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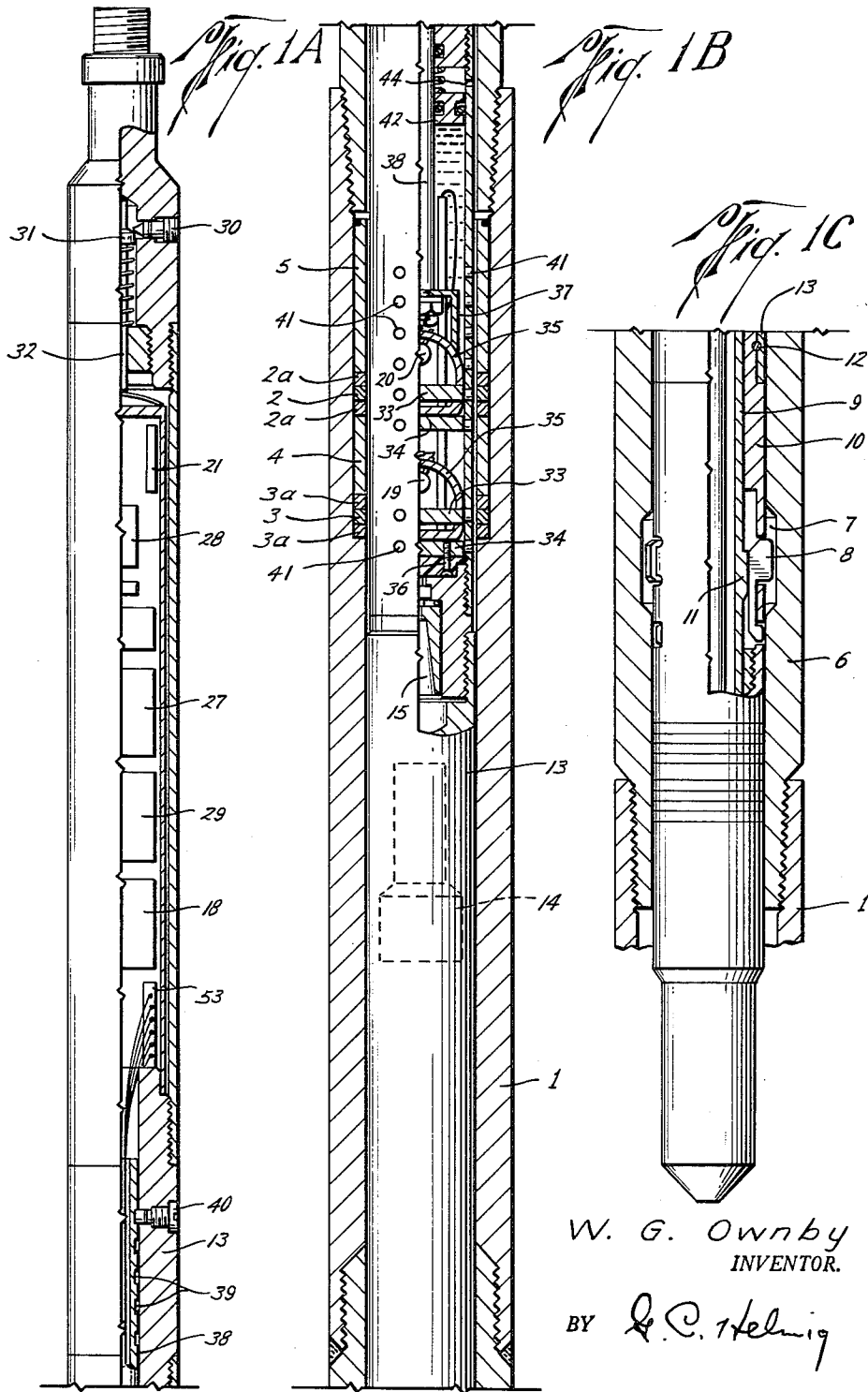
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3,105,547

SELECTIVELY ACTUATED WELL TOOL

Filed March 30, 1959

4 Sheets-Sheet 1



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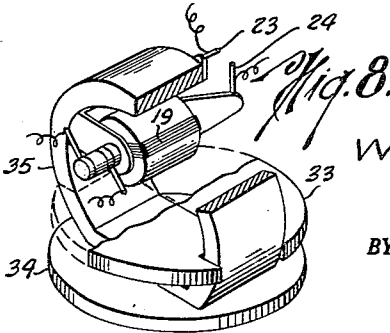
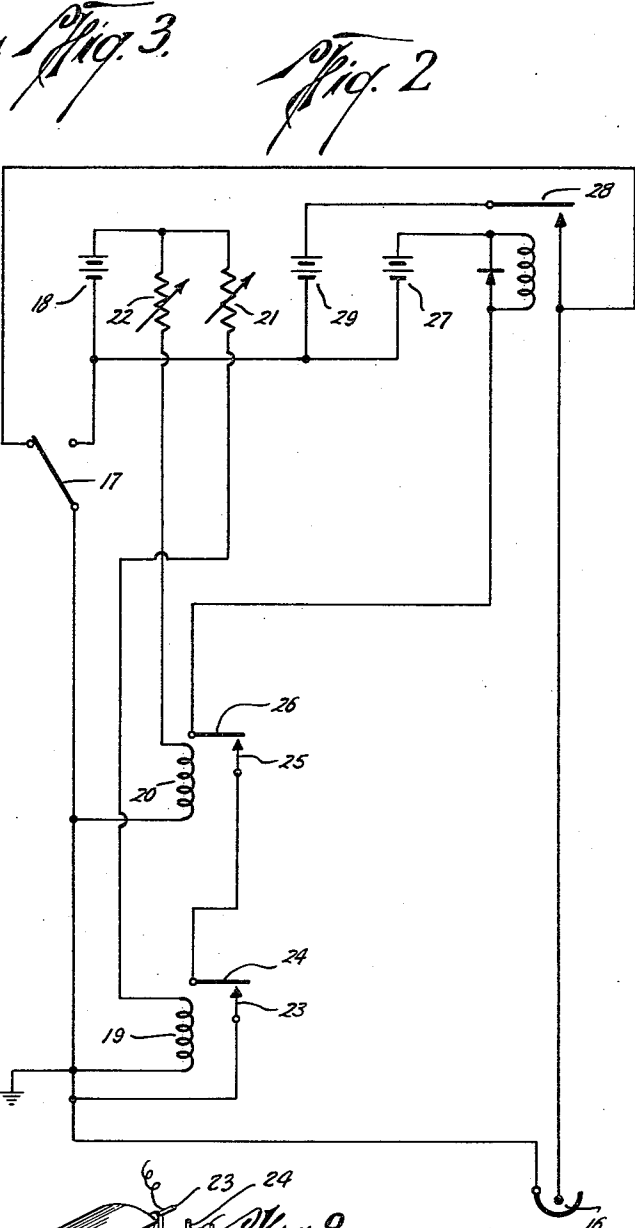
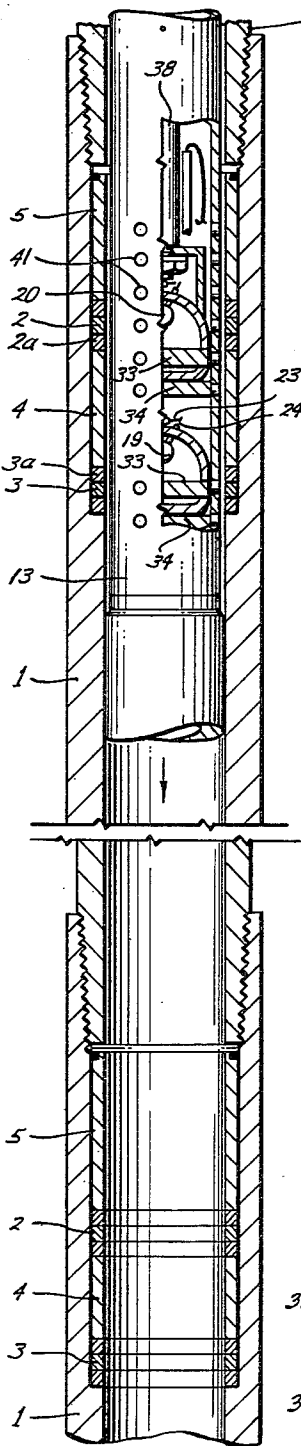
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4 Sheets-Sheet 2



