(12) UK Patent Application (19) GB (11) 2 437 433 (13) A

(43) Date of A Publication 24.10.2007

(21) Application No: 0712094.2

(22) Date of Filing: 06.10.2005

Date Lodged: 22.06.2007

(30) Priority Data:
(31) **10904071** (32) **21.10.2004** (33) **US**

(62) Divided from Application No
0520382.3 under Section 15(4) of the Patents Act 1977

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(51) INT CL:
E21B 41/00 (2006.01) ***E21B 47/00*** (2006.01)
E21B 47/06 (2006.01)

(52) UK CL (Edition X):
N0T CLASSIFIED

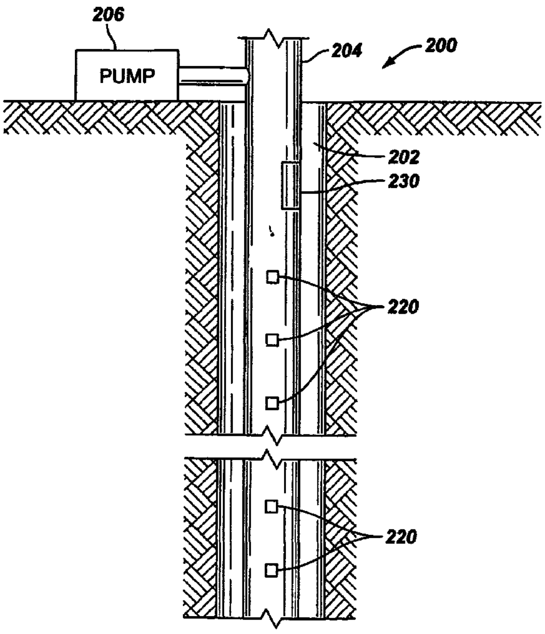
(56) Documents Cited:
US 6443228 B1

(58) Field of Search:
INT CL **E21B**
Other: **EPODOC, WPI**

(54) Abstract Title**: Free flowing tags powered by vibrational energy**

(57) A method usable with a well comprises deploying wireless tags 220 in the well to measure properties of the well as the tags flow through the well, and using vibrational energy transferred to the tags 220 during the flowing through the well to activate and power the tags 220. The tags 220 can be used to monitor various downhole conditions. The tags 220 can include a processor and the information gained by the tags 220 can be transmitted to an external reader.

FIG. 16B



GB 2 437 433 A

GB 2437433 A continuation

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FIG. 1

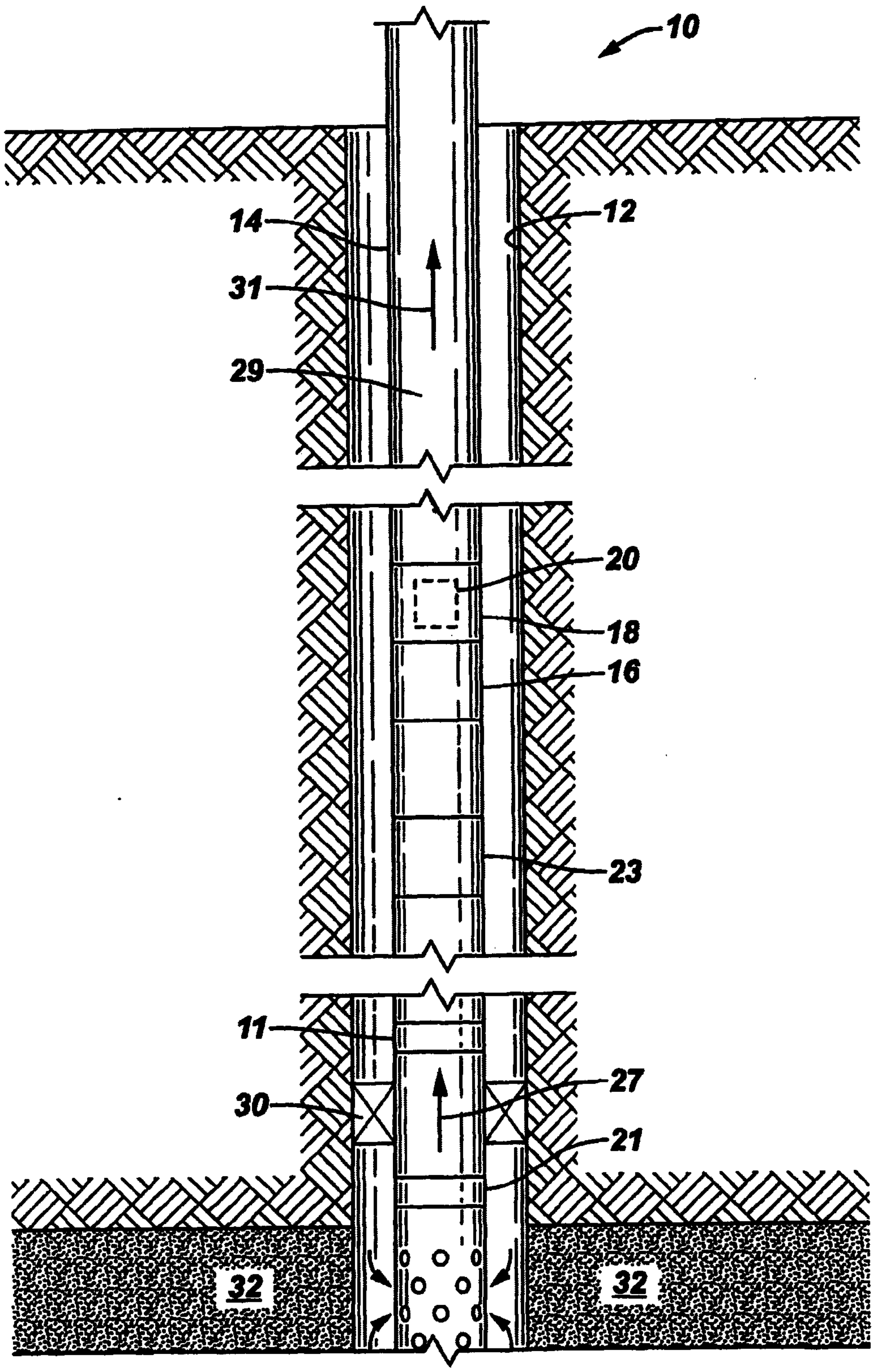


FIG. 2

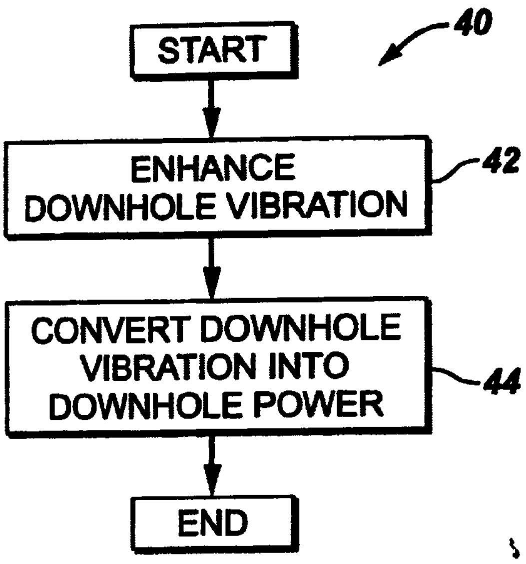


FIG. 3

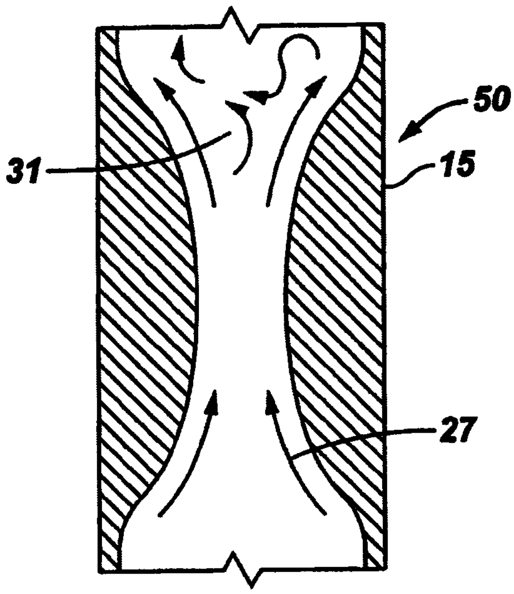


FIG. 4

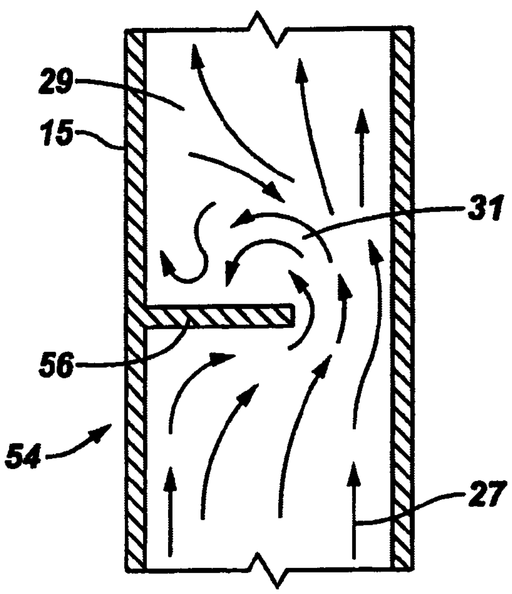


FIG. 5

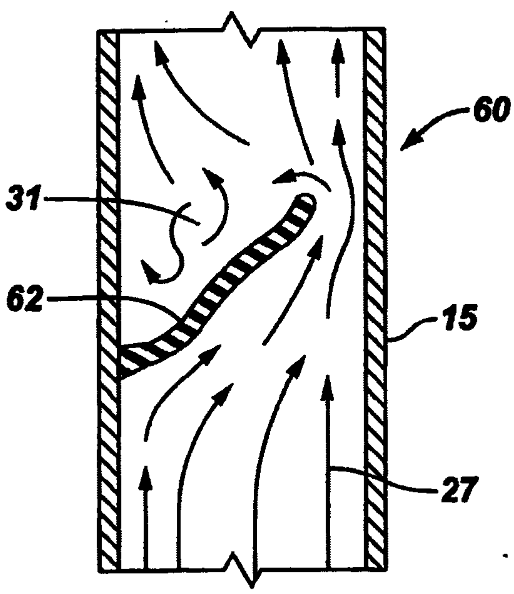
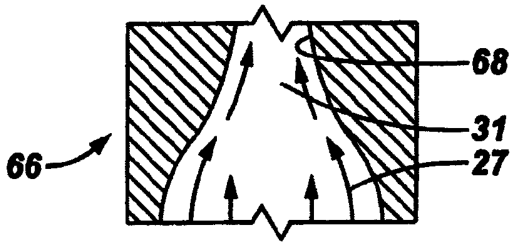


