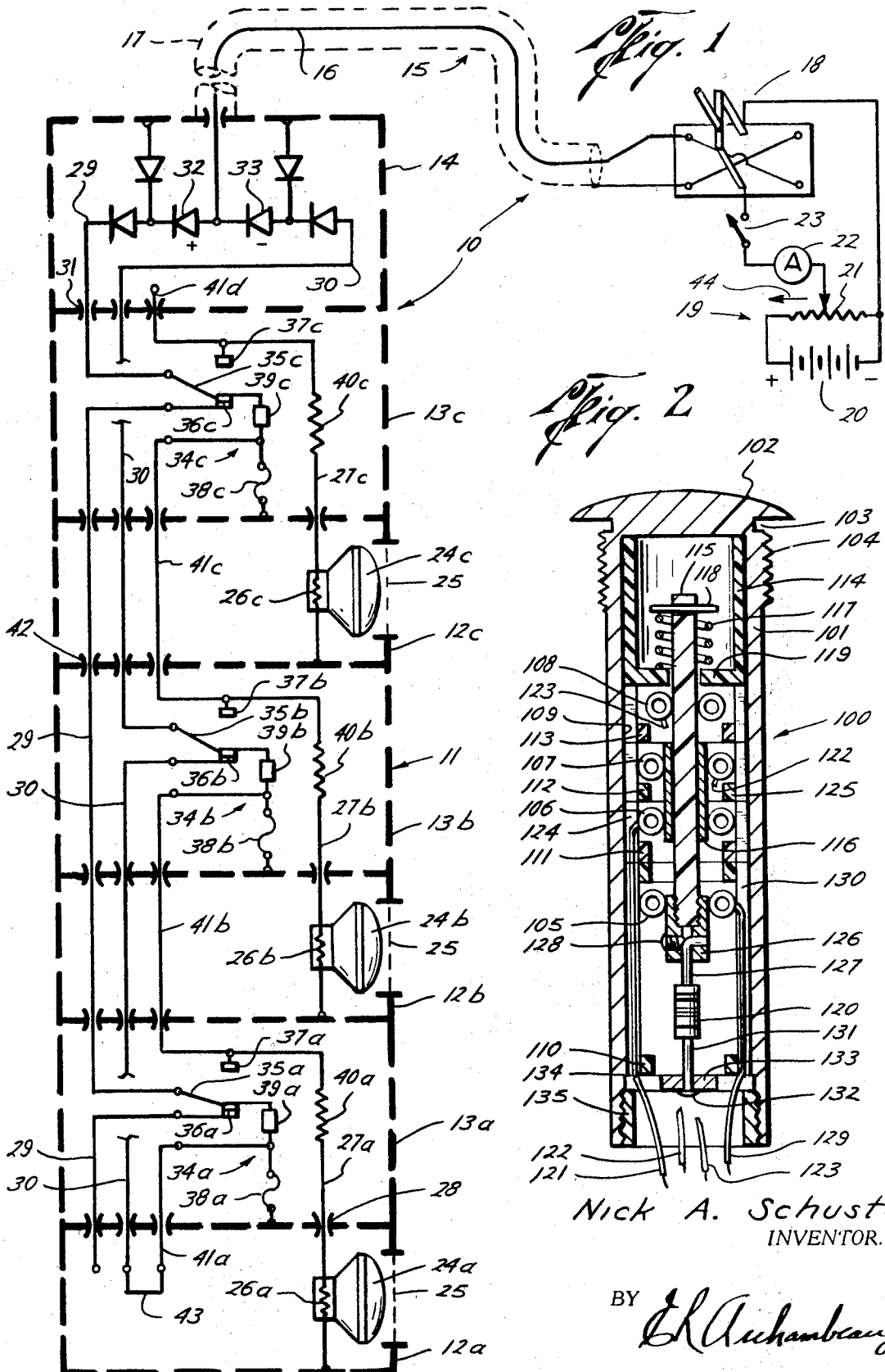


June 30, 1970

N. A. SCHUSTER
CONTROL APPARATUS FOR SELECTIVELY OPERATING
ELECTRICAL WELL-COMPLETION DEVICES
Filed Sept. 23, 1968

3,517,758



Nick A. Schuster
INVENTOR.