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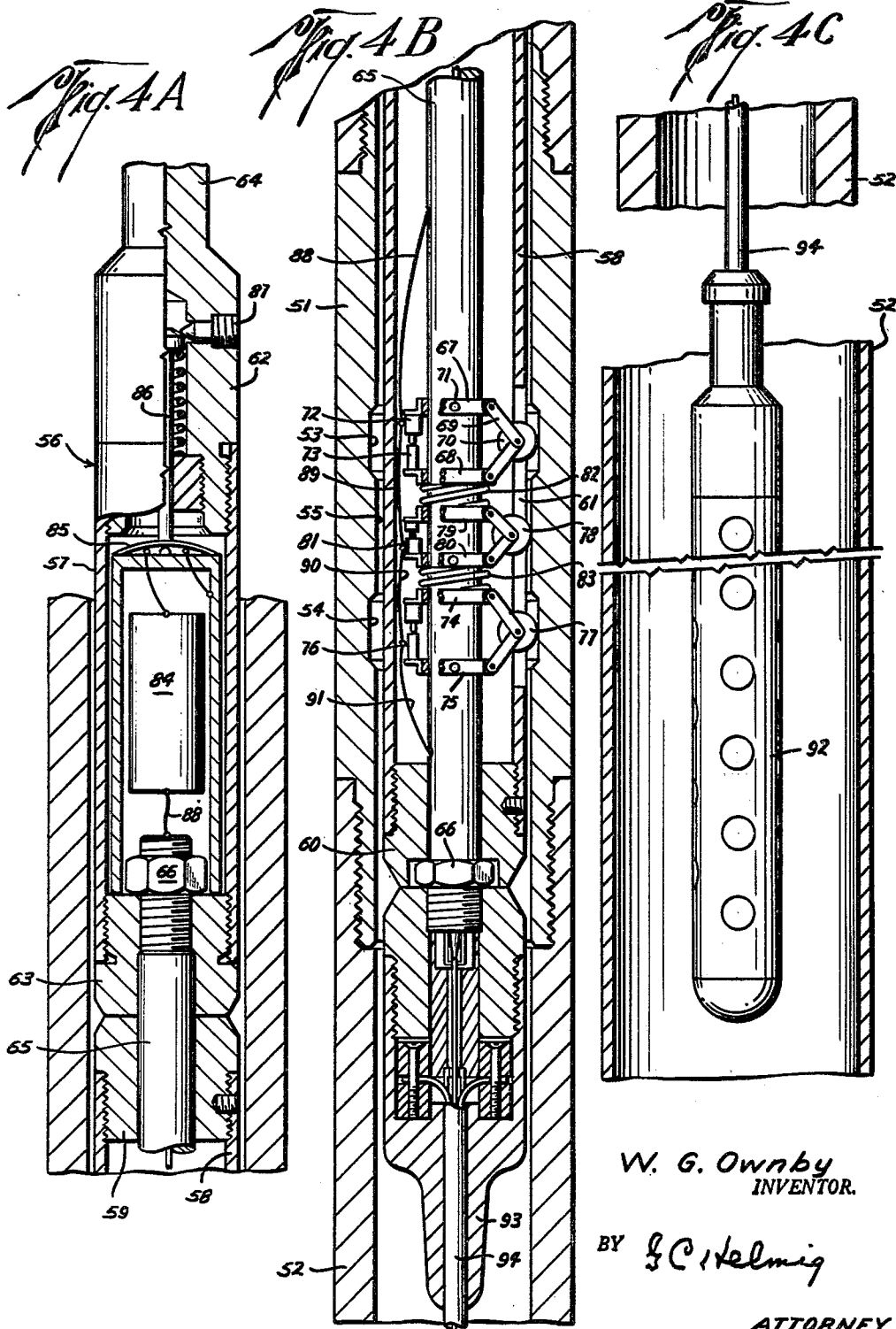
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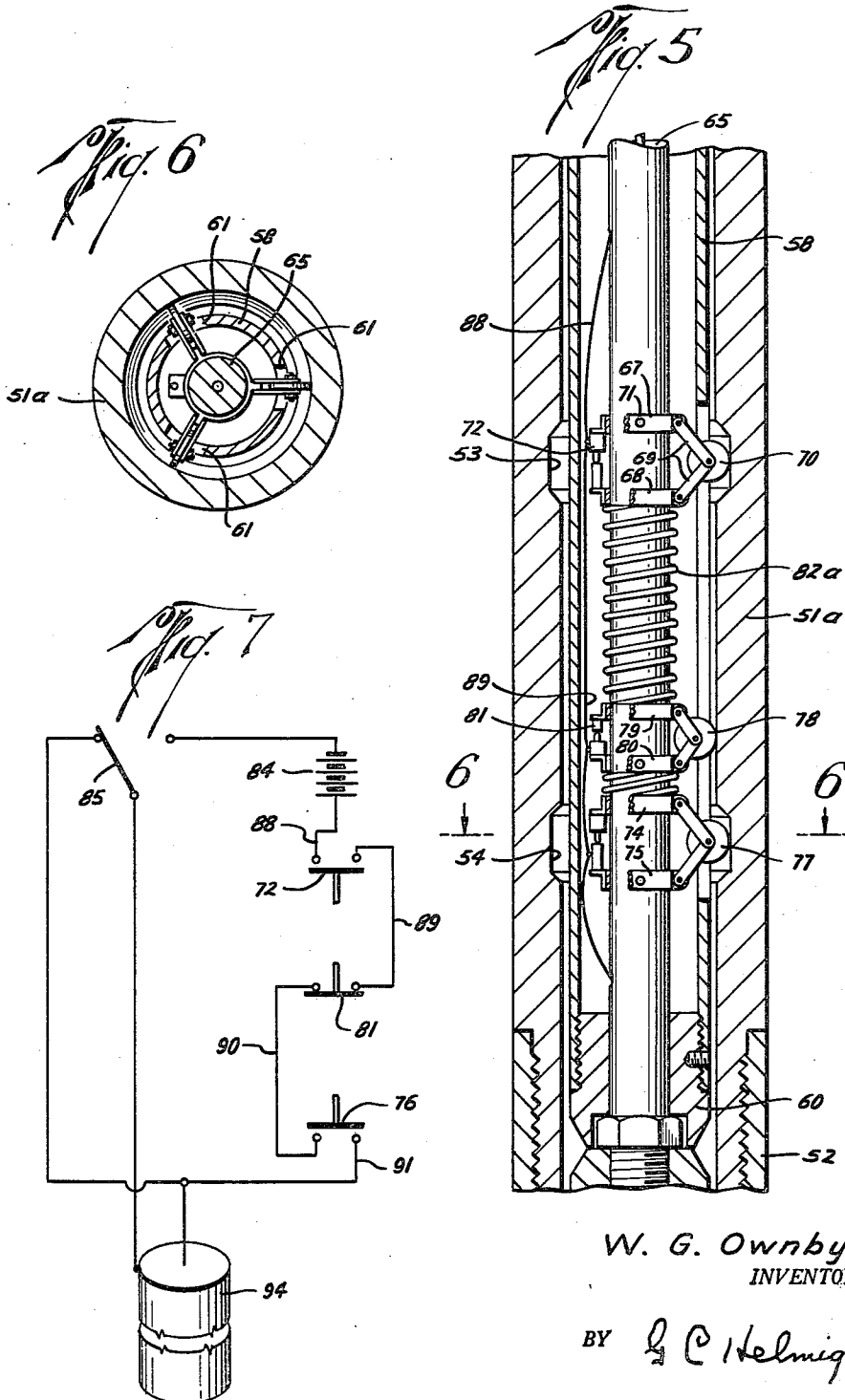
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4 Sheets-Sheet 4



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3,105,547

SELECTIVELY ACTUATED WELL TOOL

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Filed Mar. 30, 1959, Ser. No. 803,049

32 Claims. (Cl. 166—65)

This invention relates to well tools and more particularly to an improved wire line type of equipment to be lowered into a well for automatic operation upon reaching a preselected depth and the present application is a continuation in part of pending application Serial Number 778,826, filed December 8, 1958, now abandoned.

