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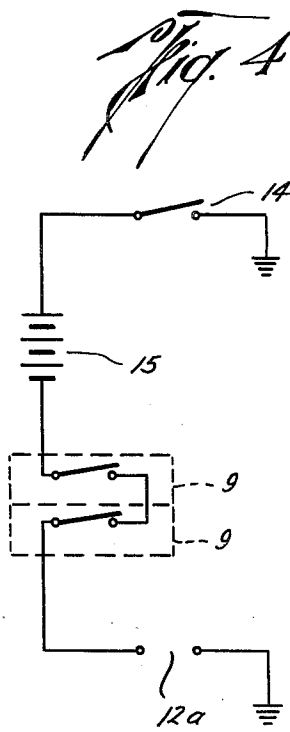
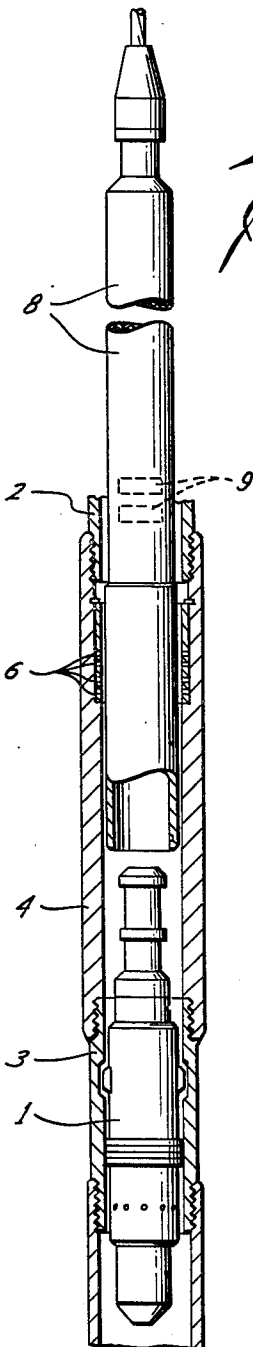
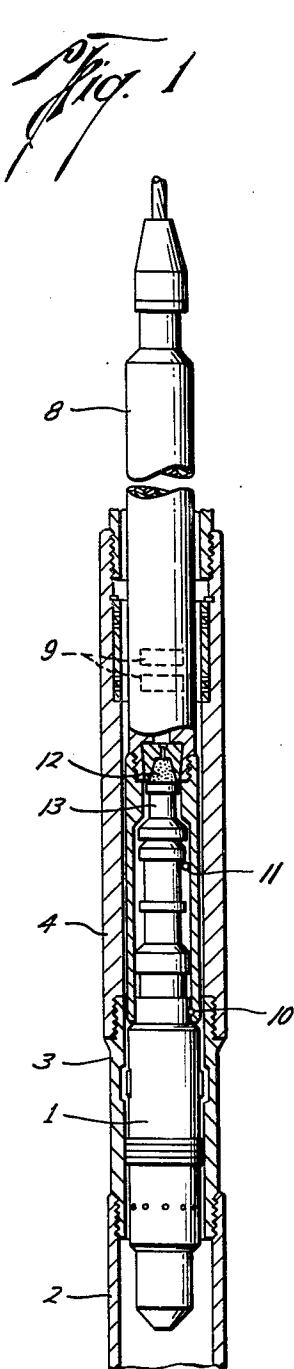
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MAGNETICALLY ACTUATED WELL WORKING TOOL

