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XR 3,570,594

United States Patent

[11] **3,570,594**

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[54] **SUBSURFACE CONTROL APPARATUS FOR USE IN OIL AND GAS WELLS**
11 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **166/64,** 166/66
[51] **Int. Cl.** **E21b 23/00,** E21b 47/12
[50] **Field of Search** ..... 166/64, 63, 65, 65 (M), 66; 324/(Inquired)

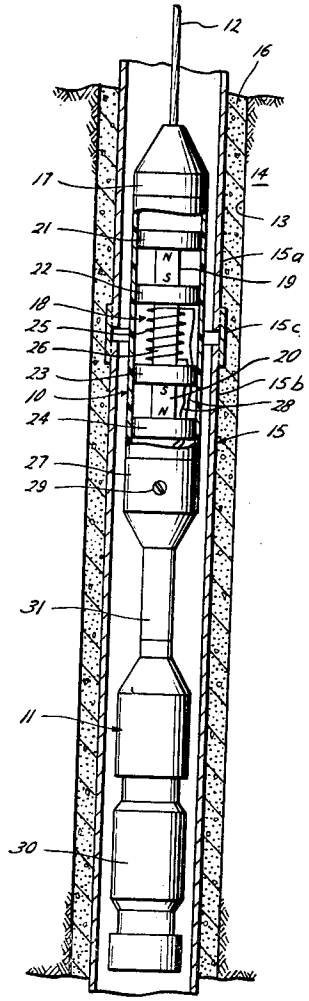
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ABSTRACT: A magnetic pipe joint detector and digital logic circuits electrically coupled thereto are located in a fluidtight housing which is lowered through a string of pipe in an oil or gas well by means of a wire line. Coupled to the housing for lowering therewith is a downhole device which requires operation after it is lowered into the well. After the device reaches approximately the desired depth in the well, the housing is raised past a predetermined number of pipe joints. The logic circuits detect this occurrence and activate a timer which, after a predetermined time interval, initiates the operation of the downhole device.