An object of the invention is to provide a tool to be lowered into a well and to carry a signal detector which responds to a given signal in triggering the performance of an operation at a selected depth.

A further object of the invention is to provide an improved tool having several signal detectors co-operatively dependent on one another to control a work performing operation upon their simultaneous responses to signals received at a given location.

Another object of the invention is to employ several permanent magnets located in a well tubing string and arranged in sets at given depth stations and with the magnets of each set spaced apart in different relations and to use a lowering tool having magnetically actuated switches whose pole pieces are adjustable to key their relation selectively to any one of the sets of permanent magnets whereby the switches act to close a control circuit under magnet influence in unison only when they are in the magnetic fields of the selected set of permanent magnets, the completion of the control circuit serving to trigger a release of energy suitable for the job in hand.

A still further object of the invention is to enable the owner of a well to install a series of spaced apart tool receiving nipples in a well string for the subsequent latching of a well working tool in any one nipple and to associate with each nipple a magnetic field arrangement different from the others and to which there can be coded the field detector of a tool lowering device so that latch actuation will be effect at the proper moment for anchoring the tool in the desired nipple.

Another object of the invention is to provide an electro-mechanical locating and actuating running tool having an electrically operated work performing device connected in a control circuit containing a number of series connected switches responsive to radial disposition of tubing string feelers or surface followers which are set in predetermined axially spaced apart relation coded or in correspondence to known mechanical surface formations in a special nipple incorporated at a given location in a string of well tubing sections whereby when the location of the nipple is reached by a tool being passed through the string the fact will be signaled by transmission of feeler movement or displacement to close the several switches simultaneously and complete a circuit for current flow to the work performing device.

In the accompanying drawing, illustrating preferred but not necessarily the only embodiments of the invention, FIG. 1A is an elevational view with parts in section of the upper portion of a tool according to one form; FIGS. 1B and 1C are elevations respectively showing an intermediate portion of the tool and a lower tool fragment and a hanger detachably connected thereto, parts of the apparatus being in section and the tool being located in a well production string shown in section; FIG. 2 is a wiring diagram of the circuitry employed in the tool; FIG. 3 is a vertical section of a well production conduit with the improved tool located therein during a lowering operation; FIGS. 4A, 4B and 4C are vertical

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sectional views illustrating respectively an upper portion of a selectively actuated well tool, a lower portion thereof and a work performing device suspended therefrom with the lower part of FIG. 4C being in a larger casing; FIG. 5 is a vertical section corresponding generally to FIG. 4B but illustrating an alternative setting of the parts; FIG. 6 is a transverse section as on line 6—6 of FIG. 5; FIG. 7 is a wiring diagram of the circuit employed in the mechanical-electrical embodiment and FIG. 8 is a perspective view with broken-away parts of a magnetic field sensing switch.

The usual well production conduit comprises a string of steel tubing sections including the section 1 in the drawing, and according to this invention certain of the tubing sections are specially formed with upper counter-bored ends of given length. Within the enlarged diameter upper counterbored pocket of each of the several specially formed tubing sections and as seen in FIGS. 1B and 3, there will be fitted a series of separate rings including annular permanent magnets, spacer tubes for setting the magnets at selected axial distances apart and nonmagnetic rings, one on each side of each magnet. As illustrated, each pocket has two spaced apart magnets comprising an upper magnet 2 and a lower magnet 3 so magnetized that their pole portions are radially inwardly and outwardly thereof. On opposite sides of the magnet 2 are the rings 2a of nonmagnetic material. Similar nonmagnetic rings 3a are placed above and below the magnet 3. The lower set of rings 3 and 3a is bottomed on the shoulder at the lower end of the counter-bore and separating the two sets of rings is a tubular spacer 4 of magnetic material. An upper spacer tube 5, also of magnetic material, occupies the pocket above the upper magnet ring. By installing spacer tubes 4 and 5 of varying lengths, the axial spacing between the two magnets can be varied to provide any of several distinctly different reference markers or detector signaling fields and according to the present invention, a number of sets of magnets are to be used at spaced apart depths as the station markers and the spacing between the magnets of each set will be different, advantage being taken of the spacing differences for selectively coding thereto field sensing detectors or magneto mechanisms for controlling their simultaneous responses.

The radially inward and outward faces of each permanent magnet ring are of opposite polarity and for the purpose hereof the inner face may be considered as a north pole and the outer or peripheral face may be considered as the south pole of the magnet. The magnetic field between the poles is extended by the shields or guards afforded by the nonmagnetic rings above and below each magnet. Thus the flow path extends into the tubing bore from the north pole and both upwardly and downwardly around the nonmagnetic rings and through the tubing wall to the south pole, and the field can be employed for a response in or to signal operation of a magneto mechanism when the same traverses or is properly brought into intersecting relation with the field.

Such response can be employed for effecting operation of work performing equipment of various kinds and an example of such operation is the actuation of a latch for securing a tool hanger in a landing nipple. Accordingly, the drawing illustrates a conventional tool hanger and a tubular receiver or landing nipple 6 incorporated in the tubing string, and one of such nipples is immediately below each of several magnet carrying tubing sections. That is to say, at a given distance below the lower magnet 3 of each magnet mounting tubing section, there will be a latch keeper notch 7 in a nipple 6.

The keeper notch 7, as seen in FIG. 1C, has projected thereinto a number of latch lugs 8 forming parts of a conventional tool hanger assembly and which comprises es-

essentially a pair of telescopically fitted inner and outer concentric tubes 9 and 10. The innermost tube constitutes a slidable plunger having an annular camming enlargement 11 which upon downward retraction of the plunger 9 is brought into alignment with and projects the latches 8 outwardly from their locating tube 10. Upward projection of the plunger 9 carries the camming enlargement 11 above the latches 8 and enables their retraction from the keeper notch 7. Thus removal of a previously latched-in tool hanger will necessitate the use of a wire line pulling tool which can be clutched onto a fishing neck at the upper end of the plunger 9 for raising it upwardly, first permitting latch retraction and then carrying the whole hanger assembly out of the well.

Hanger installation is by means of a running tool arranged so that when the retracted latches come into alignment with a keeper notch of a nipple at a preselected location, a controlled force can be applied for a relative downward projection of the plunger 9 in its housing 10. Thereafter, separation of the running tool from the latched hanger can be effected, for example, by breaking a shear pin connection 12 connecting the upper end of the housing or outer tube 10 with the lower end of the running tool.

