

Aug. 13, 1968

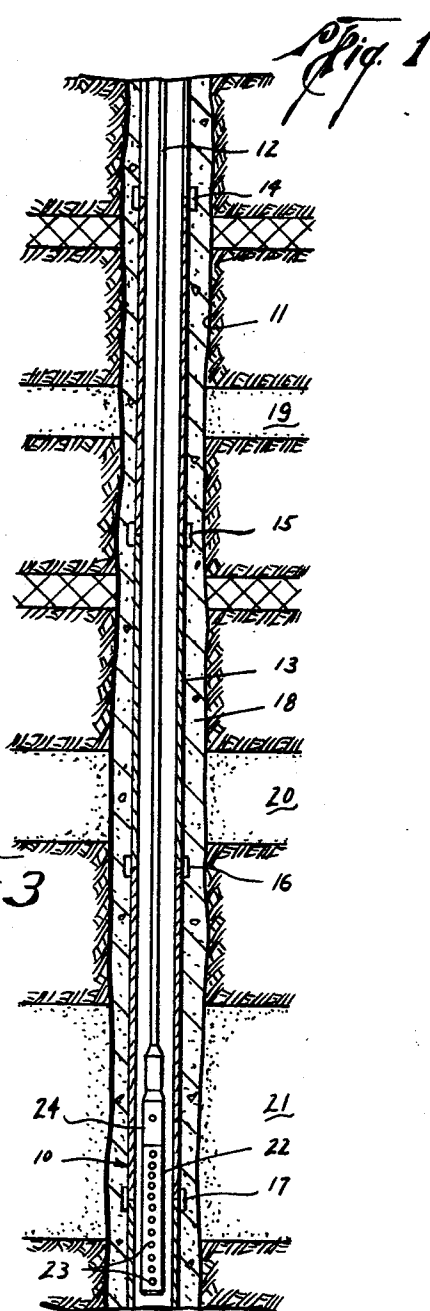
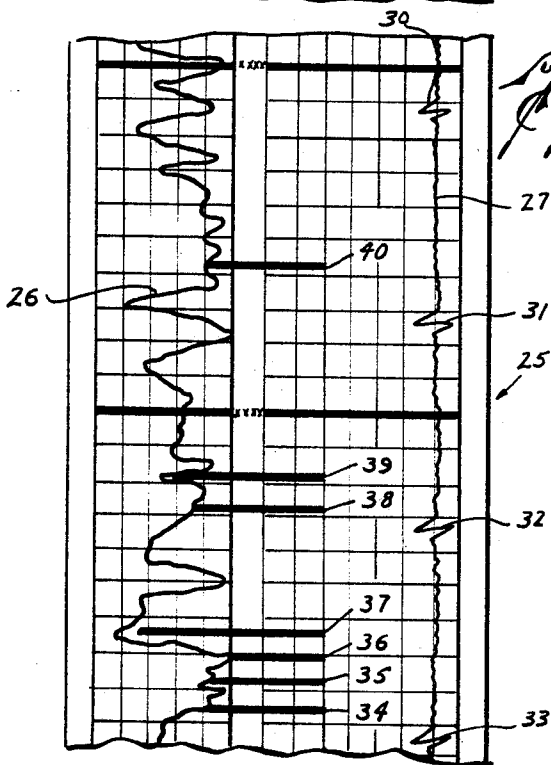
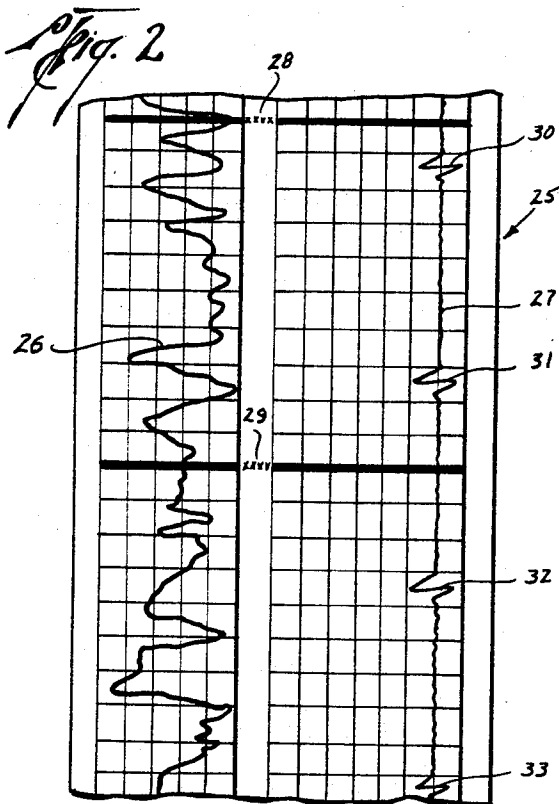
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3,396,788

DEPTH CONTROL METHODS AND APPARATUS

Filed Aug. 31, 1966

5 Sheets-Sheet 1



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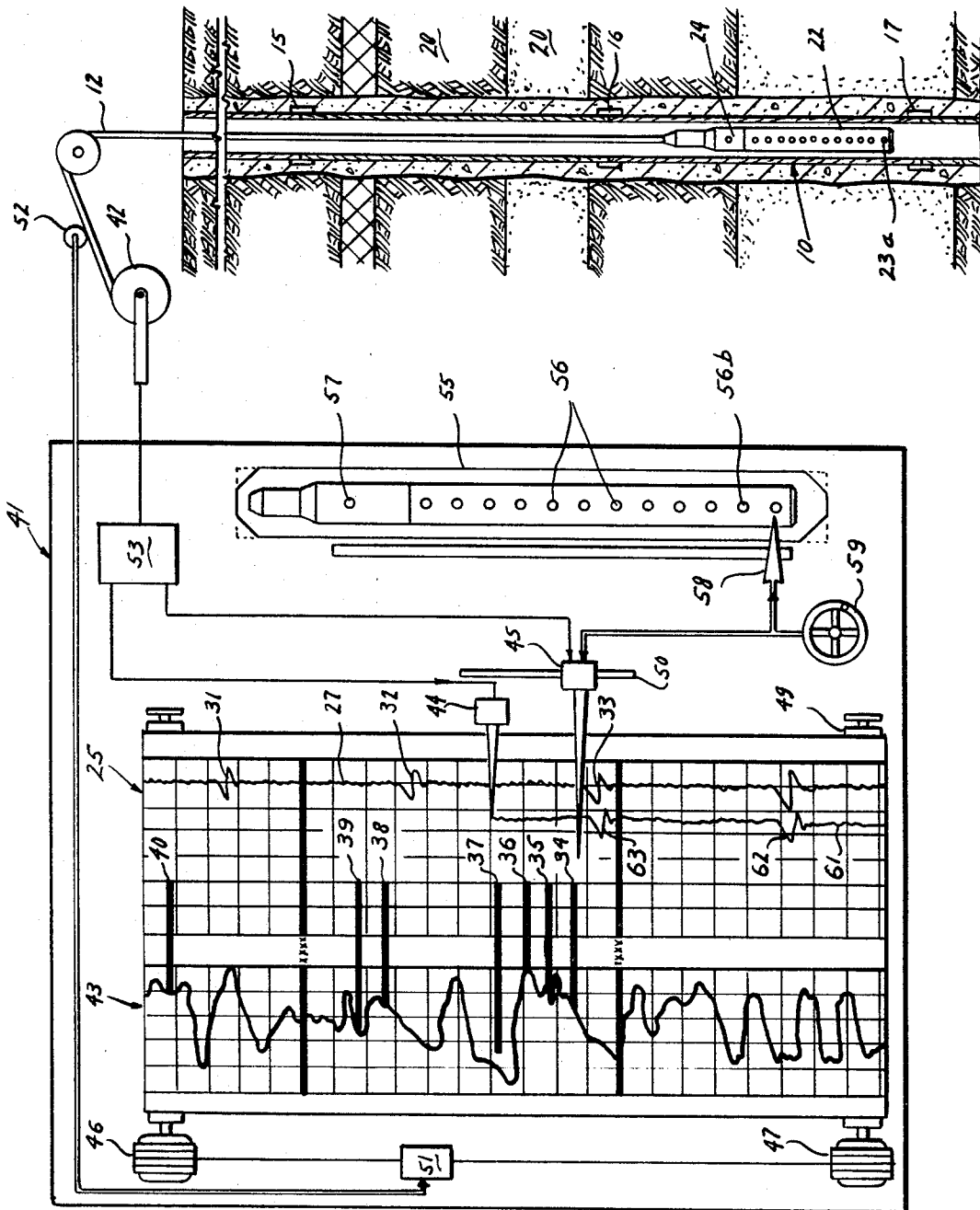
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DEPTH CONTROL METHODS AND APPARATUS