Filed Jan. 30, 1961

5 Sheets-Sheet 1



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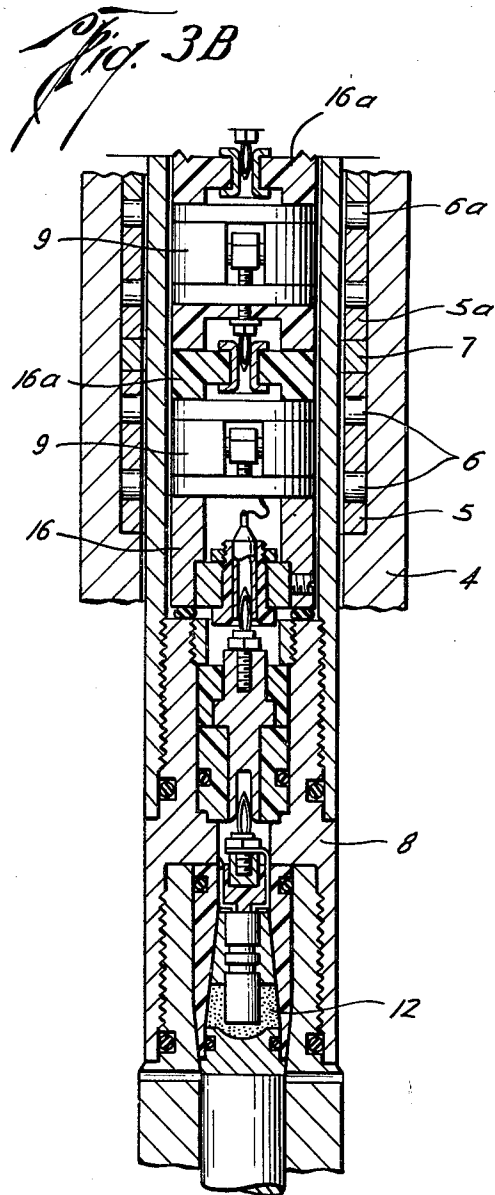
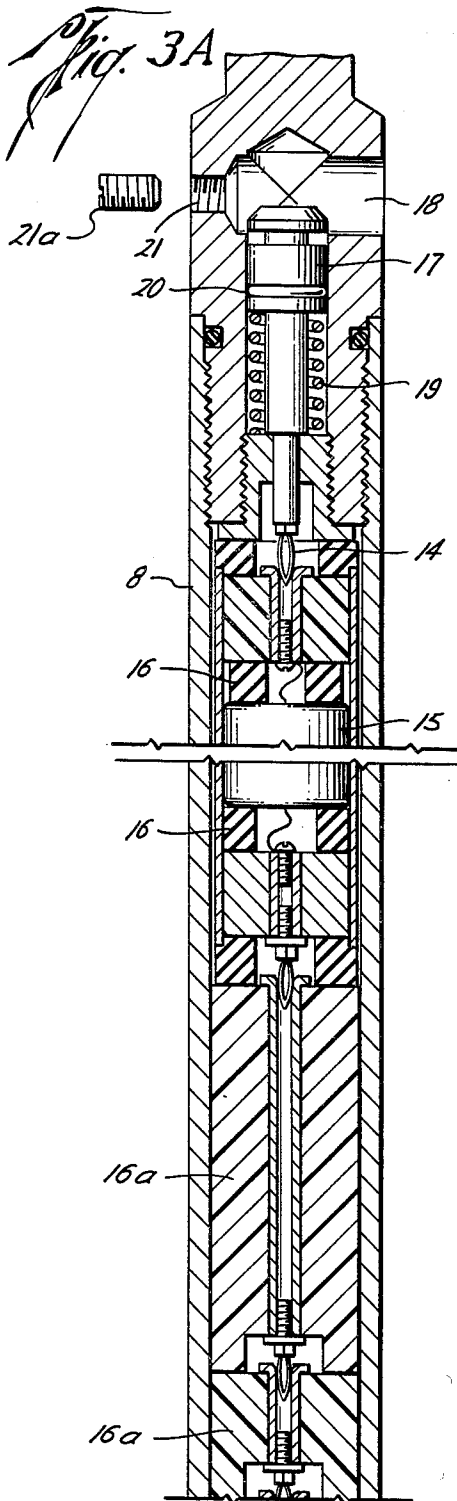
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MAGNETICALLY ACTUATED WELL WORKING TOOL

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5 Sheets-Sheet 2



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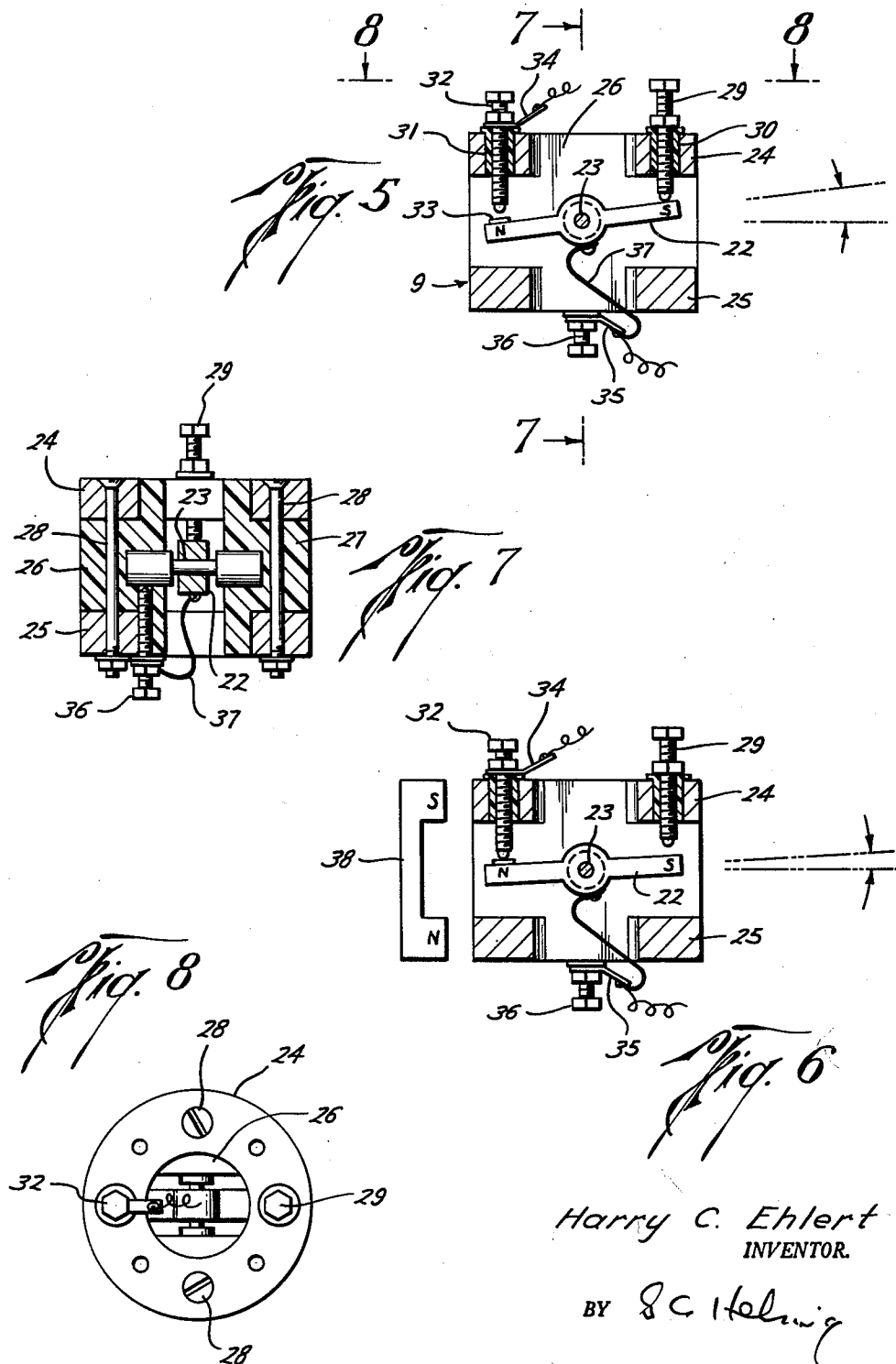
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MAGNETICALLY ACTUATED WELL WORKING TOOL

