Aug. 15, 1944. R. M. OTIS 2,356,082

METHOD OF AND APPARATUS FOR FIRING GUN PERFORATORS

Filed May 26, 1943 2 Sheets-Sheet 1

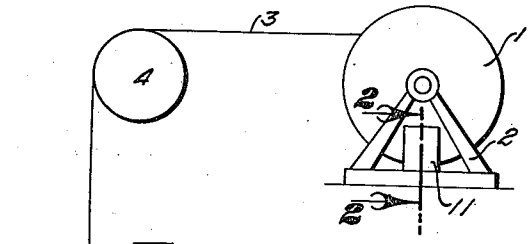


FIG. 1

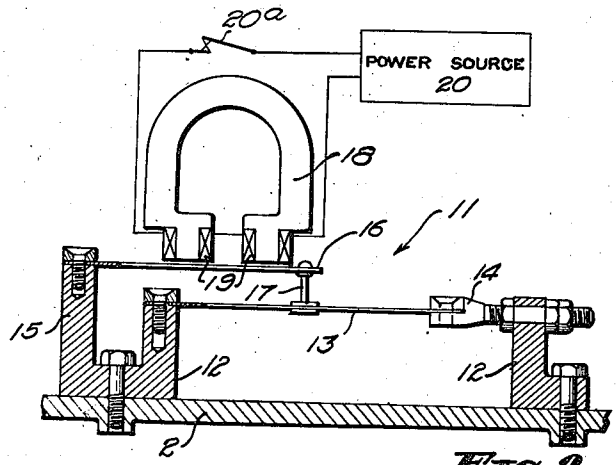
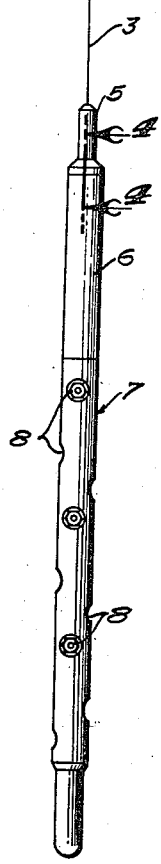


FIG. 2



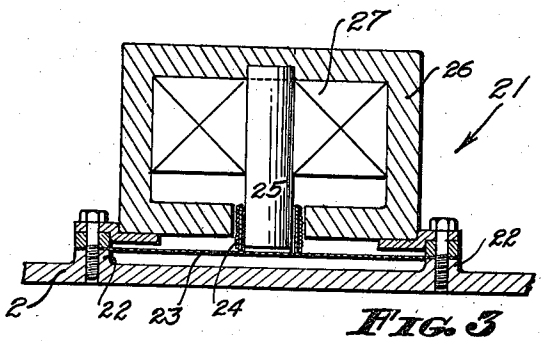


FIG. 3

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METHOD OF AND APPARATUS FOR FIRING GUN PERFORATORS

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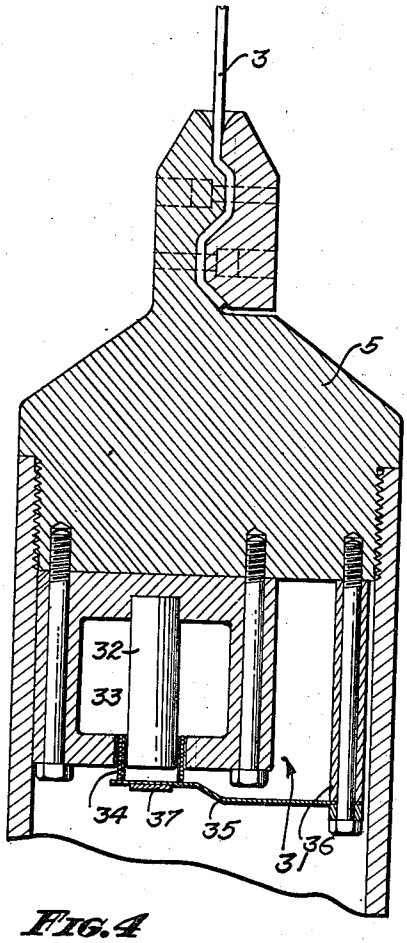