The running tool disclosed herein includes a wire line suspended hollow tubular barrel 13 housing plunger operating mechanism. Such mechanism includes a slidable hammer or jar 14, shown by dotted lines in FIG. 1B, and which can be forced downwardly to strike the upper end of and to push down the hanger plunger 9. Hammer force may be supplied by various agencies, including an energy storing spring held under stress by a solenoid releasable detent, but as illustrated in the drawing, the release of operating energy is supplied by an explosive charge mounted in the chamber 15 above the hammer 14 and provided by a squib with an electrically responsive firing cap. In the upper part of the running tool there will be housed the electrical components arranged in a circuit as diagrammed in FIG. 2 for firing the explosive charge or squib 16.

In the wiring diagram, a main or manually set off and on switch 17 is shown in a position to open a control circuit and to close a grounding circuit for the squib 16 as a safety factor against accidental ignition. When the device is ready for use and before it is lowered through the well, the main switch 17 is thrown into engagement with a contact for closing a circuit involving a battery 18 and a pair of oscillatory coils 19 and 20 of magneto machines, the coils being in parallel and supplied with current from the battery 18 as controlled by variable resistances 21 and 22. A switch having a fixed contact 23 and a movable contact 24 is associated with the coil 19 and a similar switch comprising a fixed contact 25 and a movable contact 26 is associated with the coil 20. The switches are series connected in a control circuit having therein a battery 27 and the coil of a relay switch 28. When both switches are concurrently closed due to magnetic field responses at the coils 19 and 20 as will be described, the relay switch 28 will be actuated for supplying current from a battery 29 to fire the squib 16. The squib thus constitutes an electrically responsive actuator for the explosive charge or other work performing device and the switch assemblies constitute field sensing or detector units since magnetic fields at the previously mentioned station markers are detected or sensed by switch closing responses upon tool traverse of the field.

The main switch 17 has its positions controlled by means of a set screw 30 shown in FIG. 1A. This set screw is arranged for lateral adjustment to move its tapered tip for position setting engagement with the conical upper end of a head 31 on a switch actuating slidable stem 32 normally urged upwardly by a coil spring. When the screw 30 is threaded inwardly, the switch 17 will be in the grounded relationship shown in FIG. 2 and when the screw 30 is backed outwardly, as seen in FIG. 1A, the

main switch will be in position for current flow in the circuit having the battery 18. The wiring for the various components corresponding to those diagrammed in the upper part of the circuit of FIG. 2, lead to a connector panel 53 of FIG. 1A from which other wires lead downwardly to the components represented in the lower half of the diagram of FIG. 2.

The coil 19 controlling the contacts 23 and 24 and the coil 20 controlling the contacts 25 and 26 are parts of a pair of axially spaced apart magneto mechanisms located in the housing 13 and each mechanism also includes two soft iron disks 33 and 34 spaced apart axially a distance which will approximate the vertical dimension of each of the nonmagnetic rings 2a and 3a. Thus when any disk comes into transverse alignment with any permanent magnet, the disk will constitute a pole piece or pole portion of the mechanism for co-operation with the inner face of the magnet and the field between the north and south poles of the magnet will be extended to include that pole piece and its companion disk pole piece. In simplified form, FIG. 8 illustrates the magneto mechanism controlling the switch contacts 23 and 24. It includes the oscillatory coil 19 and co-operating field pole pieces arranged for current flow from battery 18 through the coil so that whenever a magnetic field of proper polarity is extended across the coil windings, the coil will swing to close the contacts 23 and 24. The lower pole piece disc 34 has secured centrally of its upper face a transverse strap from whose opposite ends rise the two legs of an upstanding semicircular or inverted U-shaped extension 35 which projects through peripheral notches in and has clearance relation to the upper pole piece 33. For convenience of assembly, the upper pole piece 33 is formed as two half segments joined together and fixedly secured in insulated relation with the bottom pole piece 34 and its upward extension 35. Within the space surrounded by the semicircular pole extension 35 and the upper pole piece 33 so as to be influenced by a magnetic field across the pole pieces and wound on a pivotally mounted cylindrical core for oscillation, is the coil 19 in the form of a rectangular winding of fine wire whose opposite ends, as shown in FIG. 2, are in circuit connection with the battery 18. Supported by and movable with the oscillatory coil 19 is the switch contact element 24 for co-operation with the fixedly positioned switch contact 23 and these normally open switch contacts are parts of the control circuit (see FIG. 2) containing the battery 27.

When the master switch 17 is thrown for passage of current from the battery 18 through the oscillatory coil 19, the switch contacts 23 and 24 remain open except when the coil 19 is within a magnetic field of proper polarity for influencing the coil 19 to swing, in a counterclockwise direction as viewed in FIG. 8, and shift the switch contact 24 into closing relation with the fixed contact 23. This operation is in accord with the principle of the d'Arsonval galvanometer. The upper magneto mechanism, including the coil 20 for circuit connection with the battery 18 and the contacts 25 and 26 in the control circuit of the battery 27, is identical in arrangement and operation of parts to the lower magneto mechanism just described and in conjoint use the switches 23—24 and 25—26 are in series connection in the control circuit of the battery 27.

In tool passage through the tubing string, a magnetic field of proper polarity to swing either coil into contact closing relation will be impressed on the coil when its associated upper pole piece 33 comes into substantial alignment with the inner face or north pole of any permanent magnet and at which time the lower pole piece 34 is in the flux path toward the magnet south pole. Because of the series connection of the two switches 23—24 and 25—26, the magnetic field response of either magneto mechanism by itself fails to complete the control circuit of the battery 27. Completion of the control circuit and closure of the relay switch 28 in the firing circuit containing the battery

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29 occurs only upon simultaneous closure of both series connected switches when both upper pole pieces 33 of the two spaced apart sets are concurrently aligned with the north poles of the permanent magnets 2 and 3, as illustrated in FIG. 1B. Actuation of the firing circuit calls for the spacing between the upper pole pieces of the two sets to be coded or matched with the spacing between the permanent magnets.

Dependency on the simultaneous alignment of upper pole pieces 33 of both spaced apart sets with the spaced apart magnets in the tubing string enables selective actuation of the control circuit at a given depth since the two magnets in each of the several sets are spaced apart differently than those of other sets and only one set of magnets of the group will match the setting of the two pole pieces 33 for the tool carried magnetically responsive coils. FIG. 3 shows a lowering tool passing one set of magnets and having its pole pieces spaced differently from the magnets whereby their traverse of and response to the respective magnetic fields occurs at different times and the series connection of the switches in the control circuit keeps the control circuit open and precludes operation of the firing circuit switch. With a tubing string having a series of magnet containing or signaling stations, the magnetic switches can be coded to a particular one set of magnets by a presetting of the spacing between two upper sensing or detector pole pieces for determining the release of the work performing energy, whether at the first or other of the magnet sets in the tubing assembly.

For selectively setting the relative spacing of the magnetic switches to coded relation with any set of magnets, there is here provided a novel control or position selector means for adjustably varying the axial spacing between the two field influenced switch units. As shown, the lowermost unit is fixedly positioned by a screw stud 36 in FIG. 1B, extending through a fixed insulator plate and into threaded engagement with the lower pole piece 34. The upper magnetic switch is suspended by a U-shaped coupling 37 on the lower end of a rod 38 slidably mounted at its upper end in a reduced diameter opening through the housing. This upper end of the stem 38 has a series of axially spaced apart annular grooves 39, any one of which can be brought into alignment with and receive a projecting end of a set screw 40 threaded in the lateral bore in the wall of the housing 13. The grooves 39 are uniformly spaced apart and the spacing is equal to the difference in lengths between successively longer magnet spacing tubular members 4 of a set and which are installed in any desired order between the magnets of the different groups. Thus it will be noted in FIG. 3 that the spacer 5 of the topmost group is of shorter length than the spacer 4 in the lowermost group of magnets illustrated. The spacing distance between the several grooves 39 is followed in placing a number of magnetic inserts 41 through the wall of the housing 13 for alignment in all settings and contact with the pole pieces 33 and 34 for minimizing resistance in the magnetic flux path. Several vertical rows of such magnetic inserts preferably are provided in circularly spaced apart relation.