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5 Sheets-Sheet 3



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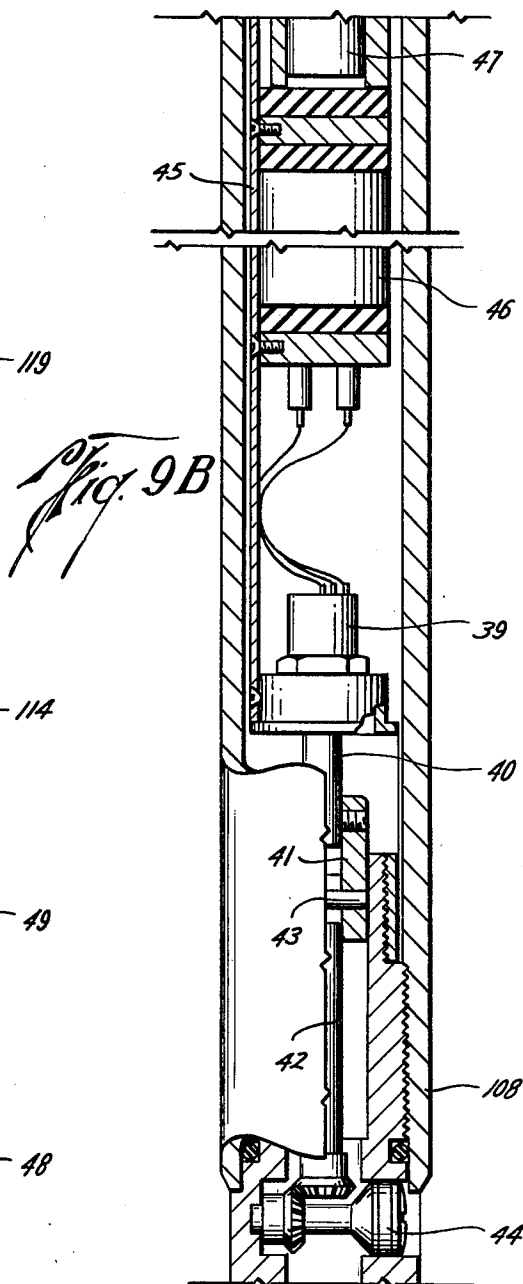
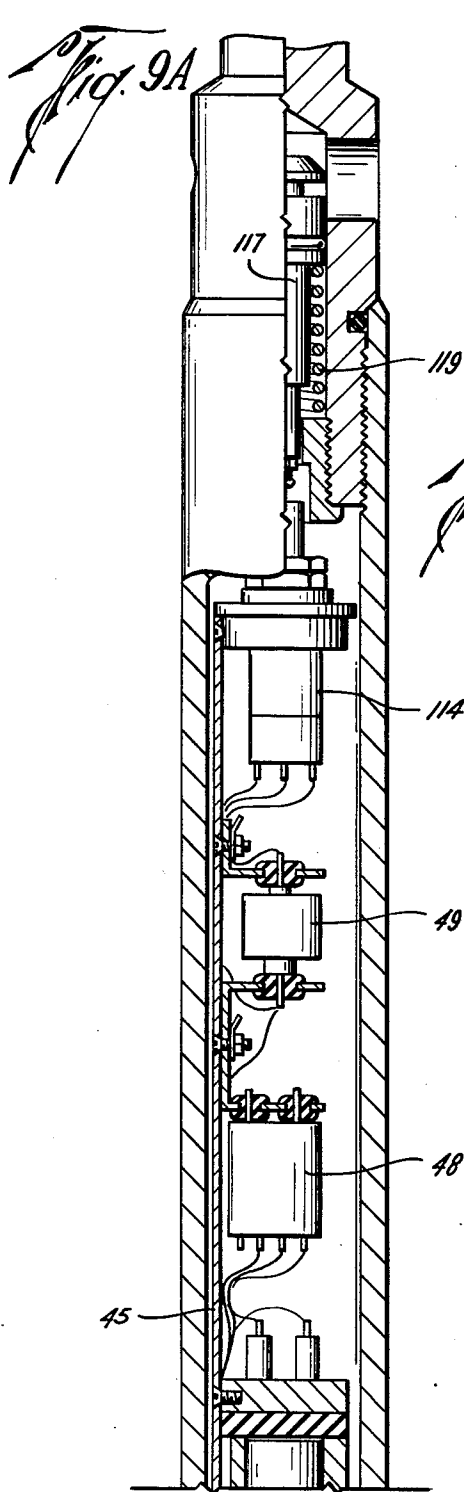
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MAGNETICALLY ACTUATED WELL WORKING TOOL

