A technique that is usable with a well includes communicating a ballistic wave from a first point in a well to a second point in the well without propagating the ballistic wave along a detonating cord. The first and second points are separated by at least one foot. The technique includes responding to the ballistic wave near the second point to activate a downhole tool.
FIG. 1

START

GENERATE AT LEAST ONE HIGH INTENSITY IMPULSE WAVE

COMMUNICATE THE HIGH INTENSITY IMPULSE WAVE(s) THROUGH BARRIER

INITIATE ACTUATOR IN RESPONSE TO HIGH INTENSITY IMPULSE WAVE(s)

END

FIG. 2

COMPUTER

IMPULSE GENERATOR

BARRIER(s)

ACTIVATOR

BALLISTIC DEVICE
FIG. 3

START

CONTROL IMPULSE GENERATOR TO GENERATE COMMAND-ENCODED HIGH INTENSITY IMPULSE WAVES

ALLOW IMPULSE WAVES TO PROPAGATE THROUGH BARRIER(s)

DECODE COMMAND FROM IMPULSES WAVES

INITIATE ACTIVATOR IN RESPONSE TO DECODED COMMAND

END
Fig. 6

- SENSOR
- PROCESSOR
- VOLTAGE BOOSTER
- EFI
- BALLISTIC DEVICE

Fig. 7

1. START
2. GENERATE COMMAND-ENCODED HIGH FREQUENCY ACOUSTIC ENERGY
3. ALLOW HIGH FREQUENCY ACOUSTIC ENERGY TO PROPAGATE THROUGH BARRIER(s)
4. DECODE COMMAND FROM RECEIVED HIGH FREQUENCY ACOUSTIC ENERGY
5. INITIATE ACTIVATOR IN RESPONSE TO DECODED COMMAND
6. END
FIG. 9A

START

600

FIRE ACCEPTOR CHARGE 540 IN UPPER CASING CONVEYED PERFORATING GUN 520a TO INITIATE DETONATION WAVE ON DETONATING CORD 532 OF UPPER GUN 520a

604

USE DETONATION WAVE TO FIRE PERFORATING CHARGES 530 OF UPPER GUN 520a

608

USE DETONATION WAVE TO FIRE DONOR CHARGE 550 OF UPPER GUN 520a TO CREATE BALLISTIC WAVE THAT PROPAGATES WITHOUT AID OF DETONATING CORD TO LOWER CASING CONVEYED PERFORATING GUN 520b

612
FIG. 9B

1

FIRE ACCEPTOR CHARGE 540 IN LOWER CASING CONVEYED PERFORATING GUN 520b IN RESPONSE TO BALLISTIC WAVE TO INITIATE DETONATION WAVE ON DETONATING CORD 532 OF LOWER GUN 520b

USE DETONATION WAVE TO FIRE SHAPED CHARGES 530 OF LOWER GUN 520b

USE DETONATION WAVE TO FIRE DONOR CHARGE 550 OF LOWER GUN 520b TO FIRE GUN BELOW LOWER GUN 520b

END
COMMUNICATING THROUGH A BARRIER IN A WELL

CROSS REFERENCE TO RELATED APPLICATION


BACKGROUND

[0002] The invention generally relates to a communicating through a barrier in a well.

[0003] For purposes of enhancing production from a well, the well may be perforated. In a typical perforating operation, a perforating gun is run downhole on a conveyance mechanism, such as a string or wireline, to the location where a production zone is to be established. A firing head of the perforating gun typically is then remotely activated from the surface of the well for purposes of initiating a detonation wave on the gun’s detonating cord that extends from the firing head. The detonation wave causes the gun’s perforating charges (shaped charges, for example) that are in ballistic communication with the detonating cord to fire. When fired, the perforating charges produce corresponding perforation jets, which perforate the well casing (if the well is cased) and form perforation tunnels into the surrounding formation.