FIG. 7

FIG. 6



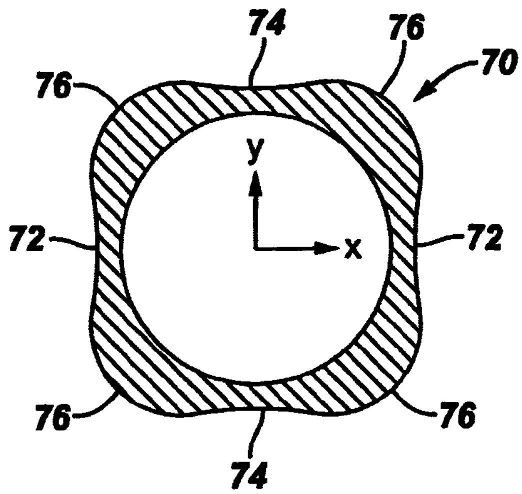


FIG. 8

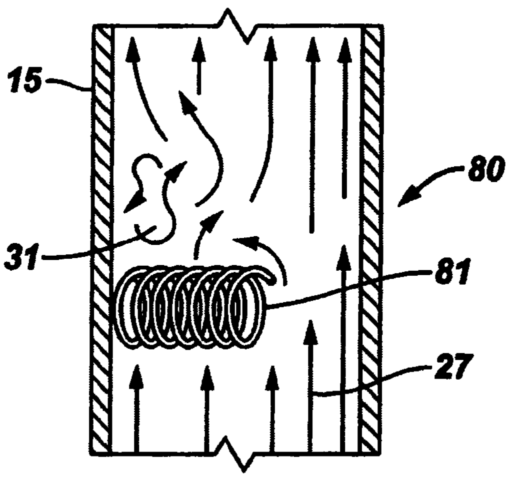


FIG. 9

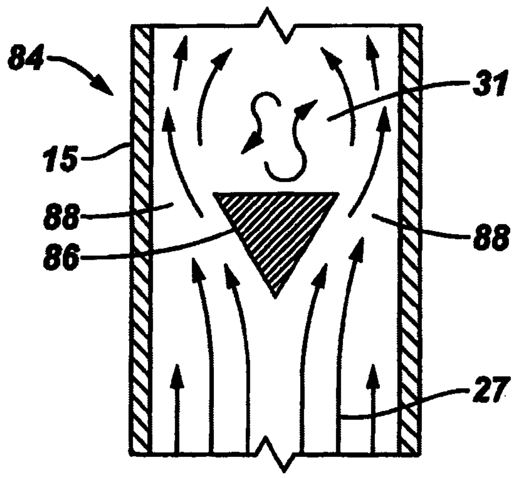


FIG. 10

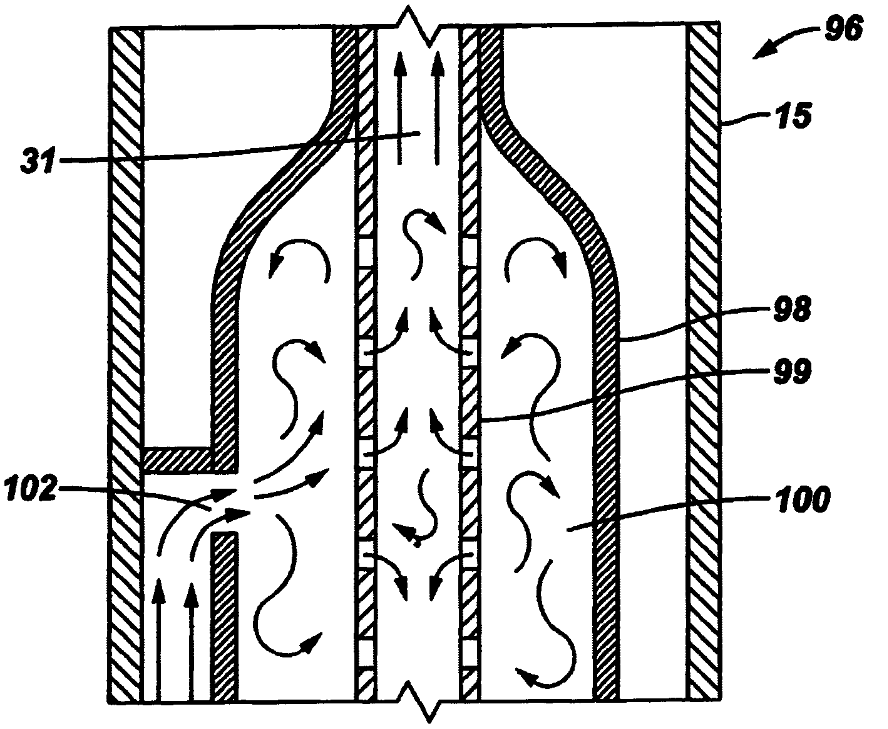


FIG. 11

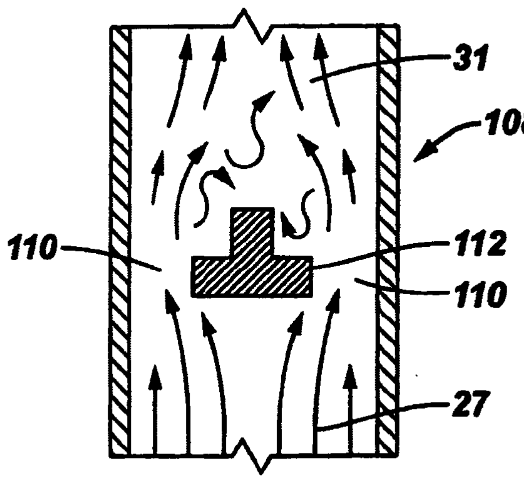


FIG. 12

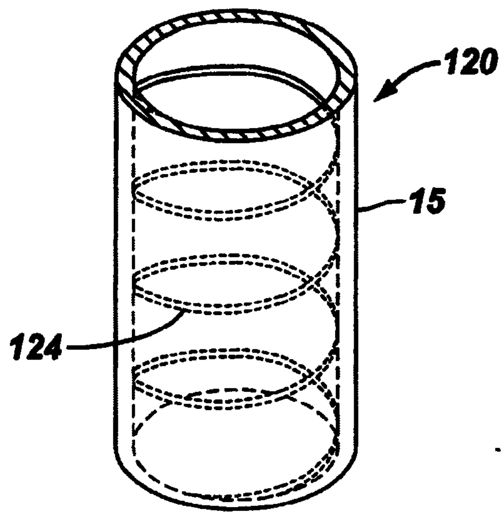


FIG. 13

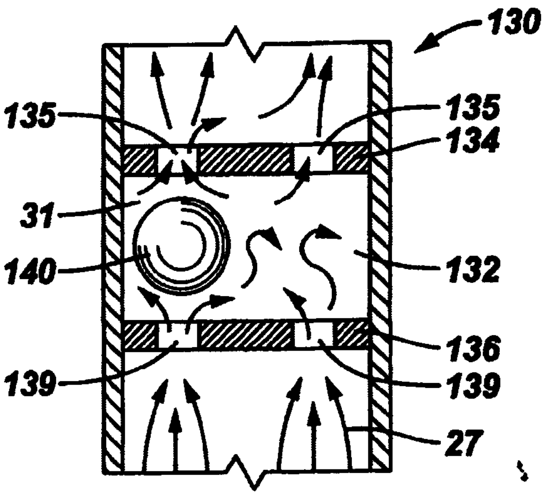


FIG. 14

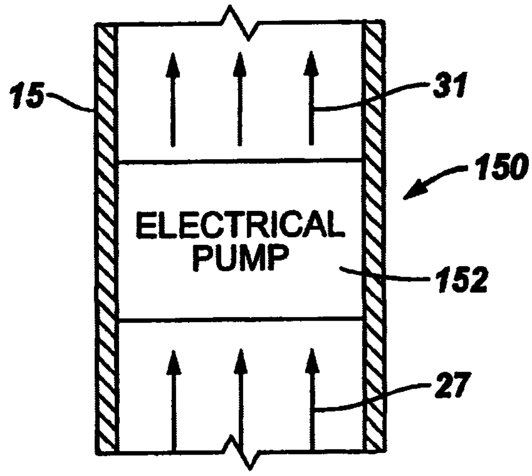


FIG. 15

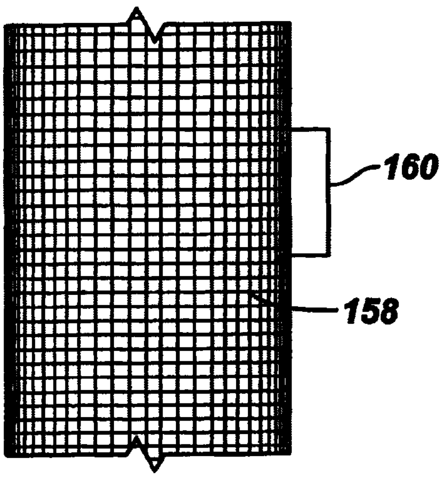