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5 Sheets-Sheet 4



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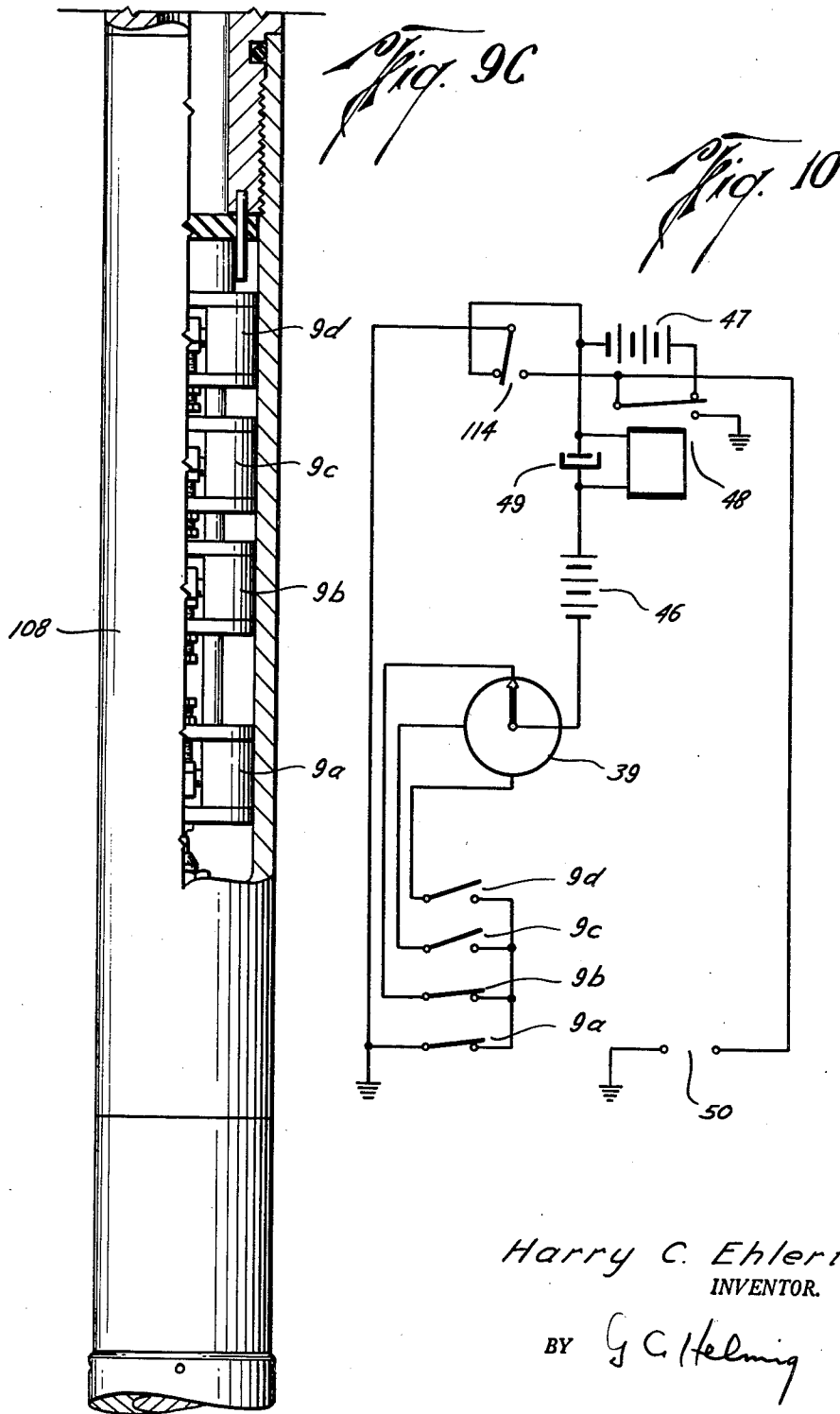
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MAGNETICALLY ACTUATED WELL WORKING TOOL

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5 Sheets-Sheet 5



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MAGNETICALLY ACTUATED WELL WORKING TOOL

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10 Claims. (Cl. 166—65)

This invention relates to well working tools to be run by wire line suspension equipment and operated automatically at a preselected subsurface location. More particularly, the invention concerns an improved tool which can be preset for signaled operation as it traverses any selected one of several subsurface signaling stations each providing a distinctively different signal but only one of which will be sensed for work performing response of the tool in a particular selective setting.

An object of the invention is to provide a tool which can be more safely handled with less likelihood of premature and unintentional release of energy before being run into a well hole and before reaching a point at which signaled operation is desired.

Another object is to provide a tool whose work performance is effected through control units connected in series relation for dependency on one another for conjoint effectiveness and arranged for response in the case of one unit to a given subsurface signal and in the case of the other unit to downhole environmental conditions so that tool actuation is ineffective in the absence of concurrent responses.

A further object is to provide a tool having a set of series connected control elements whose simultaneous action is required to render the tool operable for work performance and one of which elements has an actuator that normally assumes a position to disarm the operating mechanism and is shifted to an arming position by the action thereon of higher than atmospheric fluid pressure encountered at downhole depths.

A still further object of the invention is to provide an electric control circuit and a set of series connected circuit closing devices, one constituting a normally open arming switch arranged for closing response to physical conditions of environment and one or more others involving a normally open switch which is highly sensitive and responsive to a magnetic signal when under the influence thereof.

Another object is to provide a circuit controlling switch unit having a pair of contacts of which one is movable toward and away from the other with the pivotal movement of a permanently magnetized lever fulcrumed intermediate its opposite poles and between a pair of spaced apart pole pieces which co-operate with the permanent magnet for attracting the pivoted magnet in one direction of rotation about the fulcrum axis and for causing a reverse rotational movement when the spaced apart pole pieces are subjected to or come within a signaling magnetic field of a polarity for repelling the poles of the magnetized lever.