BY *Chambers*
ATTORNEY

1

3,517,758

CONTROL APPARATUS FOR SELECTIVELY OPERATING ELECTRICAL WELL-COMPLETION DEVICES

Nick A. Schuster, Darien, Conn., assignor to Schlumberger Technology Corporation, New York, N.Y., a corporation of Texas

Filed Sept. 23, 1968, Ser. No. 761,454

Int. Cl. E21b 43/17

U.S. Cl. 175—4.55

17 Claims

ABSTRACT OF THE DISCLOSURE

This disclosure is directed to control circuits for well-completion apparatus having one or more electrically-responsive devices that are to be selectively operated. The circuitry includes one or more normally-disabled controls that are selectively actuated by a predetermined electrical current. Upon application of sufficient current thereto, each selectively-operable control enables its associated electrical device and connects it into a selected circuit for subsequent operation.

Present-day well-completion techniques often require that a plurality of electrically-responsive explosively-actuated devices, such as control valves for sampling tools, shaped charge perforators, or formation-coring bullets, be selectively actuated so that only a single trip into a well is required to successively perform a number of completion operations. For example, in perforating a well that is to be completed at different depths, apparatus carrying a number of shaped charges is lowered into the well to a selected position. Then, the first of the shaped charges are detonated. Thereafter, the perforating apparatus is re-positioned to another depth and one or more of the remaining shaped charges are detonated. This procedure is repeated until all of the desired perforations have been made.

Those skilled in the art will, of course, appreciate that whatever arrangement is used to selectively detonate such explosive devices must be highly reliable to avoid, for example, perforating a well casing at an incorrect depth. Accordingly, heretofore, typical control systems have employed such safety measures as detonators that are responsive to different levels of electrical current, successively-indexed multi-contact switches, or normally-open switches that are closed only as a result of the detonation of a previous explosive device. Although control systems of this nature have generally been successful, there is, however, still a need for selectively-operable control systems that are sufficiently reliable for use with such well-completion tools having a number of explosive devices and without requiring elaborate circuitry.

Accordingly, it is an object of the present invention to provide new and improved relatively fool-proof control systems for selectively controlling one or more electrical devices in a well-completion tool.

This and other objects of the present invention are attained by circuitry respectively connecting each selectively-operable electrical device in a well tool to electrical control means including a movable member that is releasably held in one position by a current-destructible conductive member until sufficient current is passed therethrough to release the movable member for movement to a second position.

The novel features of the present invention are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may be best understood by way of the following description of exemplary apparatus employing the principles of

2

the invention as illustrated in the accompanying drawings, in which:

FIG. 1 schematically illustrates perforating apparatus employing electrical circuitry arranged in accordance with the principles of the present invention; and

FIG. 2 depicts a current-responsive control suitable for use in the new and improved circuitry shown in FIG. 1.

