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Stroud et al.

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[54] **SELECTIVE FIRING INDICATOR AND RECORDER**

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[51] **Int. Cl.** **E21b 43/116**

[58] **Field of Search** 175/4.51, 4.54, 4.55, 175/4.56, 4.6

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[57] **ABSTRACT**

In a multiple perforating gun wherein each in a series of guns is successively fired, the firing arming the next gun in the series, resistors are provided in series with the gun actuating circuit in such a fashion, and in connection with surface control, readout, and recorder equipment, that the condition of the tool is continuously displayed and indicated, whereby a tally may be kept as to the exact guns fired, and down-the-hole irregularities such as shorts or open circuits may be evidenced.

9 Claims, 3 Drawing Figures

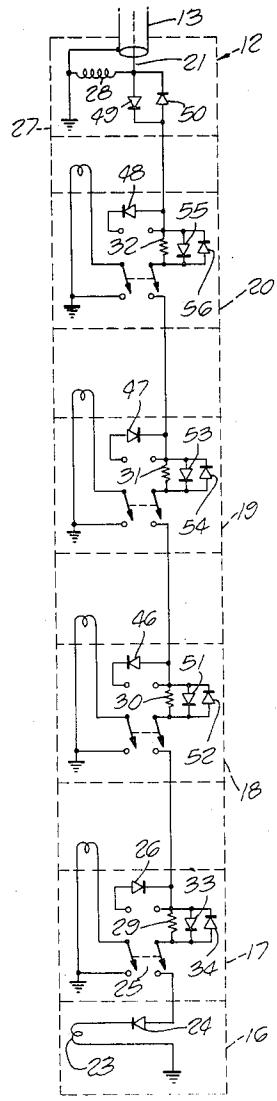
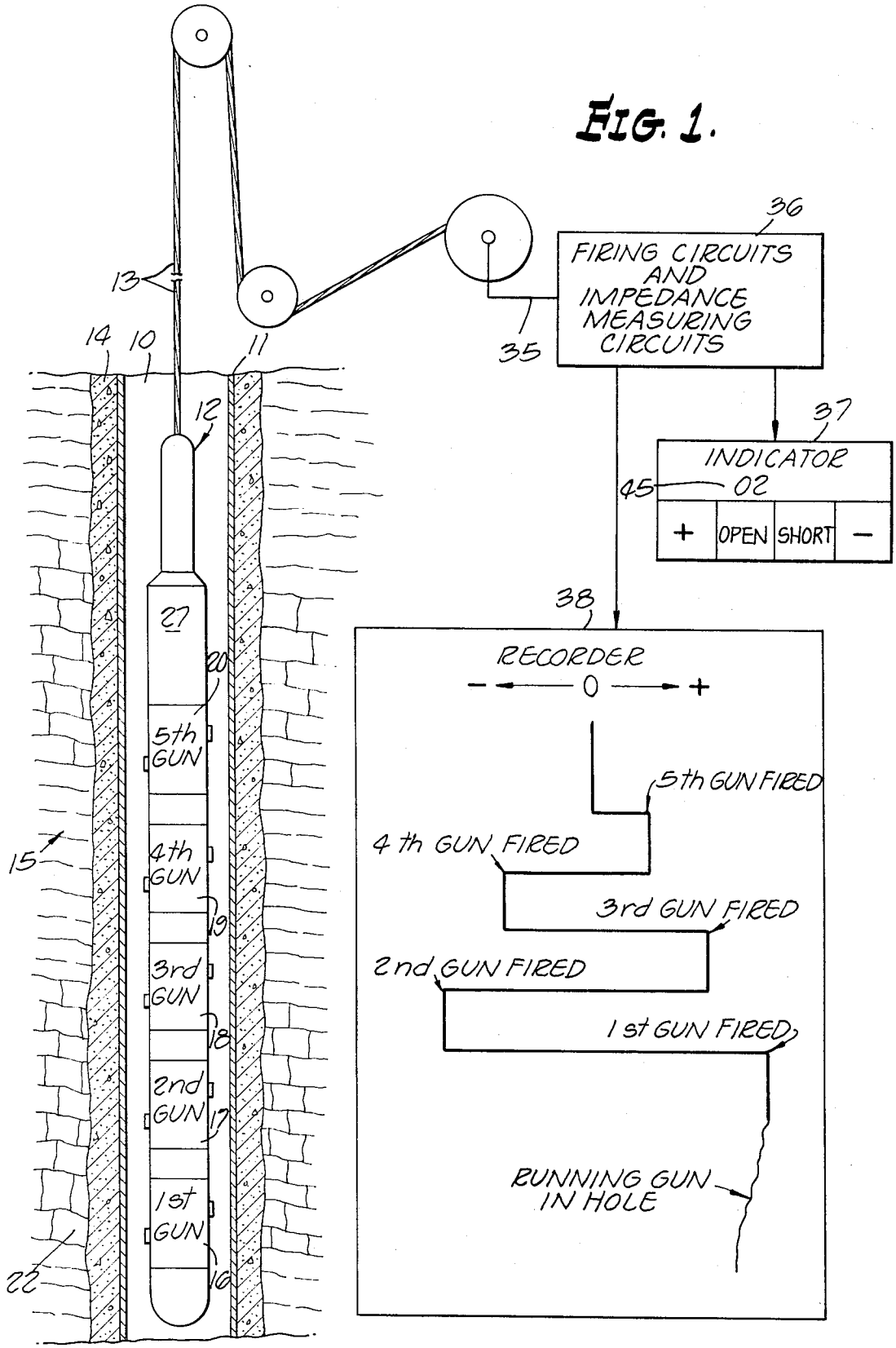