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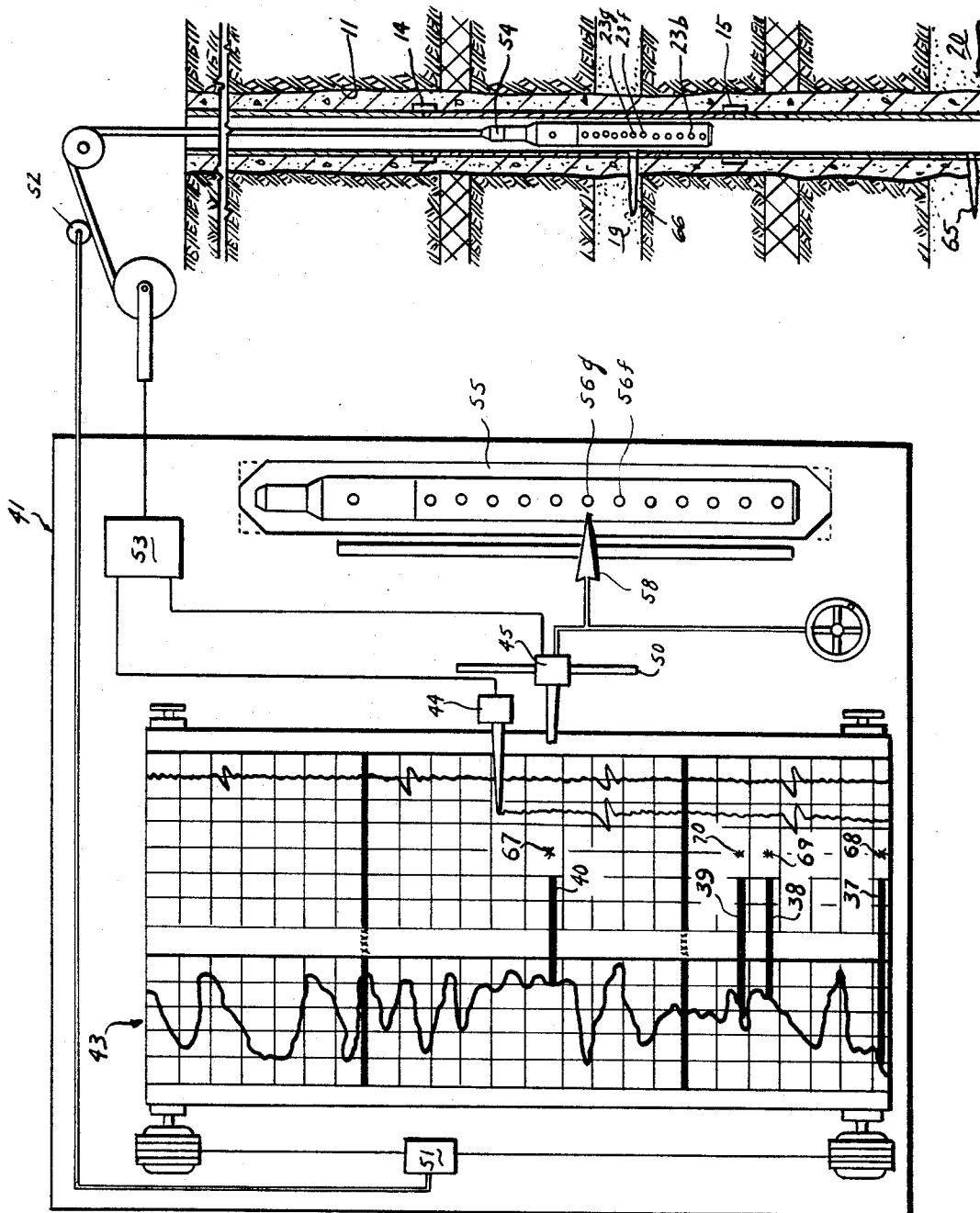
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Fig. 4

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Aug. 13, 1968

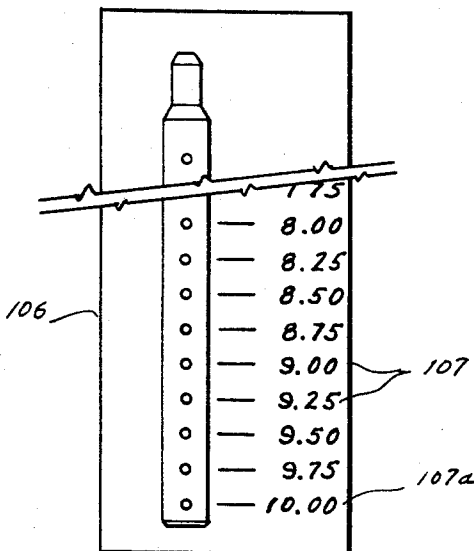
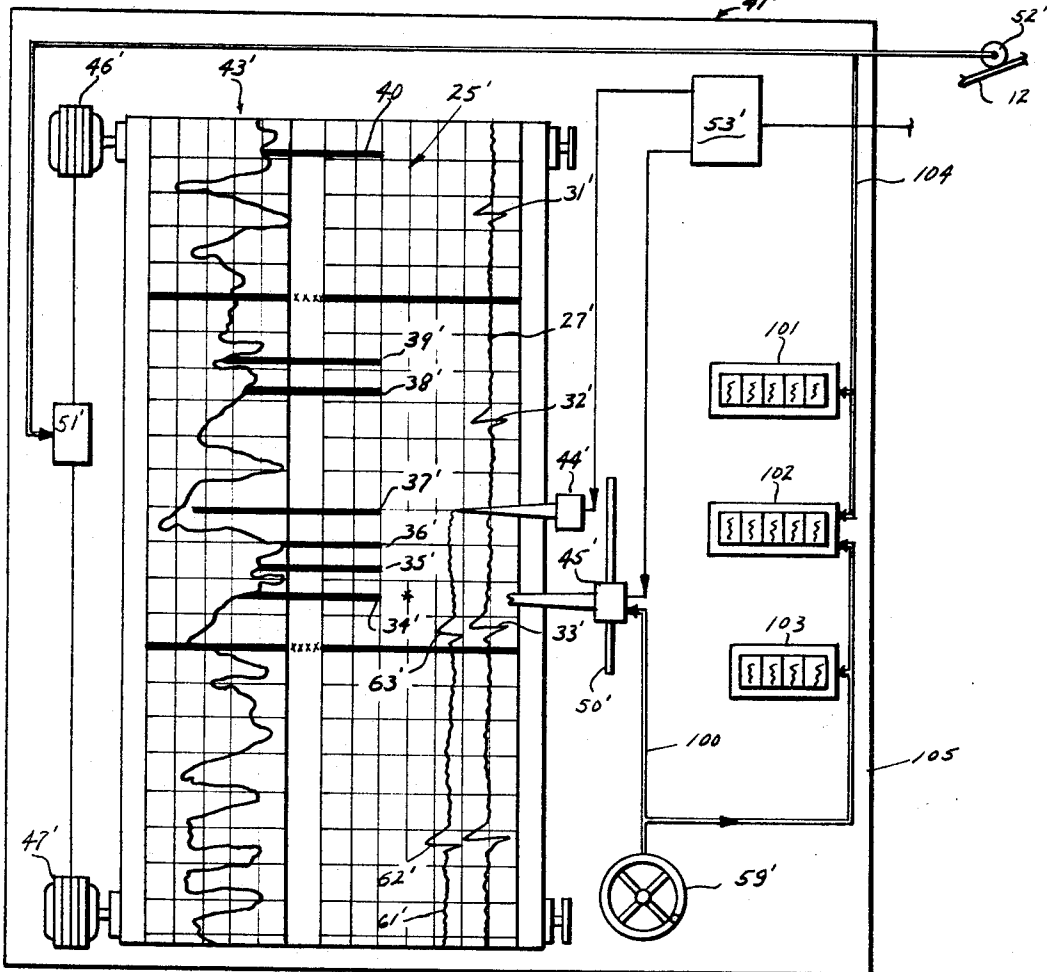
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3,396,788