Turning now to FIG. 1, a schematic representation is shown of a preferred embodiment of new and improved electrical circuitry 10 arranged in accordance with the present invention. The present invention can, of course, be used to selectively operate many types of electrical devices typically found in well tools. The preferred use of the invention is, however, for controlling such electrically-responsive explosively-actuated devices as the control valves shown in Pat. No. 3,329,208, the coring bullets shown in Pat. No. 3,329,217, or (as shown in FIG. 1) perforating apparatus 11 which, for example, is arranged in accordance with Pat. 3,329,218. It will be realized, of course, that the control circuitry 10 can be either distributed throughout the apparatus 11 in any convenient arrangement or else the circuitry can be concentrated into a single section thereof. However, to arrange the various elements of the circuitry 10 as fully-interchangeable integrated units as well as to allow any number of these integrated units to be assembled without special consideration, the perforating apparatus 11 includes a plurality of tandemly-connected, fluid-tight housing sections 12, 13 and 14 that are adapted for suspension as a single body in a well bore (not shown) from a cable 15 that is spooled in the usual manner on a winch (not shown) at the surface. As is typical, the suspension cable 15 has a single central conductor 16 that is enclosed within an electrically-conductive armored sheath 17 which serves as another electrical conductor. Both of these conductors 16 and 17 are appropriately connected to the surface by a conventional reversing switch 18 to a selectively-operable power source 19 such as provided by a battery 20 having a potentiometer 21 across it and in series with an ammeter 22 and a control switch 23. In this manner, an operator may conveniently select both the polarity and the voltage potential that is to be applied to the conductors 16 and 17 as well as to regulate the magnitude of the current flowing through the cable conductors.

Perforating means are provided such as typical shaped charges 24 that are respectively fluidly sealed within each of the housing sections 12 and oriented along a laterally-directed perforating axis intersecting a replaceable closure 25 in the side of each section. The perforating means further include electrically-responsive detonating means, such as typical initiators 26, that are arranged within detonating proximity of the rear of each of the shaped charges 24. Inasmuch as the armored sheath 17 is electrically connected to all of the housing sections 12-14, each of the initiators 26 is conveniently arranged for one side of its filament to be in electrical contact with the assembled housing sections (as schematically shown in FIG. 1) and the other side of the filament is connected to a conductor 27 that is passed through a fluid-tight seal or connector plug (as at 28) into the adjacent housing section 13. In this manner, well-bore fluids entering the housing sections 12 upon detonation of the shaped charges 24 are prevented from entering the separate housing sections 13 and contacting the various components of the circuitry 10.

The particular manner of connecting the circuitry 10 of the invention to the surface equipment is, of course, dependent upon the number of electrical conductors in the suspension cable. Where, for example, a multi-conductor cable is used, one cable conductor may be connected to the housing sections and two other cable conductors are simply connected to separate conductors, as

3

at 29 and 30, that begin in the upper housing section 14 and are respectively carried through appropriate fluid-tight seals or mating connector plugs, as at 31, into the alternately-disposed housing sections 12 and 13 depending therebelow. On the other hand, since it is usually preferred to use less-bulky monoconductor suspension cables, as at 15, for perforating tools, one or more oppositely-poled diodes as at 32 and 33 in the upper housing section 14 are both connected to the central cable conductor 16 and respectively connected to the conductors 29 and 30. Thus, when the reversing switch 18 is thrown so as to connect the positive pole of the battery 20 to the central cable conductor 16, current will readily flow through the diodes 32 and the conductor 29, and the diodes 33 will block current flow through the conductor 30. On the other hand, when the reversing switch 18 is in its other operating position, current will flow only through the diodes 33 and the conductor 30, and no current will flow through the conductor 29.

The circuitry 10 of the present invention also includes a control device, such as a single-pole double-throw switch 34 in each of the housing sections 13, that is selectively operable from the surface for the successive detonation of the shaped charges 24. In the preferred manner of accomplishing this, each of these switches 34 is comprised of a movable contact 35 that is initially engaged with a first fixed contact 36 and is movable to a second fixed contact 37 only upon the failure of a current-destructible restraining link 38 that is either destroyed or substantially weakened upon passage of excessive current therethrough. An electrical insulator 39 isolates the link 38 from the switch contacts 35-37. The conductors 27 from the explosive initiators 26 are respectively connected to the second fixed contact 37 of their associated control switch 24, and preferably have a current-limiting device, such as a resistor 40, serially connected between this contact and the initiator. Conductors 41 are also connected between each of the second fixed contacts 37 of one switch 34 and the destructible link 38 for the next successive switch.