[0004] Several different techniques have been used in the past for purposes of remotely activating the firing head from the surface of the well. For example, a firing head that is constructed to initiate a detonation wave in response to being impacted by a pin may be deployed downhole. The pin to activate the firing head may be dropped through the central passageway of a string (which conveys the perforating gun downhole) from the surface of the well. As another example, the firing head may be constructed to respond to tubing conveyed pressure (TCP), so that fluid pressure inside the string may be increased to a predetermined level to trigger the firing of the perforating gun’s charges. As yet another example, the perforating gun may be run downhole on a wireline, and the firing head may be designed to fire the charges of the perforating gun in response to the appropriate electrical signal that is communicated downhole to the gun’s firing head via the wireline.

[0005] The above-recited techniques to activate the firing head assume that pathways (electrical, fluid, etc.) are available are available. However, communicating with a perforating gun or, in general, any downhole tool, may be challenging if fluid or electrical pathways are not available. In this regard, the presence of communication across barriers, such as fluids, cement, screens, packers, plugs, etc. may present challenges in establishing communication between the surface and a downhole tool and between downhole tools.

[0006] Thus, there exists a continuing need for better ways to communicate with a tool that is located downhole in a well.

SUMMARY

[0007] In an embodiment of the invention, a technique that is usable with a well includes generating first command-encoded impulse stimuli in the well to cause second command-encoded stimuli to emerge from a communication barrier in the well. The technique includes responding to the second command-encoded stimuli to initiate an activator of a downhole tool.

[0008] In another embodiment of the invention, a system that is usable with a well includes a transmitter and a receiver. The transmitter generates first command-encoded impulse stimuli in the well to cause second command-encoded stimuli to emerge from a communication barrier in the well. The receiver responds to the second command-encoded stimuli to initiate an activator of a downhole tool.

[0009] In yet another embodiment of the invention, a technique that is usable with a well includes communicating acoustic energy having most of its spectral energy at frequencies greater than approximately 300 Hertz into the well and activating a downhole tool in response to the communication of the acoustic energy.

[0010] In yet another embodiment of the invention, a method that is usable with a well includes communicating a ballistic wave from a first point in the well to a second point in the well without propagating the ballistic wave along a detonating cord. The first and second points are separated by more than one foot. The technique includes responding to the ballistic wave near the second point to actuate a downhole tool.

[0011] Advantages and other features of the invention will become apparent from the following drawing, description and claims.

BRIEF DESCRIPTION OF THE DRAWING

[0012] FIGS. 1, 3 and 7 are flow diagrams depicting techniques to communicate through downhole barriers according to embodiments of the invention.

[0013] FIG. 2 is a schematic diagram depicting a system to communicate through one or more downhole barriers according to an embodiment of the invention.

[0014] FIGS. 4, 5 and 8 depict wells according to embodiments of the invention.

[0015] FIG. 6 is a schematic diagram of an activator according to an embodiment of the invention.

[0016] FIGS. 9A and 9B depict a technique to fire casing conveyed perforating guns according to an embodiment of the invention.

DETAILED DESCRIPTION

[0017] Referring to FIG. 1, in accordance with an embodiment of the invention, a technique 10 for communicating with a downhole tool includes generating at least one high intensity impulse wave, pursuant to block 12. The high intensity impulse wave(s) possess the capability of being communicated (block 14) through one or more “communication barriers,” such as (a non-exhaustive exemplary list) one or more of the following in alone or in combination: a fluid layer, cement, a screen, a packer, a plug and the metal wall of a string. Although the communication barriers may block the communication of conventional stimuli, the high intensity impulse wave(s) propagate through the communication barrier(s) to allow initiation (block 16) of an activator of the tool, which is located downhole of the barrier(s).