DEPTH CONTROL METHODS AND APPARATUS

Filed Aug. 31, 1966

5 Sheets-Sheet 4



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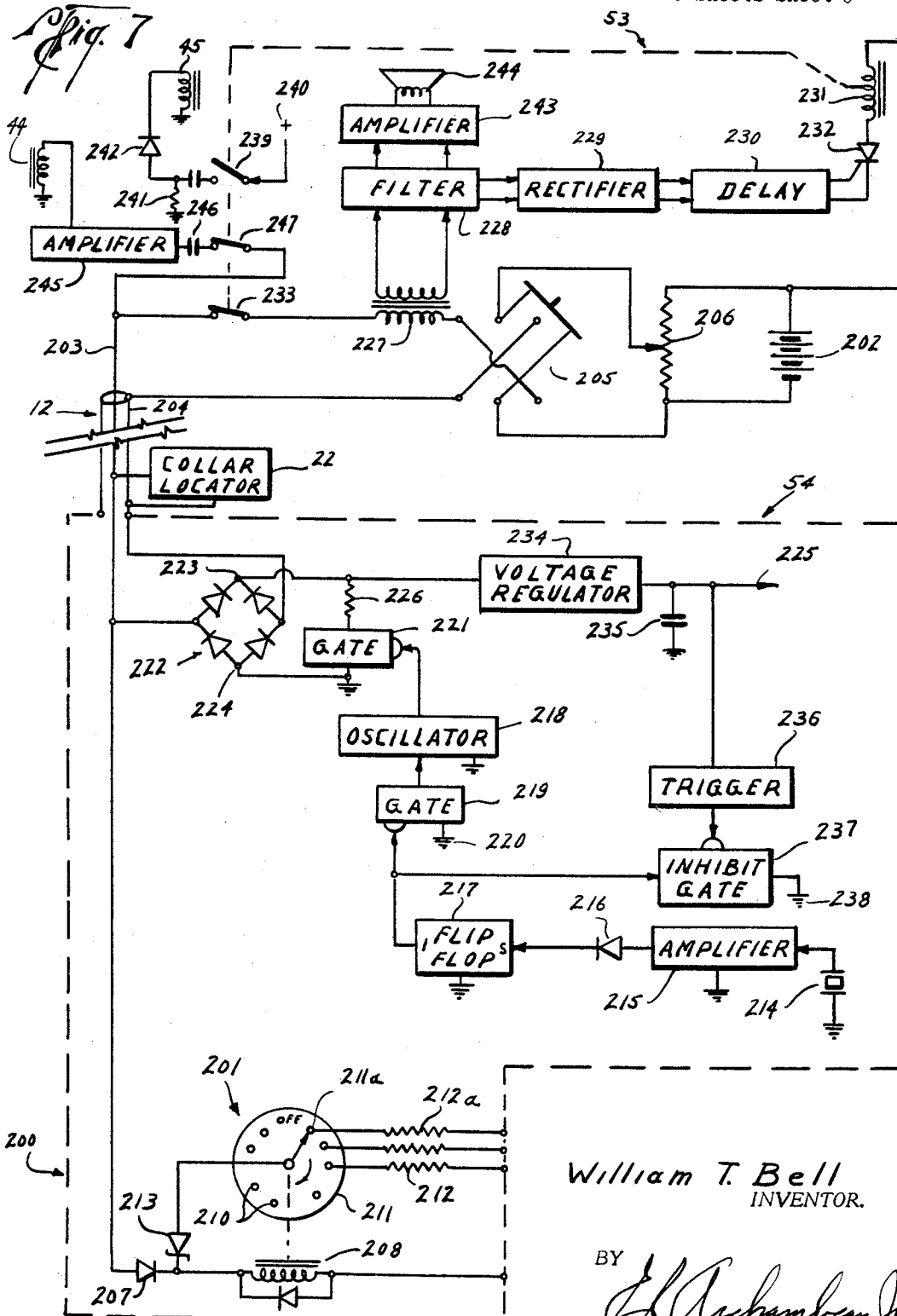
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DEPTH CONTROL METHODS AND APPARATUS

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5 Sheets-Sheet 5



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3,396,788

DEPTH CONTROL METHODS AND APPARATUS
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Filed Aug. 31, 1966, Ser. No. 576,402

26 Claims. (Cl. 166—4)

This invention relates to methods and apparatus for positioning well tools in a well bore; and, more particularly, to new and improved methods and apparatus for accurately positioning selectively operable well completion devices at predetermined depths in a well bore and displaying indications of their location therein as well as providing a record of this information.

Once the casing has been set in a well bore, the usual practice is to obtain a log that will in some manner identify at least certain formations and determine their depth. In one manner of doing this, a logging tool is passed through the well bore to simultaneously obtain a log of the natural or induced formation radioactivity as well as some detectable indicia of the positions of the casing collars as a function of well depth. In this manner, the depths of particular formations in relation to certain ones of the collars can be established. Subsequently, by using these logs and, for example, employing a casing collar locator with a completion tool, the completion tool can be located fairly accurately at any particular depth in the well bore. To accomplish this, the position of the completion tool is ascertained by visually comparing the original collar log with the collar log being obtained as the completion tool is being positioned. Then, by using this comparative data, the cable is payed out or reeled in as required to bring the completion tool to the particular depth desired.

One of the most frequent uses for such a depth-correlating procedure is to position a perforator in a well bore. To perforate a well at several depths, a perforator having a number of selectively operable perforating devices thereon is dependently coupled from a casing collar locator and lowered into the well bore. It will be realized, of course, that although the collar locator is a known distance above each of the perforating devices, these different spacings must be taken into consideration to locate each device. For example, assuming that the first device to be actuated is at the lower end of the tool, a particular correction must be made to compensate for the spacing of the collar locator from that device. Then, as further perforating devices are successively actuated, this spacing will decrease as the devices are fired, with a different spacing correction being required to accurately locate each device.

Accordingly, where a number of completion operations are to be carried out at different depths in a well bore, it is essential to know at all times not only the spacing between the collar locator and the device next to be actuated but also the actual depth of that device as well. Although the above-mentioned procedure itself is basically accurate, where a number of operations are to be made in a well bore at several depths, it is not at all too uncommon to make some error that causes the well to be completed incorrectly. For example, in addition to making such simple errors as subtracting rather than adding the spacing to the depth indicated by the collar log, it is not at all too uncommon to sometimes even overlook the successive changes in spacing as the various devices are actuated. Thus, where a larger number of completion devices are to be actuated at various depths in a well bore, one or more such human errors can result in the well being incorrectly completed.

Consequently, it is an object of the present invention to

provide new and improved methods and apparatus for accurately positioning well tools in a well bore and providing visual indications as well as a record of the position of the tool.

This and other objects of the present invention are accomplished by obtaining a first log showing thereon one or more distinctive reference points as a function of depth and designating on this log at least one predetermined depth. Then, as a well tool is being positioned, a second log is obtained and correlated with the first log to locate the well tool at the predetermined designated depth. A visual indication is provided of the depth at which each of several selectively operable devices are as it is to be actuated. An indication of the position of these selective devices in relation to this predetermined depth is also related to the first log.

The novel features of the present invention are set forth with particularity in the appended claims. The operation together with further objects and advantages thereof, may best be understood by way of illustration and example of certain embodiments when taken in conjunction with the accompanying drawings, in which:

FIG. 1 shows a typical perforator in a well bore to be perforated at a number of depths;

FIG. 2 is a typical log of the portion of the well bore illustrated in FIG. 1;

FIGS. 3-5 schematically illustrate successive steps in the practice of an improved species of the present invention;

FIG. 6 depicts an alternate embodiment of the present invention; and

FIG. 7 depicts a circuit diagram of apparatus that may be used in the practice of the present invention.

Turning now to FIG. 1, a typical well tool 10 is shown suspended in a well bore 11 from a cable 12. As is customary, the well bore 11 is completed by a string of casing joints 13 connected to one another by couplings or collars, as at 14-17, and secured in place in the well bore by cement 18.

It will be understood, of course, that the present invention is applicable to any operation involving the positioning of one or more devices in a well. Moreover, it is to be realized that any one or more means can be used to provide a log indicating the relation of particular earth formations to each other as well as to some identifiable point in the well bore.