FIG. 16A

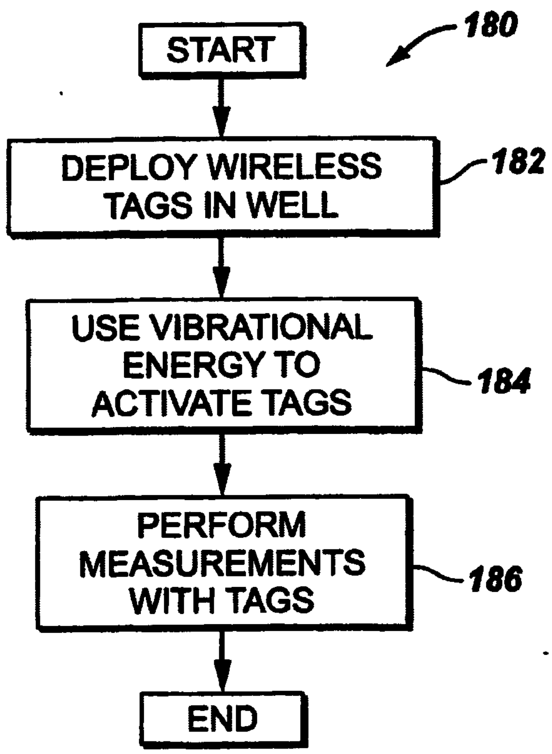


FIG. 16B

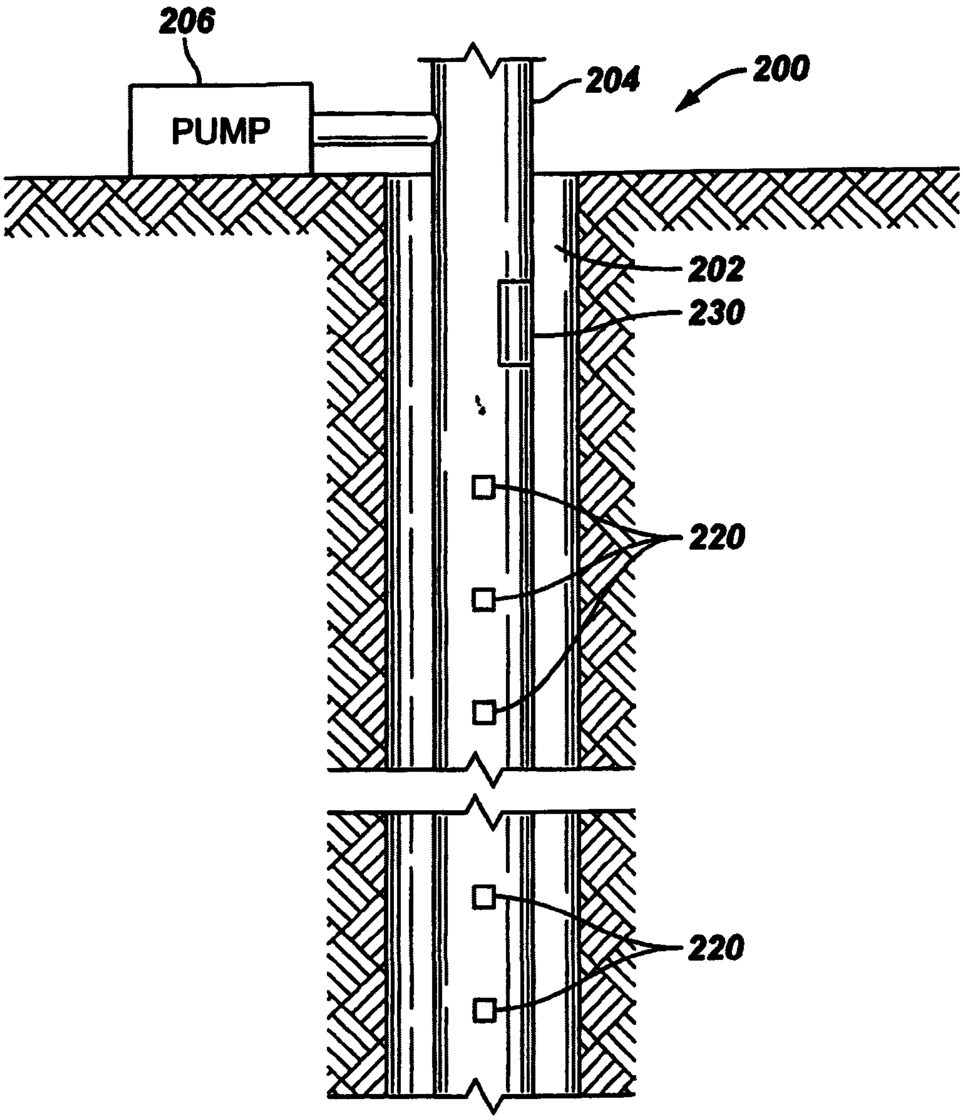


FIG. 17

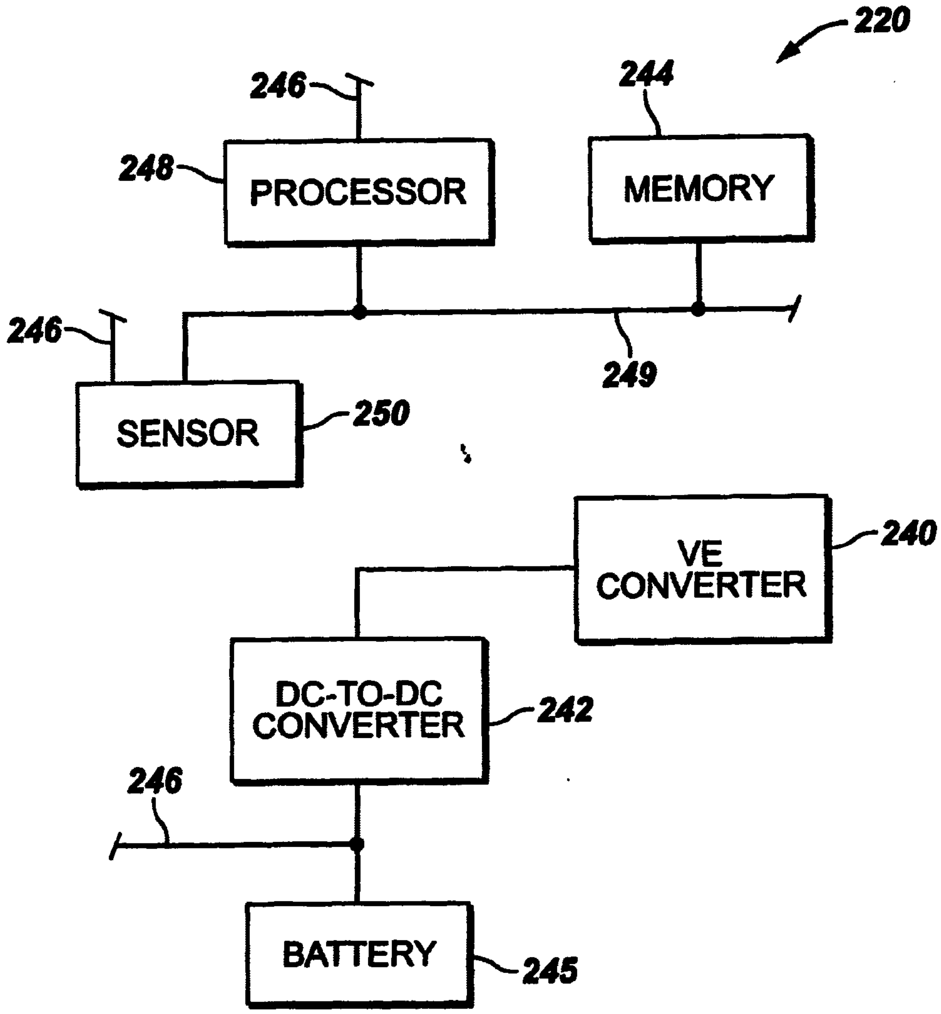

220
246
244
248
PROCESSOR
MEMORY
246
249
SENSOR
250
VE CONVERTER
240
DC-TO-DC CONVERTER
242
246
BATTERY
245

FIG. 18A

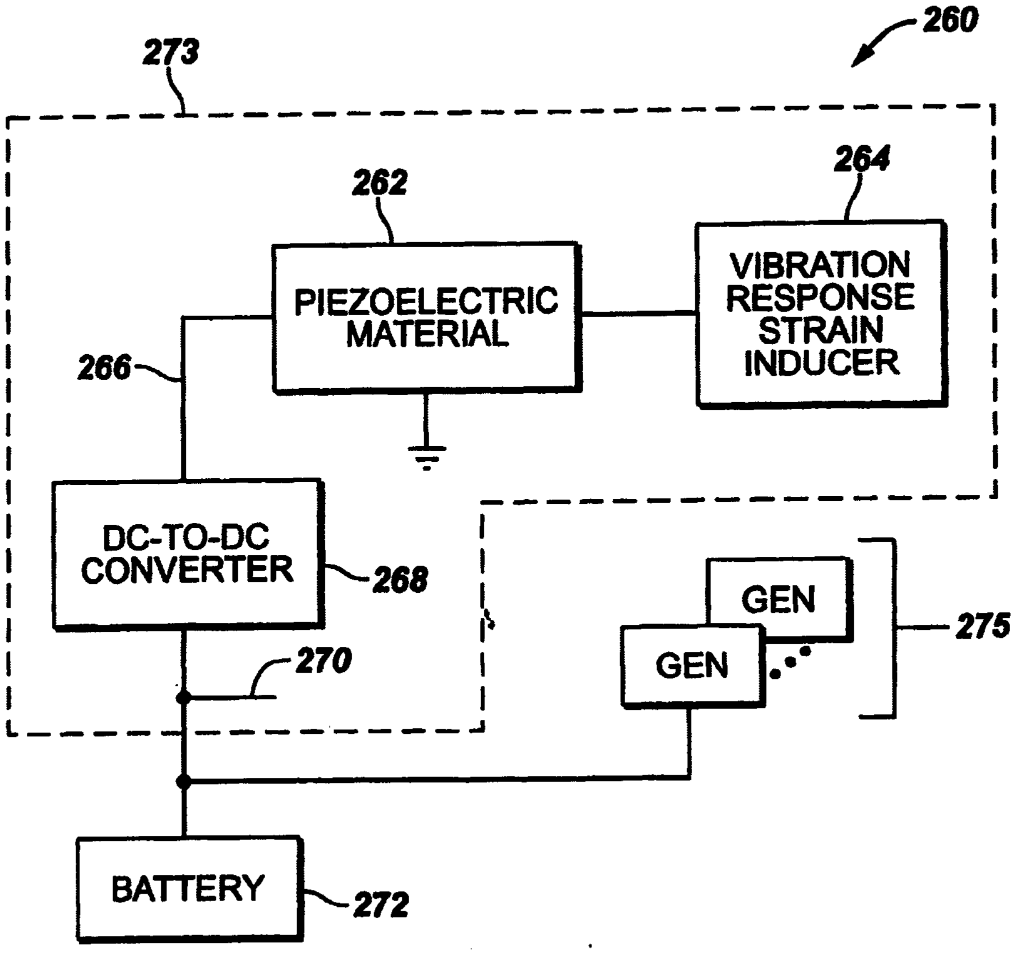


FIG. 18B

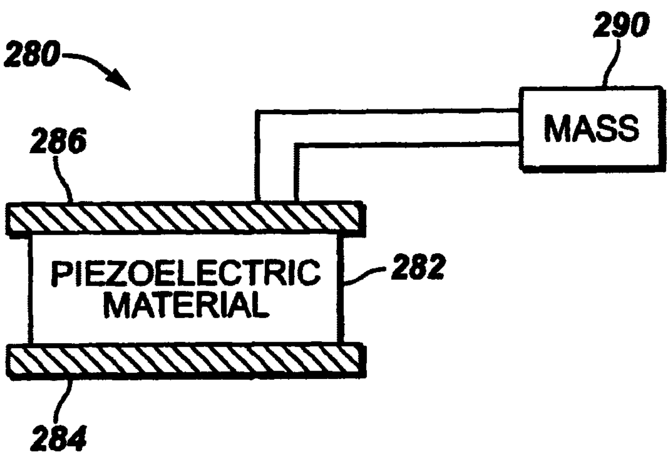


FIG. 19A

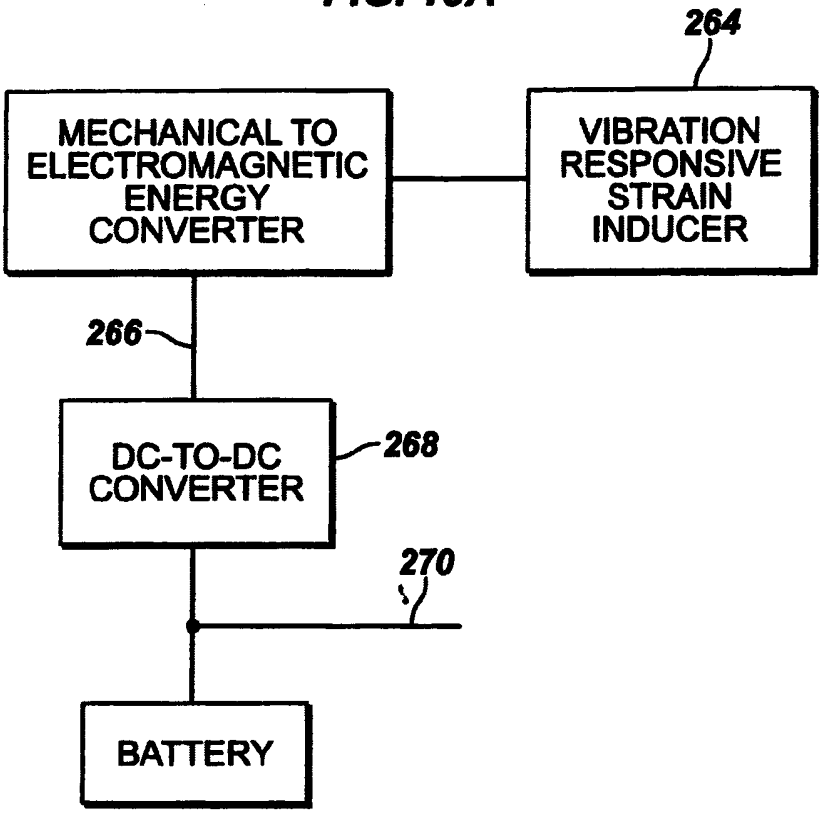
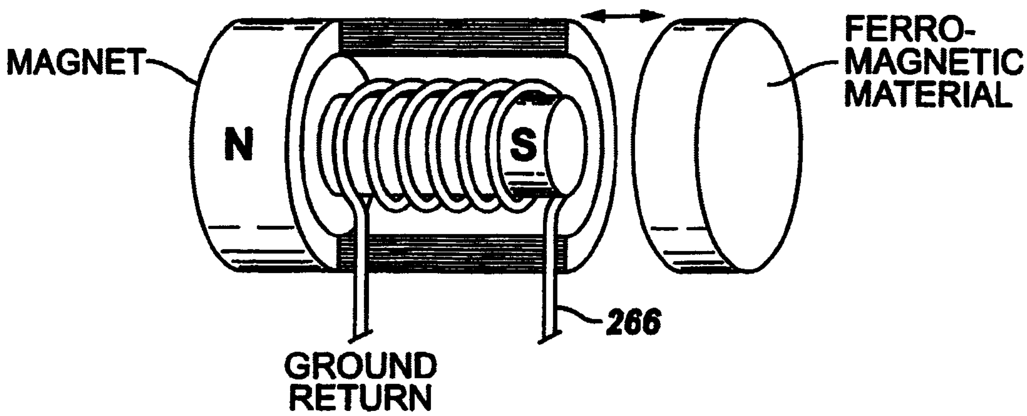