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Fig. 1

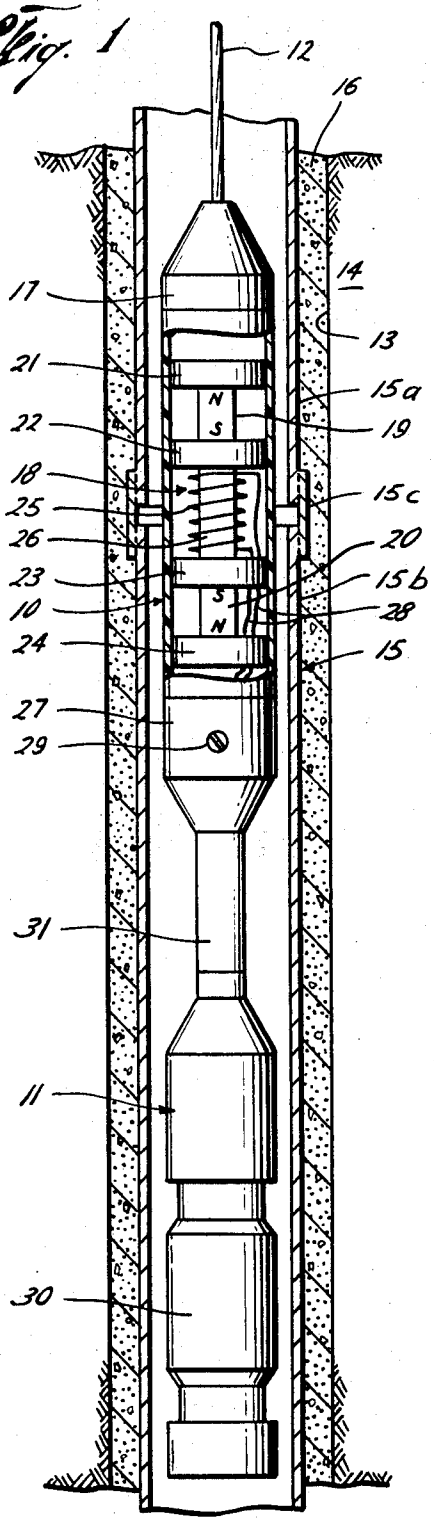


Fig. 2A

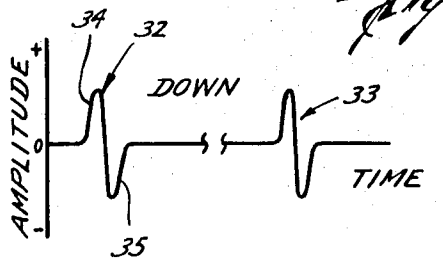


Fig. 2B

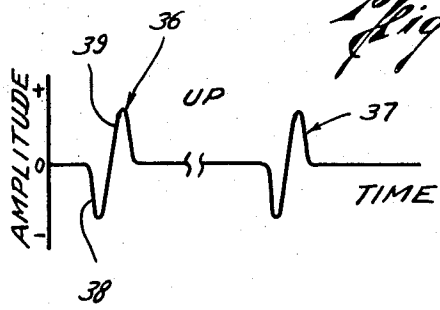
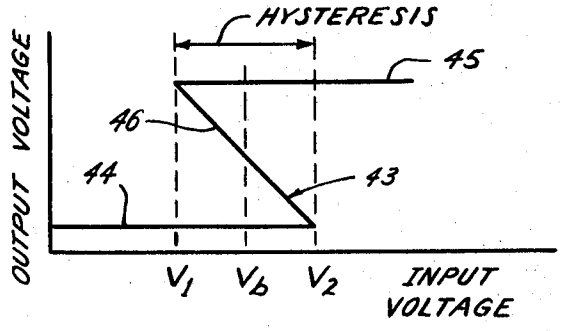


Fig. 4



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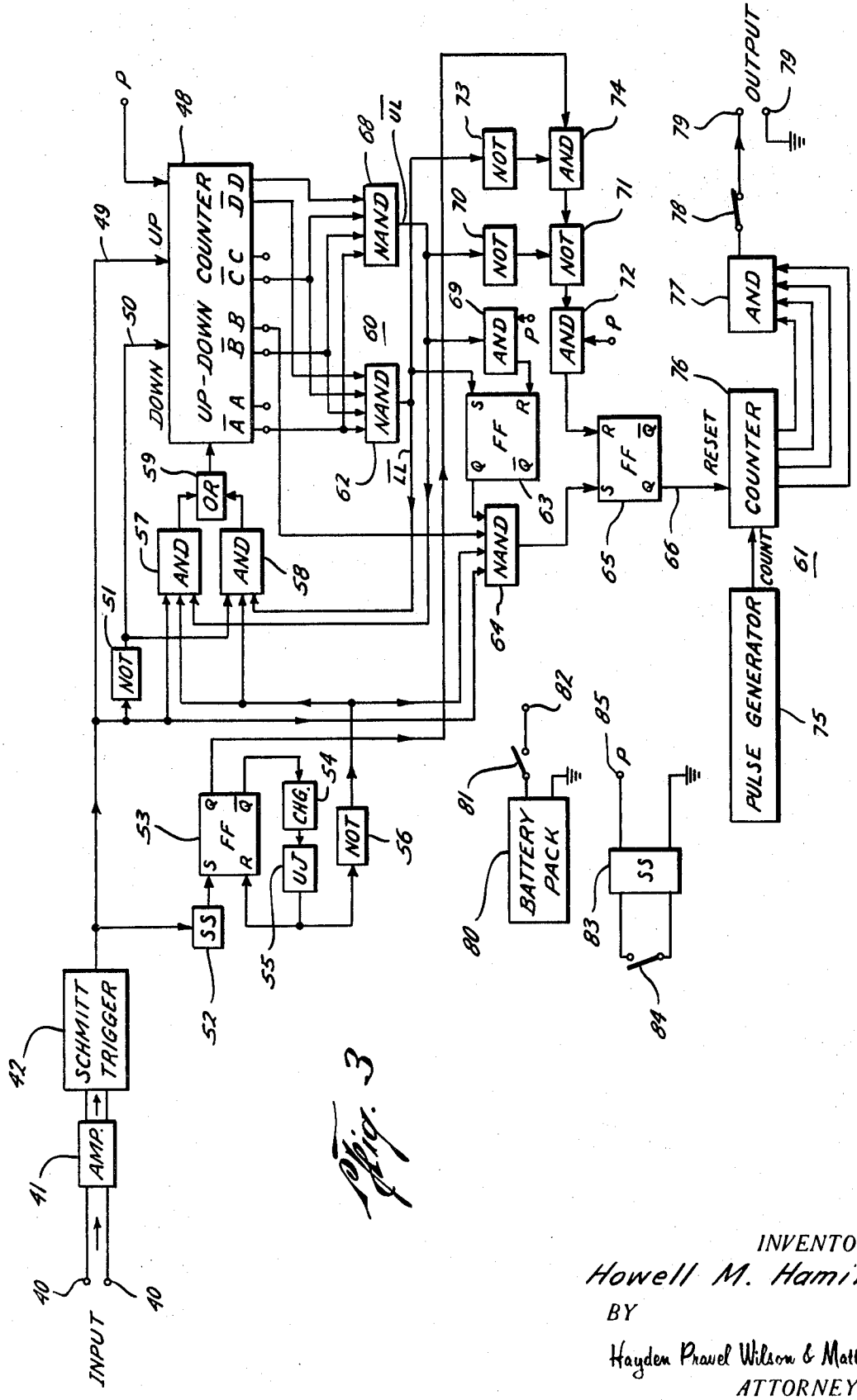