As one example of the present invention, however, it is assumed that the well tool 10 is to be used to make a selected number of perforations (not shown) in several producible earth formations 19-21. To accomplish this, the well tool 10 is appropriately arranged to include a perforator 22 having thereon a number of perforating devices as, for example, a plurality of shaped charges 23 that may be selectively detonated as required. Inasmuch as the particular arrangement of the perforator 22 plays no part in the present invention, it is necessary only to understand that the perforator is suitably arranged so a predetermined number of one or more of its shaped charges 23 can be detonated upon command from the surface. To assist in positioning the perforator 22 at the correct depth, depth-correlating means, such as a casing anomaly or collar locator 24 which, for example, may be one of those shown in Patent No. 3,144,876 to Nick A. Schuster are mounted on the upper end of the well tool 10. Such locators, as at 24, can also detect previously located magnetic anomalies as, for example, a short "pup" joint or other device in the string 13. It should also be understood that any detecting means that can detect an identifiable formation characteristic such as, for example, the natural or induced radioactivity of earth formation can also be used in the place of or in conjunction with the locator 24.

Turning now to FIG. 2, a typical log 25 on paper, film, or the like, is shown of that portion of the well bore 11 illustrated in FIG. 1 such as would customarily be obtained after the casing 13 has been set to provide an accurate indication of the depth of the collars 14-17 and, in one manner or another, their spatial relation to the productive earth formations 19-21. To obtain this log 25, a well tool (not shown) including detecting means of some nature for identifying particular earth formations as well as determining depth is passed through the cased well bore 11. In one manner of accomplishing this, the detecting means could include radioactivity-measuring means that can either detect previously placed radioactive markers for depth-reference points in the formations and/or on the collars or also measure only the natural or induced radioactivity of the formations. Irrespective of how a given characteristic of the formations is detected, where the collars, as at 14-17, are used as depth-reference points, another means for determining depth could also be a typical casing collar locator.

Accordingly, although other means of presenting such information can be used, the log 25 will be assumed to include some indicia of some characteristic of at least the formations of interest as, for example, a continuous trace 26 on the left of the log indicating natural or induced radioactivity. For purposes of depth correlation, the relative positions of the collars in the casing string 13 may be assumed as being represented as either a series of separate indicia marks or a continuous trace, as at 27, that is recorded as a function of depth, as at 28 or 29, and having irregularities, as at 30-33, respectively representative of the collars 14-17.

Accordingly, as known by those skilled in the art, once this log 25 has been obtained, the trace 26 can be compared with one or more other logs (not shown) made previously to determine which of the formations are most likely capable of being produced. By comparing previously obtained logs of the same or different nature with the trace 26, the various formations can be identified and their relative locations determined with respect to one another as well as to the casing collars 14-17.

Turning first to the preferred species of the present invention as also described in a copending application Ser. No. 576,340, filed concurrently herewith by Nick A. Schuster and William T. Bell. It is believed to be easier explained to describe first this improved species and then describe an alternate species of the present invention. Accordingly, as seen in FIG. 3, the log 25 is first marked in some suitable manner, as by the lines at 34-40, to designate the depth at which each perforation is desired. Then, as best seen in FIG. 4, the prepared log 25 is arranged on means, such as a control panel 41, arranged in accordance with the present invention. The completion apparatus 10 is suspended in the well bore 11 from the cable 12 and spooled in the usual manner from a winch 42 with the cable 12 being connected to the control panel 41.

The control panel 41 is comprised of recording means, such as a chart recorder 43 or the like, arranged to accept the log 25 and including selectively responsive marking means, such as a pair of conventional recorder pens 44 and 45, and driving means, such as selsyn motors 46 and 47, that are suitably arranged to drive the spools 48 and 49 on which the log 25 is rolled in either direction. The recorder pen 45 is movably mounted on and arranged for movement along a support 50 parallel to the longitudinal axis of the log 25. Although the recorder pens 44 and 45 can be as normally provided on conventional chart recorders, either one or both of them may be so-called solenoid-actuated "event markers" that produce a suitable indication upon receiving a signal of a particular nature. Control means 51 and 52 are provided to drive the recorder motors 46 and 47 so that the log 25 will be synchronously advanced or reversed in unison with the unreeling or reeling in of the cable 12.

To actuate the recorder pens 44 and 45, means, as at 53, are provided to respond to a first signal indicative of the depth of the well tool 10 as well as to respond to a second signal indicating that the well tool has been actuated. In one manner of accomplishing this, the recorder pen 44 is coupled through the responsive means 53 to the collar locator 24 to provide a record as desired each time a collar in the casing string 13 is passed by the collar locator. The other recorder pen 45 is coupled through the responsive means 53 to means, as at 54, on the well tool 10 for detecting the detonation of each of the shaped charges 23 and providing a signal in response thereto for actuating the recorder pen 45. As will subsequently be described in detail with respect to FIG. 6, this actuation-responsive means 54 can be arranged to respond to detonation or concussion shocks of the shaped charges 23 to momentarily interrupt current through the cable 12 and, by virtue of the responsive means 53, actuate the pen 45.

On the right of the control panel 41 and parallel to the longitudinal axis of the log 25, scaled facsimiles of the perforator 22 and collar locator 24 are provided which are preferably comprised of a replaceable template 55 or the like that may be mounted thereon in some suitable manner. As shown in FIG. 4, this template 55 is accurately scaled to represent not only the relative positions 56 and spacing of each of the shaped charges 23 on the perforator 22 but also to show the relative position 57 of the casing collar locator 24. A movable pointer 58 is provided on the control panel 41 adjacent to the template 55 and arranged to be moved parallel to the longitudinal axis of the template by a control knob 59 which, by means of a pulley arrangement, gear train, pantograph, or other suitable mechanism 60, will also simultaneously position the shot-indicator recording pen 45. By suitably arranging the mechanism 60, movement of the control knob 59 will shift the pointer 58 a scaled distance along the template 55 that is directly proportional both to the scaled distance that the recorder pen 45 is being simultaneously shifted longitudinally in relation to the scale of the log 25 as well as to the actual distance along the perforator 22 corresponding to the positions 56 being indicated by the pointer.

In other words, by preparing a suitable template 55, the spacing between the casing collar locator position 57 and the particular position 56 of the pointer 58 at any given time will be representative of the actual distance between the collar locator 24 and the corresponding shaped charge 23 on the perforator 22. Similarly, the recording pen 45 will be appropriately adjusted by the control knob 59 and mechanism 60 so that the shot-indicator pen 45 will indicate on the log 25 the true depth of the shaped charge 23 next to be fired on the perforator 22. The collar-locator recording pen 44 always indicates on the log 25 the true depth of the collar locator 24. Thus, the actual distance between the collar locator 24 and a given shaped charge 23 will be simultaneously presented by the scaled spacing or chart divisions on the log 25 between the pens 44 and 45 and the visual portrayal on the template 55 of the spacing between the pointer 58 and the position 57.

After the log 25 has been marked to provide the indications 34-39 representative of the depths at which each of the perforations are to be made, the marked-up log (FIG. 3) is then mounted on the reels 48 and 49 on the control panel 41. A suitable template 55 is prepared and mounted on the panel 41 and the well completion apparatus 10 is then lowered into the well bore 11.

During the descent of the perforating apparatus 10 into the well bore 11, the log 25 and the usual depth-measuring totalizers or registers and the like (not shown) as typically used are "tied-in" to the collars in the casing string. Although this can be done in several manners, by observing the correspondence of the newly-obtained col-

lar log with an older collar log the operator can keep track of just where the apparatus 10 is in the well. Then, since the depth of each collar is known from the older collar log, the operator can adjust the depth-measuring registers as the apparatus 10 is being lowered to keep them in the proper relation to the known depths of the collars. It is, of course, not necessary to actually record a new collar log as the tool 10 is being lowered since visual observation of the measurements being obtained on the measuring instrument typically used will indicate how closely the old collar log is being followed. Thus, in one manner or another, by merely keeping the depth-measuring registers or "odometer"-like totalizers in step with the old collar log as the apparatus 10 is being lowered, the log 25 will still be unmarked.

The well completion apparatus 10 is preferably lowered below the first depth at which a perforation is to be made. Then, as best seen in FIG. 4, as the well tool 10 is moved upwardly in the well bore 11, the collar locator 24 will detect each of the casing collars as the tool is raised thereby. The control means 51 and 52 and motors 46 and 47 are simultaneously driving the log 25 at a speed directly proportional to the rate of ascent of the perforating apparatus 10. As the log 25 is moved, the collar-locator recorder pen 44 will make a trace 61 having successive irregular marks, such as at 62 and 63, indicative of the casing collars that the well completion apparatus 10 has just passed.