As is schematically depicted in FIG. 1, the conductors 29 and 30 extend the full length of the apparatus 11 and are alternately divided and successively connected in a staggered sequence to the moving and fixed contacts 35 and 36 of the several switches 34. Thus, as illustrated, the conductor 29, for example, is divided and connected only to the odd-numbered switches (as at 34a and 34c) and the conductor 30 is divided and connected only to the even-numbered switches (as at 34b). It will be realized, of course, that to facilitate their connection and disconnection as well as to make the units fully interchangeable, the conductors 29, 30 and 41 are all connected to fluid-tight electrical plugs, as at 42, that are readily mated as the housing sections 12, 13 and 14 are assembled. Thus, since only three duplicate units are shown in FIG. 1, the conductor 41d has no mating contact in the housing section 14 and the conductor 41a must be connected, as by a jumper 43 to the lower end of the conductor 30 to complete the circuitry 10. It will also be appreciated, of course, that those portions of the conductors 29, 30 and 41 passing through the housing sections 12 should be protected in some manner from the explosive forces of the shaped charges 24.

Accordingly, once the perforating apparatus 11 is assembled and the circuitry 10 is connected as shown in FIG. 1, the apparatus is lowered on the suspension cable 15 to the first position in a well bore (not shown) where a perforation is to be made. It will be appreciated that so long as the switches 34 are in their depicted positions, not only will the initiators 26 be disconnected from the firing circuit (as represented by the conductors 29 and 30) but the initiators will also be safely shunted by their respective resistors 40 and destructible links 38. Thus, stray electrical currents cannot inadvertently detonate the

4

disabled shaped charges 24 and the perforating apparatus 11 cannot be armed until the power source 19 is connected in a selected manner to the cable conductors 16 and 17 and a current of a predetermined magnitude is obtained.

Once the perforating apparatus 11 is positioned in the well bore so as to bring the shaped charge 24a to a selected depth, the reversing switch 18 is thrown to the left (as viewed in FIG. 1) to connect the negative pole of the battery 20 to the central cable conductor 16. Then, after the switch 23 is closed, the potentiometer 21 is advanced (as shown by the arrow 44) to increase the current flowing through the firing circuit conductor 30. It will be appreciated that at this point all current flowing through the conductor 30 must pass (by way of the jumper 43) through the link 38a. Thus, by continuing to advance the potentiometer 21, the magnitude of current flowing through the destructible link 38a will ultimately exceed the predetermined current level required to blow the link 38a and release the movable switch contact 35a for movement to the fixed contact 37a. It will be appreciated that the insulator 39a electrically isolates the switch 34a from the conductive link 38a.

Once a passage of current through the conductor 30 fails the link 39a and the movable switch contact 35a engages the fixed contact 37a, the other conductor 29 of the firing circuit is then connected through the fixed contact 37a to the initiator 26a as well as to the next conductive link 38b. At this time, however, the diodes 32 prevent any current from flowing in the firing circuit conductor 29. Thus, the shaped charge 24a cannot be detonated until the reversing switch 18 is thrown (to the right as viewed in FIG. 1) to its other operating position.

It should be noted also that failure of the conductive link 38a will open the circuit path so that upon seeing the ammeter 22 drop to zero, it will be known that the switch 34a has been actuated. Reversal of the reversing switch 18 connects the positive terminal of the battery 20 to the firing circuit conductor 29 and the conductors 41b and 27a. Thus, the current flowing at this time in the firing circuit will initially divide at the switch contact 37a and flow through both the destructible link 38b and the initiator 26a. It is preferred, however, to actuate the switch 34b before the shaped charge 24a is detonated. Accordingly, by selecting the resistors 40 to have a relatively high resistance in relation to the resistance of the links 38, most of the current flowing in the firing circuit conductor 29 will pass through the destructible link 38b until this link fails. Once the link 38b has failed, however, all of the current flowing in the conductor 29 will be diverted to the initiator 26a. Then, if necessary, the potentiometer 21 is advanced until the shaped charge 24a is detonated. Here again, once the shaped charge 24a is detonated, the circuit will be broken and the cessation of current flow as indicated by the ammeter 22 will provide a reliable indication at the surface that the shaped charge 24a has been detonated.

