A system that is usable with a subterranean well includes a winding, a member and a circuit. The winding is located downhole in the well, and the member moves relative to the winding in response to vibration occurring in the well to cause a signal to be generated on the winding. The circuit is coupled to the winding to respond to the signal to provide power to operate a component located downhole in the well.
FIG. 2

START

ENHANCE DOWNHOLE VIBRATION

CONVERT DOWNHOLE VIBRATION INTO DOWNHOLE POWER

END

FIG. 3

FIG. 4

FIG. 5
FIG. 13

FIG. 14

ELECTRICAL PUMP

FIG. 15

FIG. 16A

START

DEPLOY WIRELESS TAGS IN WELL

USE VIBRATIONAL ENERGY TO ACTIVATE TAGS

PERFORM MEASUREMENTS WITH TAGS

END
FIG. 16B
**FIG. 19A**

MECHANICAL TO ELECTROMAGNETIC ENERGY CONVERTER

VIBRATION RESPONSIVE STRAIN INDUCER

DC-TO-DC CONVERTER

BATTERY

**FIG. 19B**

MAGNET

FERROMAGNETIC MATERIAL

GROUND RETURN

266
FIG. 22

TELEMETRY

SUBSEA WELLHEAD

400

402

406

410

ROBOT

412

414
1. Induce vibrations in gravel pack flow use vibrational energy from flow to power downhole tool.

2. Induce vibration in cement flow use vibrational energy from flow to power downhole tool.

3. Detect vibrational energy downhole evaluate possible blockage in response to detected energy.

4. Detect vibrational energy downhole use detection to handshake with special downhole tool.
HARVESTING VIBRATION FOR DOWNHOLE POWER GENERATION

BACKGROUND

[0001] The invention generally relates to harvesting vibration for downhole power generation.

[0002] 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.

[0003] 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.

[0004] 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.

[0005] Thus, there is a continuing need for better ways to generate power downhole in a subterranean well.

SUMMARY

[0006] In an embodiment of the invention, a system that is usable with a subterranean well includes a winding, a member and a circuit. The winding is located downhole in the well, and the member moves relative to the winding in response to vibration occurring in the well to cause a signal to be generated on the winding. The circuit is coupled to the winding to respond to the signal to provide power to operate a component located downhole in the well.

[0007] Advantages and other features of the invention will become apparent from the following description, drawing and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a schematic diagram of a well according to an embodiment of the invention.

[0009] FIG. 2 is a flow diagram depicting a technique to generate downhole power according to an embodiment of the invention.

[0010] FIGS. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14 depict mechanisms to enhance the generation of downhole vibrational energy according to an embodiment of the invention.

[0011] FIG. 15 depicts a system located on a sandscreen to aid in the generation of downhole power according to an embodiment of the invention.

[0012] FIG. 16A is a flow diagram depicting a technique to power wireless tags according to an embodiment of the invention.

[0013] FIG. 16B depicts a system to deploy wireless tags according to an embodiment of the invention.

[0014] FIG. 17 is a schematic diagram of a wireless tag according to an embodiment of the invention.

[0015] FIG. 18A is a block diagram of a system to harness and store vibrational energy downhole according to an embodiment of the invention.

[0016] FIG. 18B depicts a piezoelectric material based vibration energy converter.

[0017] FIG. 19A is a block diagram of an electromagnetic based system to harness and store vibrational energy downhole according to an embodiment of the invention.

[0018] FIG. 19B depicts an electromagnetic based vibration energy converter.

[0019] FIGS. 20A, 20B and 20C are schematic diagrams of vibrational energy harvesting mechanisms according to an embodiment of the invention.

[0020] FIG. 21 is a schematic diagram of a portion of a drilling string according to an embodiment of the invention.

[0021] FIG. 22 is a schematic diagram of a subsea well according to an embodiment of the invention.

[0022] FIG. 23 is a flow diagram depicting a technique to power a downhole tool according to an embodiment of the invention.

[0023] FIG. 24 is a flow diagram depicting a technique to use vibration in a cementing operation according to an embodiment of the invention.

[0024] FIG. 25 is a flow diagram depicting a technique to evaluate potential blockage of a downhole pipe according to an embodiment of the invention.