FIG. 4

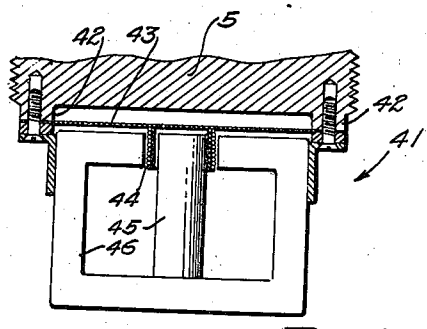


FIG. 5

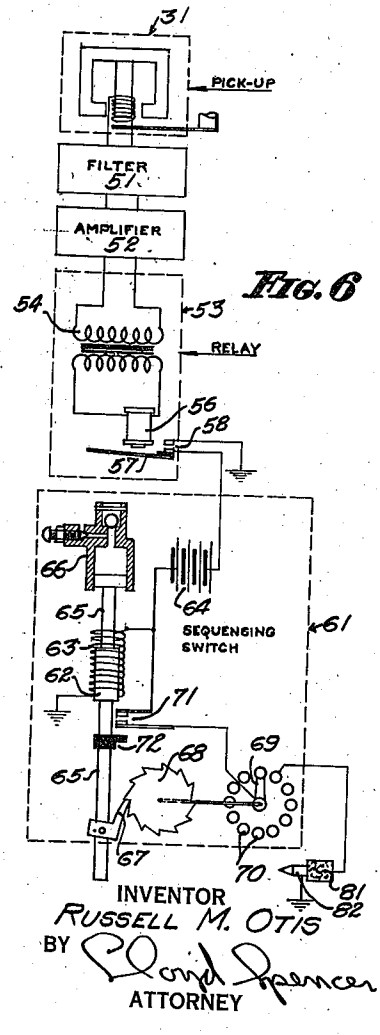


FIG. 6

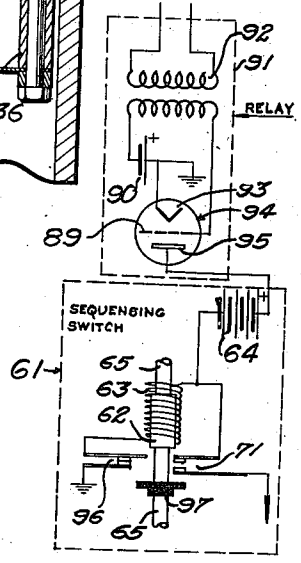


FIG. 7

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METHOD OF AND APPARATUS FOR FIRING GUN PERFORATORS

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Application May 26, 1943, Serial No. 488,803

18 Claims. (Cl. 164—0.5)

My invention relates to method of and apparatus for firing gun perforators, and among the objects of my invention are:

First, to provide a method and apparatus of this character whereby a multiple unit gun perforator may be suspended from a conventional multiple or single strand wire line and fired one unit at a time or in volleys as desired by means of control at the well mouth without resort to an insulated conductor between the gun perforator and the well mouth, or employement of a go-devil or other device intended to move along the suspension line;

Second, to provide a means and apparatus of this character whereby elastic vibrations are transmitted from the well mouth down a bare wire line or down the casing itself and caused to actuate a controller mechanism, thereby to initiate firing of the gun perforator;

Third, to provide a receiving and gun control apparatus of this character which, although responsive to elastic vibrations of high frequency, within or above the highest frequencies of audible sound, is unaffected by any vibrations resulting from discharge of the gun perforator even though such vibrations or their harmonics are within the intended range of operation of said apparatus;

Fourth, to provide a receiving and control apparatus for gun perforators capable of fitting within the confined space available between a gun perforator and its suspension line, and which is fully capable of withstanding the pounding and jarring occasioned by movement through the well bore at high speed and discharge of the gun perforator; and

Fifth, to provide a method and apparatus of this character which, by reason of the fact that it permits use of a single strand wire line, permits substantial reduction in the size, weight and cost of the surface equipment required to operate a gun perforator such as hoist, truck and associated parts; for example, a single strand wire line may weigh only 20 pounds per 1000 feet whereas a conventional conductor core line weighs about 300 pounds per 1000 feet, thus a much lighter hoist truck may be employed than has heretofore been possible, with attendant saving in cost and equipment.