[0018] In accordance with some embodiments of the invention, the technique 10 may be implemented in a subsea or subterranean well system, an exemplary embodiment 50 of which is depicted in FIG. 2. As depicted in FIG. 2, the system 50 includes an impulse generator 58, which, in accordance with some embodiments of the invention, may be a device that generates high intensity impulse waves, which are communicated downhole from the surface of the well. For example,
in accordance with some embodiments of the invention, the impulse generator 58 may be in communication with a fluid layer in the well so that the generator 58, when activated, forms a high intensity fluid impulse wave, or “fluid hammer,” in the fluid layer. The fluid hammer propagates from the impulse generator 58 through the fluid layer and the resulting energy from the initial fluid hammer may likewise propagate through one or more barriers 60 (in addition to the fluid layer) that intervene between the generator 50 and to an activator 64 of a downhole tool. In accordance with some embodiments of the invention, each of the high intensity impulse waves, such as the fluid hammer, which is generated by the impulse generator 58 may be an impulse of at least 2.7 Nm. As another example, the fluid hammer may be one or more pressure waves, each of which has a magnitude exceeding 200 pounds per square inch (psi) for a duration less than approximately 500 milliseconds (ms), in accordance with some embodiments of the invention.

The impulse generator 58 may take on numerous forms, depending on the particular embodiment of the invention. For example, in accordance with some embodiments of the invention, the impulse generator 58 may be formed from a surface fluid pump and a valve. The valve may be controlled such that when the fluid pump builds up sufficient pressure in a surface flow path, the valve opens to communicate a high intensity impulse to the well fluid.

In other embodiments of the invention, the impulse generator 58 may be formed from a mandrel that includes a piston head for the purposes of generating a fluid hammer in a fluid layer in communication with the piston head. The impulse generator 58 may be ballistically or pressure activated (as examples) in accordance with some embodiments of the invention. Thus, many variations are possible and are within the scope of the appended claims.

Depending on the particular embodiment of the invention, the activator 64 may respond directly to a received impulse wave, without performing stimuli discrimination, other than not responding to impulse waves below a certain threshold. However, in other embodiments of the invention, the impulse waves may be encoded with a command, and for there embodiments of the invention, the activator 64 may decode received impulse waves for purposes of extracting and acting upon the encoded commands and not responding to other impulse waves and/or commands.

As a more specific example, in accordance with some embodiments of the invention, the activator 64 may be a ballistic-based activator, such as the firing head of a perforating gun. Encoding a command into the impulse waves ensures that the firing head does not inadvertently fire in response to impulse waves that are not produced by the impulse generator 54 or impulse waves that are generated by the impulse generator 54 and are intended for a different activator. Furthermore, the encoding may involve encoding an address with the command for purposes of selecting one tool from another. This may be particularly advantageous, for example, when several perforating guns are part of a single string.

For embodiments of the invention in which the activator 64 is a firing head, the activator 64 is capable of extracting a fire command from a series of impulse waves that encoded with a fire command. Upon verifying receipt of the fire command, the activator 64 initiates a detonation wave on a detonating cord 66 that extends from the activator 64 to a ballistic device 68, which may be, for example, the first of many perforating charges to be fired in response the detonation wave.

It is noted that the activator 64 may be an activator for a tool other than a perforating gun. For example, in accordance with other embodiments of the invention, the activator may be used for purposes of controlling operating of a packer, valve, plug, etc., as just a few examples. Furthermore, the activator may be ballistically-based or non-ballistically based, depending on the particular embodiment of the invention. For example, in some embodiments of the invention, the activator may respond to a command-encoded or non-command-encoded impulse wave by using fluid pressure to operate a downhole element (such as a sleeve of a valve, for example).

For purposes of encoding a command into the impulse waves, the valve and/or the pump of the impulse generator 58 may be controlled by a computer 52, which may include a processor 54 that executes program instructions 55 (stored in a memory 56 of the computer 52) for purposes of controlling the surface element to generate the impulse.

In this regard, in accordance with some embodiments of the invention, the generation of the impulse waves may be precisely-regulated by the computer 52 for purposes of encoding the impulse waves with a command.

