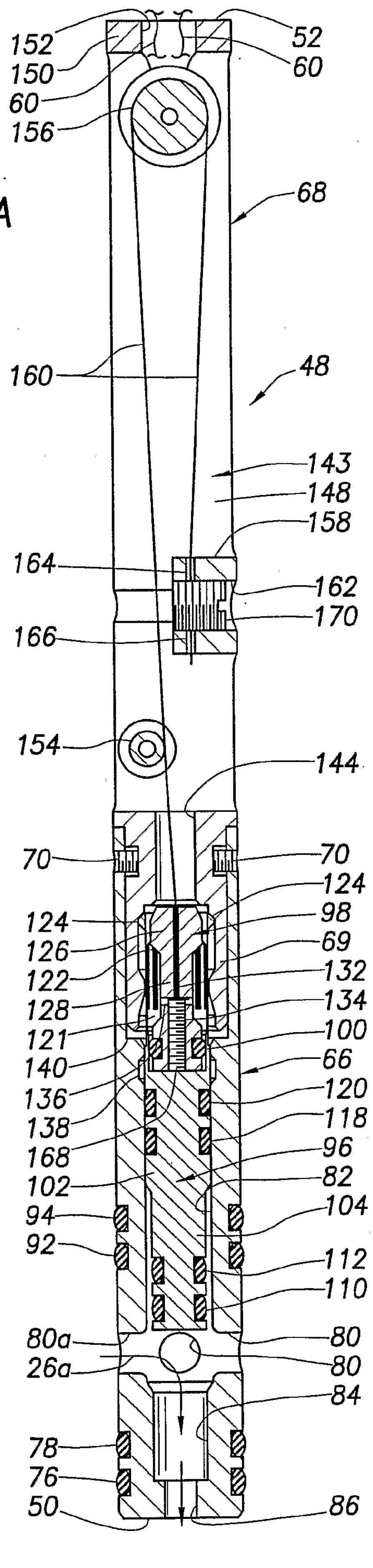

152
150
60
156
52
60
68
148
48
143
160
158
164
162
170
166
154
70
70
144
69
140
98
124
66
126
124
122
138
136
122
121
132
128
134
142
100
94
168
92
120
102
118
82
80a
80
104
96
110
78
112
76
84
50
86

FIG.3

FIG.3A


152
150
60
156
52
60
68
160
48
143
148
158
164
162
170
166
154
144
70
70
124
124
98
126
69
122
132
128
134
121
100
140
66
136
120
138
118
168
96
102
82
94
104
92
112
110
80a
80
26a
80
84
78
76
50
86

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/26724

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B34/06 E21B34/10 F16K31/00

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)
IPC 7 E21B F16K

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4 619 320 A (ADNYANA DEWA N ET AL) 28 October 1986 (1986-10-28) column 3, line 19 -column 4, line 25	1-3, 9-12,31, 35-38
A	column 4, line 16 -column 4, line 57	13,24, 39,47
Y	US 5 613 634 A (VERONESI LUCIANO ET AL) 25 March 1997 (1997-03-25) column 2, line 3 -column 3, line 2	1-3, 9-12,31, 35-38
Y	US 6 433 991 B1 (READ DENNIS M ET AL) 13 August 2002 (2002-08-13) column 2, line 56 -column 3, line 46	1-3, 9-12,31, 35-38
A	column 10, line 8 -column 10, line 56	13,24, 39,47
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 May 2003	21/05/2003

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	Morrish, S

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/26724

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 841 510 A (MATSUSHITA ELECTRIC WORKS LTD) 13 May 1998 (1998-05-13) column 2, line 23 -column 3, line 56 ---	1-3, 9-12,31, 35-38
A	EP 0 697 315 A (DAE WOO ELECTRONICS CO LTD) 21 February 1996 (1996-02-21) abstract ---	1,13,24, 31,39,47
A	GB 2 371 578 A (BAKER HUGHES INC) 31 July 2002 (2002-07-31) abstract -----	1,13,24, 31,39,47

INTERNATIONAL SEARCH REPORT

In[redacted]ation on patent family members

Internat pplication No
PCT/US 02/26724

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 4619320	A	28-10-1986	CA	1222446	A1	02-06-1987
US 5613634	A	25-03-1997	WO	9612994	A1	02-05-1996
US 6433991	B1	13-08-2002	AU	3459101	A	14-08-2001
			BR	0107795	A	18-02-2003
			CA	2399071	A1	09-08-2001
			EP	1252440	A1	30-10-2002
			GB	2376049	A	04-12-2002
			NO	20023660	A	01-10-2002
			WO	0157395	A1	09-08-2001
EP 0841510	A	13-05-1998	CN	1182848	A ,B	27-05-1998
			DE	69709529	D1	14-02-2002
			DE	69709529	T2	23-05-2002
			EP	0841510	A1	13-05-1998
			JP	11153234	A	08-06-1999
			KR	263955	B1	01-09-2000
			TW	386150	B	01-04-2000
			US	5865418	A	02-02-1999
EP 0697315	A	21-02-1996	KR	143349	B1	01-08-1998
			KR	158799	B1	01-12-1998
			AU	695570	B2	13-08-1998
			AU	3355495	A	07-03-1996
			BR	9508874	A	30-12-1997
			CA	2197639	A1	22-02-1996
			CN	1157597	A	20-08-1997
			EP	0697315	A2	21-02-1996
			JP	10504254	T	28-04-1998
			WO	9605092	A1	22-02-1996
			US	5622413	A	22-04-1997
GB 2371578	A	31-07-2002	AU	1352902	A	01-08-2002
			CA	2369860	A1	26-07-2002
			NO	20020409	A	29-07-2002
			US	2002108755	A1	15-08-2002