Detonation of the next shaped charge 24b requires that the reversing switch 18 again be reversed. Upon reversal of the switch 18, the initiator 26b and link 38c are initially paralleled. In the same manner as already described, the destructible link 38c is first failed to actuate the switch 34c. Then, once sufficient current flows through the initiator 26b, the shaped charge 24b will be detonated and the ammeter 22 will again provide a positive indication at the surface. It will be appreciated that if additional shaped charges 24 and switches 34 were positioned between the housing sections 12c and 13b, the successive actuation of these other switches 34 and detonation of these additional shaped charges 24 would, of course, be accomplished in the same fashion by alternately applying current to first one and then the other of the firing circuit conductors 29 and 30 in successive turns.

5

The last control switch 34 in the perforating apparatus 11 is preferably actuated prior to the detonation of the next-to-last shaped charge 24. Thus, referring again to FIG. 1, it will be recognized that when the reversing switch 18 is operated to direct the current flow to the fixed switch contact 37b, the conductive member 38c will initially be broken to actuate the uppermost switch 34c before the shaped charge 24b is detonated. Once the next-to-last shaped charge 24b is detonated, only the last initiator 26c is now connected to the firing circuit. Thus, upon the subsequent reversal of the switch 18, all current flowing in the conductor 29 will pass through the initiator 26c.

There are, of course, a variety of prior-art failure-actuated switches that presumably are functionally equivalent to those shown at 34 in FIG. 1. However, those skilled in the well tool art will appreciate that few—if any—of these prior-art switches would be capable of reliably functioning in a typical well-completion tool such as the perforating apparatus 11. For example, in addition to the extreme pressures and temperatures typically encountered in well bores, any successful control switch of this nature must be of exceptionally rugged construction to withstand the severe physical shocks imposed on a well-completion tool during the course of even a routine operation. It will also be appreciated that for purposes of economy, any control switch must be relatively inexpensive.

Accordingly, in FIG. 2 a preferred embodiment is shown of a control switch 100 for use in the circuitry 10 of the present invention. Although the switch 100 could, of course, be simply disposed within one of the housing sections of a well-completion tool, it is preferred to arrange the switch to be secured in an access port in the tool housing for purposes of convenience.

In this preferred embodiment, the control switch 100 has a tubular case 101 with a suitably arranged closure member 102 on its outer end just ahead of a circumferential sealing ring groove 103 and external threads 104. By making at least a substantial portion of the tubular case 101 of an electrically-conductive material, once the threads 104 are matingly engaged with complementary threads in an access port in a tool body, the tubular case 101 will be electrically connected to the tool body. A plurality of fixed electrical contacts 105–108 are spatially disposed along the internal bore 109 of the case 101 and electrically insulated from one another and the case by suitable non-conductive materials which may be conveniently formed as a stack of spools or sleeves 110–114. In the preferred manner of arranging these fixed contacts 105–108, small garter springs of electrically-conductive materials are employed.

A shaft 115 of an electrically-nonconductive material and carrying a conductive contact member, such as a tube 116, on its intermediate portion is suitably positioned in the case 101 for axial movement from the position shown to a more-forward position. To move the shaft 115 forwardly, means are provided such as a compression spring 117 around the forward end of the shaft that is yieldably constrained between a transverse pin 118 thereon and an inwardly-directed shoulder 119 on the insulating sleeve 114. The shaft 115 is, however, releasably retained in the illustrated position by an electrically-destructible link, such as a fuse strip of a durable material or a common carbon resistor 120, secured in tension between the rear of the shaft and the case 101.