FIG. 1.


36
FIRING CIRCUITS AND IMPEDANCE MEASURING CIRCUITS
35
37
INDICATOR
45
02
+
OPEN
SHORT
−
38
RECORDER
− 0 +
5th GUN FIRED
4th GUN FIRED
3rd GUN FIRED
2nd GUN FIRED
1st GUN FIRED
RUNNING GUN IN HOLE
13
14
10
11
12
27
20
5th GUN
4th GUN
19
3rd GUN
18
2nd GUN
17
1st GUN
16
15
22

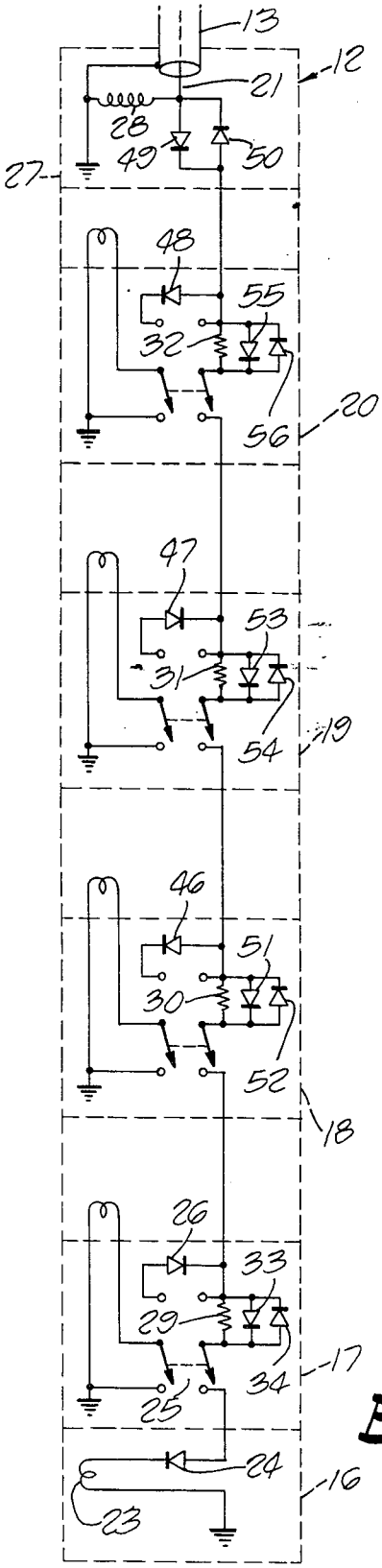

13
12
21
28
49
50
27
48
55
32
56
20
47
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51
30
52
18
26
33
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34
17
25
24
16
23

FIG. 2.