Other objects and advantages will become apparent during the course of the following specification having reference to the accompanying drawings wherein FIGS. 1 and 2 are part elevation and part vertical sectional views of tubing string fragments representative of a pair

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of vertically spaced apart signaling stations with a wire line tool illustrated in FIG. 1 in a nonresponsive relation to the signaling station and responsive to the signaling station of FIG. 2 but immediately following the completion of a work performing operation; FIGS. 3A and 3B are companion views showing one embodiment of the tool in vertical section; FIG. 4 is a wiring diagram of the control circuit involved in the tool structure disclosed in FIGS. 3A and 3B; FIG. 5 is a vertical section of the magnetic switch unit with the parts in open circuit relation; FIG. 6 is a view similar to FIG. 5 but showing the contacts closed; FIGS. 7 and 8 are a vertical section and an elevation respectively as on lines 7—7 and 8—8 of FIG. 5; FIGS. 9A, 9B and 9C are vertical sectional views of a modified embodiment of the improved tool, and FIG. 10 is a wiring diagram illustrating the circuitry employed in the tool as shown in FIGS. 9A, 9B and 9C.

The improved tool here disclosed is adapted for harnessing a signaled release of energy for performing any of various conventional downhole operations, inclusive of the introduction of an inhibitor fluid; the perforation of tubing and the setting of well completion and flow control equipment. For illustrative purposes, FIG. 1 and FIG. 2 show a running tool by which a tool hanger assembly 1 is to be positioned and latched at a selected depth in a tubing string 2. At each of a number of spaced apart locations as determined upon at the time the tubing is set in the well hole, there will be located a pair of co-operating tubing sections, indicated at 3 and 4, and the section 3 is in the nature of a landing nipple having an internal keeper groove while the section 4 provides for the mounting of work performing signals in given vertically spaced relation above the keeper groove. Each signaling station is illustrated as involving a stack of separate rings retained within a counterbored upper portion of the tubing section 4, the detail arrangement being best seen in FIG. 3B. As they are shown, the lowermost ring 5 is of nonmagnetic material and has embedded in it a series of permanent magnets 6 in the nature of radially disposed bar segments arranged in two vertically spaced apart rows, each containing an annular succession of circularly spaced apart magnets. When these magnets are so arranged and the inner end faces of the magnets in one row are of opposite polarity to the end faces of the magnets in the companion row, there will be provided between adjoining north and south poles an inwardly protruding magnetic field as a signal to which response can be had by a magneto device which traverses the field. Spaced upwardly above the lowermost magnet carrying ring 5 is a similar ring 5a carrying magnets 6a in circular array and in two vertically spaced apart groups or rows. The two magnet carrying rings preferably are identical subassemblies and they are to be spaced apart different distances at each of the work performing stations. For that purpose, a series of spacer rings, one of which is shown at 7 in FIG. 3B, are interposed between adjacent edges of the rings 5 and 5a. The differently spaced relationship of the magnetic signaling fields is illustrated in FIGS. 1 and 2.

Thus in FIG. 1, the wire line suspension tool 8 is illustrated as running past the signaling station with the laterally projectable latching dogs of the tool hanger 1 retracted. A pair of magneto devices 9 are illustrated by dotted lines in a spaced apart relation differing from

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that of the magnets in FIG. 1, so that these devices will not be simultaneously within the fields of the pair of fields at the signaling station illustrated. The spaced apart relations of the two signaling fields and of the two magnetic field responsive magneto devices 9 are identical in the FIG. 2 illustration or are coded to one another for the signaled operation of the work performing tool. FIG. 2 actually shows the relationship of the parts following completion of the operation with the tool hanger latched in place and the running tool elevated thereabove as at the start of elevation.

The hanger tool 1 is of a known type and involves a tubular body slidably mounting a reciprocable plunger and carrying laterally projectable dogs. Initially, the dogs are retracted and the plunger is in an upwardly projected relation to the housing and is to be fitted within a hollow bottom portion of the running tool 8. Shear pins 10 and 11 secure the hanger housing and the plunger to the running tool. The energy for depressing the plunger when signaled operation occurs is provided by an explosive charge 12 carried in the running tool and arranged to be electrically ignited. When ignition occurs, the expanding gases from the combustible charge act downwardly on a pistonlike projectile 13 and the force is transmitted into the plunger, first to shear the pin 11 and then to depress the plunger for expanding the locking dogs into the keeper notch of the tubing section 3. With the hanger so latched, an upward jar on the wire line suspended tool will shear the pin 10 and allow the tool to be removed from the well.

When the source of releasable energy is an explosive charge, its ignition will be by a detonator in an electric circuit completed by the concurrent response of the set of magneto devices 9 which, as will be described in detail, comprise normally open circuit closing switch units in series circuit connection with one another and also with a suitable arming switch. This circuit arrangement is seen in FIG. 4, indicating the normally open positions of both magneto devices 9 and the arming switch 14. Only when the several switches are closed at the same time can actuating current from the battery 15 reach the explosive charge detonator 12a for igniting the charge as referred to above.