With the above and other objects in view, as may appear hereinafter, reference is directed to the accompanying drawings, in which:

Figure 1 is a diagrammatical view of a gun perforator and hoisting mechanism employed in conjunction with the exercise of my invention;

Figure 2 is a sectional view taken through 2—2 of Figure 1, showing particularly one form of the signal-transmitting means;

Figure 3 is a similar view of a modified form of transmitter;

Figure 4 is an enlarged sectional view taken substantially through 4—4 of Figure 1, showing the cable head and one form of pick-up unit therein;

Figure 5 is a similar but more fragmentary view of a modified form of pick-up unit;

Figure 6 is an electrical diagrammatical view of the controlling mechanism interposed between the cable head and gun perforator proper; and

Figure 7 is a fragmentary wiring diagram of a modified form of controller apparatus.

With reference to Figure 1, a suitable hoist drum 1 is provided which is mounted on a frame 2. The hoist drum carries a wire line 3. This may be a multiple strand wire cable, such as a "sand" line, or may be a single uninsulated steel wire. Lines of the latter kind are employed in the oil fields for lowering various instruments and for measuring accurately the depth of a well bore; they are known commercially as "Halliburton" or "Measuring" lines. The wire line 3 is passed over a sheave wheel 4 and is attached to a gun perforator head 5 which, in turn, is secured to a control case 6 containing pick-up and control apparatus to be described hereinafter. The control case is secured to the gun perforator 7. The gun perforator may be any conventional type; preferably, however, the gun perforator is designed to be operated electrically, that is, it may comprise a series of individually operable gun units 8 or merely the first of the series of gun units may be electrically operated and the remainder set off by propagation of a flame from the first gun unit.

Secured in good acoustical association with the wire line 3 is a transmitter 11. This may be accomplished by securing the transmitter to the hoist drum frame 2. The transmitter 11 preferably comprises an elastic vibration generator and an acoustic coupling. The acoustic coupling includes a pair of brackets 12 which are secured to the hoist frame, between which is stretched a resilient metallic ribbon 13. One end of the ribbon is secured directly to one of the brackets 12, whereas the other end is secured to an adjustable tension clamp 14 secured to the other bracket, so that the tension of the ribbon may be adjusted.

The vibration generator includes a post 15, which may be independent or form a part of

one of the brackets 12. The post 15 extends upwardly and is attached to one end of a resilient armature strip 16. The armature strip extends over the ribbon 13 and its free end is attached thereto by a link 17. Above the armature strip 16 is a U shaped magnet 18, around the extremities of which are positioned alternating current coils 19. The alternating current coils 19 are connected to a suitable source of electrical power 20. In the structure shown the magnet 18 is a permanent magnet. However, a direct current field coil may be wound around the magnet, in either case the object being to provide a constant magnetomotive force in the magnetic circuit. The power source 20 may be any conventional mechanical or electronic oscillator designed to operate at a predetermined frequency, preferably above the audible range, for example, between 15,000 and 50,000 cycles. A suitable switch 20*a* is employed so that the power may be applied at will to the alternating current coils.

An alternative transmitter 21 is shown in Figure 3. This transmitter includes an annular rib 22 which may be secured to or formed integrally with a portion of the hoist drum frame to form an acoustic connection therewith. The rib supports the periphery of a resilient diaphragm 23 upon which is mounted an alternating current coil 24, preferably of light construction. A core is provided which comprises a central pole piece 25, one end of which seats in a cup-shaped shell 26 which forms with the other or outer end of the pole piece an annular air gap adapted to receive the coil 24 so that the coil may be oscillated within the relatively strong field formed between the pole piece and shell. Again, as in the first described transmitter, the core comprising the pole piece 25 and shell 26, or a portion thereof, may consist of a permanent magnet or, as illustrated, a direct current field coil 27 may surround the pole piece. In other words, a permanent magnet may be employed in Figure 3 analogous to the permanent magnet shown in Figure 2, or a magnet utilizing a D. C. field coil may be employed in Figure 2 analogous to the arrangement shown in Figure 3.