Fig. 3

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SUBSURFACE CONTROL APPARATUS FOR USE IN OIL AND GAS WELLS

BACKGROUND OF THE INVENTION

This invention relates to control apparatus for controlling the subsurface operation of a device lowered into an oil or gas well by means of a wire line or cable. While not limited thereto, the present invention is particularly useful in the setting of plugs and packers, the firing of explosive shots and shaped charges and the like.

In order to set a packer or fire a shot lowered into a well by means of a wire line, it has heretofore been the practice to employ a wire line or cable having located within the interior thereof an insulated electrical conductor. After the packer or shot is lowered to the desired depth, an electric current is sent down the insulated conductor to the packer or shot for setting or firing same. While this method usually accomplishes the desired purpose, there is, nevertheless, room for improvement. For one thing, this method requires the use of a relatively expensive form of wire line or cable. For another thing, it is subject to the accidental actuation of the electric firing switch at the surface of the earth before the downhole device reaches the desired depth in the well. For a further thing, if the cable conductor should become broken or shorted out at some point between the surface and the downhole device, then it becomes impossible to operate the downhole device.

SUMMARY OF THE INVENTION

It is an object of the invention, therefore, to provide a new and improved self-contained wireline control unit adapted to be lowered into an oil or gas well and which does not require any electrical connection with equipment located at the surface of the earth.

It is another object of the invention to provide new and improved subsurface control apparatus which provides an improved degree of safety in controlling the operation of downhole devices.

In accordance with the invention, subsurface control apparatus for use in an oil or gas well having a string of pipe therein comprises housing means adapted to be lowered through the string of pipe and including means for coupling thereto and lowering therewith a downhole device which requires operation after it is lowered into the well. The control apparatus also includes magnetic detector means located in the housing means for generating an electrical signal each time the detector means moves past a pipe joint. The control apparatus further includes electronic logic circuit means located in the housing means and responsive to the signals produced by the magnetic detector means for producing a control signal for initiating the operation of the downhole device.

For a better understanding of the present invention, together with other and further objects and features thereof, reference is had to the following description taken in connection with the accompanying drawings, the scope of the invention being pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring to the drawings:

FIG. 1 shows the combination of a control apparatus and a downhole device suspended in a subsurface section of an oil or gas well, a magnetic pipe joint detector portion of the control apparatus being shown in a cross-sectional manner;

FIGS. 2A and 2B are waveform diagrams of different electrical signals produced by the magnetic pipe joint detector of FIG. 1;

FIG. 3 is a block diagram of electronic logic circuits contained in the control apparatus of FIG. 1; and

FIG. 4 is a graph of the input-output signal transfer characteristic of a Schmitt trigger circuit used in the logic circuits of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, there is shown a combination of apparatus comprising subsurface control apparatus **10** having a downhole device **11** mechanically coupled to the lower end thereof. This apparatus is shown as being suspended in a subsurface section of an oil or gas well by means of a wire line **12**. Wire line **12** extends upwardly to a suitable reeling mechanism (not shown) located at the surface of the earth. Wire line **12** does not include any electrical conductors. It is a steel wire or cable used purely for mechanical hoisting purposes.