Accordingly, by observing the correspondence (or lack of correspondence) of the marks (as at 33) on the previous collar log trace 27 with those (as at 63) on the newly obtained trace 61, final adjustments may be made on the recorder 43 so as to bring the irregularities 33 and 63 on the two traces 27 and 61, respectively, into register with one another. Once this has been accomplished, it will be appreciated, of course, that the collar-locator recorder pen 44 will indicate and record on the log 25 the precise depth at which the collar locator 24 is at that point. Similarly, the shot-indicator recorder pen 45 will be pointing on the log 25 to the depth at which the particular shaped charge 23 to be fired is then actually positioned. The shot-indicator pen 45 may or may not be providing a continuous trace as desired. Similarly, it is, of course, not necessary to continuously record a trace, as at 61, on the log 25 so long as a record of some nature, as at 62 or 63, is provided of the collars passed.

By keeping the newly recorded collar log trace 61 synchronized with the original collar log trace 27, whenever the well apparatus 10 has reached the depth at which the first perforation is to be made, the shot-indicator recorder pen 45 will provide a visual indication which, when it is brought into register or alignment with the first mark 34 on the log 25, will indicate that the first shaped charge 23a is precisely located at that depth. It is, of course, apparent that with this displayed presentation, no calculation need be made to know positively that the well completion apparatus 10 is correctly positioned at the correct depth in the well bore 11. The correspondence of the collar log traces 27 and 61 will assure the observer that the tool 10 is at the correct depth. Moreover, once the shot-indicator pen 45 is aligned with the mark 34 previously drawn on the log 25 to designate the precise depth at which the first perforation is to be made, there is no reason to become confused about the precise location of the shaped charge 23a.

Accordingly, once the perforator 22 has been actuated and the concussion-responsive means 54 initiated, the electrical means 53 will actuate the shot-indicator recorder pen 45 to print a mark (not shown in FIG. 4) on the log 25 immediately opposite the mark 34. This will provide a positive permanent indication on the log 25 that this perforation was made at the correct depth.

Once this first perforation has been made, the control knob 59 is then adjusted to shift the pointer 58 upwardly to the next position 56b on the template 55 and, at the

same time, also move the shot-indicator recorder pen 45 upwardly on its support 50. This simultaneously shifts the shot-indicator recorder pen 45 relative to the collar-locator recorder pen 44 so as to space the two pens apart a distance which can be scaled on the vertical scale of the log 25 and will also be proportionally scaled to the actual spacing between the casing collar locator 24 and the shaped charge 23b next to be fired.

Turning now to FIG. 5, the well completion tool 10 has been raised in the well bore 11 until it is now adjacent to the formation 19. As the well tool 10 was being raised, it was successively halted as indicated by the correspondence of the pen 45 and the marks 35-39 to permit the second through sixth of the shaped charges 23 to be detonated so as to produce corresponding perforations (only the last one being shown at 65). Then, after making the perforation 65, the control knob 59 was again adjusted to move the movable pointer 58 from opposite the sixth position 56f on the template 55 to the seventh position 56g as seen in FIG. 5. Movement of the control knob 59, of course, simultaneously shifted the shot-indicator recorder pen 45 upwardly on its support 53 to correctly space the pens 44 and 45 relative to one another a scaled distance representative of the actual distance between the shaped charge 23g and the collar locator 22. Once this is done, the cable 12 will be reeled-in to raise the tool 10 in the well bore 11 until the mark 40 on the log 25 is brought into alignment with the now-stationary shot-indicator pen 45.

Once the shot-indicator pen 45 and mark 40 are aligned, the observer will be assured that the perforator 22 is correctly positioned in the well bore 11 and is in fact in position to safely make the seventh perforation. When the perforator 22 is actuated, the shaped charge 23g will produce the perforation 66 and the resultant shock on the electrical means 54 will again actuate the electrical means 52 to cause the shot-indicator pen 45 to make a confirming mark 67 adjacent to the previously drawn mark 40 on the log 25.

Accordingly, this confirming mark 67 will provide a positive and permanent record that the perforation 66 was made while the seventh shaped charge 23g on the perforator 22 was at that depth. Moreover, the correspondence, as at 31 and 62, of the collar logs 27 and 61 will verify that the perforating apparatus 10 was at the correct depth at that time and provide a record thereof. It will be noted that similar confirming marks 68-70 were respectively made opposite the pre-drawn marks 37-39.

It will be appreciated that although the procedure has been described as using the collar log trace 27 for depth correlation, the formation log at 26 could be used just as well. This would not change the operation and the pen 44 would instead be appropriately arranged to provide a verifying identification such as a continuous trace similar to that at 27 (but reproducing the log trace 26 of course). In this event, it would not even be necessary to include a collar locator 24 on the apparatus 10.

As an alternate, the log 25 could be obtained at the beginning of the above-described operation. If this were done, the well tool 10 would include the appropriate logging device either alone or in conjunction with the collar locator 24. The tool 10 so equipped would be first used to produce the log 25. Then, after the designations, as at 34-39, are placed, the operation would be conducted as described.

Turning now to FIG. 6, an alternate and less sophisticated embodiment of the present invention is shown. It will be appreciated that FIG. 6 shows that many of the same features already described are included in this second embodiment and so, where applicable, the same reference numerals but with prime marks added have been employed. It will be understood, therefore, that these common means are basically the same as those described earlier.

In general, the control panel 41' is similar to the panel

41, with the chart recorder 43' being arranged to accept the log 25' with its previously designated locating marks as at 34'-40'. Indicating means, such as the event markers or recorder pens 44' and 45', are provided to indicate respectively the depths at which the collar locator 24 and a selected one of the shaped charges 23 are with respect to the log 25'. The recorder pen 45' is slidably mounted on the support 45' and arranged for movement thereon by a suitable mechanism 100 controlled by the control knob 59'.

Three display means, such as for example "odometer"-type totalizing registers 101-103 are mounted on the panel 41', with the totalizers 101 and 102 being arranged to respond to travel of the tool 10 by means, as at 104, of suitable electronic means, electro-mechanical devices, or typical arrangements of gears, pulleys, clutches and the like. The totalizer 103 is arranged to display only a fixed differential between the totalizers 101 and 102 and is adjusted by means, as at 105, controlled by the knob 59'. This adjusting means 105 is also connected to the totalizer 102 to adjust the reading displayed there in accordance with the differential being displayed on the totalizer 103.

The totalizer 101 is arranged to continuously display the true depth at which the collar locator 24 is at any given time. It will be recognized, of course, that the depth displayed at any given time on the totalizer 101 will be the same depth indicated by the recorder pen 44' on the log 25' once the log is "tied-in." The totalizer 102 is arranged to keep pace with the totalizer 101 as it changes; however, this totalizer 102 will instead be displaying a depth that is greater than that displayed on the totalizer 101 by whatever differential is displayed on the totalizer 103. Thus, by interconnecting the totalizers 102 and 103 through the mechanism 105, each time the control knob 59' is changed to reset the differential on the totalizer 103, the totalizer 102 will be simultaneously adjusted by the same amount so that at any given moment the difference between the readings displayed on the totalizers 101 and 102 will be displayed on the totalizer 103. Inasmuch as it is usually necessary to know this differential in increments of less than a foot, the totalizer 103 is preferably arranged to display the differential in tenths of a foot. It will be noted also that the totalizer 102 will display the depth at which the recorder pen 45' is indicating on the log 25'. Moreover, the differential displayed on the totalizer 103 will be equal to the spacing between the pens 44' and 45' as scaled on the log 25'.

Accordingly, once the prepared log 25' is "tied-in," both the totalizer 101 and the recorder pen 44' will visually display the depth at which the collar locator 24 is at any given time. Similarly, the totalizer 102 and recorder pen 45' will each be providing an indication of some depth greater than that of the collar locator 24 which difference is indicated on the totalizer 103. It will be recalled that this differential is established by adjusting the knob 59' to set both the recorder pen 45' and the totalizer 103. This adjustment will also appropriately reset the totalizer 102 to display a depth differing from that shown on the totalizer 101 by this difference.

By previously preparing a tabulation, drawing, or even a facsimile, as at 106, of the well tool 10 being used, an indication is provided of the spacing between the collar locator 24 and each of the shaped charges 23. In this manner, the spacing between the collar locator 24 and each shaped charge 23 can be compared with the differential reading displayed on the totalizer 103. By knowing (as shown on the drawing 106) the distance below the collar locator that a particular shaped charge 23 is located, the control knob 59' can be used to position the recorder pen 45' as desired as well as adjust the readings on the totalizers 102 and 103.