In view of the foregoing, a technique 80 that is depicted in FIG. 3 may be used to communicate through one or more barriers according to some embodiments of the invention. Pursuant to the technique 80, an impulse generator is controlled (block 82) to generate command-encoded high intensity impulse waves. The impulse waves are then allowed to propagate through one or more barriers of the well, pursuant to block 86. A command may then be decoded (block 90) from the impulse waves and an activator may be initiated (block 94) in response to the decoded command. Thus, for example, the activator 64 (FIG. 2) may compare a time-signature of a series of receive pulses for purposes of identifying a particular command (a fire command, for example). Upon recognizing the command, the activator 64 may then be initiate a operation of a downhole tool. Other variations are possible and are within the scope of the appended claims.

Referring to FIG. 4, in accordance with some embodiments of the invention, the above-described high intensity impulse wave communication technique may be used with a well, such as an exemplary well 100. A string 120 may extend downhole inside a wellbore 110 of the well 100 and may include multiple perforating guns, such as an upper perforating gun 140 and a lower perforating gun 150. The wellbore 110 may or may not be cased (via a casing string 112), depending on the particular embodiment of the invention. Each perforating gun 140, 150 has an associated initiator 64. For example, the upper perforating gun has an associated initiator 64, for purposes of firing the perforating charges of the gun 140, and the perforating gun 150 has an associated initiator 64, for purposes of firing its perforating charges.

It is noted that the well 100 may be a subterranean or subsea well, depending on the particular embodiment of the invention. Additionally, the string 120 may be coiled tubing or formed from jointed sections, depending on the particular embodiment of the invention.

As depicted in FIG. 4, in accordance with some embodiments of the invention, the impulse generator 58 is located at the surface of the well 100. The impulse generator 58 may generate high intensity fluid-based impulse waves in
the central passageway of the string 120 (as depicted in FIG. 4). However, in accordance with other embodiments of the invention, the impulse generator 58 may generate high intensity fluid-based impulse waves in fluid that is located in an annulus of the well 100. Thus, many variations are possible and are within the scope of the appended claims.

Due to the energy of the impulses that are generated by the impulse generator 58, the impulses overcome barriers such as screens, packers, string housing, etc. that may otherwise impede communication between the surface and either initiator 64, and 64a.

Referring to FIG. 5, in another embodiment of the invention, a well 200 may be used for purposes of communicating through a downhole barrier. The well 200 has a similar design to the well 100 (with similar reference numerals being used), except that the well 200 does not include a surface-based impulse generator 58. Instead, in this particular embodiment of the invention, the string 210 (replacing the string 120) includes a string-based impulse generator 204. Thus, the generator 204 may be located downhole in the well away from the surface and may be in communication via wires, fluid, etc. with the surface of the well. A particular advantage of this arrangement is that the impulse generator 204 may be located in proximity to a particular fluid of the well to which the impulses are to be applied. Additionally, the downhole location of the generator 204 may bypass one or more downhole barriers. The impulse generator may be electrically, hydraulically, mechanically or ballistic-based, depending on the particular embodiment of the invention.

FIG. 6 depicts an exemplary embodiment of the activator 64 when used as a firing head. The activator 64 may include a sensor 310 for purposes of detecting transmitted impulses. For example, in accordance with some embodiments of the invention, the sensor 310 may be an acoustic-based sensor for purposes of detecting energy that propagates through a wall of a string in which the sensor 310 is housed. A processor 314 is electrically coupled to the sensor 310 for purposes of analyzing the energy that is sensed by the sensor 310. Thus, the processor 314 may, via the sensor 310, analyze received pressure impulses and compare these impulses to a predetermined time signature for purposes of decoding commands. In response to detecting a fire command, the processor 310 may activate a voltage booster 320, which boosts a voltage that is provided by a downhole voltage source 322 for purposes of activating an exploding foil initiator (EFI) 326. The activation of the EFI 326, in turn, causes corresponding activation of the ballistic device 68. As examples, the ballistic device 68 may be a pyrotechnic, a secondary explosive, etc.