The subsurface section of oil or gas well shown in FIG. **1** includes a borehole **13** drilled through a subsurface earth formation **14**. A string of casing pipe **15** is located in the borehole **13**. Such casing string **15** is made up of a series of lengths or sections of casing pipe connected together in an end-to-end manner by means of casing collars. These pipe sections are typically on the order of 30 feet in length. Typical pipe sections are indicated at **15***a* and **15***b*, a typical casing collar being indicated at **15***c*. The annulus between the string of casing pipe **15** and the wall of the borehole **13** is filled with cement **16**.

The subsurface control apparatus or control unit **10** includes a fluidtight housing **17** which is adapted to be lowered through the string of pipe **15** by the wire line **12**. This housing **17** is mechanically connected to the lower end of the wire line **12**. Located inside of the housing **17** is a magnetic pipe joint detector **18**. This magnetic detector **18** produces an electrical signal each time it moves past the joint between two sections of casing pipe. The particular form of detector **18** which is illustrated in FIG. **1** is of a type commonly referred to as a casing collar locator. As such, it can be thought of as detecting the presence of a casing collar, such as the casing collar **15***c*.

The magnetic detector or collar locator **18** includes a pair of permanent magnets **19** and **20** for producing magnetic flux. The collar locator **18** also includes a series of pole pieces **21**, **22**, **23** and **24** located at the ends of the permanent magnets **19** and **20** for enabling the magnetic flux to link or couple with the well pipe **15**. The collar locator **18** further includes a coil winding **25** wound on a core member **26** located intermediate the permanent magnets **19** and **20** and extending between the pole pieces **22** and **23**. Pole pieces **21**, **22**, **23** and **24** and the core member **26** are formed of a ferromagnetic material such as iron. The portion of the housing **17** in the vicinity of the collar locator **18** is formed of a nonmagnetic material such as an epoxy-impregnated fiberglass-type plastic material.

When the collar locator **18** is in the middle of a section of casing pipe, the magnetic environment is of a uniform nature and no magnetic flux passes through the coil **25**. As the collar locator **18** moves past a magnetic anomaly, such as the casing collar **15***c*, the balance of the magnetic circuits is disturbed and magnetic flux is caused to pass through the coil **25**. This change in magnetic flux induces an electrical signal in the coil **25**, such signal thus denoting the passage of a casing collar.

The subsurface control apparatus **10** further includes electronic logic circuits located inside of a lower section **27** of the housing **17**. These logic circuits are electrically connected to the collar locator coil **25** by means of lead wires **28**. As will be seen in connection with FIG. **2**, these logic circuits include a switch mechanism for enabling the initial turning on and starting of such logic circuits. This switch mechanism is controlled from the exterior of the housing **17** by means of a control shaft **29** having an exposed slotted head which may be manipulated by means of a screwdriver or the like.

The downhole device **11** illustrated in FIG. **1** takes the form of a packer mechanism having an expandable packer element **30** which, when expanded, engages the inner wall of the casing pipe **15** for purposes of providing a partition across the interior of the casing pipe **15** for isolating a lower portion of the pipe from the portion of pipe thereabove. The packer device **11** also includes a setting tool **31** mechanically coupled between the upper end of the packer device **11** and the lower

end of the control apparatus **10**. This setting tool **31** responds to an electric current supplied thereto by the logic circuits contained in the lower housing section **27** and thereupon operates to drive the setting or packer expanding mechanism contained in the packer device **11**.

It should be noted that the showing of a packer device is purely for sake of an example. The control apparatus **10** can, in fact, be used for initiating or controlling the operation of various other types of devices which require operation after they are lowered to a desired depth in an oil or gas well.