It will, of course, be appreciated, from FIG. 2 that the conductive sleeve 116 is cooperatively arranged to interconnect the contact springs 106 and 107 so long as the shaft 115 is held in its normal position. In this shaft position, the conductive sleeve 116 has radially expanded the contact springs 106 and 107 somewhat in relation to a more-relaxed contracted position (such as the illustrated position of the non-contacted spring 108) to insure satisfactory electrical contact. Forward movement of the axial shaft 115 will, however, drive the sleeve 116 into

6

the center of the forward contact spring 108 and expand that spring as the rearward contact spring 106 relaxes onto the insulated shaft to the rear of the conductive sleeve. Conductors 121–123 are respectively connected to the contact springs 106–108 and mouted out of the rear of the case 101 by way of circumferentially-spaced longitudinal slots or grooves, as at 124, formed in the walls of the insulating sleeves 110–113. To retain the contact springs 105–108 in their respective positions, the insulating sleeves 110–113 are preferably formed with inwardly-projecting shoulders as at 125.

Since the axial shaft 115 is of a non-conductive material, a coupling 126 of a conductive material is secured (as by the illustrated threads) to the rearward end of the shaft. The forward terminal wire or lead 127 of the resistor 120 is preferably passed through a suitable opening in the coupling 126 and clamped thereto by a set screw 128. The contact spring 105 is suitably positioned to at least be initially in electrical contact with the coupling 126 and has a conductor 129 connected thereto that is routed out the rear of the case 101 by way of a longitudinal groove 130 in the insulating sleeve 110. The rearward terminal wire or lead 131 of the resistor 120 is passed through a suitable opening and soldered, as at 132, to an electrically-conductive cross-shaped transverse member 133. To facilitate the replacement of the resistor 120, the transverse member 133 is preferably secured against a rearwardly-directed case shoulder 134 by a suitable threaded lock ring 135. It will also be noted that in addition to assuring satisfactory electrical contact between the case 101 and transverse member 133, the insulating sleeves 110–114 are appropriately arranged to have a stacked height just sufficient to be snugly clamped into their respective positions by the transverse member.

Accordingly, it will be appreciated that so long as the body of the resistor 120 remains intact, it will retain the axial shaft 115 in its rearward position against the force of the spring 117. By selecting the resistor 120 to have a minimum wattage rating as well as a particularly-low electrical resistance, it will be quite easy to pass sufficient electrical current through the resistor to quickly disrupt or destroy the mechanical strength of the resistor body so that the spring 117 will be capable of repositioning the shaft 115 once the body of the resistor parts. For example, if the resistor 120 is a typical ¼-watt carbon resistor with a resistance of 33-ohms and a current-limiting resistor (as at 40 in the circuitry 10) of 330-ohms is associated therewith, application of only 30-volts to the paralleled resistors will cause 0.9-ampere to flow through the resistor 120 and only 0.1-ampere will flow through the current-limiting resistor and the initiator (as at 26) connected thereto. The excessive power dissipation (nearly 27-watts) caused by such disproportionate current flow through the resistor 120 will, of course, quickly destroy the resistor 120. As a practical matter, therefore, it has been found that the body of such a low-resistance, low-wattage resistor will often be either completely parted or sufficiently weakened mechanically long before such current levels are reached. Thus, although the body of the resistor 120 is initially sufficiently stout to withstand severe impact shocks and the extreme environmental conditions of a well bore, the resistor body can always be reliably parted with a minimum of current that is well below the electrical current required to detonate a typical explosive device.