[0025] FIG. 26 is a flow diagram depicting a technique to communicate with a downhole tool according to an embodiment of the invention.

[0026] FIG. 27 is a schematic diagram depicting a system in which vibrational energy is used to communicate with downhole tools according to an embodiment of the invention.

[0027] FIGS. 28, 29 and 30 are schematic diagrams of mechanisms to harness vibrational energy to generate electrical power according to embodiments of the invention.

DETAILED DESCRIPTION

[0028] Referring to FIG. 1, an embodiment 10 of a well in accordance with the invention 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).

[0029] 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.

[0030] 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 uphele. 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.

[0031] Thus, referring to FIG. 2, in some embodiments of the invention, a technique 40 may be used to harvest vibrational energy downhole. More specifically, in accordance with the technique 40, the downhole vibration is enhanced (block 42) such as 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.

[0032] 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.

[0033] Other types of vibrational 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.

[0034] 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.

[0035] 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 that varies in diameter.

[0036] 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 Y directions and contracts in the positive and negative X directions. This process repeats to establish the fundamental vibration mode.

[0037] As depicted in FIG. 7, in some embodiments of the invention, the thickness of the wall of the production string 70 may be radially varied to select the axis and otherwise enhance the fundamental vibration mode. More specifically, the cross-section of the string may include thiner 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.

[0038] 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.

[0039] 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.

[0040] 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.

[0041] 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.

[0042] 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.

[0043] In some embodiments of the invention, an electrical device that consumes harvested power downhole may also be used to generate 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.

[0044] 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 in other embodiments of the invention, these mechanisms may be located in other regions of the well. For example, in some embodiments of the invention, 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.

[0045] As a more specific example, referring to FIG. 15, in some embodiments of the invention, 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. In some embodiments of the invention, the mechanism 160 may be located inside the sandscreen 158. Furthermore, in some embodiments of the invention, 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.

[0046] Although in the embodiments described above, the power generation mechanism 20 is depicted (FIG. 1) as being attached to the string 14, in other embodiments of the invention, the power generation mechanism 20 may not be fixed in position relative to the string 14. For example, in some embodiments of the invention, 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.

[0047] 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.

[0048] Thus, referring to FIG. 16A, in some embodiments of the invention, 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.

[0049] 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.

[0050] In some embodiments of the invention, 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.

[0051] Referring to FIG. 17, in some embodiments of the invention, 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 248. 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 246. 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.

[0052] 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 246, as just a few examples.

[0053] In some embodiments of the invention, the tag 220 may include a reserve energy source, such as a battery 244, 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.

[0054] In some embodiments of the invention, the power harvesting circuitry (whether on a wireless tag or 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.

[0055] 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.

[0056] 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.

[0057] Additionally, in some embodiments of the invention, a particular well may include several generators 273 that are connected in parallel to the voltage 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.

[0058] In accordance with an embodiment of the invention, the vibration responsive strain inducer 264 and piezoelectric material 262 may, in some embodiments of the invention, 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 284 and 286. 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.

[0059] Referring both to FIGS. 19A and 19B, in some embodiments of the invention, the power harvesting circuitry (whether on a wireless tag or 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 ferromagnetic 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.

[0060] 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.

[0061] 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.

[0062] As another example of a strain-inducing mechanism in accordance with the invention, 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.

[0063] 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. Thus, other variations are possible and are within the scope of the appended claims.

[0064] 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.

[0065] 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 111 (also of the string 14) to detect one or more characteristic(s) of the flow 27. The sensor 111 may include one or more of a pressure sensor, a temperature sensor, a fluid composition sensor and a Micro Electrical Mechanical Sensor (MEMS), depending on the particular embodiment of the invention.

[0066] 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 111 and valve 21 receive all of their operating power from the power generating tool 18.

[0067] 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.

[0068] 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 generation 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.

[0069] 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.

[0070] 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.

[0071] For example, FIG. 23 depicts an embodiment of a technique 430 in accordance with the invention, 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).

[0072] 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.

[0073] Not only may the vibrational energy be used to produce downhole power, other uses of the vibrational energy may be used, in accordance with particular embodiments of the invention. 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 slumber 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, in some embodiments of the invention, 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.