The circuit and its operating components are housed and properly positioned in relation to one another within the tool body 8, which for convenience is made up of a number of separately formed parts threaded together in end to end succession with suitable seals, such as conventional O-rings, at the several joints. Also at the various detachable joint couplings, there will be located detachable pin and socket electrical connectors for completing the current flow circuit between the electrical components. Within the sealed chamber of the tool body, there are shown in FIGS. 3A and 3B the pair of magneto devices 9—9, the battery 15 and the arming switch 14 comprising a fixedly mounted socket member and a movable plug for travel into and out of contact with the socket, the drawing illustrating the switch 14 as being closed and as being grounded through the wall of the body 8. The circuit components within the chamber, together with a number of intervening spacer rings 16—16 and 16a of insulating material, fill the hollow chamber space and properly locate the elements in reference to each other. The set of spacer rings indicated at 16a are of different axial dimension and can be disposed interchangeably relative to one another. The purpose of these spacer rings is to enable the magneto devices 9—9 to be spaced apart in different relationships by substituting or compounding of spacer rings 16a so that such spacing between the magneto devices can be made to conform with the spacing of magnetic signaling fields at any of the several signaling stations. When an operation is to be performed at a given station, the tool is assembled at the surface to present its signal actuated magneto devices 9—9 in a spaced rela-

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tion coded to match that of the fields of a selected signaling station.

The movable plug of switch element 14 is mounted at the lower end of a reciprocatory plunger 17 whose upper end is exposed by means of a lateral opening 18 in the tool body 8 to pressures exteriorly of the tool. Normally, the plunger is projected upwardly from the switch closing position shown under the elastic force of a coil spring 19 interposed between the housing seat and the bottom of the piston head enlargement at the upper end of the plunger 17. The strength of the spring is selected for projecting the plunger when fluid pressures on opposite ends of the plunger are balanced. The slidable piston head is sealed to the tool housing 8 as by means of an O-ring 20. When the tool is assembled at the surface, the sealed chamber and the underside of the plunger 17 will be at atmospheric pressure and the switch 14 will be held open under the force of the spring 19 and thus will de-arm the electric circuit so that no premature release of energy will occur due to any unintentional or accidental closing of the switch contacts of the magneto devices 9—9, as might possibly occur due to jarring or other forces.

The arrangement is such that under usual conditions of use the tool will remain in unarmed condition so long as it remains above the surface. In the descent of the tool in a well, well fluid pressure in excess of surface atmospheric pressure will tend to depress the plunger 17 against the force of the spring 19. When such depression occurs, the arming switch 14 will be closed and will condition the circuit for completion when the magneto devices 9—9 traverse the magnetic fields to which the magneto devices have been coded.

Under certain conditions, it will be desirable to provide the tool body 8 with a screw threaded lateral port 21 at its upper end in alignment with the head of the plunger 17. This threaded opening is for optional reception of a set screw 21a which can be adjusted inwardly into bearing contact with the head of the plunger 17 at either or both of its opposite stroke limits. When so held at the upper stroke limit, the arming switch itself will be precluded from accidental depression. On the other hand, when the set screw interlocks with the piston head at the lower limit of piston stroke, the arming switch 14 will be locked in its closed position. This latter condition may be desirable in certain instances, as, for example, when downhole well pressures are insufficient for reliance to effect actuation of the arming switch. The plunger would then be depressed by prying it downwardly with a screw driver or other type of tool, and held by the set screw immediately before lowering the tool into the tubing string.

Each magneto device 9 is preferably constructed as shown in the detail views FIGS. 5—8. As so disclosed, the unit includes a magnetized rocker level 22 fulcrumed centrally of its opposite arms on a shaft 23 for rocking in opposite direction of rotation in the space between a pair of annular pole pieces 24 and 25 secured to the top and bottom faces of a pair of transversely spaced apart spacer blocks 26 and 27 of insulating material on opposite sides of the magnetized lever 22 whose axle shaft has its opposite ends mounted in the spacer blocks. The parts are held in assembled relation by means of brass studs 28 which pass through both of the annular rings or pole pieces 24 and 25 and the spacer blocks 26 and 27. The magnetized lever 22 is constituted by a permanent magnet and as illustrated its pivot shaft 23 is mounted closer to the lower pole piece 25 than to the pole piece 24. Accordingly, whenever the swing position of the north pole of the lever is below the horizontal plane of the shaft 23 as viewed in FIG. 5, the lines of force between the poles will provide an attraction tending to rock the lever in a counterclockwise direction with the north pole moving toward the pole piece 25 and the south pole moving toward the upper pole piece 24. A stop to limit such movement is provided by an adjustable screw stud 29

fitted to an insulator sleeve 30 and projected downwardly through the pole piece 24 so that its terminal tip portion is in the upward swing path of the south pole of the pivoted lever. Directly above the north pole of the pivoted lever is an insulator sleeve 31 extending through the pole piece 24 and adjustably receiving the threaded stud 32 whose tip portion is to be engaged by the north pole as a stop in the path of clockwise movement of the pivoted lever. This tip of the stud 32 provides one of a pair of co-operating switch contacts, the other of which contacts is indicated as a small metal wafer 33 on the upper face of the north pole of the lever 22. A terminal connector 34 is held on the stud 32 for its wired connection in an electric circuit to be controlled. A similar circuit connector terminal 35 is held by a fastening stud 36, which passes upwardly through the bottom pole piece 25 and the spacer block 26 for contact at its tip portion with the adjacent mounted end of the supporting shaft of the magnetized rock lever 22. The stud can therefore serve as a current conductor between the magnetized lever and the terminal 35 and an additional path for current flow is afforded by a flexible lead wire 37 joined at one end to the connector terminal 35 and at its opposite end to the hub portion of the rock lever 22.