The transmitter, in either case, operates as follows: The length of the ribbon 13 and its tension or the size and tension of the diaphragm, together with the mass associated with the ribbon or diaphragm, are chosen so that the resonant frequency of the system corresponds to the frequency of the energizing current provided by the power supply 20. This frequency may, for example, be 20,000 cycles per second. The remaining parts are designed so as to operate most efficiently at this selected frequency. It is desirable that the effective distance between the brackets 12 and the diameter of the annular rib 22, as the case may be, be approximately an odd multiple of one-half the wave length of sound in the material of the frame 2 at the operating frequency. When the diaphragm or the ribbon, as the case may be, is vibrated at the operating frequency this frequency is transmitted acoustically to the frame of the hoist, to the hoist itself and from the hoist to the wire line. It should be noted that in either case, that is, either the diaphragm or the ribbon need move only a slight amount to exert a very large tensional force between the bracket 12 or across the diameter of the annular rib 22, as the case may be, so that a very efficient transmission of a given acoustic signal may be accomplished.

Thus, by means of the transmitter alternating current of a given frequency is translated to elastic vibration of the same frequency which is transmitted acoustically down the wire line. Because the frequency is preferably relatively high and, therefore, the wave length in steel is short, a matter of from four to twelve inches, there is little or no radiation of the energy from the wire line to the surrounding casing or formation at the points of contact of the wire line therewith, so that the signal reaching the gun perforator may be strong enough to operate a relatively insensitive pickup unit, thus permitting the pickup unit and parts associated therewith in the gun perforator to be constructed ruggedly and fully capable of withstanding the shocks they may receive due to jostling of the gun perforator as it is lowered or raised in the well bore, or to the firing of the gun perforator.

Reference is directed to Figure 4: The wire line 3 is preferably clamped in direct acoustical contact with the gun perforator head 5. The pickup, indicated generally by 31, preferably comprises a central pole piece 32 and a U shaped or cylindrical pole piece fitting therearound and forming with the extremity of the central pole piece a magnetic gap in which is mounted an armature coil 34. The armature coil 34 is mounted on the end of resilient strip 35 which is secured to a suitable support 36. The strip 35 forms an acoustic coupling between the coil 34 and the gun perforator lead 5. In addition to the coil 34, the extended end of the strip 35 may have a weight member 37. The mass of the weight member and armature coil, together with the length and stiffness of the strip 35, is selected to resonate at some predetermined frequency corresponding to the frequency of the transmitter 11 or 21. Initial adjustment may be accomplished by cutting away the weight member until the proper mass is left to cause the strip 35 and attached coil 34 to resonate at the selected frequency. It will be seen that the pickup 31, as shown in Figure 4, is the reverse of the transmitter shown in Figure 2; that is, the elastic vibrations are translated back to alternating electromotive force of the same frequency. Illustrated in Figure 5 is a modified form of pickup 41 which is essentially a reversal of the transmitter shown in Figure 3. Pickup 41 includes an annular rib 42 secured to or integral with the cable head 5 and which carries a diaphragm 43. The diaphragm carries an armature coil 44 which oscillates in the air gap between pole pieces 45 and 46, and thereby generates alternating electromotive force of a corresponding frequency. It is preferred that the pickup 31 or 41 utilize a permanent magnet to eliminate the necessity of a D. C. source for supplying a field coil, and the space within the control case 6 is limited. The pickup 31 or 41 (pickup 31 being used for purpose of illustration) forms a part of the gun perforator control apparatus, shown diagrammatically in Figure 6. The armature coil 34 or 44, as the case may be, is preferably connected to an electric filter 51 (more specifically, a band pass filter) designed to pass a relatively narrow band including the frequency for which the transmitter and pickup are tuned and reject other frequencies. The output from the filter is supplied to a suitable vacuum tube amplifier 52 which may, insofar as this application is concerned, be conventional and includes its own power supply (not shown). The output from the amplifier 52 is fed into a relay 53, preferably through transformer 54. The relay includes a relay coil 56 in

series with the secondary of the transformer. The relay coil 56 actuates an armature 57 which is adapted to close a pair of normally open contacts 58.