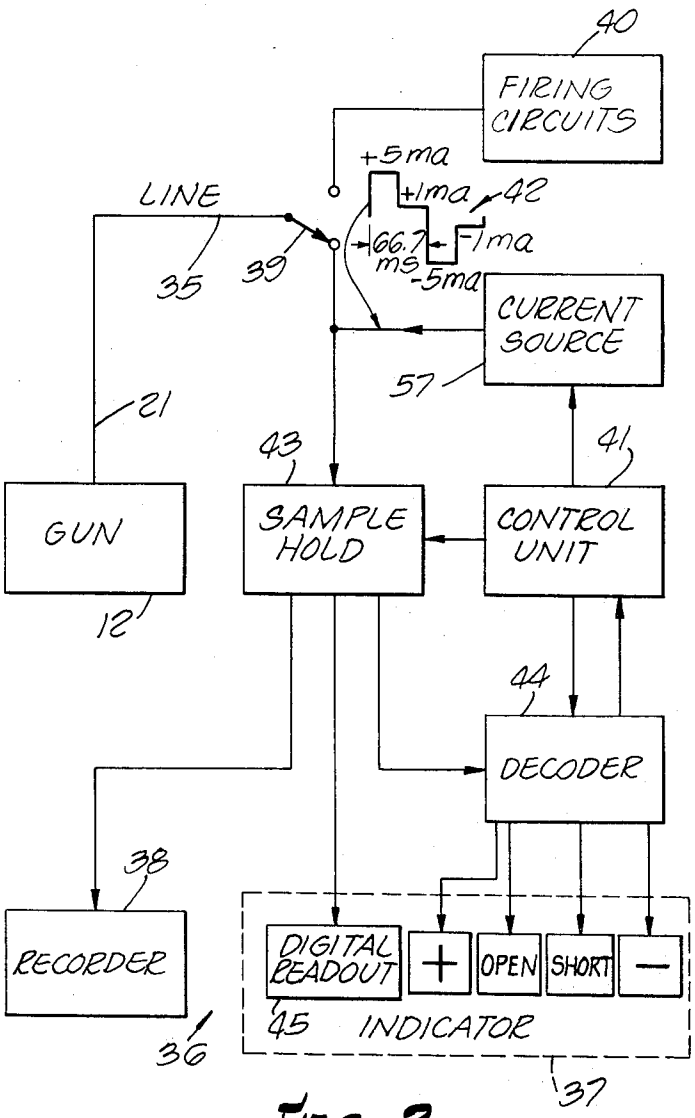

40
FIRING CIRCUITS
+5ma
+1ma
42
LINE
66.7 ms
-1ma
-5ma
35
39
CURRENT SOURCE
57
21
43
41
GUN
SAMPLE HOLD
CONTROL UNIT
12
44
DECODER
38
RECORDER
DIGITAL READOUT
+
OPEN
SHORT
—
45
INDICATOR
36
37

FIG. 3.

SELECTIVE FIRING INDICATOR AND RECORDER

BACKGROUND OF INVENTION

This invention relates to the monitoring of an explosive tool for use in a well bore.

In performing completion operations in a well, it is often necessary to selectively activate electrically detonated explosive devices, so that a number of completion operations at separate well depths may be performed with a single trip into a well.

For example, one of the steps in completing oil and gas wells is perforating the casing to allow entry of the oil or gas. In some wells the oil or gas bearing formation is continuous. The casings in these wells are perforated with one or more guns until the entire productive zone is opened.

The productive formation is not always continuous in all wells. There may be wells that have non-productive streaks in the oil-bearing zone and it would not be desirable to perforate these intervals. Multiple short gun runs, blanked-off shots of long guns, and spacers between guns have all been used to selectively perforate the productive zones in these wells. A better solution is a multi-gun tool where the operator can selectively fire each gun separately. Selective fired guns have been used for many years and a number of problems have been encountered. The selected gun may fail to fire because of electric circuit failures, including shorts or opens in the wire ine or in the down hole circuit. At times the wrong gun or guns may become armed due to an electrical or mechanical failure. If the wrong gun is fired, the well may be perforated in the wrong zone and expensive repairs, such as cementing, may be required. These problems have been minimized by improved gun design, but have not been eliminated.