Accordingly, to employ the control panel 41' for accurately placing the shaped charges 23, the control knob 59' is adjusted to successively bring the reading on the totalizer 103 to each of the measured dimensions, as at

107, in turn that a selected one of the shaped charges is below the collar locator 24. Once the totalizer 103 is displaying this differential, as at 107a, the recorder pen 45' will have been moved along the support 50' to the same scaled spacing according to the chart divisions on the log 25'. The readings on the totalizer 102 will be greater than those on the totalizer 101 by this differential. Accordingly, as the well tool 10 is maneuvered in the well bore 11, the totalizer 101 will indicate the depth of the collar locator 24 and the totalizer 102 will indicate the depth of the selected shaped charge 23. The totalizer 103 will show a figure equal to the differential between these depths and therefore (by reference to the drawing 106) serves as an indirect reminder as to which of the shaped charges 23 is next to be detonated.

When the well tool 10 has reached the depth at which the first shaped charge 23a is to be detonated, the tool will be halted when the pen 45' is aligned with the prepared mark 34'. The shaped charge 23a may then be detonated and a perforation (not shown) will be produced at the correct depth. As previously described, the recorder pen 45' will produce an identification mark on the log 25' immediately in alignment with the mark 34' to provide a verification record of the depth perforated.

The knob 59' is then re-adjusted to reset the differential reading on the totalizer 103 to that indicated on the drawing 106 to be the spacing for the next shaped charge. This adjustment also brings the recorder pen 45' proportionately closer to the pen 44'. Then, the well tool 10 is again raised in the well bore 11 until the recorder pen 45' is aligned with the next prepared mark 35'. The procedure is again repeated to detonate the remaining shaped charges 23.

It will be recognized that so long as the log 25 (or 25') is in position on the recorder 43 (or 43'), it will be readily determinable that the tool 10 is correctly positioned. Once the log 25 (or 25') is removed, however, there is nothing by which it can be determined whether the tool 10 was at the correct depth when the shaped charges 23 were detonated. Accordingly, to provide such a record, the event marker or pen 44 (or 44') could be arranged to also make a characteristic mark (not shown) each time that the event marker or pen 45 (or 45') makes a mark as at 67-70. In one manner of accomplishing this, a second marker could be aligned horizontally (as seen in the figures) with the pen 44 (or 44') and connected to make a mark as in the margin of the log 25 (or 25') each time the pen 45 (or 45') is actuated.

Turning now to FIG. 7, a schematic representation is shown of a suitable firing circuit 200 for selectively detonating the shaped charges 23 and the concussion-responsive means 54 for detecting their detonation in either of the embodiments of the present invention. Inasmuch as the firing circuit 200 and detecting means 53 and means 54 are respectively arranged in accordance with commonly owned earlier-filed application Ser. No. 420,345, now Patent No. 3,327,791, filed Dec. 22, 1964, by John W. Harrigan, Jr. and Ser. No. 569,316, filed Aug. 1, 1966 by George W. Brock, only a brief explanation of the principles of each of these inventions and their relation to one another and to the present invention is believed to be sufficient.

Briefly stated, the firing circuit 200 is comprised of a solenoid-actuated selector switch 201 that is selectively operated by a DC power source 202 at the earth's surface and connected across the inner conductor 203 and outer armor sheath 204 of the monocable 12. To regulate the output of the power source 202, a conventional polarity-reversing switch 205 and potentiometer 206 are appropriately arranged. By connecting a polarity-responsive device, such as a diode 207, between the central conductor 203 and the solenoid 208 of the selector switch 201, the selector switch will be actuated only when a voltage of the correct polarity is applied across the monocable 12.

The selector switch 201 includes a rotatable switch

contact 209 that is selectively moved by the solenoid 208 around a plurality of contacts 210 spaced around a switch wafer 211. Each of these contacts 210 are connected to one side of a typical detonator 212 (schematically represented as resistors in FIG. 7), with the other sides of these detonators being returned through the body of the perforator 22 to the monocable sheath 204. In this preferred arrangement, the solenoid 208 is arranged to drive a pawl (not shown) that indexes a rotatable ratchet wheel (not shown) connected to the rotatable switch arm 209. By arranging the pawl to remain engaged with the ratchet so long as the solenoid 208 is energized, the switch arm 209 will be indexed only one position at a time to the next contact 210 to be connected. Then, when the solenoid 208 is de-energized, the pawl will be restored to its initial position and come to rest on the next tooth on the ratchet to await another energization. Thus, only by successively energizing and de-energizing the solenoid 208 can the contact arm 209 be advanced around the various contacts 210.

To control the detonation of the shaped charges 23, a Zener diode 213 is connected between the polarity-determining diode 207 and the switch contact arm 209. By selecting the Zener diode 213 to have a Zener level somewhat in excess of the voltage required to actuate the solenoid 208, the selector switch 201 can be actuated to connect the next shaped charge 23 into the firing circuit 200 without immediately detonating it. Thus, it is not until after the solenoid 208 has moved the switch arm 209 to the next one of the contacts 210 that the voltage across the monocable 12 will reach the Zener level so as to cause the Zener diode 213 to conduct and apply voltage to the detonator 212 in the circuit at that time. Then, by continuing to advance the potentiometer 206, the voltage will reach a magnitude sufficient to detonate the desired shaped charge 23. It will be recalled, of course, that once the contact arm 209 has been advanced to one of the contacts 210, it cannot advance further until the voltage is first removed and then re-applied to the solenoid 208. This will assure that voltage is at least applied in turn to each of the shaped charges 23 and minimize the risk of unintentionally skipping of a shaped charge.

Turning now to the shot-detecting means 52 and concussion-responsive means 54 depicted in FIG. 7. Briefly, the concussion-responsive means 54 includes signal-generating means, such as a transducer or piezoelectric crystal 214, that upon being subjected to a physical shock or the like to the well completion tool 10 will cause a detectable signal to be sent to the earth's surface through the cable 12. Once this signal has reached the surface, the shot-detecting means 53 are employed first to ascertain with reasonable certainty that the signal is not spurious and then secondly to actuate the shot-detector pen 45 (or 45').

To accomplish this, the output of the crystal 214 is amplified by an amplifier 215 and connected, by way of a forwardly-biased diode 216, to the "set" input of a flip-flop circuit 217 that controls an oscillator 218 which, when running, will generate a repetitive output signal such as, for example, a sine wave or a square wave. In one manner of controlling the oscillator 218, one of the outputs of the flip-flop 217 is connected to the control terminal of a gate 219 that is in turn connected to the "initiate" input of the oscillator as seen in FIG. 7. This gate 219 is of the so-called "enable"-type wherein application of a signal to its control terminal will cause a very low impedance to be across it. Thus, by connecting the gate 219 between an appropriate connection on the oscillator 218 and ground, as at 220, initiation of the gate 219 by the flip-flop 217 will connect the oscillator to ground and start the oscillator. For reasons to be explained shortly, the output of the oscillator 218 is connected to the control terminal of another so-called "enable"-type gate 221.

Connected across the monocable 12 is a bridge circuit 222 which, as will be readily appreciated by those skilled in the art, will maintain the polarity of one of its output terminals 223 positive and that of the other output terminal 224 negative in either position of the polarity-reversing switch 205. In this manner, whether the positive terminal of the DC source 202 is connected to the inner conductor 203 or is connected to the sheath 204, the output terminal 223 will always be positive. The purpose of this, however, is to maintain a positive voltage on those conductors, as at 225, supplying B+ voltage to the various components in the downhole circuitry and has no particular bearing on the operation as such as now to be described.

One end of a resistor 226 is connected between the positive terminal 223 of the bridge circuit 222 and the previously mentioned "enable"-type gate 221 which is in turn connected to ground and the negative terminal 224 of the bridge circuit. It will be appreciated, of course, that when the gate 221 is not operating, the other end of the resistor 226 is not connected to ground and is merely "floating." When the "enable"-type gate 221 is operated, however, it will connect the "floating" end of the resistor 226 to ground with a low impedance so that the resistor is then across the output terminals 223 and 224 of the bridge circuit 222. By using a low value of resistance for the resistor 226, each time it is connected across the bridge circuit 222 by operation of the gate 221, the impedance across the monocable conductors 203 and 204 will be significantly decreased. Accordingly, since the gate 221 will be repetitively enabled and disabled by the oscillator 218, the impedance across the monocable conductors 203 and 204 will be changing at the same rate to develop cyclic current changes in the monocable 12 at the same frequency as the oscillator.