Referring to FIGS. **2A** and **2B**, there are shown waveform diagrams of different signals induced in the coil **25** of the collar locator **18**. FIG. **2A** shows the case where the collar locator **18** is moving past the casing collars in a downward direction. The collar locator signal indicated at **32** is produced as the collar locator **18** moves past a first casing collar and a subsequent signal indicated at **33** is produced as the collar locator **18** moves past the next casing collar. Considering the signal **32** in detail, it includes a positive fluctuation **34** followed by a negative fluctuation **35**. Assuming that the signal **32** is produced by the casing collar **15***c*, then the positive fluctuation **34** is produced as the pole piece **23** moves past the casing collar **15***c*, while the negative fluctuation **35** is produced as the pole piece **22** moves past the collar **15***c*.

FIG. **2B** shows typical collar locator signals produced when the collar locator **18** is moving in an upwardly direction through the casing pipe **15**. The signals for two different collars are indicated at **36** and **37**. As indicated by the signal **36**, the upward movement produced collar locator signals include a negative-going fluctuation **38** followed by a positive-going fluctuation **39**. This order of occurrence of the negative and positive fluctuations is just the reverse of the downward movement case depicted in FIG. **2A**. As will be seen, this difference enables the logic circuits to determine whether the control apparatus **10** is moving in a downward or upward direction.

Referring now to FIG. **3**, there is shown the electronic logic circuits located in the lower portion **27** of the housing **17**. The lead wires **28** from the collar locator coil **25** are connected to input terminals **40** of the FIG. **3** circuits. These input terminals **40** are coupled by way of an amplifier circuit **41** to a form of bistable circuit represented by a Schmitt trigger circuit **42**. The input-output signal characteristic of the Schmitt trigger circuit **42** is indicated in FIG. **4** by curve **43**, input voltage values being plotted along the horizontal axis and output voltage values being plotted along the vertical axis of the FIG. **4** graph. Curve **43** includes a low output level portion **44**, a high output level portion **45** and an unstable transition portion **46** located therebetween.

As the input voltage to Schmitt trigger **42** rises from a zero value, the output voltage will remain at the lower level **44** until the input voltage reaches a value of V_2. When the input voltage exceeds V_2, the Schmitt trigger circuit **42** will make an abrupt transition to the higher level **45** by way of transition portion **46**. Similarly, if the input voltage is initially greater than V_2, then as it decreases the output voltage will remain at the upper level **45** until the input voltage falls below the voltage level V_1. At this point, the Schmitt trigger circuit **42** makes an abrupt transition to the lower level **44**. From this it is seen that the Schmitt trigger circuit **42** exhibits hysteresis. In other words, to effect a transition in one direction, the input voltage must first pass beyond the voltage level at which the reverse transition took place.

The Schmitt trigger circuit **42** is biased so that when the signal level at the input terminals **40** is zero, the circuit **42** is operating at the input voltage level V_b in the FIG. **4** graph, this being a level approximately midway in the hysteresis region of the input-output characteristic **43**. The amplified positive and negative fluctuations in the collar locator signals, as they appear at the input of the Schmitt trigger **42**, serve to add to or subtract from this V_b bias level. These fluctuations are of sufficient amplitude such that a positive fluctuation will increase the input voltage to a point above the V_2 trip level and a negative fluctuation will decrease the input voltage to a point below the V_1 trip level. As a consequence, if the last occurring fluctuation of a given collar locator signal is a positive fluctuation, the output voltage of the Schmitt trigger circuit **42** will remain at the upper level **45** following the conclusion of the collar locator signal. Conversely, if the last occurring fluctuation is a negative one, then the output voltage of the Schmitt trigger **42** remains at the lower level **44** following the conclusion of the collar locator signal.

Since the remainder of the circuits in FIG. **3** are of the binary type, it is desired that the high level output of the Schmitt trigger **42** correspond to the binary one level of the system and that the low level output correspond to the binary zero level of the system. This can be accomplished by proper selection of the circuit parameters in the Schmitt trigger **42**, or, in the alternative, a level adjusting buffer circuit can be connected to the output of the Schmitt trigger circuit **42** for accomplishing this result. For sake of simplicity, the former shall be assumed to be the case.

The FIG. **3** logic circuits further include counting circuit means for counting the collar locator signals produced during downward and upward movements of the collar locator **18**. In the present embodiment, this counting circuit means takes the form of a four-stage binary up-down counter **48**. Counter **48** is provided with a pair of output lines for each of the four stages, one line of each pair being connected to one side of its stage and the other being connected to the complement side of the stage. Output lines A and $\overline{A}$ (not A) are for the first stage, output lines B and $\overline{B}$ are for the second stage, and so forth.