Accordingly, it will be appreciated that by virtue of the cooperative arrangement of the circuitry 10 of the present invention, one firing circuit conductor (for example, conductor 29 in FIG. 1) is initially connected to only the current-destructible link 38 of the first control switch 34 to be actuated and the other firing circuit conductor (e.g., conductor 30) is isolated. Thus, to selectively detonate the first shaped charge 24 to be fired, this first link 38 must be broken to connect the shaped charge into the firing circuit. Once the first conductive link 38 is broken

to actuate its associated switch 34, the shaped charge 24 that is to be detonated first is connected to the other firing circuit conductor so as to require a further deliberate manipulation at the surface (e.g., reversal of the switch 18) before that shaped charge is detonated. The new and improved circuitry 10 is further adapted so that the next section of the perforating apparatus 11 is preferably armed before the first shaped charge 24 is detonated.

Once the initial shaped charge 24 is detonated, the succeeding shaped charges 24 are selectively detonated only by alternately connecting the power source 19 to first one and then the other firing circuit conductors 29 and 30. This, of course, prevents inadvertent detonation of any of the shaped charges 24 and requires a deliberate manipulative operation at the surface to detonate each shaped charge in turn. Moreover, by monitoring the ammeter 22, the circuitry 10 provides a positive indication at the surface of each successive step in the operation of the perforating apparatus 11. Once the next-to-last shaped charge 24 is ready for detonation, the last control switch 34 will be actuated. Then, only after the next-to-last shaped charge 24 is detonated and the reversing switch 18 again repositioned is the final shaped charge connected into the firing circuit.

While a particular embodiment of the present invention has been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. In a well tool arranged to carry an electrical device and adapted for suspension in a well bore, circuit means adapted for selectively operating such an electrical device from the surface comprising: first means on said well tool including a member adapted for movement between at least two spaced positions for selectively disabling and enabling such an electrical device; an electrically-conductive current-destructible member adapted to fail upon passage of electrical current therethrough of at least a predetermined magnitude releasably retaining said movable member in the first of its said spaced positions until said conductive member fails; second means selectively operable from the surface and adapted for connecting a source of electrical power to said conductive member to pass electrical current therethrough of at least such a predetermined magnitude; and means operable upon failure of said conductive member for moving said movable member to the second of its said spaced positions.

2. The well tool of claim 1 wherein said circuit means further include conductor means adapted to extend between said well tool and the surface; and said first means further include switching means on said well tool operable upon movement of said movable member and adapted for connecting said conductor means to such an electrical device whenever said movable member is in that one of its said spaced positions where that electrical device is enabled.

3. The well tool of claim 1 wherein said first means further include switching means operable upon movement of said movable member, and said circuit means further include conductor means adapted to extend between the surface and said well tool and including first conductor means adapted for selectively connecting a source of electrical power to said conductive member and second conductor means connected to said switching means and adapted for selective connection thereby to such an electrical device whenever said movable member is in that one of its said spaced positions where that electrical device is enabled.

4. In a well tool including at least one electrical device and adapted for suspension in a well bore, circuit means adapted for selectively operating said electrical

device from the surface comprising: switching means on said well tool connected to said electrical device and moveable from a first to a second position; an electrically-conductive current-destructible member releasably retaining said switching means in said first position and adapted to fail upon passage of electrical current therethrough of at least a predetermined magnitude for releasing said switching means for movement to said second position; conductor means adapted to extend between the surface and said well tool and including first conductor means adapted to selectively connect a source of electrical power to said conductive member and second conductor means connected to said switching means and adapted for selective connection thereby to said electrical device whenever said switching means is in one of said positions.

5. The well tool of claim 4 wherein said electrical device is operable upon passage of electrical current therethrough.

6. The well tool of claim 5 wherein said first conductor means include a first diode adapted to pass direct current of only a first polarity between said conductor means and said conductive member and said second conductor means include a second diode adapted to pass direct current of only a second polarity between said conductor means and said switching means.

7. The well tool of claim 4 wherein said electrical device includes an explosive, and means responsive to passage of electrical current therethrough for detonating said explosive.

8. The well tool of claim 7 wherein said first conductor means include a first diode adapted to pass direct current of only a first polarity between said conductor means and said conductive member and said second conductor means include a second diode adapted to pass direct current of only a second polarity between said conductor means and said switching means for detonating said explosive.