FIG. 19B



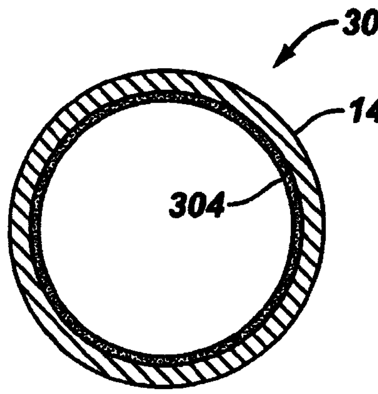


FIG. 20A

FIG. 20B

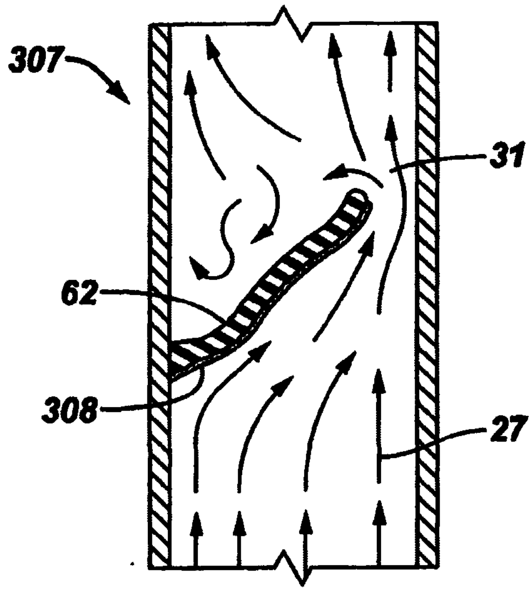


FIG. 20C

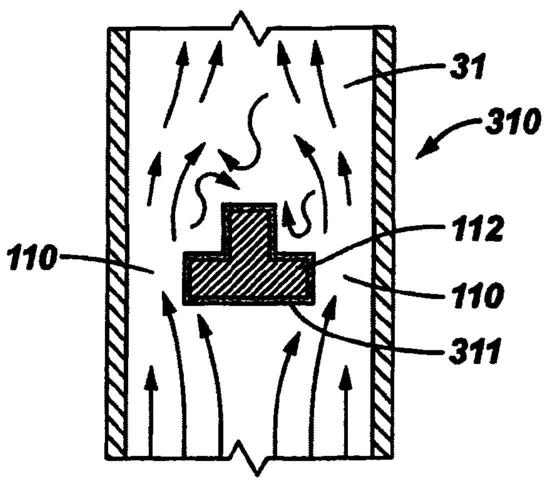


FIG. 21

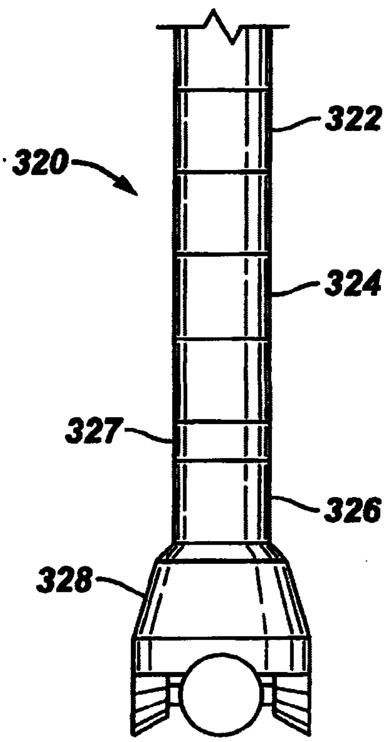


FIG. 22

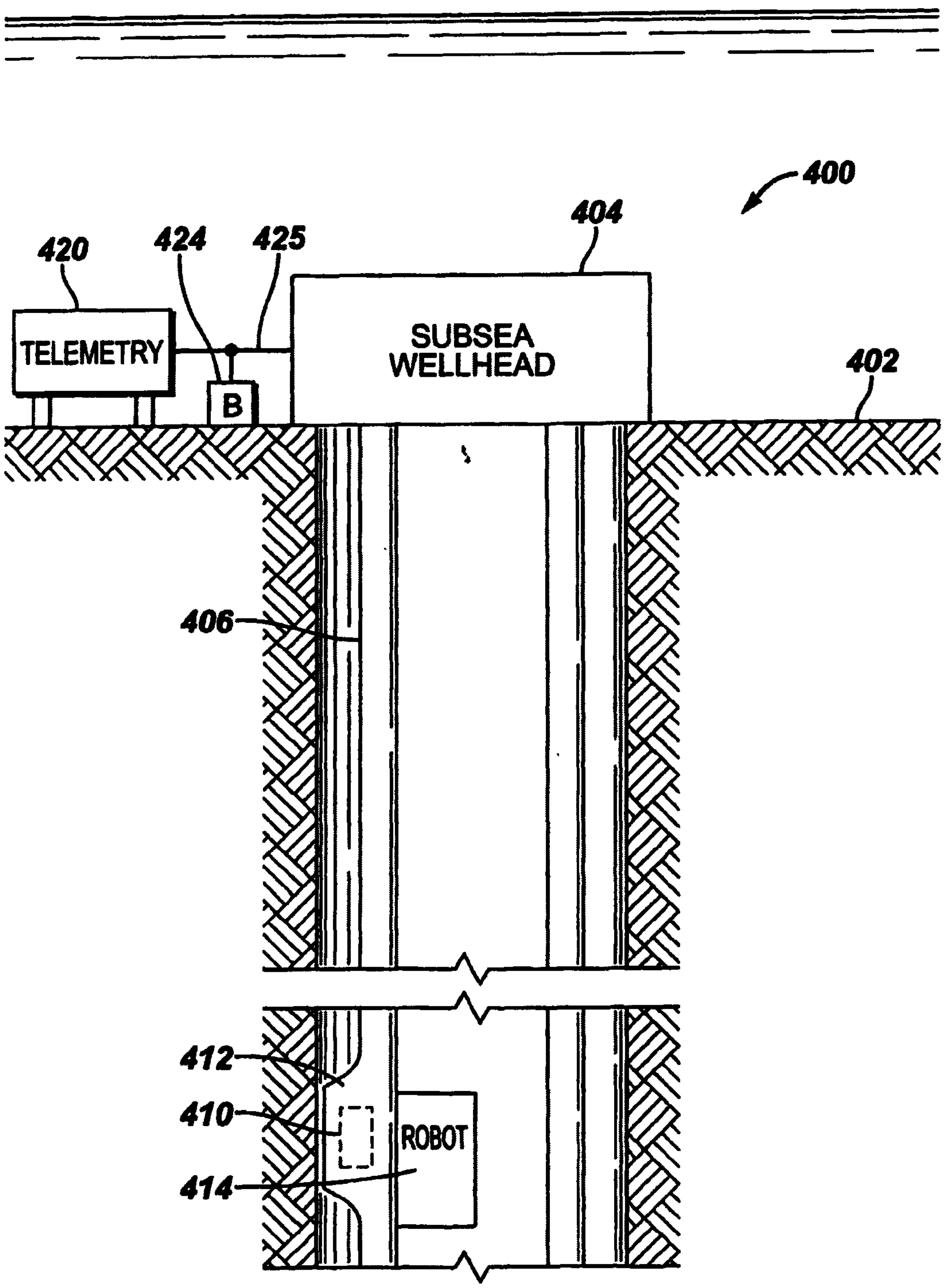

400
404
420
424
425
TELEMETRY
B
SUBSEA
WELLHEAD
402
406
412
410
ROBOT
414

FIG. 23

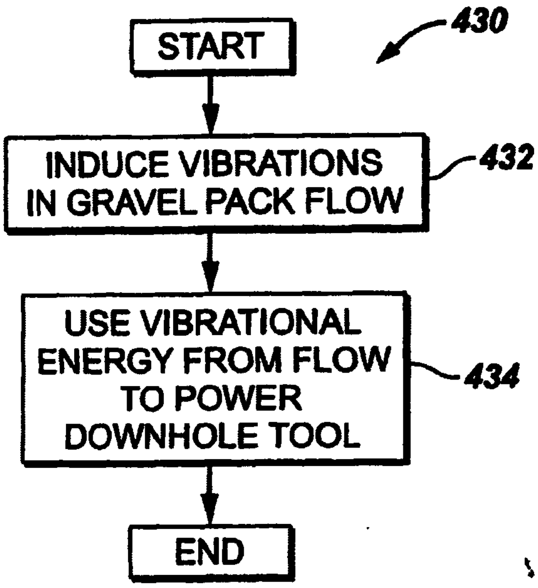


FIG. 24

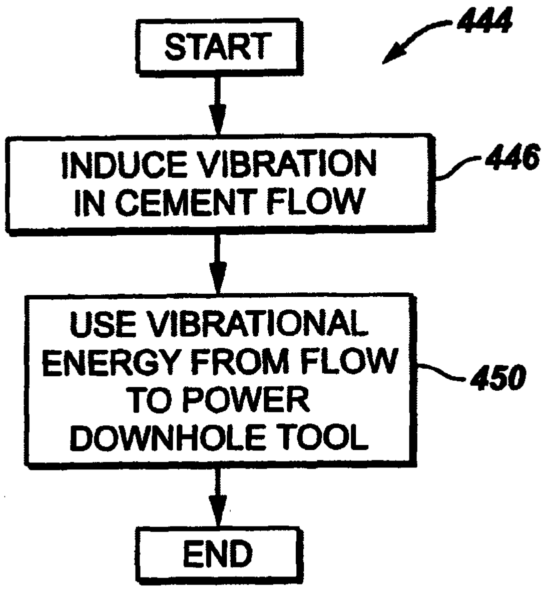


FIG. 25