To minimize fluid pressure differentials between the inside and the outside of the housing 13 as might otherwise occur at different levels and temperature conditions, the housing chamber enclosing the magnetic switches is preferably filled with a liquid, such as silicon oil, to a level determined by a floating piston 42 at the upper end of the housing chamber, and a coil spring 43 exerts a light force downwardly on the piston. A lateral port 44 through the wall of the housing communicates the chamber above the piston 42 with the outside of the casing for an equalization of pressure. Submersion in oil of the delicate parts protects them from inertia forces and improves electrical characteristics.

Inasmuch as the action of the earth as a magnet will induce magnetism in a piece of magnetic material pro-

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jected vertically through the ground and whose upper and lower ends are then of opposite polarity, it may be feasible in some installations and in place of permanent magnets, to employ terrestrial magnetism for the controlled actuation of the magneto mechanism. This would involve a tubing string including magnetic and non-magnetic tubing sections of predetermined lengths coupled end to end and selectively in given order, whereby a signaling station is constituted at a short nonmagnetic tube section which couples adjacent ends of two magnetic sections. The separated but mechanically coupled ends are then magnetic poles of opposite polarity and present a magnetic field from one to the other. Two such adjoining couplings will afford a pair of spaced apart magnetic fields and several sets of different vertical spacing can be incorporated in the tubing string, as in the case of the permanent magnet installation.

As an alternative for signaling performance of work and completion of an electric current flow control circuit through selective switch actuation in response to traverse of magnetic fields as heretofore described, the arrangement illustrated in FIG. 4B and its companion views provides a mechanical system for triggering release of energy when the running tool reaches a predetermined depth location during passage through the tubing string. The illustrated mechanical switch actuating linkage is for use with tubing string installations which incorporate internally grooved nipples as commonly employed in sets of several spaced apart nipples differently grooved and located at varying depths in a given well for co-operation with various types of conventional well working tools arranged for selective reception in the nipples. One of such nipples 51 is shown in FIG. 4B as an insert or tubing string section between adjoining lengths of the tubing string 52 and the nipple interior diameter conforms generally to that of the other tubing string sections except for a pair of axially spaced apart internal grooves 53 and 54 separated by a given length of land 55. The axial length of the land 55 and/or of each groove 53 and 54 will differ in each of several nipples in a string and will provide discriminatorily dissimilar station markers or signaling devices at spaced apart depths. In making up the string, the nipples are assembled with tubing sections in selected order and for axially spaced apart locations at predetermined final depths in the well hole. Differing nipples in a set enable coding thereto of a working tool to be run into the tubing string at any later time and including marker detector means for co-operation with a particular nipple.

For selective co-operation with a double grooved nipple 51, a running tool as here proposed includes a wire line suspended body carrying a number of axially spaced apart and radially movable feelers or tube surface followers arranged to ride or track down the interior surface of the tubing string during tool descent and individually to move radially inwardly and outwardly as controlled by contact with surface irregularities or gaps in tube internal surface continuity. Relative radial disposition of the feelers is utilized when all are in given correlated settings as governed by alignment with groove and land formations or station markers of a selected nipple, for effecting signaled responses to said reference markers and simultaneously closing a number of switches serially connected in an electric control circuit in completing the circuit and thereby effecting a desired operation.

As shown in the drawing, the running tool assembly 56 comprises a hollow body or housing enclosing and mounting the several operating parts and conveniently made up of an assembly of tubular members joined in end to end succession. Primarily, the housing comprises a pair of upper and lower tubes 57 and 58. The lower tube 58 has opposite ends internally screw threaded for reception of end coupling plugs or spacer sleeves 59 and 60 and the tube wall intermediate its ends has a set of three windows or axially elongated slots 61 equally circum-

ferentially spaced apart, as seen in FIG. 6. The upper housing tube 57 also is internally threaded at opposite ends and receives coupling plugs 62 and 63 (see FIG. 4A), of which the plug 62 terminates in a fishing neck 64, as well as a threaded stud similar to that shown at the top of FIG. 1A, by which a suspension wire line is to be connected. Another hollow tube or tie rod 65 of smaller diameter than the lower tube 53 is nested concentrically within the lower tube and extends throughout the length thereof and through and slightly beyond the spacing and coupling plug 60 at the rod lower end and through and slightly beyond the spacing and coupling plugs 59 and 63 at the upper tie rod end so as to be centralized within the tool body 56. Clamping nuts 66, threaded on opposite ends of the central tube 65, bear on end faces of the coupling plugs 60 and 63 and hold the upper and lower tubes 57 and 53 in assembly.

A set of three axially spaced apart feeler and switch subassembly units are sleeved and mounted on the central tube or rod 65 and each includes one or more wall feeler members to extend through windows 61 in the outer tube 53. Three such feelers for each switch unit are contemplated for centering the running tool during its travel in a tubing string. These subassemblies are generally similar but not necessarily interchangeable.

The uppermost unit includes a pair of axially spaced apart and relatively movable tube embracing bands or collars 67 and 68 interconnected by end to end pairs of swinging or folding shackle links 69 having their remote ends hinged to the upper and lower collars 67 and 68 and their adjoining ends pivoted on a trunnion pin or axle shaft for a rotatably mounted and tubing string engageable tracking wheel or follower roller 70. The collar 67 threadably contains one or more set screws 71 by which the collar is adjustably fixedly fastened to the mounting tube 65 in a selected axial set position. Its companion collar or band 68 is free to slide or move axially toward and from the fixed collar 67 as determined by lateral movement and position of the tubing string follower wheel 70 as transmitted through the extensible shackle links 69. A microswitch 72 is bracketed or fixedly carried on the stationary collar 67 and contains a pair of contacts to be opened and closed by a bridging blade a slidable nose projection for bearing abutment and movement with a post 73 on the slide collar 68.

As previously indicated, the remaining two feeler and switch units are similar to that just described. The lowermost unit has a slide collar 74 and an adjustably fixed collar 75 carrying a microswitch 76 which operating nose is engaged by an abutment on the slide collar and the collars are interconnected by foldable motion transmitting linkage responsive to follower 77 carried thereby. The intermediate unit has the follower wheel 78 and motion transmitting linkage for controlling travel of a slide collar 79 relative to a fixed collar 80 for opening and closing the microswitch 81 mounted on the fixed collar.

A coil compression spring 82 surrounds the mounting rod 65 between the slide collars 68 and 79 of the upper and intermediate units and yieldably biases each collar toward its fixed mounting collar, or more particularly urges the interconnecting links and the feeler members carried thereby radially outwardly from an inwardly contracted relationship. A spring coil 83 is interposed between the fixed collar 80 of the intermediate unit and the slide collar 74 of the lowermost unit for outwardly biasing the feeler members of the lowermost unit. These coil springs 82 and 83 accommodate a range of relative axially spaced settings of the adjustably fixed collars 67, 75 and 80 but springs of different length may be substituted to fit various spaced relations of the spaced apart units. Thus FIG. 5 shows a relatively long coil spring 82a interposed between the slide collars of the upper and the intermediate feeler units when these units are widely spaced apart for a coded relation to a nipple, indicated at 51a, whose internal grooves are widely spaced apart.