The select fire gun consists of several guns connected in series with down-the-hole switches, i.e., "switch subs. " The circuits in these switch subs are such that the bottom gun is set to fire first. The blast from this first gun switches the first switch sub and the second gun is armed. Consecutive guns are of opposite polarity, eliminating multiple gun firings.

Each time a switch sub switches, a resistor is dropped from the circuit, the next gun is armed, and its diode is of opposite polarity.

SUMMARY OF THE INVENTION

The present invention relates to a method and apparatus for measuring the complete electrical impedance of a wire line explosive tool, including the wire line, so that from this measurement the condition of the down hole tool may be determined. The term "electrical impedance" as used above is meant to include situations involving non-sinusoidal quantities of non-linear systems.

One object of this invention is to provide an arrangement for measuring the electrical impedance of a wire line explosive tool and from this measurement to determine if the explosive tool is armed and ready to fire.

Another object is to provide a system to measure the electrical impedance of a wire line tool, including the wire line, and from this measurement to determine if there is a short circuit or an open circuit in the wire line and tool system.

Another object is to provide an assembly to measure the electrical impedance of a wire line multi-gun explosive tool in such a way as to be able to determine which gun is armed and ready to fire.

Another object is to provide an arrangement to measure the electrical impedance of a wire line explosive tool, including the wire line, continuously while running the tool in a well bore so that from this measurement changes in the operating condition of the wire line and tool system may be determined.

Other objects of the invention will appear as the description thereof proceeds.

DESCRIPTION OF DRAWINGS

FIG. 1 is a drawing partly in cross-section and partly schematic of a down-hole perforating tool and surface recorder and indicator employing one embodiment of the invention.

FIG. 2 is a schematic drawing of the down-hole multi-gun perforating tool circuit.

FIG. 3 is a block diagram of the measuring system including the recorder and indicator.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, 10 designates a bore hole containing casing 11 to be perforated by a gun assembly 12 which is lowered into the bore hole by a wire line 13. As is well known in the art, the purpose of the gun assembly is to perforate, as by shaped charges or projectiles, through the casing and cement 14 into preselected portions of the formation 15.

The gun assembly 12 comprises a series of vertically spaced guns 16, 17, 18, 19, 20, although of course more or fewer may be used according to circumstances. As many as ten or twenty are commonly used. It will be observed that the first gun 16 is positioned opposite the formation stratum 22.

Referring to FIg. 2; this shows the five guns, 16–20 inclusive, together with the wiring diagram for each. It will be noted that the cable 13 has a single conductor 21, but it should be noted that a direct current pulse can be applied to the conductor 21 in either of two polarities, positive or negative.

The first gun 16 is caused to fire by applying a positive pulse to conductor 21. In this first gun 16, 23 designates the electric blasting cap, which is detonated when a current passes through it and which then fires the projectiles of the gun. The diode 24 of gun 16 is arranged to pass the actuating positive pulse. It will be observed that all of the other guns in assembly 12 present an open circuit to a positive or negative pulse by reason of the fact that their switches are in the "down" or open position, as shown in FIG. 2.

The firing of gun 16 by mechanical action throws switch 25 of gun 17 to the "up" position. This action has already been explained, and need not be detailed here since this overall arrangement is well known to those skilled in the art.

Gun 16 having been fired and switch 25 having been closed as already explained, the second gun, 17, is now ready for firing. This may be done when desired by applying a negative firing pulse to conductor 21. It will be observed that diode 26 in gun 17 is arranged with opposite polarity to that of diode 24 in the first gun 16.

This sequence is repeated; each time a gun is fired, it throws the switch on the gun immediately above, so that that gun is put into position for firing. For the latter, a pulse of pularity opposite to that used for the previous gun is employed.

The arrangement depicted in FIGS. 1 and 2 includes an optional casing collar locator 27, containing a casing collar locator coil 28, all of conventional construction.

It will be seen that each gun contains a resistance 29, 30, 31, and 32. These resistors are initially all in series. As each successive gun is fired, and the switch of the gun next above is thrown from the "down" to the "up" position, the resistor associated with that switch and that gun is shorted out, as may be seen by noting the switch connections of, for example, switch 25.