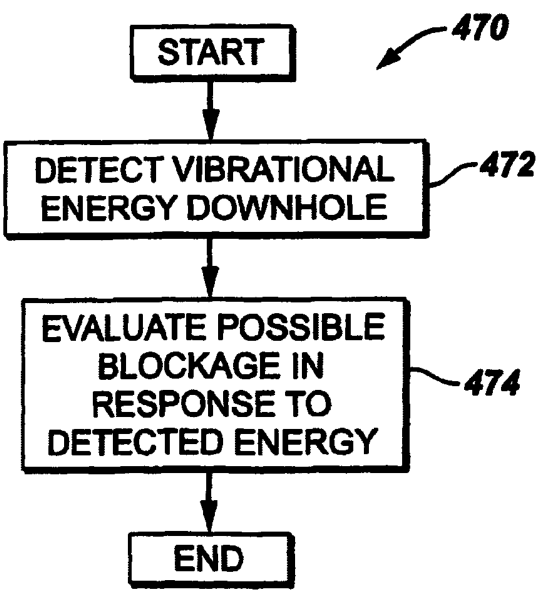


FIG. 26

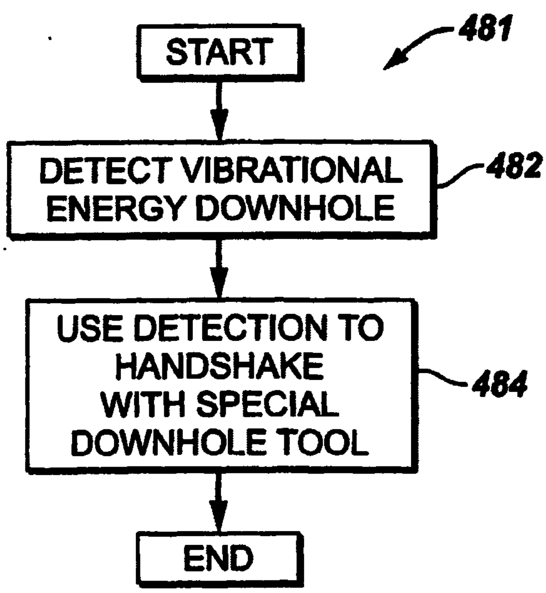


FIG. 27

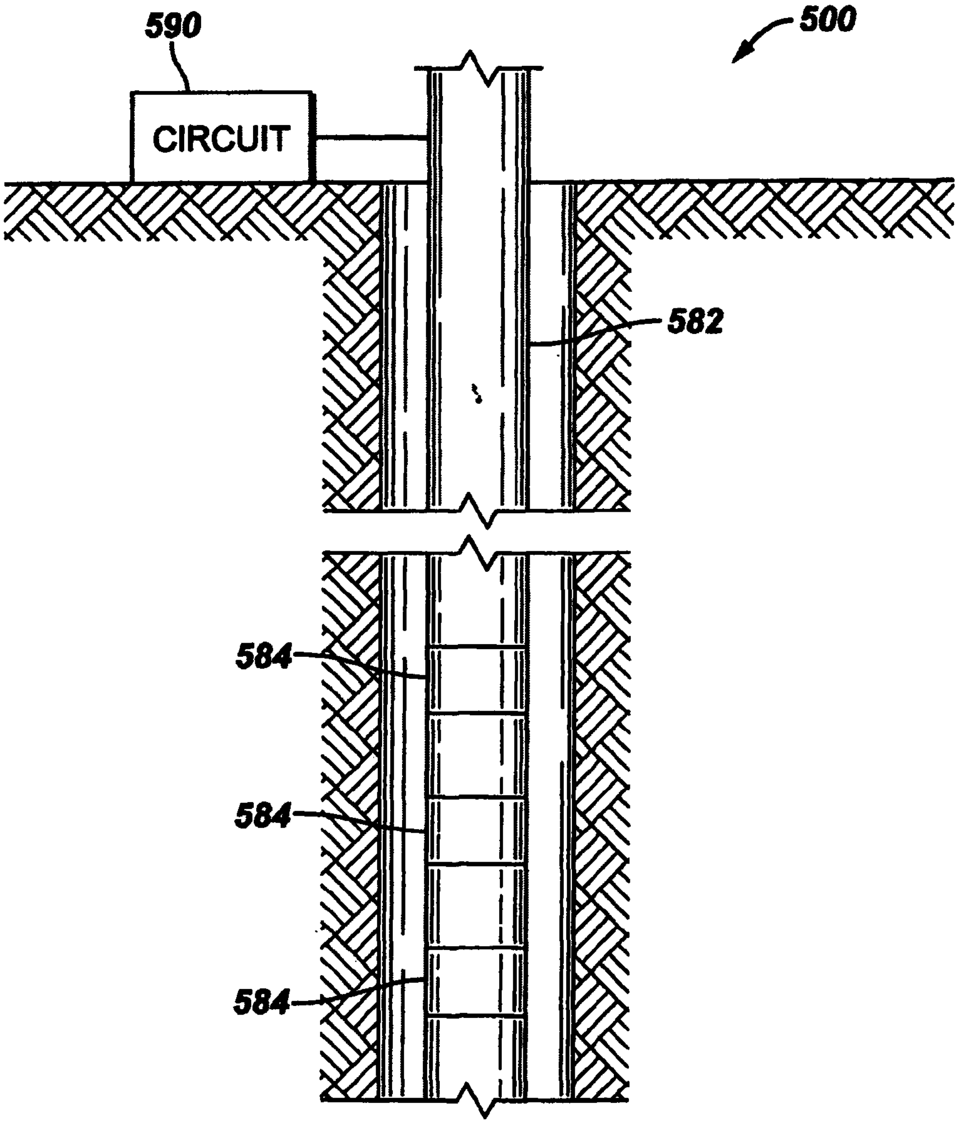


FIG. 28

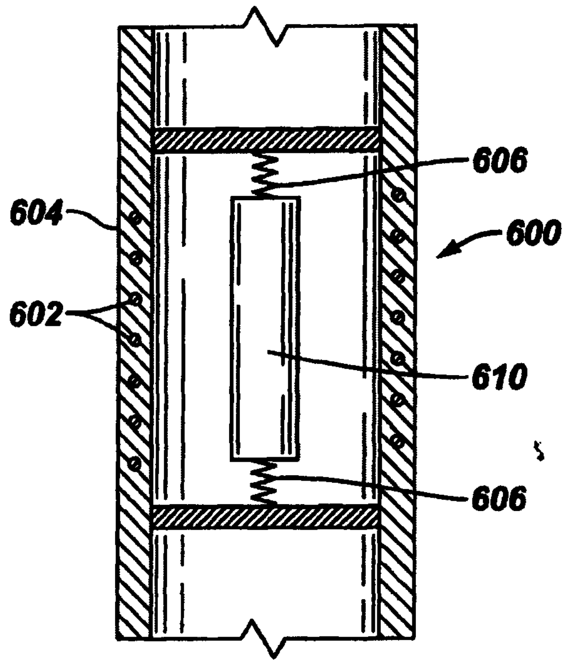


FIG. 29

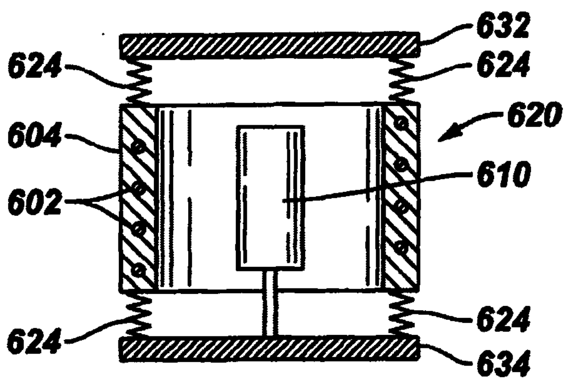
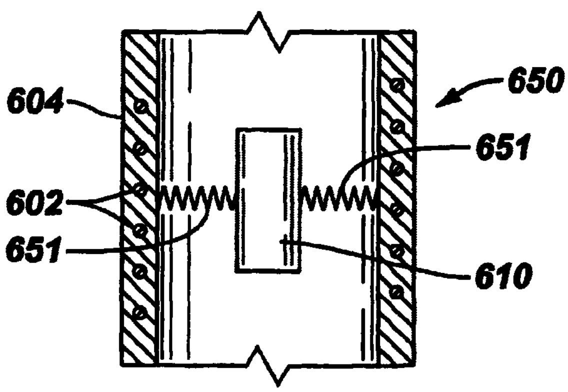


FIG. 30



HARVESTING VIBRATION FOR DOWNHOLE POWER GENERATION

BACKGROUND

The invention generally relates to harvesting vibration for downhole power generation.