In the arrangement illustrated, the contacts of the intermediate microswitch 81 may be considered as normally closed and the contacts of the two endmost switches 72 and 76 may be considered as normally open; the normal relationship being that obtaining when the several feeler members are in their radially contracted or laterally inward positions. Thus, prior to the introduction of the running tool into a tubing string and with all feelers free of radially restraint, all of them will be extended outwardly under the elastic force of the coil springs 82 and 83; wherefore the switches 72 and 76 are closed and the intermediate switch 81 is opened. Upon insertion of the running tool into the tubing string at the start of the lowering-in operation and when all feelers are contracted by engagement with tubing string internal surfaces of uniform internal diameter, the inward contraction of the feelers opens the endmost switches 72 and 76 and closes the intermediate switch 81.

As the tool is run into the tubing, the several feelers 70, 77 and 78 track on the tube interior and each will tend to move out as it comes into alignment with any outward depression or clearance such as may be presented at certain tubing joints and at nipple grooves or the like. Annular enlarged space at any region and which in axial dimension is less than the space between the endmost sets of feelers, on being traversed by the tool will enable each set of three feelers to drop out or extend into the radially enlarged space as each set in succession traverses or comes into alignment with the space but no more than any two of the microswitches will be closed at any instant during complete traverse of the space by the tool. Should any such annular clearance space or outward tube depression be of greater axial length than the distance between the endmost sets of feelers, then again at least one microswitch will be open throughout the traverse of the depression by the three switches. In other words, if all three sets of feelers are expanded coincidentally, the centermost switch 81 will be open and if the switch 81 is closed while either of the endmost switches 73 and 76 has its feeler contracted, its associated microswitch will be open. However, if the spacing between the three sets of feelers is coded beforehand for alignment to a particular double groove spacing arrangement of a given nipple 51, as illustrated in FIG. 4B, then as tool descent brings the followers into the relationship in which the centermost center feelers 78 engage the land 55 and are contracted and the endmost feelers 70 and 77 are extended into the grooves 53 and 54, then all three microswitches 72, 76 and 81 will be closed. Therefore, regardless of tubing internal surface shape and irregular formations or diametrical variations, one or more of the switches will be opened except when all three are positioned by their follower co-operation to a given nipple as in FIG. 4B.

Series connection of the several switches in a control circuit for electric current flow only when all three switches are concurrently closed is contemplated for the performance of work at a predetermined location, such as previously described for setting a hanger latch mechanism or for various other jobs, inclusive of a tube perforating operation. Circuit wiring of long distance extended clear back to the surface is eliminated by mounting a small battery or dry cell 84 within the upper housing tube 57, as seen in FIG. 4A. One terminal of the battery may be grounded to the tool wall through a master switch 85 containing contacts which are closed when a plunger 86 slidably mounted in the plug 62 is depressed by an inward adjustment of a stud 87 threaded through the plug wall and formed with an inner conical tip in camming engagement with the upper terminal of the plunger 86. This main switch 85, by manipulation of the screw stud 87, is adjusted to open position at all times except in the interval between the start of a lowering operation and the final removal of the running tool from a well. The other battery terminal is joined by a

conductor wire 88 extended downwardly through the tube 65 and passed through the wall of the tube for connection with one contact of the uppermost switch 73. A short length conductor wire 89 joins the other contact of the uppermost switch with one terminal of the centermost switch 81, whose other terminal is joined by a conductor wire 90 with a contact of the lowermost switch 76. The remaining contact of the lowermost switch 76 is joined by a conductor wire 91 extended downwardly for connection with a conventional electric plug connector at the bottom of the tube 65. Through the plug connector, the control circuit may be continued to a suitable work performing tool suspended from the well tool 56 and to be energized whenever the battery circuit is completed.

Devices which are coded, as in either embodiment previously described, for response to a selected tubing string insert are especially adapted for performance of perforating jobs through small diameter tubing. For such usage, a conventional perforator 92 of either the bullet gun type or shaped charge explosive type may be hung below the running tool, as in FIG. 4C, from an adapter 93 threadedly coupled to the lower end of the tube or tie rod 65 and from which extends a shielded or armored conductor cable 94. One end of the conductor cable has a detachable plug connection with the connector terminal of the conductor wire 91 for current flow to the perforator 92 and from which the circuit is completed through the cable metallic shield to the grounded housing of the running tool 56. Suspension cable length is preselected to present the perforator at a distance below the running tool and microswitch assemblies to correspond with the distance between the region to be perforated and the tubing string nipple to which the series connected switches are coded for their concurrent closing of the control circuit. Thus, upon lowering of the perforator to a position opposite a preselected region of the tubing and the surrounding formation to be pierced, there will be completed automatically the control circuit through which current will be supplied for effecting the perforating operation. This control circuit, as previously described, is diagramed in FIG. 7 with the master switch 85 in its safety off-position, with the intermediate switch 81 in its normally closed position and with the endmost switches 72 and 76 in their normally open positions.

In conventional oil and gas well completion practices, a string of casing is inserted and cemented throughout a substantial portion of the bore hole length during and immediately following the drilling operation and one or more narrow diameter tubing strings are run inside the casing and properly packed or cemented for zone isolation and production. Thereafter, it is customary to make a combination radioactivity and collar log to correlate pipe joints with the traversed formations and then run a perforator through the tubing to a selected production zone and actuate the perforator to pierce through the casing and the formation and provide flow channels through which well fluids can pass for production upwardly within the tubing string. If perforating can be performed after the narrow tubing and its associated production equipment at the surface have been set, then a relatively light fluid can be employed instead of the ordinary heavy drilling mud normally used to minimize blowouts but which also presents difficulties, and particularly that of mud filter cake deposits which seal off the perforations. It is desirable, also, to be able to do workover jobs with equipment lowered through the narrow tubing under pressure for such things as supplemental perforating without the need for recirculating heavy mud with likelihood of contaminating the formation. The equipment here described can be lowered through narrow tubing by means of a slick, small and solid wire line, and accurately perform perforating jobs under well pressure. High accuracy of measurement is obtainable by a coded switch actuation of a triggering nipple adjacent the

zone to be perforated. More successful performance of perforating operations is to be had than when measurements are referenced from the well head and are subject to influences of cable stretch, frictional engagement with the well surface and flotation conditions. Tubing string nipples to which a running tool triggering mechanism may be adjusted or coded for actuation provide a reference marker closely adjacent the zone to be worked. Marker location will be relatively permanent and determinable from installation records or detectable by simple collar locator tools which also can record a radioactive log for reliable depth location. The zone of interest can be perforated by automatic response to running tool position without dependence on observation of surface indications of tool travel or wire line suspension cable measurement.

What is claimed is:

1. Well working equipment to be passed through a well tubing string having a number of station markers providing spaced apart sets of variously spaced apart magnetic fields extending into the interior space of the tubing string, said equipment including a tool to be passed through said tubing string space, energy releasing means constituting a part of said tool and having an activating device therefor responsive to the supply of electric current to the device, a current supplying circuit containing said device, switches in series relation in said circuit, switch closing means including magnetically responsive elements connected each to a different switch and means mounting said elements for relative adjustment in the tool to spaced apart relations which correspond to the spaced relations of said variously spaced apart magnetic fields.

2. In combination, a tubing string, spaced apart pairs of permanent magnets carried by the tubing string with the magnets of each pair spaced one from another a distance different from the space distances between the magnets of other pairs, a tool to be passed through the tubing string and having an electrically actuated device therein, a pair of spaced apart switch closing elements responsive to the influence thereon of said magnets upon traverse thereof, means adjustably mounting said elements on the tool for relative adjustment of the spacing therebetween to matched correspondence with the space distance between the magnets of any of said pairs, normally open switches connected to the elements respectively for switch closure upon magnetic response of the elements and a switch controlled circuit supplying current to said device and containing said switches in series connection therein.