To detect these cyclic changes in the current flowing through the monocable 12, the shot-detecting means 52 includes a transformer 227 that has its primary in series with the central monocable conductor 203 and its secondary connected to a bandpass filter network 228 designed to pass only the frequency of the cyclic changes. Thus, the cyclic changes in the current flowing through the monocable 12 will induce a corresponding signal in the secondary of the transformer 227. The signal passing through the filter 228 is rectified by a rectifier 229 and directed through a delay circuit 230 to means, such as a relay solenoid 231 controlled by a silicon-controlled rectifier 232, for actuating the shot-detector pen 45 (or 45') and opening normally-closed relay switch means 233 in series with the central conductor 203. This delay circuit 230 is of the well-known type wherein a voltage must be present on the input for a given period of time before a signal is generated. The silicon-controlled rectifier 232 inherently functions to continue conducting once it is initiated so long as power is not removed. Thus, so long as no signal has been sent through the delay circuit 230, the rectifier 232 will not conduct and the solenoid 231 will remain de-energized. Once it is initiated, the silicon-controlled rectifier 232 will continue conducting to energize the relay solenoid 231 so long as power is applied. When the power is interrupted, however, the silicon-controlled rectifier 232 will discontinue its operation until a second signal is applied through the time-delay circuit 230.

It should be noted in passing that the downhole portion of the circuitry 54 also includes a suitable voltage regulator 234 connected to the positive terminal 223 of the bridge circuit 222. A large capacitor 235 is also connected across the output of the voltage regulator 234 to prevent transients from affecting the B+ voltage to the balance of the circuits.

It will be noted that the time-delay circuit 230 and flip-flop 217 will prevent the presence of transients on the monocable 12 from initiating the shot-detecting means 52. Since transients are typically of a short interval, a suf-

ficient delay interval in the delay circuit 230 will prevent a transient from actuating the relay solenoid 231. The flip-flop 217, will, of course, maintain the oscillator 218 operating so long as power is applied thereto. Thus, the oscillator 218 will continue operating until the relay solenoid 231 is engaged. Operating of the relay contacts 233 will remove power from the downhole circuitry.

Because of the inherent nature of flip-flops, however, it is possible that the flip-flop 217 can be "set" in the wrong state so that it would immediately start the oscillator 218 when sufficient voltage is first applied across the monocable 12 as the solenoid 208 is being energized. This would, of course, cause the oscillator 218 to operate prematurely without energization of the crystal 214.

Accordingly, to ensure that the flip-flop 217 is properly set so as not to initiate the oscillator 218 until a concussion energizes the crystal 214, a reset circuit comprised of a voltage-sensitive control 236 (such as a Schmitt trigger or the like) connected from the output of the voltage regulator 234 to the control input of a so-called "inhibit" gate 237 is provided. The inhibit gate 237 is in turn connected between the output of the flip-flop 217 and ground. Thus, until the gate 237 is energized by the trigger 236, the previously mentioned output of the flip-flop 217 is grounded, as at 238, to prevent it from prematurely initiating the oscillator 218. When the output voltage of the voltage regulator 234 reaches a first predetermined value, however, the potentiometer 206 is being advanced, the connection of this flip-flop output to ground through the gate 237 will ensure that the flip-flop 217 is set in the correct reset state. Then, at some higher second voltage, the voltage-sensitive trigger 236 will supply an output signal to the inhibit gate 237 to disconnect the grounded connection 238 from the output of the flip-flop 217. Once its output is ungrounded, of course, the flip-flop 217 will function as soon as the crystal 214 is energized. It will be understood, of course, that these first and second voltages are well below the voltage required to operate either the solenoid 208 or the Zener level of the Zener diode 213.

In operation, therefore, the perforating apparatus 10 is positioned as already described with reference to FIGS. 4 and 5. When the coincidence of the shot-detector pen 45 (or 45') with one of the marks, such as 34 (or 34') for example, indicates that the first shaped charge 23a is at the correct depth, the perforating apparatus 10 is halted. Then, the potentiometer 206 is slowly advanced. As the voltage across the monocable 12 is first increased, the output voltage of the voltage regulator 234 will be below the threshold level of the trigger 236 thereby ensuring that the flip-flop 217 will be placed into the reset state. When the flip-flop 217 is in this reset state the inhibit gate 237 holds the "1" output of the flip-flop at ground potential so that the oscillator 218 can not be initiated. At some higher voltage output of the voltage regulator 234, the voltage-sensitive trigger 236 will energize the inhibit gate 237 and remove the "1" output of the flip-flop 217 from ground potential so that whenever the crystal 214 is energized by a concussion shock, the set input of the flip-flop will be energized to start the oscillator 218. It will be recognized, of course, that the threshold level of the trigger 236 is well below the voltage necessary to energize the selector switch 201.

The voltage across the monocable 12 will subsequently reach a level whereby the solenoid 208 will index the contact arm 209 to the first contact 211a to connect the detonator 212a for the first shaped charge 23a into the firing circuit 200. Then, once the voltage across the monocable 12 has reached the Zener level of the Zener diode 213 voltage will be applied to the detonator 212a. Once the potentiometer 206 has been advanced still further, the detonator 212a will be actuated and the shaped charge 23a detonated if all is functioning properly. If no detonation occurs, failure of the shot-detection circuit 53 to function will immediately give notice to the operator

who will then take whatever remedial action is desired.

Assuming, however, that the shaped charge 23a does detonate, the resultant shock to the perforating apparatus 10 will momentarily impulse the crystal 214. This will then energize the flip-flop 217 and start the oscillator 218 which will then cause the resistor 226 to be repetitively connected and disconnected across the monocable 12. As previously explained, this cyclic change of impedance across the monocable 12 will induce a corresponding cyclic signal in the transformer 227. Since the frequency of this signal is in the bandpass range of the filter 228, it will be rectified by the rectifier 229 and applied to the input of the time-delay circuit 230. Once the rectifier signal is applied to the input of the delay circuit 230 for a sufficient time, the silicon-controlled rectifier 232 will be enabled which in turn energizes the relay solenoid 231.

Once the relay solenoid 231 is energized, the normally-closed relay contacts 233 will open and normally-open relay contacts 239 will be closed. These contacts 239 connect a DC source 240 to an R-C circuit 241 that, by way of a diode 242, is connected to the shot-indicator pen 45 (or 45'). The momentary "spike" produced by the closing of the switch contacts 239 will pulse the shot-indicator pen 45 (or 45') to produce a mark, as at 67 (or 67'). Opening of the switch contacts 233 will, of course, break the circuit between the monocable 12 and DC power source 202. Once the circuit is broken, no further power can be applied down the monocable 12 since the relay solenoid 231 will continue to draw current through the silicon-controlled rectifier 232 until power to the rectifier 232 is interrupted. Thus, it is necessary for the operator to return the potentiometer 206 to its original "zero" position to discontinue the conduction of the rectifier 232 and reclose the normally-closed relay contacts 233 and reopen the normally-open contacts 239. It should be noted in passing that, if desired, an amplifier 243 and speaker 244 can be used to provide an audible signal in addition to the permanent record and visual indication provided by the shot-detector pen 45 (or 45').

The collar-locator 24 is connected across the monocable 12 in the usual manner. Where a continuous trace, as at 61, is to be made, the recorder pen 44 (or 44') is connected to the monocable 12 by an amplifier 245. To prevent DC from reaching the amplifier 245, a blocking capacitor 246 is connected between the amplifier input and the central conductor 203. As a further safety measure, normally-closed relay contacts 247 can be provided so as to momentarily interrupt the circuit whenever the solenoid 231 is energized. It will be understood, of course, that other means can also be employed to translate the output signal of the collar locator 24 into some mark or indication on the log 25 (or 25').