As before indicated, the switch contacts provided by the tip of the stud 32 and the wafer 33 normally are held open by the magnetic attraction between the poles of the permanent magnet comprising the rock lever 22 and the respective spaced apart pole pieces 24 and 25. That attraction can be overcome by imposing on the pole pieces a magnetic field of different or, in other words, opposite polarity. Thus, as seen in FIG. 6, a magnet 38 is shown positioned beside the unit with its opposite poles arranged to co-operate with the pole pieces 24 and 25. When the south pole of the magnet 38 is uppermost, then the field from the magnet 38 through the pole pieces 25 and 24 will tend to impart a clockwise direction of rotation to the magnetized lever 22, whose north pole is repelled away from the north pole of the magnet 38 and the pole piece 25, while the south pole of the magnetized lever is attracted toward the bottom pole piece and is at the same time repelled away from the upper pole piece 24 and the south pole of the magnet 38. The imposition of the field of the magnet 38 in overcoming the hold-open tendency of the permanent magnet comprising the rock lever is instantaneous and results in a snap action. In like manner, removal of the field of the magnet 38 from influence on the switch unit results in a quick snap-open operation.

The degree of angular movement between open and closed positions can be controlled by relative adjustment of the stop studs 29 and 32 and ordinarily a small range of movement is to be preferred. The projected angularly related broken lines to the right of FIGS. 5 and 6 indicate respectively the inclination from a horizontal plane passing through the pivot axis of the lever in open position and in closed position. At both limits, the north pole in relation to the spaced apart pole pieces is always closer to the bottom pole piece 25. The adjustable stop screws could be set so that the north pole on clockwise rotation would move above the axis and to an extent that the magnetic lines of force of the magnet would then tend to maintain that position. For a subsequent reverse or counterclockwise movement, a magnet such as 38 but with the poles reversed in position to present its north pole uppermost, could then be presented to the pole pieces 24 and 25 to restore or rock the permanent magnet lever to its original position. Furthermore, it will be obvious that the electric circuit contacts, if desired, can be transferred from the north pole end of the lever to the south pole end of the lever for co-operation with the screw stud 29 in providing a normally closed electric switch for such situations wherein it is desired to employ an extraneous magnetic field for opening an electric circuit.

The same magnetic switch can be employed in a multiple stack in a modified well working tool which differs

only slightly from that heretofore described. In this instance, the stack of magnetic switches includes a succession of units 9a, 9b, 9c and 9d held in fixed spaced apart relation within the tool body 108. For selectively setting or combining the switches in given pairs coded to a particular spacing of magnetic fields of the tubing string stations and for closing a firing circuit on concurrent switch operation, it is here proposed to employ a rotary multiple-way switch 39 by which any one of the switches 9b, 9c or 9d may be paired with the switch 9a. The rotary switch is to be set selectively in advance of a tool lowering operation and for that purpose it has a downwardly extending operating stem 40 carrying a sleeve or socket 41 to receive the upper bifurcated end of a rotatable operating shaft 42. A crosspin 43 is carried by the socket sleeve 41 to extend interiorly thereof and to be received within the bifurcated end of the stem 42. Bevel gears connect the lower end of the stem 42 to a transverse shaft 44 having a screw driver slotted head presented at a window in the side wall of the housing 108 and by which a manual adjustment of the rotary switch 39 is effected. For convenience, the rotary switch 39, as well as other of the circuit components, provide a subassembly, all fastened to a tie strap 45 for insertion and removal as a unit within the chamber of the hollow tool body 108. Such additional components include dry cell batteries 46 and 47, a relay switch 48 and a condenser 49 associated with the coil relay 48 and the arming switch 114. As in the case of the arming switch 114, the switch 114 is normally open and is arranged to be closed by a fluid pressure responsive plunger 117 when the latter is depressed against the elastic force of the coil spring 119.

Assuming that the rotary switch 39 has been adjusted to select or compound the switches 9a and 9b, then when these two switches are concurrently closed at a time when the arming switch 114 also is closed, current from the battery 46 will be delivered to the coil of the relay 48 for closing the firing circuit from the battery 47 to a detonator 50 or other electrically responsive device whose actuation releases or sets in motion a source of work performing energy.

The circuit as shown in FIG. 10 differs from the more simple circuit of FIG. 4 in the inclusion of a firing circuit relay 48 and condenser 49. A definite amount of energy is thus supplied independently of differences in tool speed through the signaling fields. The circuit also possesses desirable safety features, especially when the working force to be released is an explosive charge. On completion of the control circuit through the relay coil, the capacitor charges up quickly and on reaching a minimum operating voltage, the relay responds to complete the firing circuit to the detonator. Although the contacts of the detector units may open shortly thereafter, the relay contacts remain closed because of the energy stored in the capacitor. Opening of the relay contacts is thus delayed until voltage across the capacitor falls below the drop-out voltage of the relay and the time can be adjusted by varying the resistance of the relay coil, the value of the capacitor, or both. Since the capacitor requires time to charge, premature firing is prevented in the event the detector units are jarred closed momentarily. The use of a double pole relay and on-off switch effects grounding of the triggering terminals at all times other than when the relay switch is actuated. Accordingly, premature firing is avoided upon internal malfunctioning or otherwise.

In use of the tool having its magneto devices in given axially spaced apart relation and in coded or matching correspondence with the spacing of the magnets at any selected signaling station of a tubing string and with the arming switch preconditioned for action, the tool is lowered through the tubing string and automatically actuated upon reaching the known depth of the preselected station. During tool descent, the switch controlled cir-

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cuit remains open so long as less than all of the series connected switches are closed. One or more but not all of the switches at the same time may close at various tool positions above the selected station; as, for example, sufficient well hole pressure to close the arming switch may exist at a depth higher than the selected station and individual magneto devices will respond but not in unison during a traverse of magnetic fields at those magnets whose spaced apart relation differs from the spacing between the magneto devices. Only when travel of the tool brings it into the selected station in the tubing string will axial spacing between the magneto devices 9—9 match or coincide with the axial spacing of the magnetic fields for the concurrent influencing of the magneto devices of the set and the resulting simultaneous switch closing action. Such occurrence with the arming switch also closed establishes the condition in which all of the series connected switches are instantly closed for completing the electrical circuit and directing current flow to fire the explosive charge.