The circuit closed by the contacts preferably controls a sequencing switch 61. The sequencing switch comprises a reciprocable armature 62 surrounded by a solenoid 63. The solenoid coil is grounded at one end and connected through a battery 64 to the contacts 58, and back to ground. A stem 65 extends upwardly, as well as downwardly, from the armature 62 and one end carries a piston forming a part of a dash pot 66. The dash pot is designed to permit ready upward movement of the armature when the coil is energized, but to regulate or slow down return movement of the armature when the coil is de-energized.

The stem 65 carries a pawl 67 which engages a ratchet 68. Connected to the same shaft as the ratchet is a sweeper arm 69 which is adapted to engage in sequence a plurality of contacts 70. A pair of contacts comprising a main switch 71 is connected in series with the sweeper arm; this switch is adapted, when the armature is raised, to be closed by an arm 72 attached to the stem 65.

When the main switch 71 is closed an electric circuit is completed from ground through the contacts 58, battery 64, switch 71, sweeper arm 69, one of the contacts 70, to the fuse wire of an explosive cartridge 81 of the corresponding gun unit, and back to ground. Each of the gun units 8 contains such a cartridge 81, as well as a bullet 82.

With reference to Figure 7, the circuit shown in Figure 6 applies in most respects to Figure 7, with the exception that a "Thyratron" or similar trigger tube is employed in place of the relay 53. The Thyratron relay 91 is supplied through a transformer 92 one end of which is connected to the grid 89 of a Thyratron tube 94 while the other end is connected to the negative side of a biasing battery 90 the positive side of which is connected to the grounded cathode 93 of the Thyratron tube. The plate of the tube is connected to the positive terminal of the battery 64, the negative terminal of which connects with one end of the solenoid coil 63. In this embodiment, the other end of the solenoid coil 63 is connected through a switch 96 to ground. The switch 96 is normally closed but is adapted to be opened by a double arm 97 carried on the armature stem 65. The double arm 97 is substituted for the arm 72 shown in Figure 6 and engages and closes switch 71 just before engaging and opening switch 96. The circuit employed in conjunction with the Thyratron tube is in itself conventional and is therefore shown fragmentarily.

Operation of the pickup and control apparatus is as follows: A signal in the form of elastic vibrations sent from the transmitter down the wire line 3 is picked up by the pickup unit, translated into alternating electromotive force, filtered, amplified and supplied to the relay 53 or 91. Closing of the relay switch 58 energizes the solenoid coil of the sequencing switch 61, which draws its armature 62 and attached stem 65 upward, rotating the ratchet 68 to select a predetermined gun unit. As the armature reaches its upper position the circuit is completed through the cartridge by the closing of the switch 71. In the case of the Thyratron relay, the voltage of the biasing battery 90 is chosen so that the tube is normally non-conducting, but when the signal is received the voltage applied in the grid circuit is sufficient to overcome the biasing voltage and cause the tube to conduct from plate to cathode. The tube continues to conduct until the plate circuit is interrupted. As soon as the tube becomes conducting, the solenoid 63 is energized which lifts the armature 62 and attached stem 65, rotating the ratchet 68, closing the switch 71 and firing the gun perforator. Shortly thereafter the switch 96 is opened, interrupting the plate circuit of the Thyratron tube and causing it to be non-conducting until another signal is received.

Batteries to supply the electrical energy for the various parts of the controller apparatus are, of course, contained within the case 6. While a sequencing switch is shown, in order that the several gun units of the gun perforator may be fired in sequence it should be noted that the sequencing switch may be omitted. In this case the cartridges may be electrically connected in parallel and fire simultaneously, or only the first cartridge, or a special cartridge, may be electrically fired to initiate the operation, the operation being carried on by the transmission of a flame from one cartridge to the other. In other words, any of the gun perforators now in commercial operation may be arranged for control by my method and apparatus.

By reason of the dashpot 66, the armature 62 does not return to position until after the vibrations generated by discharge of the gun perforator have subsided, so that even though some acoustic vibrations (whether fundamental vibrations or harmonics thereof) are generated incidentally to discharge of the gun, the control apparatus is momentarily inoperative to cause another cyle of operation. This time delay is also useful to render less critical the duration of the signal so that the signal can be stopped by the operator before a succeeding cycle is initiated.