[0074] 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.

[0075] As a more specific example, FIG. 27 depicts a well 500 in accordance with the invention 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.

[0076] Alternatively, in some embodiments of the invention, 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.

[0077] 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.

[0078] 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.

[0079] 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.

[0080] 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.

[0081] 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. 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.

What is claimed is:

1. A system usable with a subterranean well, comprising:
   a winding located downhole in the well;
   a member to move relative to the winding in response to vibration occurring in the well to cause a signal to be generated on the winding; and
   a circuit coupled to the winding to respond to the signal to provide power to operate a component located downhole in the well.
2. The system of claim 1, wherein the member comprises a magnetic material.
3. The system of claim 1, wherein the winding is attached to a tubular string extending into the well, and the coil moves relative to the string.
4. The system of claim 1, wherein the coil is attached to a tubular string extending into the well, and the winding moves relative to the string.
5. The system of claim 1, wherein the relative motion occurs along a direction generally traverse to a longitudinal axis of a tubular string that extends into the well.
6. The system of claim 1, wherein the relative motion occurs along a direction generally aligned with a longitudinal axis of a tubular string that extends into the well.
7. The system of claim 1, wherein the circuit comprises a voltage regulator to generate a regulated voltage to power the component in response to the signal.
8. A system usable with a subterranean well, comprising:
   a tubular string comprising a central passageway and a flow diverter located in the central passageway to enhance vibrational energy in the tubular string in response to a flow contacting the flow diverter; and
   a power generator located downhole in proximity to the flow diverter to respond to the vibrational energy to generate power for a downhole component.
9. The system of claim 8, wherein the flow diverter comprises a wedge-shaped member.
10. The system of claim 8, wherein the flow diverter comprises a blind T.
11. The system of claim 8, wherein the flow diverter comprises a cantilevered member extending from an interior sidewall of the tubular member.
12. The system of claim 8, wherein the flow diverter is located within approximately ten feet of the power generator.
13. A system usable with a subterranean well, comprising:
   a tubular string comprising a central passageway having a varying cross-section to enhance vibrational energy in the tubular string in response to a flow through the cross-section; and
   a power generator located downhole in proximity to the varying cross-section to respond to the vibrational energy to generate power for a downhole component.
14. The system of claim 13, wherein the varying cross-section maintains an approximate circular shape.
15. The system of claim 13, wherein the varying cross-section comprises a Venturi-type cross-section.
16. The system of claim 13, wherein the varying cross-section is located within approximately ten feet of the power generator.
17. A system usable with a subterranean well, comprising:
   a chamber located downhole in the well, the chamber comprising at least one opening to receive an inlet fluid flow and at least one opening to provide an outlet fluid flow;
   an untethered member to move freely in the chamber in response to the inlet fluid flow to generate vibrational energy; and
   a power generator located downhole in proximity to the chamber to respond to the vibrational energy to generate power for a downhole component.
18. The system of claim 17, wherein the untethered member comprises a ball.
19. The system of claim 17, wherein the untethered member is located within approximately ten feet of the power generator.
20. A system usable with a subterranean well, comprising:
   a tubular string extending into the well, the string comprising a passageway to receive a fluid flow;
   a flexible member comprising a first end attached to the tubular string and a second free end located in the passageway to generate vibrational energy; and
   a power generator separate from the flexible member and located downhole in proximity to the flexible member to respond to the vibrational energy to generate power for a downhole component.
21. The system of claim 20, wherein the flexible member comprises a spring.
22. The system of claim 20, wherein the spring is located within approximately ten feet of the power generator.
23. A system usable with a subterranean well, comprising:
   a downhole component located in the subterranean well to receive power and perform a downhole function in response to the received power; and
   a power generator located downhole in proximity to the downhole component to respond to vibrational energy from the downhole component to generate the power received by the downhole component.
24. The system of claim 23, wherein the downhole component comprises at least one of an electrical submersible pump, a rod-type pump and a beam-type pump.
25. The system of claim 23, wherein the downhole component is located within approximately ten feet of the power generator.
26. A system usable with a subterranean well, comprising:
   a tubular string extending into the well, the tubular string comprising a wall defining a passageway through the string and having a varying thickness to amplify a fundamental mode of vibration of the tubular string; and
   a power generator located downhole and coupled to the tubular string to respond to vibrational energy from the tubular string to generate power for a downhole component.
27. The system of claim 26, wherein the wall comprises thinner regions separated from each other by approximately ninety degrees about a longitudinal axis of the tubular string.
28. A system usable with a subterranean well, comprising:
   a multiphase fluid mixer located in the subterranean well; and
   a power generator located downhole in proximity to the mixer to respond to vibrational energy from the mixer to generate power for a downhole component.
29. The system of claim 28, wherein the downhole component is located within approximately ten feet of the power generator.
30. A system usable with a subterranean well, comprising:
   a tubular member located downhole in the subterranean well, the tubular member comprising a wall defining a
passageway to receive a fluid flow and a groove formed in the wall to enhance vibrational energy produced by the fluid flow; and