Tracing the circuit path from the top of FIG. 2 to the bottom, it may be seen that the impedance from conductor 21 to ground, before any of the guns are fired, consists of the resistors 29, 30, 31, and 32 in series, together with the effective forward or reverse impedance, depending upon the polarity of the measuring current, of firing diode 24; together with the resistance of the blasting cap device 23, all in series. When the casing collar locator 27 is included in the arrangement, this total impedance is shunted by coil 28, but the resistance of the latter is so high as to have a negligible effect on the overall resistance measured. Each of the resistors 29, 30, 31, and 32 may optionally be shunted by a pair of diodes 33 and 34 (for the case of resistor 29), in parallel connection with opposing polarities. These resistor-shunting diodes, such as 33 and 34, are of a conventional type that will pass (in a forward direction) the relatively high firing current, typically 0.5 ampere, but on the other hand present an impedance in both forward and reverse directions which is substantially infinite compared to the resistance of the resistor being shunted, for example resistor 29, for the very low voltage drop across them during the measuring pulses, to be described in detail later. The purpose of these optional resistance shunting diodes is to reduce the effective impedance for the firing current, so that they become more useful as the total number of guns in the arrangement increases.

A typical value of resistance 29 is 10 ohms. A suitable diode type for both the shunting diodes 33, 34 etc. and for the firing diodes 24, 26, etc. is 1 N 4004.

Turning now to FIG. 1, it will be seen that the above-ground end 35 of conductor 21 is connected with the above-ground control, indicating, and recording apparatus, which is shown for the sake of clarity in block diagrams, 36 indicating the circuitry handling the firing of the guns as well as the impedance measurement; 37 being the visual readout, and 38 being the recorder, with a typical recording shown in the block. The actual circuit and apparatus details of this surface equipment, including that shown in FIG. 3, is conventional and details need not be set forth to those skilled in the art. FIG. 3 is a block diagram which again shows the indicator 37 and recorder 38, and presents the firing and impedance measuring apparatus in separate blocks. Switch 39 is shown in the impedance measuring position in which it is normally except during firing, when it is thrown to the other position. The firing circuits 40 are conventional.

Turning now to the impedance measuring circuit, this is arranged so as to measure the magnitude of the line and tool resistance as well as to determine the polarity for minimum resistance, in a manner to be described later. The recorder 38 continuously records the resistance measured, and is conveniently of a zero center type, indicating zero resistance at the center and deflections to the right for conditions of positive minimum resistance and deflections to the left for conditions of negative minimum resistance, all as will be clear from an inspection of FIG. 1.

The indicator 37 actuates a "short" light for an abnormally low resistance and an "open" light for an abnormally high resistance. A + light indicates the condition of the minimum resistance being positive, while a − light indicates the condition of the minimum resistance being negative. In addition, the indicator panel contains a digital counter which is responsive to the total resistance of line and gun, and is calibrated so that the counter number indicates which gun is armed and ready to fire. A typical arrangement of indicator lights and digital counter is shown in block 37 of FIG. 1.

While the "tool," i.e., the multiple gun, is being run into the hole, the first or lowest gun is armed and ready to fire, as already explained. The invention makes possible a continuous recording of the resistance so that any change in the condition of the wire line or the tool will be detected. Normally, as already explained, the first gun is wired for positive voltage firing so that the polarity for minimum resistance will be positive; and moreover, the recorder will deflect to the right as seen in FIG. 1, block 38. While running the gun in the hole, the temperature of the wire line may increase due to the increase in temperature with depth and the line resistance may increase slightly, again as indicated in FIG. 1.

As already described, after the gun is properly positioned, the first gun is fired using the firing circuit. The blast from the explosion in the first gun 16 operates switch 25 in the second gun, thus removing the first gun from the firing circuit and connecting the second gun 17 in turn to the firing circuit. As already noted, the second gun 17 is wired for negative voltage firing. Accordingly, after switch 25 has been thrown, as just described, the recorder 38 will deflect to the left and the magnitude of the deflection from zero will be slightly less, as shown in FIG. 1, because the total resistance is slightly lowered when the first gun is removed from the circuit. The indicator light 37 will change from + to − because of the negative circuit in the second gun; and the digital counter in indicator 37 will change from 01 to 02 in response to the lowered total resistance.