In brief, my method consists in generating elastic vibrations, preferably of supersonic frequency, which are transmitted preferably through a wire line, preferably a single strand, uninsulated steel wire, from the transmitter to the gun perforator, then picking up the signal or vibrations so transmitted and translating them to alternating electromotive force and causing them to operate a relay or switch which closes the electrical circuit to the gun perforator and, as a refinement, to operate a transmitter at the surface periodically so as to cause operation through a pickup unit of a sequencing switch for the purpose of firing individually the several gun units of a gun perforator.

The term "elastic vibration" or "acoustic vibration" is used herein to describe vibration of the nature of sound which, in the present instance, is preferably produced and transmitted in solid materials, such as the metals which comprise the frame 2, hoist 1, line 3, and cable head 5. These elastic vibrations may be of any suitable frequency within the range of audible sound or in the range of supersonic vibrations above the range of audible sound.

Various changes and alternate arrangements may be made within the scope of the appended claims, in which it is my intention to claim all novelty inherent in the invention.

I claim:

1. A method of firing a gun perforator in a well, characterized by: generating adjacent the top of said well an elastic vibration; acoustically transmitting said vibration down said well; picking up said vibration adjacent said gun perfora-

tor; and initiating operation of said gun perforator in response to said picked-up vibration.

2. A method of firing gun perforators, characterized by: suspending a gun perforator from an acoustically conductive line; generating in acoustical communication with the upper part of said line elastic vibrations of selected frequency; maintaining acoustical communication with said line adjacent said gun perforator and selectively picking up said vibrations to initiate operation of said gun perforator.

3. A method of controlling the firing of a gun perforator while suspended in a well bore from a wire line, characterized by: generating an elastic vibration signal of predetermined supersonic frequency; acoustically transmitting said signal from the upper part of said line to said gun perforator; picking up and amplifying said signal; and then causing the signal as amplified to initiate operation of said gun perforator.

4. A method of controlling the firing of an electrically responsive gun perforator while suspended in a well bore from a wire line, characterized by: generating an alternating current of preselected frequency; translating said alternating current to elastic vibration of corresponding frequency; transmitting acoustically said elastic vibration from the upper part of said wire line to the lower end thereof; picking up said elastic vibration and translating the same into alternating electromotive force; and employing said alternating electromotive force to operate an electrical relay, thereby to initiate operation of said gun perforator.

5. An apparatus for firing a gun perforator while suspended in a well bore from a wire line, comprising: an acoustic transmitter and an acoustic receiver tuned to substantially the same frequency, the transmitter being located adjacent the upper end of the wire line and the receiver adjacent the lower end thereof adjacent the gun perforator, both said transmitter and receiver being disposed in acoustical communication with said wire line; a relay adapted to be actuated by said receiver; and means adapted to be actuated by said relay for controlling the firing of said gun perforator.

6. An apparatus for firing gun perforators while suspended within a well bore from a wire line, comprising: a transmitter of elastic vibrations disposed in acoustical communication with the upper part of the wire line adjacent the well mouth; a pickup of elastic vibrations disposed in acoustical communication with the lower end of the wire line and adapted to translate said vibrations to electrical impulses; and an electrical relay operated by said impulses for initiating operation of said gun perforator.

7. An apparatus for firing gun perforators while suspended within a well bore from a wire line, comprising: a transmitter including a vibratable element acoustically connected with the upper part of said line, and electrical means for causing vibration of said element; a pickup unit suspended from said line with said gun perforator, including a vibratable element in acoustical connection with the lower end of said line and tuned to the frequency of the vibrations emanating from said transmitter, and an electrical means for translating said vibrations to electrical impulses; and an electrical relay operated by said electrical impulses for initiating operation of said gun perforator.

8. An apparatus, as set forth in claim 5, wherein said means for controlling the firing of said gun perforator is arranged to control a multiple unit gun perforator and includes a source of electrical energy, a sequencing switch for connecting said source to the units of said gun perforator in sequence, and means for introducing a time delay between operations of said switch whereby vibrations created by discharge of one gun unit subside before the sequencing switch is again operable.