What is claimed is:

1. In a well working tool for travel through a tubing string having spaced apart stations each providing signaling means distinctly unlike others, said tool comprising a body, a source of working energy carried by the tool body, means mounted by the tool body and responsive to station signaling means upon traverse thereof and arranged to be preset for effective response solely to the signaling means of a preselected station, other means active in response to well subsurface physical environment, and means active to release said source of working energy upon concurrent effective response of both the environment responsive means and the signal responsive means.

2. In a well working tool as in claim 1 together with a shiftable stem constituting a part of the environment responsive means and being movable relative to the tool body between inactive and active positions of said environment responsive means and a stem engageable element operable to fix the stem against movement relative to the tool body and thereby maintain said environment responsive means in one of said positions.

3. In a well working tool for travel through a tubing string having spaced apart signaling stations each providing spaced apart sets of magnetic fields spaced differently from the fields of other stations, said tool comprising a body, a releasable store of work performing energy carried by the body and adapted to be electrically brought into action and electric control means therefor including first and second normally inactive circuit completing devices co-operatively related to preclude energy release unless the devices are concurrently active, said first device being responsive to subsurface environment conditions and the second device comprising a pair of spaced apart units which are responsive to magnetic fields of tubing string stations traversed by the tool, and means to condition the spacing between said units to coincide with the spacing of the magnetic fields of a selected station.

4. In a well working tool for travel within a tubing string having means providing spaced apart sets of spaced apart magnetic fields spaced differently in each set, said tool including an electrically releasable source of working energy, a number of normally inactive control devices having series electrical connection for effecting release of the energy source when all of said devices are concurrently active, an actuating member for one of said devices exposed to well pressure fluids and responsive to given fluid pressure thereon, a set of magnetic field responsive elements operably connected with the others of said devices, and selectively set means to present said elements in spaced apart relation corresponding to the field spacing in any of said sets of magnetic fields.

5. In a well working tool for travel within a tubing string having means providing spaced apart sets of mag-

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netic fields of like number in each set and spaced differently in each set, said tool including an electrically releasable source of energy and control means therefor having serially connected circuit closing devices, one of such devices being responsive to given physical environment conditions within a tubing string to establish its circuit closing relation and others of the devices corresponding in number to tubing string magnetic fields in said sets and being responsive to said magnetic fields to establish circuit closing relations, and means to present the last mentioned devices in spaced apart relations corresponding to field spacings respectively for concurrent response thereto.

6. In a well working tool for travel within a tubing string having means providing spaced apart sets of magnetic fields spaced apart differently in each set, said tool including an electrically releasable source of energy, a number of normally open circuit control switches arranged for series connected circuit closing relation to release the energy of said source, means responsive to subsurface physical conditions to close one of said switches, means responsive to magnetic fields to close the other of said switches, means mounting the others of said switches in spaced apart relation determined by the different spacing of the tubing string fields of the several sets whereby selected ones of the switches will be spaced apart in matching relations respectively to field spacings of the several sets, and means to place selected ones of said other switches in series circuit relation with said one of said switches.

7. In a well working tool for travel within a tubing string having means providing spaced apart sets of magnetic fields spaced apart differently in each set, said tool including an electrically releasable source of energy, a number of normally open circuit control switches arranged for series connected circuit closing relation to release the energy of said source, means responsive to subsurface physical conditions to close one of said switches, means responsive to magnetic fields to close the other of said switches, and means operable to present said other switches in spaced apart relations matching the field spacings of the sets selectively.

8. In a well tool adapted to be run in a well and to be actuated upon receipt of a signal from a subsurface signaling station, a tool body, an electrically actuated element carried by the body, a first circuit closing device and a second circuit closing device connected in series circuit relation and operative to actuate said element when the devices are concurrently in circuit closing relation, signal responsive means to effect circuit closing relation of the first device, and a well fluid pressure responsive control member connected with the second circuit closing device and shiftable mounted on the tool body for movement between circuit opening position and circuit closing position.

9. In a well tool adapted to be run in a well and to be actuated upon receipt of a signal from a subsurface signaling station, a tool body, an electrically actuated element carried by the body, a first circuit closing device and a second circuit closing device connected in series circuit relation and operative to actuate said element when the devices are concurrently in circuit closing relation, signal responsive means to effect circuit closing relation of the first device, a well fluid pressure responsive plunger slidably mounted on the tool body and connected with the second circuit closing device to effect its circuit closing relation and securing means operable selectively to tie the plunger to the body against slide movement.

10. In a well tool adapted to be run in a well and to be actuated upon receipt of a signal from a subsurface signaling station, a tool body, an electrically actuated element carried by the body, a first circuit closing device and a second circuit closing device connected in series circuit relation and operative to actuate said element when the devices are concurrently in circuit closing relation,

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signal responsive means to effect circuit closing relation of the first device, a well fluid pressure responsive control member connected with the second circuit closing device and shiftably mounted on the tool body for movement between circuit opening position and circuit closing position, and an adjustable interlock between the tool body and said control member operable to hold the control member in one of said positions.

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