In a like manner, after the second gun 17 is positioned opposite the second zone to be perforated and has been fired, the blast from the explosion in the second gun will throw the second switch, i.e., that in gun 18, causing the recorder to deflect to the right for a positive third gun, as shown in FIG. 1, block 38. At the same time, the digital indicator will change from 02 to 03, and the + light will be lighted.

In a continuing and successive manner, each gun, when positioned and fired, will operate the switch immediately above it, which will arm the next gun up. Each time this happens, the polarity indication in indicator 37 will change, and the recording pen will move to the opposite side of the zero center, as the figure shows.

If a fault such as a short circuit occurs in the line or tool while running into the hole or during the firing sequence, the resulting low resistance will light the "short" light and the recorder deflection will be substantially reduced. If an open circuit occurs, the resulting high resistance will light the "open" light and the recorder will be deflected off scale. If a wrong gun should become armed due to a mechanical or electrical

failure, the digital readout in indicator 37 will show which gun is now armed and the recorder will show a reduction in the total resistance.

Turning now to FIG. 3, this shows the arrangements of the components of the surface control, indicating and recording assembly. The impedance from line 35 to ground may be measured in a number of fashions. For example, it is possible to apply a constant voltage and measure the current. We find it more convenient and we prefer to apply a constant current, following impedance changes by noting the change in voltage required. Because of the non-linear circuits involved, resulting from the operating characteristics of the diodes, we find it convenient to use a current source having four levels, two positive and two negative, and to generate clock pulses which cause the current source to generate four levels of current in sequence, as shown by wave form diagram 42 in FIG. 3, which shows current as ordinates and time as abscissae. Conveniently, as shown by wave form 42, a pulse of high level positive current at 5 milliamperes is followed by a pulse of the same duration of low level positive current at 1 milliampere, which is followed in turn by a high level negative current of −5 milliamperes and then by a low level negative current of −1 milliampere. Each pulse duration may be about 33 milliseconds, as shown by 42 in FIG. 3. This cycle is then repeated continuously, except during the actual firing when switch 39 is momentarily placed in its firing position. These currents are applied to the line 35 and in consequence to the subsurface tool, i.e., the gun assembly 12. At each of the four current levels just described, and illustrated at 42, the line voltage is sampled and stored in the sample hold unit 43. The two voltage samples from the positive and negative high current levels are compared and measured. The result of this measurement is sent to the decoder 44.

Decoder 44 serves to interpret the above measurement and to energize the appropriate light in indicator panel 37 if the two voltage samples are above a predetermined level. For example, if this predetermined level is 4 volts, then the "open" light is energized. If the two voltage samples are below a predetermined level, which may be 4 volts for example, the "short" light is energized. If the positive current sample voltage is above 4 volts and the negative current sample is less than 4 volts, then the − sign light is energized. If the negative current sample voltage is above 4 volts and the positive current sample voltage is less than 4 volts, the + light is energized.

The digital meter readout 45 which is part of the indicator assembly 37 is operated from the current sample voltages. When the + light is energized, the low level positive sample voltage is subtracted from the high level of positive sample voltage and the resulitng voltage is sent to the digital readout 45. With the proper scale factor and calibration, the digital readout 45 will indicate the gun number assembly which is armed and ready to fire. When the − sign light is energized, the high level negative sample voltage is subtracted from the low level sample voltage and the resulting voltage is sent to the digital readout 45 as already described.

The recorder 38 is operated from the current sample voltage in the following manner. The high level positive sample voltage is sent to the recorder in all cases except when the − light is energized, in which case the high level negative sample voltage is sent to the recorder 38.

It will be observed that one of the advantages of using constant current instead of constant voltage for the measuring operation is that the complication is avoided of unwanted shunting of the measuring resistor, e.g. 29, by the shunting diodes, e.g., 33 and 34. Thus, if the measuring resistor 29 is 10 ohms and the maximum measuring current is 5 milliamperes, then the maximum voltage impressed across the shunting diodes 33 and 34 during the high current measuring pulse is 50 millivolts, which is well below the forward voltage characteristic of diodes 33 and 34 which is several hundred millivolts even at the relatively high subsurface temperatures encountered during the use of the tool.