9. In a well tool including explosive means adapted for detonation in response to electrical current, means adapted for selectively detonating said explosive means from the surface comprising: first and second electrical conductors; switching means including a member adapted for movement between spaced positions, and means responsive to movement of said movable member to one of said spaced positions for connecting said second conductor to said explosive means; means normally disabling said switching means and including an electrically-conductive current-destructible member connected to said first conductor and adapted to fail upon passage of electrical current therethrough of at least a predetermined magnitude, and means on said conductive member releasably restraining said movable member from moving to said one spaced position until said conductive member fails; and means operable from the surface and adapted for selectively supplying electrical current to said first and second conductors.

10. The well tool of claim 9 wherein said explosive means include first and second explosive devices respectively having first and second electrically-responsive detonators operatively associated therewith; and further including first electrical conductor means operatively connecting said first detonator to said first electrical conductor to parallel said conductive member and said first detonator; and second electrical conductor means operatively connecting said second detonator to said switching means for selective connection thereby to said second conductor upon movement of said movable member to said one spaced position.

11. The well tool of claim 9 wherein said first conductor means include electrical-resistance means having a different resistance than the electrical resistance of said conductive member for selectively regulating the current flow through said first detonator and said conductive member.

12. The well tool of claim 9 wherein said first conductor means include electrical-resistance means having a greater resistance than the electrical resistance of said conductive member selectively dividing the current flow through said first detonator and said conductive member for limiting the current flow through said first detonator until said conductive member has failed.

13. In a well tool including first and second explosive means adapted for detonation in response to passage of electrical current therethrough, means adapted for selectively detonating said explosive means from the surface comprising: first and second electrical conductors; first and second switching means respectively including a member adapted for movement between spaced positions, a plurality of electrical contacts, means responsive to movement of said movable member from one of said positions to another of said positions for electrically interconnecting two of said electrical contacts, means adapted to move said movable member to said other position, an electrically-conductive current-destructible member adapted to fail upon passage of electrical current therethrough of at least a predetermined magnitude, and means on said conductive member releasably restraining said movable member from movement from said one position to said other position until said conductive member fails; first circuit means operatively connecting said first conductor to said conductive member of said first switching means and to one of said two contacts of said second switching means as well as connecting the other of said two contacts of said second switching means to said second explosive means; and second circuit means operatively connecting said second conductor to said conductive member of said second switching means and to one of said two contacts of said first switching means as well as connecting the other of said two contacts of said first switching means to said first explosive means.

14. The well tool of claim 13 further including means operable from the surface for passing electrical current selectively through said electrical conductors.

15. The well tool of claim 13 wherein at least said second switching means include a third electrical contact, means operable so long as said movable member of said second switching means is in said one position for electrically connecting said one and said third contacts of said second switching means; and said first circuit means further include another electrical conductor electrically connecting said third contact of said second switching means to said conductive member of said first switching means.

16. The well tool of claim 13 wherein said second circuit means further include electrical-resistance means connecting said other contact of said first switching means to said first explosive means and having a different resistance than the electrical resistance of said conductive member of said second switching means for selectively regulating the current flow through said first explosive means and said conductive member of said second switching means.

17. The well tool of claim 16 wherein the resistance of said electrical-resistance means is greater than the electrical resistance of said second conductive member of said second switching means for limiting the current flow through said first explosive means until failure of said conductive member of said second switching means.

References Cited

UNITED STATES PATENTS

2,762,884	9/1956	Van Eyk	337—145
2,832,265	4/1958	Reid et al.	337—145
3,010,396	11/1961	Coleman	175—4.55
3,246,707	4/1966	Bell	175—4.55 X
3,327,791	6/1967	Harrigan	175—4.55
3,441,093	4/1969	Boop	175—4.55

DAVID H. BROWN, Primary Examiner

U.S. Cl. X.R.

166—65; 337—145