A typical subterranean well includes various devices that are operated by mechanical motion, hydraulic power or electrical power. For devices that are operated by electrical or hydraulic power, control lines and/or electrical cables typically extend downhole for purposes of communicating power to these tools from a power source that is located at the surface. A potential challenge with this arrangement is that the space (inside the wellbore) that is available for routing various downhole cables and hydraulic control lines may be limited. Furthermore, the more hydraulic control lines and electrical cables that are routed downhole, the higher probability that some part of the power delivery infrastructure may fail. Other risks are inherent in maintaining the reliability of any line or cable within the well's hostile chemical, mechanical or thermal environment and over the long length that may be required between the surface power source and the downhole power operated device.

Thus, some subterranean wells have tools that are powered by downhole power sources. For example, a fuel cell is one such downhole power source that may be used to generate electricity downhole. The subterranean well may include other types of downhole power sources, such as batteries, for example.

A typical subterranean well undergoes a significant amount of vibration (vibration on the order of Gs, for example) during the production of well fluid. In the past, the energy produced by this vibration has not been captured. However, an emerging trend in subterranean wells is the inclusion of devices to capture this vibrational energy for purposes of converting the energy into a suitable form for downhole power.

Thus, there is a continuing need for better ways to generate power downhole in a subterranean well.

SUMMARY

According to a first aspect of the invention, there is provided a method usable with a well, the method comprising:

deploying wireless tags in the well to measure properties of the well as the tags flow through the well; and using vibrational energy transferred to the tags during the flowing through the well to activate the tags.

According to a second aspect of the invention, there is provided apparatus usable with a well, the apparatus comprising:

a processor to measure a property of the well as the apparatus flows through the well; and

a vibrational energy converter to generate power for the processor in response to vibrational energy transferred to the apparatus when the apparatus flows through the well.

Advantages and other features of the invention will become apparent from the following description, drawing and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of a well.

Fig. 2 is a flow diagram depicting a technique to generate downhole power.

Figs. 3 to 14 depict mechanisms to enhance the generation of downhole vibrational energy.

Fig. 15 depicts a system located on a sandscreen to aid in the generation of downhole power.

Fig. 16A is a flow diagram depicting a technique to power wireless tags.

Fig. 16B depicts a system to deploy wireless tags.

Fig. 17 is a schematic diagram of a wireless tag.

Fig. 18A is a block diagram of a system to harness and store vibrational energy downhole.

Fig. 18B depicts a piezoelectric material based vibration energy converter.

Fig. 19A is a block diagram of an electromagnetic based system to harness and store vibrational energy downhole.

Fig. 19B depicts an electromagnetic based vibration energy converter.

Figs. 20A, 20B and 20C are schematic diagrams of vibrational energy harvesting mechanisms.

Fig. 21 is a schematic diagram of a portion of a drilling string.

Fig. 22 is a schematic diagram of a subsea well.

Fig. 23 is a flow diagram depicting a technique to power a downhole tool.

Fig. 24 is a flow diagram depicting a technique to use vibration in a cementing operation.

Fig. 25 is a flow diagram depicting a technique to evaluate potential blockage of a downhole pipe.

Fig. 26 is a flow diagram depicting a technique to communicate with a downhole tool.

Fig. 27 is a schematic diagram depicting a system in which vibrational energy is used to communicate with downhole tools.

Figs. 28, 29 and 30 are schematic diagrams of mechanisms to harness vibrational energy to generate electrical power.

DETAILED DESCRIPTION

Referring to Fig. 1, a well 10 includes a tubular string 14 (a production string, for example) that extends into a wellbore of the well 10. The tubular string 14 may include a central passageway 29 that communicates a flow 27 from a subterranean formation zone 32 (or to a formation zone in the case of an injection well). The zone 32 represents one out of many possible zones of the well 10. The zone 32 may be defined (i.e., isolated from other zones) by one or more packers 30 (one being depicted in Fig. 1).

The flow 27 is a primary source of vibrational energy downhole, and this vibrational energy is captured by a vibrational energy harvesting mechanism 20 (of a power generation tool 18) for purposes of converting the vibrational energy into downhole electrical power. This electrical power, in turn, may be used to power one or more downhole power-consuming components, such as sleeve valves, ball valves, motors, actuators, sensors, sound sources, electromagnetic signaling sources, or equipment to fire "smart bullets" into a well casing, perforating gun firing heads, controllers, microprocessors, Micro Electrical Mechanical Sensors (MEMS), telemetry systems (transmitters or receivers), etc., depending on the particular embodiment of the invention.

In some embodiments of the invention, the string 14 includes one or more features to enhance the generation of vibrational energy, referred to generally herein as a "vibration enhancement mechanism 16." More specifically, the flow 27 enters the mechanism 16 that, in some embodiments of the invention, produces a locally more turbulent flow 31 that flows uphole. The creation of this more turbulent flow, in turn, amplifies the vibrational energy, thereby leading to the increased production of downhole power. The vibrational harvesting mechanism 20 may be located in proximity to (within ten feet, for example) to the vibration enhancing mechanism 16, in some embodiments of the invention. Various embodiments of the vibration enhancing mechanism are described below.

Thus, referring to Fig. 2, a technique 40 is used to harvest vibrational energy downhole. More specifically, in accordance with the technique 40, the downhole vibration is enhanced (block 42) by the vibration enhancement mechanism 16, as further described below. Next, pursuant to the technique 40, the downhole vibration is converted (block 44) into downhole power to power one or more downhole power-consuming devices.

As a more specific example, Fig. 3 depicts a cross-section of a vibration enhancing mechanism 50 in accordance with an embodiment of the invention. The device 50 may be formed from a section of the string 14 having an interior wall 15 that constricts the central passageway 29 of the string 14. More specifically, in some embodiments of the invention, the section has a circular cross-section of varying diameter; and in some embodiments of the invention, the section forms a Venturi-type flow path. This flow path, in turn, converts the entering flow 27 into a more turbulent flow 31 for purposes of creating more vibration. The flow path of the device 50 thus creates vibrational energy that is harvested by the power generator tool 18.

Other types of vibration enhancing mechanisms may be used in other embodiments of the invention. For example, referring to a cross-section depicted in Fig. 4, in some embodiments of the invention, a cantilevered member 56 may extend from the interior wall 15 of the string 14 into the central passageway 29. The member 56 introduces an obstruction in the flow path 27 to create the more turbulent flow 31.

As another example, Fig. 5 depicts a cross-sectional view of a vibration-enhancing mechanism 60 that contains a flexible member 62 that has one end that is attached to the interior wall 15 of the tubular string 14 and another free end that extends into the central passageway 29. Due to this arrangement, the flexible member 62 moves in response to the flow 27 to create the more turbulent flow 31 and thus, enhance the generation of vibrational energy.

As another example, Fig. 6 depicts a cross-sectional view of a vibration-enhancing mechanism 66 that, similar to the Venturi-type flowpath of the mechanism 50 (Fig. 3), includes a restricted flow path 68 for purposes of increasing vibration downhole. In some embodiments of the invention, the flow path 68 has a circular cross-section section that varies in diameter.

It has been discovered that a production string (a possible embodiment of the tubing string 14 (Fig. 1)) has a fundamental vibration mode in which the cross-section of the production string expands and contracts in two orthogonal cross-sectional directions. For example, as depicted in a cross-section of a production tubing section in Fig. 7, during the flow of fluid through a production tubing string, the string may include a cross-section that expands in the positive and negative Y directions while the cross-section of the production tubing contracts in the positive and negative X directions. Next, pursuant to the fundamental vibration mode, the cross-section of the production tubing expands in the positive and negative X directions and contracts in the positive and negative Y directions. This process repeats to establish the fundamental vibration mode.

As depicted in Fig. 7, the thickness of the wall of the production string 70 is radially varied to select the axis and otherwise enhance the fundamental vibration mode. More specifically, the cross-section of the string may include thinner portions 72 that extend along the X-axis and thinner portions 74 that extend along the Y-axis. The remaining portions 76 of the cross-section are thicker. Thus, due to this arrangement, the flexing of the production string 70 in the above-described cross-sectional directions is enhanced due to the thinning of the production tubing string cross-section in orthogonal directions. Increasing the flexing of the production tubing string, in turn, enhances the vibrational energy that is generated by the flow of fluids through the production tubing string. Thus, the arrangement that is depicted in Fig. 7 enhances the vibrational energy that is converted into electrical energy downhole.

As another example of a mechanism to enhance vibrational energy downhole, Fig. 8 depicts a mechanism 80 that includes a spring 81 that may be attached to, for example, the interior wall 15 of the string 14 and extend into the central passageway 29. In yet another embodiment of the invention, a vibration enhancing mechanism 84 (a cross-section of which is depicted in Fig. 9) includes a wedge-shaped flow diverter 86 that is inserted into the flow path 27 for purposes of creating a more turbulent flow. As depicted in Fig. 9, regions 88 exist between the diverter 86 and the wall of the string 14 for purposes of allowing fluid to pass therethrough. However, the flow diverter 86 introduces additional turbulence into the flow 27, thereby creating additional vibration downhole.

In some embodiments of the invention, a piece of downhole equipment that may already be located downhole may be strategically placed near the power generation tool 20 (Fig. 1) for purposes of enhancing vibration near the tool 20. For example, referring to Fig. 10, a multiphase mixer 86 may be placed in close proximity (within ten feet for example) to the power generation tool 20. The multiphase mixer 86, as its name implies, typically is used in production to blend various phases of well fluid together. The mixer 86 may include, for example, an opening 102 that receives the flow 27. The mixer 86 may also include an internal chamber 99 that includes various orifices 100 through which the flow may proceed to flow upstream and produce the flow 31 through the central passageway 29.