a power generator located downhole in proximity to the groove to respond to vibrational energy from the mixer to generate power for a downhole component.

31. The system of claim 30, wherein the groove comprises a spiral groove formed along a longitudinal axis of the passageway.

32. The system of claim 30, wherein the groove is formed on an interior surface of the wall.

33. A system usable with a subterranean well, comprising:

a sandscreen; and

a power generator mounted to the sandscreen to respond to vibrational energy from the sandscreen to generate power for a downhole component.

34. The system of claim 33, wherein the power generator is mounted to an exterior of the sandscreen.

35. A system usable with a subterranean well, comprising:

a tubular member comprises a side pocket eccentric to a central passageway of the tubular member; and

a power generator located in the side pocket to respond to vibrational energy to generate power for a downhole component.

36. A method usable with a subterranean well, 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 flow through the well to activate the tags.

37. The method of claim 36, 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 flow into electrical power to power circuitry of the tag.

38. The method of claim 36, wherein at least one of the tags measures at least one of a pressure and a temperature in the well.

39. A system usable with a subterranean well, comprising:

a plurality of generators located downhole in the well, each of the generators independently generating power in response to vibrational energy,

wherein the generators are electrically coupled together to each contribute to a stored energy.

40. The system of claim 39, wherein output terminals of the generators are coupled in parallel.

41. The system of claim 39, further comprising:

a battery, wherein the generators are each adapted to store energy in the battery.

42. A method usable with a subterranean well, comprising:

initiating a flow from a surface of the well; and

using vibrational energy from the flow to power a downhole component.

43. The method of claim 42, further comprising:

adding vibrational energy at the surface to increase power production downhole.

44. The method of claim 43, wherein the adding comprises:

pulsing the flow.

45. The method of claim 42, wherein the flow comprises a gravel slurry used in a gravel packing operation.

46. The method of claim 42, wherein the flow comprises a cement flow used in a cementing operation.

47. A method usable with a subterranean well, comprising:

detecting vibrational energy downhole in the well; and

using the detected vibrational energy to evaluate possible blockage in a downhole tubular member.

48. The method of claim 47, further comprising:

using the vibrational energy to generate power for a downhole component.

49. A method usable with a subterranean well, comprising:

detecting vibrational energy generated downhole;

identifying one of a plurality of downhole tools capable of generating the vibrational energy;

using the identification to acknowledge operation of said identified tool.

50. The method of claim 49, further comprising:

constructing each of the downhole tools to have a different vibrational frequency during operation.

51. The method of claim 49, wherein the downhole tools comprise gas lift valves.

52. A system usable with a subterranean well, comprising:

a downhole component; and

a controller to operate the component independently from a command from the surface of the well in response to a sensed characteristic downhole,

wherein at least one of the downhole component and controller receive power generated downhole from vibrational energy.

53. A system usable with a subterranean well, comprising:

a drilling string comprising a drill bit and a motor to operate the drill bit; and

a sensor to sense a drilling characteristic,

wherein the motor is located between the sensor and the motor, and sensor is powered by electrical power generated from vibrational energy downhole.

54. The system of claim 53, wherein the sensor does not receive power from any power cable extending across the motor.