It will be appreciated, therefore, that the present invention has provided new and improved methods and apparatus for accurately positioning a well tool in a well and providing both visual indications of its location as well as permanent records of the depth of the tool each time it is actuated. In practicing the present invention, it is necessary only to establish that the well tool is "tied-in" with the earlier log. Then, as desired, a permanent record can be made of some indication that can be compared with the previous log to verify the position of the tool. Each time the tool is actuated, a permanent record is also made on the log to indicate the depth of the tool at that time. In addition to the presentation on the log of the positions of the tool, the differential depth register in the one case and the scaled facsimile of the tool and movable pointer in the other case will serve as a visual indication of which portion of the tool is in readiness for operation at that time.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes

and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A method for positioning a well tool in a well bore having distinctive depth-reference means therein at a known depth, comprising: making a chart representative of depth in the well bore and marking on said chart first and second designations respectively of the known depth of the distinctive depth-reference means and of a desired depth at which a well tool is to be positioned; placing into the well bore, means for detecting the distinctive depth-reference means and a well tool spaced a known distance therefrom; moving said detecting means and said well tool into the vicinity of the distinctive depth-reference means for obtaining with first depth-indicating means a first indication in relation to said chart of the apparent depth of said detecting means and for obtaining with second depth-indicating means, a second indication in relation to said chart of the apparent depth of said well tool; correlating said first indication with said first designation to verify the accuracy of said first indication and making adjustments accordingly to obtain with said second depth-indicating means a corrected indication in relation to said chart of the true present depth of said well tool; and, thereafter, moving said well tool to bring said second depth-indicating means into correspondence with said second designation.

2. The method of claim 1 further including the step of: operating said well tool whenever said second depth-indicating means correspond with said second designation.

3. The method of claim 1 further including the steps of: marking on said chart a third designation of another desired depth at which said well tool is to be positioned; and, after adjusting said second depth-indicating means, moving said well tool to bring said second depth-indicating means into correspondence with said third designation.

4. The method of claim 3 further including the step of: operating said well tool whenever said second depth-indicating means correspond with at least one of said second and third designations.

5. A method for positioning a well tool in a well bore having distinctive depth-reference means therein at a known depth, comprising: making a chart representative of depth in the well bore and marking on said chart first and second designations respectively of the known depth of the distinctive depth-reference means and of a plurality of desired depths at which a well tool is to be positioned; placing into the well bore, means for detecting the distinctive depth-reference means and a well tool having a plurality of well-completion means thereon each spaced a known distance from said detecting means; moving said detecting means and said well tool into the vicinity of the distinctive depth-reference means for obtaining with first depth-indicating means a first indication in relation to said chart of the apparent depth of said detecting means and for obtaining with second depth-indicating means, a second indication in relation to said chart of the apparent depth of one of said well-completion means; correlating said first indication with said first designation to verify the accuracy of said first indication and making adjustments accordingly to obtain with said second depth-indicating means a corrected indication in relation to said chart of the true present depth of said one well-completion means; moving said well tool to bring said second depth-indicating means into correspondence with one of said second designations; operating said one well-completion means while said second depth-indicating means correspond with said one second designation; adjusting said second depth-indicating means until the difference in relation to said chart between said adjusted second depth-indicating means and said first depth-indicating means now equals the known spacing between said detecting means and another one of said well-completion means; moving said well tool to bring said second depth-indicating means

into correspondence with another of said second designations; and operating said other well-completion means while said second depth-indicating means correspond with said other second designation.

6. A method for perforating a well bore having distinctive depth-reference means therein at a known depth, comprising: making a chart representative of depth in the well bore and marking on said chart first and second designations respectively of the known depth of the distinctive depth-reference means and of a depth at which the well bore is to be perforated; placing into the well bore a well tool including means for detecting the distinctive depth-reference means and perforating means mounted at a known spacing from said detecting means; moving said well tool into the vicinity of the distinctive depth-reference means for obtaining with first depth-indicating means a first indication in relation to said chart of the apparent depth of said detecting means and for obtaining with second depth-indicating means a second indication in relation to said chart of the apparent depth of said perforating means; correlating said first indication with said first designation to verify the accuracy of said first indication and adjusting at least said second depth-indicating means accordingly to obtain a corrected indication in relation to said chart of the true present depth of said perforating means; moving said well tool to bring said second depth-indicating means into correspondence with said second designation; and, thereafter, actuating said perforating means while said second depth-indicating means correspond with said second designation.

7. The method of claim 6 wherein the well bore is cased and the distinctive depth-reference means includes an anomaly in the casing string; and wherein said detecting means includes means for detecting casing string anomalies.

8. The method of claim 6 further including the step of marking on said chart the position of said detecting means when said second depth-indicating means are adjusted.

9. The method of claim 6 wherein the distinctive depth-reference means includes a radioactive anomaly; and wherein said detecting means includes means for detecting radioactive anomalies.

10. The method of claim 8 wherein the radioactive anomaly is in the earth formations adjacent to the well bore.

11. The method of claim 6 further including the step of marking on said chart the position of said perforating means when said second depth-indicating means are in correspondence with said second designation.

12. The method of claim 11 further including the step of marking on said chart the position of said detecting means when said second depth-indicating means are adjusted.

13. The method of claim 11 further including the step of marking on said chart the position of said first depth-indicating means when said perforating means is operated.

14. A method for perforating a well bore at a plurality of depths and which has distinctive depth-reference means therein at a known depth, comprising: making a chart representative of depth in the well bore and marking on said chart a first designation of the known depth of the distinctive depth-reference means and a plurality of second designations each showing a depth at which the well bore is to be perforated; placing into the well bore a well tool including means for detecting the distinctive depth-reference means and a plurality of perforating means each mounted at a known spacing from said detecting means; moving said well tool into the vicinity of the distinctive depth-reference means for obtaining with first depth-indicating means a first indication in relation to said chart of the apparent depth of said detecting means and for obtaining with second depth-indicating means a second indication in relation to said chart of the apparent depth of one of said perforating means; correlating said first

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indication with said first designation to verify the accuracy of said first indication and adjusting said first and second depth-indicating means accordingly to obtain corrected indications in relation to said chart of the true present depths respectively of said detecting means and of said one perforating means; moving said well tool to bring said second depth-indicating means into correspondence with one of said second designations; actuating said one perforating means while said second depth-indicating means correspond with said one second designation; adjusting said second depth-indicating means so that the difference between said adjusted second depth-indicating means and said first depth-indicating means now equals the known spacing between said detecting means and another of said perforating means; moving said well tool to bring said second depth-indicating means into correspondence with another of said second designations; and operating said other perforating means while said second depth-indicating means correspond with said other second designation.

15. The method of claim 14 further including the step of marking on said chart the position of said detecting means when said second depth-indicating means are first adjusted.

16. The method of claim 14 further including the step of marking on said chart the position of the selected perforating means when said second depth-indicating means are in correspondence with each of said second designations.

17. The method of claim 16 further including the step of marking on said chart the position of said detecting means when said second depth-indicating means are first adjusted.

18. The method of claim 16 further including the step of marking on said chart the position of said first depth-indicating means when each of said perforating means are operated.

19. Apparatus for completing a well bore at a desired depth and in which distinctive depth-reference means are located at a known depth, comprising: a well tool adapted for movement in the well bore and including detecting means for detection of the depth-reference means and well-completion means spaced a known distance from said detecting means; chart means displaying as scaled presentations the known depth of the distinctive depth-reference means and the desired depth at which the well bore is to be completed; first and second means respectively adapted for indicating with respect to said chart means the depth

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of said detecting means and of said well-completion means; and means responsive to movement of said well tool in the well bore for maintaining said first and second indicating means and said chart means accurately aligned relative to one another.

20. The apparatus of claim 19 wherein said movement-responsive means include recorder means on which said chart means are carried and moved proportionately to movement of said well tool and further including first and second means for respectively marking on said chart means the depths of said detecting means and of said well-completion means.

21. The apparatus of claim 20 wherein said detecting means provide characteristic signals upon detection of the depth-reference means, and further including means responsive to such signals for characteristically marking on said chart means to designate the detection of the distinctive depth-reference means and verify the accuracy of said marking means.

22. The apparatus of claim 21 wherein said second marking means are responsive to operation of said well-completion means and further including third means for marking on said chart means the depth of said detecting means whenever said well-completion means are operated.

23. The apparatus of claim 21 further including means for displaying said known distance which said well-completion means are spaced from said detector means.

24. The apparatus of claim 23 further including first means responsive to movement of said well tool for displaying said known distance.

25. The apparatus of claim 24 further including second and third means responsive to movement of said well tool for respectively displaying the depths of said detector means and said well-completion means.

26. The apparatus of claim 25 further including means for simultaneously adjusting said second indicating means and said first and third displaying means.

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