In other embodiments of the invention, a vibrational energy-enhancing mechanism 108 (a cross-section of which is depicted in Fig. 11) may be used. The mechanism 108 includes a blind T 112 that is inserted into the flow path 27. The blind T 112 is surrounded by openings 110 that permit the flow of the fluid around the blind T 112. However, the inclusion of the blind T 112 in the flow path 27 creates turbulence that, in turn, enhances the vibrational energy downhole.

Referring to Fig. 12, in some embodiments of the invention, a vibration-enhancing section 120 of the string 15 may include a spiral or helical groove 124 that extends along the inner surface of the wall 15 of the string 14. As depicted in Fig. 12, the longitudinal axis of the groove 124 is concentric with the longitudinal axis of the string 14.

In some embodiments of the invention, a free flowing part may be used to enhance the generation of vibrational energy downhole. For example, a vibration enhancing mechanism 130 (a cross-section of which is depicted in Fig. 13) may include a chamber 132 (in the flow path 27) that contains a ball 140. Analogous to a policeman's or an umpire's whistle, the ball 140 is trapped inside the chamber 132, in that lower 139 and upper 135 openings in the chamber 132 are sized to permit fluid (but not the ball 140) to pass into and out of the chamber 132 and contact the ball 140. The interaction of the fluid with the ball 140 creates vibrational energy that may be harvested for electrical power.

In some embodiments of the invention, an electrical device that consumes harvested power downhole may also be used to enhance vibrational energy used for purposes of power generation. For example, as depicted in Fig. 14, in some embodiments of the invention, a vibration-enhanced mechanism 150 may include an electrical pump 152 (a beam-type pump, a rod-type pump or an electrical submersible pump (ESP)), as just a few examples. The electrical pump 152 receives the flow 27 to produce the output flow 31. The operation of and fluid flow through the pump 152 enhances the vibrational energy.

Although the vibration-enhancing mechanisms and power generating mechanisms (such as the power generator tool 18) that are described above are generally located in the central passageway of the string 14, it is noted that these mechanisms may be located in other regions of the well. For example, these mechanisms may be located on the outside of the string 14 or located in a side packet mandrel, as further described below in connection with Fig. 22.

As a more specific example, referring to Fig 15, a vibration-enhancing mechanism 160 may be located on the outside of a sandscreen 158. Thus, the mechanism 160, which may be any of the above-described mechanisms, may be located in a flow path located between the exterior and the interior of the sandscreen 158. The mechanism 160 may be located inside the sandscreen 158. Furthermore, a power generator (not shown) to generate electrical power from vibrational energy may be mounted to the sandscreen 158 and may be located either on the outside or inside of the sandscreen 158.

Although in the embodiments described above, the power generation mechanism 20 is depicted (Fig. 1) as being attached to the string 14, the power generation mechanism 20 may not be fixed in position relative to the string 14. For example, a wireless (a radio frequency (RF), for example) tag may be used to measure various properties in a subterranean well. These properties may include, for example, detection of water or chemical constituents, such as hazardous H2S, or measurement of pressure and temperatures at various positions in the well. The tag may be free-flowing, in that the tag may be released into the well and take a measurement at a particular depth in the well. Many variations are possible. For example, the tag may be activated at a particular depth, a particular temperature, a particular pressure, etc.

For purposes of supplying power to the tag, the tag may derive its power from the vibrational forces that are experienced by the tag itself. Thus, instead of being attached to a static structure, such as the string 14, for example, the tag is free-flowing and is imparted with vibrational energy as the tag flows in the well. This vibrational energy, is converted by a vibrational energy transformer of the tag into electrical power for the tag.

Thus, referring to Fig. 16A, a technique 180 includes deploying (block 182) wireless tags in a subterranean well. Vibrational energy is used (block 184) to activate (i.e., power up and continue providing power to) the tags. Once activated, measurements are then performed (block 186) with the tags.

Fig. 16B depicts a subterranean well 200 in accordance with the technique 180. As shown in Fig. 16B, the well 200 may include a tubular string 204 (a production tubing, for example) into which several tags 220 have been placed into the central passageway of the well 200. As an example, the well 200 may include a surface pump 206 that may control the flow of fluid through the well 200. For example, the pump 206 may halt fluid flow through the string 204 to allow the tags 220 to descend into the well 200. When the tags have collected the data, the pump 206 may then be re-activated to cause fluid to flow uphole and thus return the tags 220 toward the surface.

The well 200 may include a tag reader 230 to extract information from the tags 220 as the tags 220 return from downhole. As the tags 220 descend downhole, vibrational energy imparted on the tags 220 generate power on the tag 220 to activate the tag 220 so that the tag 220 may then take the appropriate measurement downhole.

Referring to Fig. 17, the tag 220 may have an architecture that is generally depicted in Fig. 17. This architecture may include, for example, a processor 248 that is coupled to a sensor 250 (a pressure or temperature sensor, for example) through a bus 249. The processor 248 may execute instructions that are stored in a memory 244 (also coupled to the bus 249) as well as store data from the sensor 250 in the memory 244. The architecture may include various other features, such as a transmitter to transmit to the reader 230 (Fig. 16B), depending on the particular embodiment of the invention.

As depicted in Fig. 17, the tag 220 includes power generation circuitry that includes, for example, a vibrational energy converter 240. As its name implies, the converter 240 produces a voltage (for example) in response to vibrational energy that occurs to the tag 220. A DC-to-DC converter 242 converts this voltage into a regulated voltage that appears on voltage supply lines 246. The voltage supply lines 246, in turn, furnish power to the various components of the tag 220, such as the sensor 250, processor 248 and memory 244, as just a few examples.

The tag 220 may include a reserve energy source, such as a battery 245, that is coupled to the output terminals of the DC-to-DC converter 242. The battery 244 serves as an energy buffer to store excess energy that is provided by the converter 240 so that this energy may be used to regulate the power that is provided to the power-consuming components of the tag 220.

In some embodiments of the invention, the power harvesting circuitry affixed to the string 14 may have an architecture 260 that is generally depicted in Fig 18A. This architecture 260 includes a vibration responsive strain inducer 264. As examples, the vibration responsive strain inducer 264 produces a mechanical force that, as its name implies, imparts a physical strain on a piezoelectric material 262. A piezoelectric material, by its very nature, produces a terminal voltage responsive to the strain that is induced on the material. Therefore, in response to the strain produced by the inducer 264, the piezoelectric material 262 produces a voltage that appears on a signal line 266. This voltage, in turn, is regulated to a specific DC level by a DC-to-DC converter 268 to produce a regulated voltage that appears on a power supply 270.

Thus, the inducer 264, piezoelectric material 262 and converter 268 form a basic power-harvesting generator 273 in accordance with an embodiment of the invention.

Although depicted in Fig. 18A as producing DC power, it is noted that in other embodiments of the invention, the generator 273 may include an inverter for purposes of generating an AC voltage. Thus, other embodiments are within the scope of the following claims.

Additionally, in some embodiments of the invention, a particular well may include several generators 275 that are connected in parallel to the supply 270. Furthermore, in some embodiments of the invention, a battery 272 may be coupled to the voltage supply line 272 for purposes of serving as an energy buffer to absorb and supply power, depending on the particular vibrational energy being experienced at the time.

In accordance with an embodiment of the invention, the vibration responsive strain inducer 264 and piezoelectric material 262 may have a form 280 that is depicted in Fig. 18B. More specifically, the arrangement 280 may include a piezoelectric material 282 that is located between fairly rigid members 286 and 284. These members may be formed from, as examples, part of housing of the string 14 as well as explicit plates. A cantilevered mass 290 is connected to the plates 284 and 286 to exert a strain force on the piezoelectric material 282 in response to the vibrational energy sensed by the mass 290. Thus, vibrational energy causes movement of the mass 290, and this movement, in turn, induces stress to cause the piezoelectric material to generate a corresponding voltage.

Referring both to Figs. 19A and 19B, in some embodiments of the invention, the power harvesting circuitry affixed to the string 14 may have an architecture 260 that is generally depicted in Fig 19A. This architecture 260 includes a vibration responsive strain inducer 264. As examples, the vibration responsive strain inducer 264 produces a mechanical force that, as its name implies, imparts a physical strain on an electromechanical energy conversion, or generator, that is depicted, as an example, in Fig. 19B. An electromagnetic energy converter, by its very nature, produces a terminal voltage induced by an electrical conductor, or coil, moving in a magnetic field that is maintained by a suitable ferro-magnetic material, permanent magnet. Therefore, in response to the strain or motion produced by the inducer 264, the electromagnetic converter produces a voltage that appears on a signal line 266. This voltage, in turn, is regulated to a specific DC level by a DC-to-DC converter 268 to produce a regulated voltage that appears on a power supply 270.

In the various embodiments of the invention, the mass that induces the strain on the piezoelectric material may not be a cantilevered mass but alternatively, may be another type of strain inducer that generates a strain on the piezoelectric material in response to vibrational energy. For example, in some embodiments of the invention, the wall of the tubular string 14 (see Fig. 1) may be lined with a piezoelectric coating 304, as depicted in Fig. 20A. More specifically, the piezoelectric material lining 304 may completely or partially coat the interior wall of the tubular string 14, according to the particular embodiment of the invention. Due to the above-described fundamental mode of vibration of the tubular string 14, this vibration induces a strain on the piezoelectric material coating 304 to generate a corresponding voltage across the material 304.

Although not depicted in Fig. 20A, in some embodiments of the invention, a thin insulation layer may be interposed between the lining 304 and the interior surface of the tubing string wall for purposes of isolating the terminal voltage appearing on the coating 304 from the tubing string 14.

As another example of a strain-inducing mechanism, Fig. 20B depicts a mechanism 304 that includes a flexible flow member 62 (see Fig. 5) that has a piezoelectric electric coating 308 lining the flexible member 62. Thus, the motion of the flexible member 62 induces a strain on the material 308 to generate a voltage on the material 308.

Thus, as can be seen, the piezoelectric coating may be applied to various downhole components that are subject to vibration, in that the vibration induces a strain on the piezoelectric coating, and this strain induces a voltage that may be converted into downhole power. As yet another example, Fig. 20C depicts the blind T 112 (see Fig. 11) that is at least partially covered by a piezoelectric coating 311.

Due to the generation of electrical power downhole, various control lines and electrical cables do not need to be extended from the surface of the well. Furthermore, generating electrical power downhole may be advantageous for purposes of reducing cabling between downhole components. For example, Fig. 21 depicts a drill string 320 that includes a mud motor 324 and a drill bit 328. The drill string 320 may include sensors 326 that are used for purposes of monitoring operation of the drill string 320 and monitoring general operation of the drilling. The sensors 326 typically are located close to the drill bit 328. A particular challenge with this arrangement is that the sensors 326 may be located away from a power source and thus, electrical cables may have to span across the mud motor 324 for purposes of delivering power to the sensors 326. However, in accordance with embodiments of the invention, the sensors 326 may be in close proximity to power generation circuitry 324 that generates electrical power from the vibration of the drill string 320, such as the vibration that occurs during operation of the mud motor 324. Due to this arrangement, cabling does not have to be extended across the mud motor 324 for purposes of delivering power to the sensors 326.