As mentioned, the casing collar locator 27 is optional. When it is included, however, it is helpful to utilize a pair of diodes, 49 and 50, of the same type already described, connected as shown in FIG. 2. The signal developed by the casing collar locator coil 28 is very low level, below the forward breakdown voltage of the diodes, so that all of this low level signal is available for detection through conductor 21, instead of being partially shunted by the impedance of the total circuit below locator 27.

The firing diodes 46, 47, and 48 are identical in nature to previously described firing diodes 24 and 26. Likewise similar, and also similar to previously described diodes 33 and 34, are the other resistor shunting diodes 51–56 inclusive.

The current source 57 shown in FIG. 3 is of course conventional, and may derive its power from a self-contained generating unit, a battery array, a power line, or the like, as field conditions dictate.

In describing our invention, we have of course given detailed descriptions of apparatus and procedural details. By way of summarizing the procedure in somewhat more general terms, it may be helpful to note that we provide a method of determining the condition of a down-the-hole electrical circuit which contains a series of actuatable elements, each of which is capable of being terminally actuated (that is, actuated once so that thereafter it cannot be further actuated) by successive electrical pulses of relatively high intensity and of alternating polarity and in which the actuating pulse by-passes the elements which have not yet been actuated through the means of bypassing resistors, each of which is switched out of the circuit only as its corresponding element becomes actuated, i.e., terminally, and so as to reach the next element in line to be actuated, and in which we pass a series of measuring pulses through the circuit of intensity insufficient to actuate the elements and of alternating polarity; and we then cause the impedances measured by these measuring pulses of alternating polarity to operate an indicating display which is responsive both to the impedance and the polarity of the measuring pulses which have been used to determine the impedance. We further pass the measuring pulses to a recorder so that we may display the results of the impedance measurements as a function of polarity, all of which as explained in detail above gives an instantaneous picture of the down-the-hole condition of the circuit and as explained not only indicates how many elements have already been actuated, but indicates the next in line to be actuated and also reveals the absence or presence of open circuits and short circuits.

It will be seen that the invention accomplishes its objects, with the important feature of the unambiguous

character of the indications and readouts which has been described. While we have described the invention with the aid of a detailed illustrative example, we wish it to be understood that we do not desire to be limited to the exact details of construction shown and described, for obvious modifications will occur to a person skilled in the art.

Having described the invention, we claim:

1. In a subsurface multiple perforating gun and surface control and measuring assembly comprising a series of guns in vertical array, and wherein each gun in said series is successively fired by a firing pulse which is passed through a circuit extending throughout the series and switched into only one gun at a time, said firing switching in the next gun in the series, each said gun carrying a diode in its firing circuit, with each successive such diode being connected with alternating polarity, the improvement which comprises the provision of a resistor in said circuit for each said gun except for the first gun, each said resistor serving to conduct said firing pulse to any next adjacent gun which is not yet switched to its firing position, and each said resistor being shorted out when its associated gun is switched into firing position;

impedance measuring means operating at a level too low to cause firing of said guns and serving to determine the direct current impedance of said circuit at both positive and negative polarities;

indicating means to indicate the results of said impedance measuring.

2. The assembly of claim 1 which comprises recording means to record the results of said impedance measurements.

3. The assembly of claim 1 including means to carry out said impedance measurements by a continuous series of successive fixed current pulses of both positive and negative current insufficient to fire any of said guns.

4. The assembly of claim 3 in which said measuring current pulses consist of a relatively high positive current, followed by a relatively low positive current, followed by a relatively high negative current, followed by a relatively low negative current, repeatedly in succession.

5. The assembly of claim 4 in which said indicating means is actuated by the voltages generated by said measuring current pulses to indicate the various conditions of said gun as to whether a short circuit exists, an open circuit exists, or whether the next gun in firing condition is actuated by a positive or by a negative pulse.

6. The assembly of claim 4 in which said measuring current pulses actuate a recorder which registers the impedance thus determined and also the polarity for minimum impedance.

7. The assembly of claim 4 in which said relatively high currents are about 5 milliamperes and said relatively low currents are about 1 milliampere.

8. The assembly of claim 7 in which the duration of each pulse is about 33 milliseconds.

9. The assembly of claim 7 in which said resistors are about 10 ohms.

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