Counter **48** is a reversible counter which can count in either an upward direction or a downward direction, depending on the levels of the signals on direction control lines **49** and **50**. The up line **49** is connected directly to the output of the Schmitt trigger **42**, while the down line **50** is coupled to the output of Schmitt trigger **42** by way of a NOT circuit **51**. NOT circuit **51** produces a binary zero level output when its input is at a binary one level and vice versa. Counter **48** counts in an upward direction when the up line **49** is at a binary one level and the down line **50** is at a binary zero level. Conversely, counter **48** counts in a downward direction when line **50** is at the one level and line **49** is at the zero level. Relative to the collar locator **18**, counter **48** counts up when the collar locator is moving up and counts down when the collar locator is moving down.

The logic circuits of FIG. **3** further include pulse generator circuit means coupled to the bistable circuit represented by the Schmitt trigger **42** for generating a delayed pulse a predetermined time interval after each change of state of a particular polarity in such bistable circuit. This pulse generator circuit means includes a single-shot or monostable multivibrator circuit **52** which is coupled to the output of the Schmitt trigger **42** and which produces a narrow negative-going output pulse each time the output of the Schmitt trigger **42** makes a positive-going (zero-to-one) transition. Each pulse from single-shot circuit **52** shifts a flip-flop circuit **53** to its set condition. This produces a binary zero level at the $\overline{Q}$ output which, in turn, activates a charging circuit **54**. This enables a capacitor in the charging circuit **54** to be charged up at a predetermined rate. This capacitor is connected to the input of a level-sensitive unijunction trigger circuit **55**. The unijunction transistor in the unijunction circuit **55** fires when the capacitor charge reaches a predetermined level. Such firing produces a narrow negative-going output pulse which is supplied to the reset terminal of the flip-flop circuit **53**. This resets flip-flop **53**. This causes the $\overline{Q}$ output to return to the one level which, in turn, disables the charging circuit **54** and discharges the capacitor therein.

The negative-going pulse at the output of the unijunction circuit **55** is inverted by a NOT circuit **56** and then supplied to first inputs of a pair of AND circuits **57** and **58**. The outputs of these AND circuits **57** and **58** are coupled by way of a common OR circuit **59** to the pulse counting input of the up-down counter **48**. As a consequence, if the other two inputs to either one of the AND circuits **57** and **58** are at the one level, then

the inverted or positive-going unijunction pulse is supplied to the counting input of the counter **48**. When so supplied, such pulse either increases or decreases the count in the counter **48** by one count, depending on the status of the direction control signals on lines **9** and **50**.

With one exception, each collar locator signal supplied to the input terminals **40** causes the Schmitt trigger **42** to undergo a positive-going, either alone or preceded or followed by a negative-going transition. Each such positive-going zero-to-one transition serves to trigger the single-shot circuit **52**. A predetermined time interval after each triggering of the single-shot circuit **52**, the unijunction circuit **55** produces the output pulse which, if other conditions are favorable (other inputs of AND circuits **57** and **58** at one level), is counted by the up-down counter **48**. This predetermined time interval or time delay is determined by the time constant in the capacitor charging circuit in the charging circuit **54**. This time delay is provided in order to enable the signal levels on direction control lines **49** and **50** to assume their final steady values before the pulse to be counted is supplied to the counting input of the counter **48**. This time delay will normally be on the order of one to four seconds and is selected to accommodate the slowest rate of movement of the collar locator **18** past a collar which is likely to be encountered. In other words, this time delay should be sufficient to allow movement of the collar locator **18** past a casing collar before the pulse to be counted is supplied to the input of the up-down counter **48**.

The one exception where a collar locator signal does not cause a triggering of the single-shot circuit **52** is the case where the movement of the collar locator **18** has just changed from upward movement to downward movement. In this case, the first collar which is passed in the downward direction produces only a negative-going transition and the single-shot **52** is not triggered. Thus, one count is lost when the collar locator movement changes from up to down.