3. Well working equipment including current actuated means, a control circuit therefor, a pair of magnetically actuated switches in series relation in said circuit and each comprising a pair of co-operating contacts, a movable coil mounting one of the contacts for movement therewith into engagement with the other contact and a pair of coil influencing pole pieces having spaced apart relation for exposure in a magnetic field, a switch containing housing to be lowered in a well, means fixedly locating said switches in the housing with the pole pieces of one switch in given spaced relation with the pole pieces of the other switch.

4. Well working equipment as set forth in claim 3, wherein the switch locating means includes a fixed connection between one of the switches and the housing and an adjustable connection between the housing and the other switch for selectively fastening the same to the housing in any of several positions by which said given spaced relation of the pole pieces is established.

5. Well working equipment as set forth in claim 3, wherein the switch locating means maintains the switches in vertically spaced apart relation and includes a fixed connection joining the lowermost switch to the housing, a post having one end vertically slidable in the housing, a set screw connection between the housing and post and

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operative to hold the slidable post in a selected position of vertical adjustment and a fixed connection joining the uppermost switch on the lower end of the post for movement with the post and the selective positioning of the uppermost switch relative to the housing.

6. Means for performing work at a preselected depth in a well, including a well tubing string, a series of sets of permanent magnets mounted in the wall of the tubing string in vertically spaced apart relation and with the permanent magnets of each set vertically spaced from one another at a distance which is different in each set, a well tool having a housing to be passed through the tubing string, electrically triggered energy releasing means carried by the tool, a control circuit therefor, spaced magnetically actuated switches, each adapted to be closed under the influence of a magnetic field, series connected in said control circuit, vertically spaced apart pole pieces for the respective magnetic switches, means positioning said pole pieces in the housing for individually traversing the fields of the permanent magnets successively during passage of the housing through the tubing string, and adjustable means operable to set the pole pieces in various vertically spaced apart positions a distance apart to correspond selectively with the vertical spacing of a given set of said permanent magnets for the unisonal magnetic influencing of the series connected switches when their pole pieces simultaneously traverse the permanent magnet fields of said given set of permanent magnets.

7. Means for performing work in a well hole, including a well conduit, a housing to be lowered in the conduit, an electrically actuated explosive charge in the housing, a control circuit for firing said charge, a pair of spaced magnetically actuated switches, each adapted to be closed under influence of a magnetic field, connected in series relation in said control circuit and provided with pole pieces positioned by the housing in vertically spaced apart relation and means in the wall of said well conduit to present magnetic fields in the path of the housing and in vertically spaced apart relation corresponding to the vertically spaced relation of said pole pieces.

8. The structure of claim 7, wherein the wall of the conduit has a number of pairs of permanent magnets differently spaced apart and said switch pole pieces are mounted in the housing for relative adjustment and can be preset to a vertically spaced apart relation in correspondence with the spacing of a selected pair of magnets.

9. Means for performing work at a selected well depth, including a tubing string having means therein at each of a number of depths to present a pair of vertically spaced apart magnetic fields whose spacing differs from that of the fields of other pairs, a housing to be passed through the tubing string, means in the housing inclusive of a source of energy, a control circuit, a pair of switches connected in series in the circuit, separate magnetic field detector units connected one to each switch and operating to close such switch in response to magnetic field influence on the detector unit and means adjustably mounting said detector units in the housing and adjustable for setting the detector spacing to match the spacing selectively of any pair of said magnetic fields.

10. Means for performing work at any of several selected well depths, including a series of reference markers located at various depths in a well hole and each being comparatively dissimilar from the others, a housing for passage through the well hole, electrically actuated work performing means carried by the housing in an initially inactive condition and means to activate said work performing means including detector means responsive to said markers, an electric current supply circuit, switch means therefor influenced by the response of said detector means to close the circuit to the work performing means and means operative on said detector means to set the same for response to any one of said reference markers selectively.

11. Means for performing work at a selected depth in

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a well hole including a number of sets of spaced apart magnets positioned in the well, magnet positioning means maintaining the magnets of the several sets spaced apart differently in each set relative to the other sets and a tool to be passed through the well, said tool comprising a housing, work performing means carried by the housing and responsive to current flow in a control circuit therefor, a set of magnetic switches, each adapted to be closed under the influence of a magnetic field, connected in series relation in the control circuit, a pair of pole pieces for each switch and means adjustably mounting the pole pieces in said housing to set the spacing therebetween to substantially correspond selectively with the spacing of the magnets in any of said sets.

12. Apparatus for the performance of work at any of several selected depths in a well including tubing string means located in a well, tool means to be passed through the well, a series of spaced apart pole portions carried by the tubing string means and arranged in sets of pole portions spaced apart differently in the several sets, a set of pole portions carried by the tool means and arranged for adjustment of the pole portions to spaced apart relations in substantial correspondence selectively with the spacing of the pole portions in any of the several sets carried by the tubing string means, means providing magnetic lines of force at and constituting functionally integral parts of the spaced apart pole portion carried by one of the means and magneto mechanism in magnetic circuit connection with the pole portions carried by the other means and responsive to said lines of force upon extension thereof through the pole portions carried by said other means upon their concurrent alignment with the pole portions in any of the sets carried by the tubing string means.

13. Well working equipment including a tubing string, a tool to be passed through the tubing string, a work performing electrically actuated device embodied in the tool for actuation at a selected depth within the tubing string, an electric control circuit for said device containing a number of series connected switches mounted by said tool and arranged for individual switch closing action, a series of switch closing and reference marker responsive detecting means, one for each said switch, carried by said tool in given spaced apart relation and a series of reference markers carried by said tubing string at a determinable well depth location and spaced apart in coded relation to the spacing of said last mentioned means for co-operation therewith in effecting simultaneous response of the series connected switches.

14. Well working equipment as in claim 13 said reference markers comprising a pair of internal grooves axially spaced apart a predetermined distance in a tubing string region at a known depth, and said reference marker responsive detecting means including radially movable feeler members, one for each switch, in motion transmitting connection therewith whereby switch open and closed positions are dependent on the radial disposition of the feeler member, means mounting said feeler members on the tool to ride on the interior of said tubing string during passage therethrough of the tool for controlling the radial disposition of the feeler members, said last mentioned means locating said feeler members in axially spaced relation corresponding to the predetermined spaced apart distance between said internal grooves for the coincident closing of said switches only when passage of the tool through the tubing string reaches said tubing string region at known depth.

15. The structure as in claim 14 wherein the means for mounting the feeler members has a range of adjustment enabling selective variation in axial spacing of the feeler members.

16. A well working tool as described in claim 13 for interchangeable use in different wells having tubing string nipples formed with axially spaced apart internal grooves to constitute said reference markers, said reference

marker responsive detecting means comprising a set of tubing string engageable feelers connected one with each switch for the actuation thereof and carried by the tool for movement radially thereof as controlled by tubing string engagement and adjustable mounting means for the feelers enabling variation in their axially spaced apart relation to correspond selectively with the spacing of nipple grooves.

17. A well working tool as described in claim 16, together with biasing means active on and urging the feelers to move radially outwardly from an inwardly contracted position and wherein the number of feeler connected switches includes two sets of switches with each switch of one set being open when its feeler is inwardly contracted and each switch of the other set being open when its feeler is radially outwardly from its contracted position.

18. A well working tool as described in claim 16 wherein said electrically actuated device is a perforating gun and is suspended a predetermined distance from the tool by means inclusive of a current conductor in said circuit.

19. In combination, a well tubing string having a plurality of spaced apart stations, each containing a set of reference markers whose disposition relative to one another is dissimilar to that of other sets, a work performing device for passage through the tubing string and actuation at a given location therein, a set of reference marker detectors responsive individually to each marker of all stations traversed thereby, means mounting said detectors for their relative adjustment with the device and enabling positioning of the detectors in selected relations corresponding with the relative dispositions of the markers in the several sets and means responsive to marker detection by all the detectors in unison and connected with and active on said work performing device to effect its actuation.