Other embodiments are possible and are within the scope of the appended claims. For example, referring to FIG. 7, in accordance with other embodiments of the invention, a technique 400 to communicate a command to a downhole activator uses high frequency acoustic energy, which is capable of propagating through one or more downhole communication barriers. As an example, in accordance with some embodiments of the invention, the high frequency acoustic energy may be energy that has most of its spectral energy located above approximately 500 Hertz (Hz).

Pursuant to the technique 400, command-encoded high frequency acoustic energy is generated (block 402) and allowed (block 410) to propagate through one or more downhole communication barriers. A command is then decoded (block 414) from the high frequency acoustic energy that is received on the other side of the barrier(s). An activator is then initiated (block 418) in response to the decoded command.

The high frequency acoustic energy may be generated by a surface or a string-based generator, depending on the particular embodiment of the invention. The generator may include, for example, a mandrel that is attached to a pin that impacts a surface upon sufficient travel of the mandrel. The mandrel may therefore be moved back and forth to continually impact the pin and the surface to generate the acoustic energy. The mandrel may be hydraulically, mechanically or electrically, or ballistically driven, depending on the particular embodiment of the invention.

Referring to FIG. 8, in accordance with some embodiments of the invention, the above-described techniques may be used in connection with a well 500. The well 500 includes a casing string 502 that extends downhole to line a wellbore 510. As depicted in FIG. 8, the casing string 502 may be fixed in place by a cement 504. The casing string 502 includes casing conveyed perforating guns 520 (an upper casing conveyed perforating gun 520a and a lower casing conveyed perforating gun 520b being depicted as examples) which as their names imply, are perforating guns that are integrated into the casing string 502.

More specifically, each casing conveyed perforating gun 520 includes, as an example, radially extending fins 524 that are in general parallel to the longitudinal axis of the perforating gun 520 and contain perforating charges 530 (shaped charges, for example). A detonating cord 532 extends around the circumference of the casing conveyed perforating gun 520 for purposes of ballistically coupling the perforating charges 530 together. Thus, in response to a detonation wave propagating along the detonating cord 532, the perforating charges 530 fire to form corresponding perforation jets that extend through the cement 504 and into the surrounding formation.

A potential challenge in using casing conveyed perforating guns is that communication with the guns may be hampered by the manner in which the guns are assembled. More specifically, the casing string 502 includes joints, such as exemplary joints 516. Thus, the casing string 502 is assembled at the surface by connecting corresponding casing string sections together at the joints. These joints, in turn, may restrict the communication with the casing conveyed perforating guns 520. More specifically, it may be quite challenging to route a detonating cord through the casing joints 516. Thus, this impairs the ability to fire the casing conveyed perforating guns 520 in a traditional top-down sequence in which the upper casing conveyed perforating gun 520a fires, then the lower perforating gun 520b fires, etc. To overcome the communication barriers that are imposed by the casing joints 516, in accordance with some embodiments of the invention, ballistic waves are communicated between the casing conveyed perforating guns 520 without the use of detonating cords.

More particularly, in accordance with some embodiments of the invention, each casing conveyed perforating gun 520 includes an acceptor charge 540 that is connected to the detonating cord 532 for the gun 520. The acceptor charge 540 is constructed to respond to a ballistic wave that propagates from a ballistic source that is not connected to the acceptor charge 540 by a detonating cord. Thus, the acceptor charge 540 may be located several feet (more than one foot, for example), if not hundreds of feet from the source that generates the ballistic wave. In response to receiving the
ballistic wave, the acceptor charge 540 initiates a corresponding detonation wave on the detonating cord 532, which, in turn, fires the perforating charges 530 of the casing conveyed perforating gun 520.