9. An apparatus, as set forth in claim 6, arranged to operate a multiple unit gun perforator wherein a sequencing switch is interposed between said relay and the gun units of said gun perforator, said sequencing switch including a source of electrical energy, a sequencing switch for connecting said source to the units of said gun perforator in sequence and means for introducing a time delay between operations of said switch whereby vibrations created by discharge of one gun unit subside before the sequencing switch is again operable.

10. An apparatus, as set forth in claim 7, arranged to operate a multiple unit gun perforator wherein a sequencing switch is interposed between said relay and the gun units of said gun perforator, said sequencing switch including a source of electrical energy, a sequencing switch for connecting said source to the units of said gun perforator in sequence and means for introducing a time delay between operations of said switch whereby vibrations created by discharge of one gun unit subside before the sequencing switch is again operable.

11. An apparatus for firing gun perforators while suspended within a well bore from a wire line, comprising: a transmitter adapted to transmit an elastic vibration of selected frequency and disposed in acoustical communication with the upper part of the wire line adjacent the well mouth; a pickup of elastic vibrations disposed in acoustical communication with the lower end of the wire line and adapted to translate said vibrations into electrical impulses; an electric band pass filter connected to receive said electrical impulses and adapted to pass those impulses contained within a relatively narrow band of frequencies including said selected frequency; and an electrical relay operated by the electrical output from said filter for initiating operation of said gun perforator.

12. An apparatus for firing gun perforators while suspended within a well bore from a wire line, comprising: a transmitter of elastic vibrations of supersonic frequency disposed in acoustical communication with the upper part of the wire line adjacent the well mouth; a pickup of elastic vibrations of supersonic frequency disposed in acoustical communication with the lower end of the wire line and adapted to translate said vibrations into electrical impulses; and an electrical relay operated by said impulses for initiating operation of said gun perforator.

13. A method of controlling the firing of an electrically responsive gun perforator while suspended in a well bore from a wire line, characterized by: generating an alternating current of preselected frequency; translating said alternating current to elastic vibration of corresponding frequency; transmitting acoustically said elastic vibration from the upper part of said wire line to the lower end thereof; picking up said vibration and translating the same into alternating electromotive force; and employing said alternating electromotive force to control said gun perforator.

14. An apparatus for firing a gun perforator while suspended in a well bore from a wire line, comprising: an acoustic transmitter and an acoustic receiver tuned to substantially the same frequency, the transmitter being located adjacent the upper end of the wire line and the receiver adjacent the lower end thereof adjacent the gun perforator, both said transmitter and receiver being disposed in acoustical communication with said wire line; and means adapted to be actuated by said receiver for controlling the firing of said gun perforator.

15. A method of operating a device located within a well, characterized by: generating adjacent the top of said well an elastic vibration; acoustically transmitting said vibration down said well; picking up said vibration adjacent said device; and initiating operation of said device in response to said picked-up vibration.

16. A method of controlling the operation of an electrically responsive well device while suspended in a well bore from a wire line, characterized by: generating an alternating current of preselected frequency; translating said alternating current to elastic vibration of corresponding frequency; transmitting acoustically said elastic vibration from the upper part of said wire line to the lower end thereof; picking up said elastic vibration and translating the same into alternating electromotive force; and employing said alternating electromotive force to operate an electrical relay, thereby to initiate operation of said well device.

17. An apparatus for operating a well device while suspended in a well bore from a wire line, comprising: an acoustic transmitter and an acoustic receiver tuned to substantially the same frequency, the transmitter being located adjacent the upper end of the wire line and the receiver adjacent the lower end thereof adjacent the well device, both said transmitter and receiver being disposed in acoustical communication with said wire line; a relay adapted to be actuated by said receiver; and means adapted to be actuated by said relay for controlling the operation of said well device.

18. An apparatus for operating a well device while suspended in a well bore from a wire line, comprising: an acoustic transmitter and an acoustic receiver tuned to substantially the same frequency, the transmitter being located adjacent the upper end of the wire line and the receiver adjacent the lower end thereof adjacent the well device, both said transmitter and receiver being disposed in acoustical communication with said wire line; and means adapted to be actuated by said receiver for controlling the operation of said well device.

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