20. A unit to be actuated at a selected location upon movement through a passage having a number of stations comprising spaced apart sets of several marker elements and having the elements of each set disposed in contrasting relation to those of other sets, said unit comprising a work performing device, a control circuit therefor, a set of switches connected in series in said circuit, separate operating means for each switch including a station marker detector active to operate the switch in response to each station marker traversed by the unit and means positioning the detectors relative one to another in preset conformity with the relative disposition of the marker elements of any set selectively for concurrent responses of the detector solely to the markers of a selected set.

21. In combination, a tubing string, a plurality of permanent magnets carried by the tubing string for the protuberance of separate magnetic fields inwardly thereof and arranged in spaced apart sets and in different spaced apart relation in each set, a work performing tool for suspended travel through the tubing string, tool carried means to release working force and control mechanism therefor including an electric circuit having series connected switches therein, separate actuating means for each switch responsive to magnetic field influence thereon and means for presetting the switch actuating means in spaced apart relation corresponding to spacing between the magnets of any one set and for simultaneous response to the fields thereof to effect concurrent actuation of said series connected switches.

22. For signaling operation of a well tool being run through a well tubing string, a well tubing string section having an annular internal pocket, a succession of separate rings stacked within said pocket, magnets carried by certain of said rings and adapted to be selectively spaced apart by the disposition between magnet carrying rings of other rings of predetermined axial lengths.

23. For signaling operation of a well tool being run

within a well tubing string, a tubing string section, mounting means on said section for locating a stack of spacer elements and magnetic field providing elements, a stack of such elements positionable by the mounting means with the elements in preselected succession, said elements being interchangeable for enabling variation in successive disposition of the spacer elements and the magnetic field providing elements.

24. For use with a well tubing string having a sub-surface signal providing marker and an internal latch keeper notch adjacent said marker, wire line equipment including a lowering tool adapted for lowering to said marker and a well tool adapted to be releasably coupled to the lowering tool and to be positioned thereby in the tubing string, said well tool comprising a tubular body, a laterally projectable latch shiftably mounted by the body for projection into and out of said keeper notch, a latch expander plunger axially slidably contained in the body and provided with latch engageable bearings controlling lateral disposition of the latch and said lowering tool comprising an initially inactive force storing means arranged to release its stored force for transmission to said plunger for sliding the same to latch projecting relation, a marker signal responsive means rendering effective the action of said force storing means when the responsive means is brought to the marker by a lowering operation and a releasable coupling initially joining said tools and being releasable in response to latched well tool resistance to movement with the lowering tool.

25. For use with a well tubing string having a series of stations at spaced apart depths and each providing a signal different in kind from others for co-operation selectively with and to signal actuation of a tool assembly upon its passage through the tubing string, a tool assembly including a pair of separate tools capable of traversing said stations, means releasably attaching the tools for support of one from the other and their passage as an assembly through the tubing string, an initially retracted tubing string engageable anchor device carried by one of the tools and radially expandable for anchoring to the tubing string, force transmitting means operable to expand said anchor device, signal actuated means carried by the other tool and arranged to be set in coded relation to and for actuation by any one selectively of the different signals, a releasable store of energy co-operating with the signal actuated means and responsive to signaled actuation thereof to supply force on the force transmitting means to expand said anchor device and said releasable attaching means being releasable upon movement of said other tool relative to the tool which has been anchored to the tubing string.

26. In combination, a well tubing string having a number of tool receiving nipples therein, permanent magnets mounted by the nipples to present inwardly protruded magnetic fields at spaced apart well depth locations, a work performing tool adapted to be passed through the tubing string for traversing any desired number of said fields, releasable energy storing means carried by the work performing tool, a field sensing assembly mounted in the tool and operatively connected with the energy storing means to release the energy thereof in response to magnetic field influence upon said sensing assembly and preset means in the tool operative to condition the field sensing assembly and restrict magnetic field response thereof to traverse by the tool of a magnetic field at a selected depth location.

27. In combination, a well tubing string having a series of spaced apart latch assembly receiving sections each including an internal keeper groove for a latch dog and signal means whose signal is distinctively unlike the signals of other signal means in the tubing string, a running tool having a releasable work performing device responsive solely to the signal of a selected signal means, a latch assembly having a body releasably secured to the running tool, a laterally projectable latch dog car-

ried by the body and adapted for projection outwardly of the body and into said keeper groove to latch the body against displacement both upwardly and downwardly, and a dog projecting plunger axially shiftably mounted in the body in co-operative relation with said work performing device for dog projecting actuation thereby upon signaled release of the work performing device, said tubing string sections, the running tool and said body all being devoid of locating abutments to interfere with travel through the tubing string of said latch assembly prior to latch dog projecting actuation by signaled response of the work performing device.

28. For use with a well tubing string having a series of spaced apart hanger anchoring sections each comprising a latch dog receiving keeper and signaling means whose signal is distinctly unlike the signals of other signaling means in the tubing string and a running tool having a releasable work performing device responsive solely to the signal of a selected signal means for effecting anchoring of a hanger; the improvement which includes a hanger body whose outside surface is devoid of external locating protuberances such as would limit free travel of the hanger through and beyond said hanger anchoring sections of a tubing string, laterally projectable latch dogs carried by the body and adapted upon projection into a keeper to latch the hanger body against displacement both upwardly and downwardly and an axially shiftable plunger within the body provided with a latch dog engageable expander formation to project the latch dog into a keeper upon plunger actuation by the signaled release of the work performing device.

29. In combination, a well tubing string having a series of spaced apart marker stations, each comprising a marker distinctly unlike the markers of other stations, a running tool for travel through the tubing string, a work performing device having actuator means responsive to electric current supplied thereto and constituting a part of said running tool and electric means wholly contained within and as a unitary assembly with the running tool and comprised of a source of current and circuit means including switch means adapted to be closed and direct current from said source to said actuating means, marker responsive means controlling closure of said switch means and other means operable to preset the marker responsive means in responsive matching relation to the marker of a selected one of said series of stations and for response solely to the selected marker.

30. For use in a well hole having a wall which contains a series of signaling stations each providing a set of inwardly protruding fields of force vertically spaced apart and in given distance relation different from the field spacing of other stations, an improved self contained tool to be run into the hole and comprising a housing, an electrically controlled work performing means carried by the housing, an electric current supply circuit therefor containing normally open switch means, vertical-

ly spaced apart field responsive devices carried by the tool and operative on the switch means to close the same upon concurrent responses of said devices to fields of force and a presetting means for selectively controlling the relative vertically spaced apart relation of the devices to match the field spacing at any signal station.

31. Means for performing work at any of several selected well depths, including a series of stations, means locating said stations at various depths in a well hole, means at each station comprising a discriminate marker comparatively dissimilar from the marker at the other stations, a housing for passage through the well hole, work performing means carried by the housing in an initially inactive condition and means to activate said work performing means including energy storage means, marker responsive mechanism having adjustable settings within the housing and controlling delivery of actuating energy from the storage means to the work performing means, and preselector means operative on said mechanism and setting the same to discriminating relation with any one marker of the several stations whereby said mechanism is responsive only to the preselected marker.

32. Well working equipment to be passed through a well tubing having spaced apart sets of variously spaced apart magnets providing magnetic fields extending into the interior space of the tubing string, said equipment including a tool to be passed through said tubing space, work performing means constituting a part of said tool and having an energy responsive device to activate the same, an energy supplying circuit containing said device, circuit completing means in series relation in said circuit and including a set of magnetically responsive control devices therefor, and means mounting said control devices for relative adjustment in the tool to selected spaced apart relations coinciding with the variously spaced apart magnetic fields of said spaced apart sets.

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