Referring back to Fig. 1, as another example of the reduction of cabling due to the generation of power downhole, the well 10 may include an intelligent completion, a completion that contains circuitry that automatically controls downhole equipment independently from any commands that are communicated from the surface of the well. For example, the string 14 may be a production string and include a valve 21 (a sleeve valve or ball valve, as examples) that is electrically operated by power that is produced by the power generator tool 18. An intelligent controller 23 of the string 14 may, for example, use a sensor 11 (also of the string 14) to detect one or more characteristic(s) of the flow 27. The sensor 11 may include one or more of a pressure sensor, a temperature sensor, a fluid composition sensor and a Micro Electrical Mechanical Sensor (MEMS.

Based on the detected characteristic(s), the controller 23 operates a valve 21 (a sleeve valve or ball valve, as examples) to control the flow 27. For example, the controller 23 may determine the flow 27 has a high water content level and close the valve 21 to shut off flow from the zone 32. As another example, the controller 23 may also control the valve 21 to regulate a pressure in the well. The controller 23, sensor 11 and valve 21, in some embodiments of the invention, receive power from the power generator tool 18. In some embodiment of the invention, the controller 23, sensor 11 and valve 21 receive all of their operating power from the power generating tool 18.

As another example of a power consuming device that may rely on energy derived from vibrational energy downhole, Fig. 22 depicts a subsea well 400 that extends beneath a sea floor 402. The subsea well 400 includes a subsea well tree and wellhead 404; and a tubular string 406 that extends into a wellbore of the well. A robot 414 may be located inside the tubular string 406. The robot 414 may generally be autonomous in that the robot 414 does not rely on a tethered connection for purposes of operating in the subsea well to perform an intervention, for example. Thus, for purposes of generating power, robot 414 may dock to power connectors that are electrically coupled to a power generation mechanism 410 that generates downhole electrical power from vibrational energy.

As an example, the power generation mechanism 410 may be located in a side pocket mandrel 412 that is formed in the tubing 406. As shown in Fig. 2, due to the inclusion of the power generating mechanism 410 and the side pocket mandrel 412, the central passageway of the tubing string 406 is unobstructed for purposes of operating the robot 410, performing an intervention with other tools, producing well fluid, etc.

The subsea well 400 may include other components that are powered by the power generating mechanism 410, such as, for example, telemetry circuitry 420 that is located on the sea floor 402 and is used to communicate (via acoustic, optical or electromagnetic communication, as examples) with a surface platform (not shown in Fig. 22). The power generating mechanism 410 may also deliver power (via communication lines 425) to electrical storage 424 (a battery, for example) that is located on the sea floor 402.

The above-described arrangements rely on the vibrational forces that are produced either by downhole equipment or by the flow of well fluid in contact with a particular vibration-enhancing mechanism. However, in some embodiments of the invention, vibrations may be intentionally introduced into a fluid or slurry that is introduced downhole from the surface.

For example, Fig. 23 depicts a technique 430 which uses vibrations in a gravel pack flow for purposes of communicating vibrational energy downhole that may be used to produce downhole power. More specifically, in accordance with the technique 430, vibrations are induced in a gravel packed flow, as depicted in block 432. For example, these vibrations may be induced by pressure pulses that are applied to a slurry flow as well as less regulated vibrational energy that is applied to the flow. Regardless of the specific form of the vibrational energy, the vibrational energy is applied at the surface of the well and is communicated downhole via the flow. Pursuant to the technique 430, this vibrational energy is used (block 434) to generate downhole power, such as for a downhole tool to be used during or after the completion of gravel packing (for example).

Referring to Fig. 24, other types of downhole flows may be used for purposes of communicating vibrational energy downhole. For example, Fig. 24 depicts a technique 444 for purposes of communicating vibrational energy via a cement flow. Pursuant to the technique 444, a vibration is introduced in the cement flow, as depicted in block 446. Similar to the gravel packed flow discussed in connection with Fig. 23, vibrational energy may be imparted to the cement flow by, for example, pulses or other types of vibrational energy. This vibrational energy is then used to generate power downhole (as depicted in block 450) for one or more downhole tools.

Not only may the vibrational energy be used to produce downhole power, it may also be used for additional purposes. For example, Fig. 25 depicts a technique 470 for purposes of using vibrational energy to detect problems with tubular passageways (production tubing passageways, gravel packing shunt tubes, etc.) downhole. In this manner, pursuant to the technique 470, vibrational energy is detected (block 472) downhole and then used to evaluate (block 474) possible blockage in response to the detected energy. The vibrational energy may be generated downhole (in response to a fluid flow, for example) and/or may be communicated downhole by a flow (a cement or gravel packing flow, as examples) from the surface of the well. As a more specific example, a circuit may analyze the spectral components of the produced vibrational energy and based on comparing the computed spectral energy to reference patterns, may determine whether or not a blockage exists in a particular downhole member.

As yet another example of the use of vibrational energy to perform a function other than solely being converted into downhole power, a technique 481, depicted in Fig. 26, uses vibrational energy for purposes of communicating with the downhole tool. More specifically, pursuant to the technique 481, vibrational energy is detected (block 482) downhole, and this detection is used (block 484) to handshake, that is to communicate commands and/or measurements with a specific downhole tool.

As a more specific example, Fig. 27 depicts a well 500 that includes a tubular string 582 that extends into a wellbore of the well 500. The string 582 includes gas lift valves 584 that may be used for purposes of injecting gas for purposes of lifting production fluid uphole. A circuit 590 on the surface of the well 500 monitors vibrational energy that is generated by the gas lift valves 584 for purposes of determining when a particular gas lift valve 584 has been activated. In this regard, in some embodiments of the invention, each gas lift valve 584 may be designed to have a unique and identifiable resonant frequency when activated. This vibrational frequency, in turn, is detected by the circuit 590 for purposes of identifying when the gas lift valve 584 has activated.

Alternatively, each gas lift valve 584 may be designed to release tags that contain a unique and identifiable code that can be communicated to a suitable circuit at the surface located as 590 in Fig. 27.

Other embodiments are within the scope of the following claims. For example, many other techniques may be used to generate electric power from vibrational energy downhole. For example, in some embodiments of the invention, a capacitor may be used that has at least one plate that is mounted to a spring. A voltage may be stored on the capacitor so that by variation of the distance between the plates of the capacitor, a varying voltage is produced. This varying voltage, in turn, may be converted into power for a particular downhole tool.

As another example of a mechanism to generate power from downhole vibrational energy, Fig. 28 depicts, as a variation on the electromagnetic energy converter depicted in Fig. 19B a mechanism 600 that includes a coil 602 that generally circumscribes a magnetically-charged ferrous material 610. The material 610, in turn, may be mounted on springs 606 to move longitudinally along the axis of the coil 602, as depicted in Fig. 28. This movement of the material 610, in turn, produces a voltage on the coil 602 and this voltage may be converted into downhole power. In some embodiments of the invention, the coil 602 may be embedded in a mandrel 604 that generally circumscribes the ferrous material 610.

In another variation, Fig. 29 depicts a power generation mechanism 620 in which the mandrel 604 (that contains the coil 602) moves instead of the ferrous material 610. More specifically, the ferrous material 610 may be relatively stationary; and the mandrel 604 is mounted on springs 624. Thus, vibration causes movement of the mandrel 604 (and coil 602) with respect to the ferrous material 610. This movement, in turn, induces a voltage on the coil 602, and this voltage may be used to generate power downhole. It is noted that many other variations are possible in the various embodiments of the invention. For example, Fig. 30 depicts a mechanism 650 similar to the mechanism 600 except that the ferrous material 610 is mounted via springs 651 so that the ferrous material 610 moves laterally with respect to the coil 602. This lateral movement, in turn, changes the magnetic permeability of the path inside the coil 602 to change the voltage that appear on the coil's terminals. As depicted in Fig. 30, in some embodiments of the invention, the spring 651 may couple the ferrous material 610 to the inner side-walls of the mandrel 604.

Other variations are possible. For example, in other embodiments of the invention, the ferrous material 610 may be distributed on a dynamo that rotates inside the coil 602 to generate voltage on the coil's terminals. The rotational speed of the dynamo increases with the level of vibration in the well.

While the present invention has been described with respect to a limited number of embodiments, those skilled in the art, having the benefit of this disclosure, will appreciate numerous modifications and variations therefrom can be made. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.

CLAIMS

1. A method usable with a well, the method comprising:

deploying wireless tags in the well to measure properties of the well as the tags flow through the well; and

using vibrational energy transferred to the tags during the flowing through the well to activate the tags.

2. The method of claim 1, further comprising, for each tag, deploying the tag in an unpowered state into the well and converting vibrational energy transferred to the tag during the flowing into electrical power to power circuitry of the tag.

3. The method of claim 1, wherein at least one of the tags measures at least one of a pressure and a temperature in the well.

4. The method of claim 1, wherein the properties comprise water or chemical constituents of the well.

5. The method of claim 1, wherein the activation of the tags comprises powering-up the tags in response to the vibrational energy.

6. The method of claim 1, further comprising:

retrieving the tags from the well; and

reading data from the tags indicative of the measured properties of the well near the surface of the well.

7. An apparatus usable with a well, the apparatus comprising:

a processor to measure a property of the well as the apparatus flows through the well; and

a vibrational energy converter to generate power for the processor in response to vibrational energy transferred to the apparatus when the apparatus flows through the well.

8. The apparatus of claim 7, wherein the apparatus is unpowered initially and powered-up when the apparatus flows through the well.

9. The apparatus of claim 7, wherein the processor measures at least one of a pressure and a temperature in the well.

10. The apparatus of claim 7, wherein the processor measures at least one of a water or chemical constituent of the well.

11. The apparatus of claim 7, wherein the vibrational energy converter is adapted to power-up the processor in response to the apparatus flowing in the well.

12. The apparatus of claim 7, further comprising a transmitter to transmit the data to a reader external to the apparatus.

Application No: GB0712094.2
Claims searched: 1-12
Examiner: Dr Lyndon Ellis
Date of search: 20 August 2007

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-12	US 6443228 B1 (Aronstam) Whole document, noting column 4, lines 62-65

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

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E21B

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
E21B	0041/00	01/01/2006
E21B	0047/00	01/01/2006
E21B	0047/06	01/01/2006