[0040] In accordance with some embodiments of the invention, the firing of the perforating charges 530 of the upper casing conveyed perforating gun 520a is initiated via a tool 560, such as a wireline tool that is lowered downhole via a wireline 559. Other tools and other arrangements may be used to initiate the firing of the perforating charges 530 of the upper perforating gun 520a, depending on the particular embodiment of the invention. For example, in accordance with other embodiments of the invention, the firing of the perforating charges 530 of the upper casing conveyed perforating gun 520a may be accomplished via a wired connection, via a detonating cord, via pulses in a fluid, etc. Thus, many variations are possible and are within the scope of the appended claims. For the embodiment that is depicted in FIG. 8, the tool 560 contains a firing head 562 that initiates the firing of a donor charge 564 for purposes of producing a ballistic wave that propagates to the acceptor charge 540 of the upper casing conveyed perforating gun 520a.

[0041] After the detonation wave propagates along the detonating cord 532 to fire the perforating charges 530 of the upper casing conveyed perforating gun 520a, the detonation wave initiates the firing of a donor charge 550 of the gun 520a. This initiation, in turn, produces a ballistic wave, which propagates without aid of a detonating cord to the lower casing conveyed perforating tool 520b. The lower casing conveyed perforating tool 520b, in turn, includes an acceptor charge 540 that responds to the ballistic wave to generate a detonation wave on its detonating cord 532 to fire the perforating charges 530 of the lower casing conveyed perforating gun 520b. This detonation wave may also initiate the firing of a donor charge 550 of the lower casing conveyed perforating tool 520b to cause the firing of the perforating charges of a casing conveyed perforating gun that is located farther down in the well.

[0042] Referring to FIG. 9A, to summarize, in accordance with some embodiments of the invention, a technique 600 to fire casing conveyed perforating guns includes firing (block 604) an acceptor charge 540 in an upper casing conveyed perforating gun 520a to initiate a detonation wave on a detonating cord 532 of the upper perforating gun 520a. The detonation wave is used (block 608) to fire perforating charges of the upper casing conveyed perforating gun 520a.

[0043] The detonation wave is also used, pursuant to block 612, to fire a donor charge 550 of the upper casing conveyed perforating gun 520a to create a ballistic wave, which propagates without aid of a detonating cord to the lower casing conveyed perforating gun 520b.

[0044] Referring to FIG. 9B, the acceptor charge 540 and the lower casing conveyed perforating gun 520b is fired (block 614) in response to the ballistic wave to initiate a detonation wave on the detonating cord 532 of the lower casing conveyed perforating gun 520b. The detonation wave is used (block 618) to fire perforating charges 530 of the lower casing conveyed perforating gun 520b. The detonation wave may also be used (block 622) to fire a donor charge 550 of the lower casing conveyed perforating gun 520b to fire a gun below the gun 520b, in accordance with some embodiments of the invention. Thus, the above-described chain may be repeated for purposes of firing additional perforating guns.

[0045] 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 method usable with a well, comprising:
   communicating a ballistic wave from a first point in the well to a second point in the well without propagating the ballistic wave along a detonating cord, the first and second points being separated by at least one foot; and responding to the ballistic wave near the second point to actuate a downhole tool.
2. The method of claim 1, wherein the downhole tool comprises a perforating gun.
3. The method of claim 1, wherein the communicating comprises:
   communicating through a communication barrier.
4. The method of claim 3, wherein the communication barrier comprises a casing joint.
5. The method of claim 1, wherein the downhole tool comprises a casing conveyed perforating gun.
6. The method of claim 1, further comprising:
   generating the ballistic wave in response to the propagation of a detonation wave along a detonating cord.
7. A system usable with a well, comprising:
   a ballistic generator located at a first point in the well to generate a ballistic wave; and
   a tool being located at a second point in the well to respond to the ballistic wave,
   wherein the ballistic wave does not propagate along a detonating cord between the first and second points, and the first and second points are separated by at least one foot.
8. The system of claim 7, wherein the tool comprises a perforating gun.
9. The system of claim 7, wherein the communicating comprises:
   communicating through a communication barrier.
10. The system of claim 9, wherein the communication barrier comprises a casing joint.
11. The system of claim 7, wherein the tool comprises a casing conveyed perforating gun.
12. The system of claim 7, further comprising:
   generating the ballistic wave in response to the propagation of a detonation wave along a detonating cord.