Note that a second input of the AND circuit **57** is connected to the output of the Schmitt trigger **42**, while a second input of the AND circuit **58** is connected to the output of the NOT circuit **51**. As a consequence, following the occurrence of an upward movement produced collar locator signal, the second input of AND circuit **57** will be at the one level, while the second input of AND circuit **58** will be at the zero level. As a result, if conditions are otherwise favorable, the delayed pulse produced by unijunction circuit **55** will be supplied to the counter **48** by way of the "up gate" AND circuit **57**. Conversely, following the occurrence of a downward movement produced collar locator signal, the delayed pulse will be supplied by way of "down gate" AND circuit **58** to the counter **48**.

The logic circuits of FIG. **3** also include circuit means coupled to the counting circuit means represented by the up-down counter **48** and responsive to the downward and upward counts of such counting circuit means for detecting the occurrence of a predetermined pattern of downward and upward counts and thereafter supplying the control signal to the packer device **11** for purposes of initiating the setting of such device. This circuit means includes detector circuit means, indicated generally at **60**, for producing an activating signal upon the detection of the selected pattern of downward and upward counts and timer circuit means, indicated generally at **61**, for producing the packer device control signal a predetermined time interval after the initial occurrence of the activating signal.

Considering first the detector circuit means **60**, such circuit means includes a NAND circuit **62** for recognizing when the up-down counter **48** contains a binary count of **0000**. When this condition occurs, the $\overline{A}$, $\overline{B}$, $\overline{C}$ and $\overline{D}$ output lines of the counter **48** are all at the binary one level and, hence, the output of the NAND circuit **62** goes to the zero level. For any other count condition, the output of the NAND circuit **62** is at the binary one level. For present purposes, the **0000** condition should be thought of as the lower limit (LL) condition. The presence of a one level signal at the output of NAND circuit **62** indicates that the counter **48** is not at the lower limit condition. Among other things, this one level signal is supplied to the down gate AND circuit **58** for enabling such circuit to be activated when the other two inputs are at one level. The negative-going one-to-zero transition produced at the output of the NAND circuit **62** at the moment it reaches the lower limit condition is supplied to a flip-flop circuit **63** for shifting such circuit to its set condition. This causes the Q output of flip-flop **63** to go to the one level, which one level signal is supplied to a first input of a NAND circuit **64**. This tells the NAND circuit **64** that the counter **48** has been to the lower limit.

Thereafter, NAND circuit **64** operates to detect the occurrence of upward movement of the control apparatus **10** past a minimum of three casing collars. Following the counting of the second upward movement produced collar locator signal, the B output line of the second stage of the up-down counter **48** goes to the one level. This one level signal is supplied to a second input of the NAND gate **64**. As a consequence, if the control apparatus **10** is still moving in an upwardly direction when the delayed pulse for the third casing collar is produced by the unijunction circuit **55**, then this pulse will be passed by the NAND circuit **64** to a further flip-flop circuit **65**. The inverting action of the NAND circuit **64** causes the output pulse therefrom to be of negative-going polarity and such pulse serves to shift the flip-flop circuit **65** to its set condition. This causes the Q output line **66** of the flip-flop **65** to go to the one level. This one level signal on the line **66** constitutes the timer activating signal which activates the timer circuits **61**.

A further NAND circuit **68** is coupled to appropriate ones of the output lines of the up-down counter **48** for detecting the occurrence of a binary **0001** condition (a decimal count of eight) in the counter **48**. This condition should be though of as being the upper limit (UL) condition and, when it occurs, the output of NAND circuit **68** goes to a zero level. Otherwise, the output of NAND circuit **68** is at the one level (not upper limit level). The not upper limit one level signal is supplied back to the up gate AND circuit **57** for enabling such circuit to be activated when the control apparatus **10** is moving in the upwardly direction and the counter **48** is not at the upper limit. If the control apparatus **10** should be moved upwardly past a net total of eight casing collars, then the resulting negative-going one-to-zero transition at the output of the NAND circuit **68** is supplied by way of an AND circuit **69** to the flip-flop **63** for shifting same to its reset condition. This disables the NAND circuit **64**. The P input of AND circuit **69** is normally at the one level.

This negative-going transition at the output of NAND circuit **68** is also supplied by way of NOT circuit **70**, NOR circuit **71** and AND circuit **72** to the flip-flop circuit **65** for purposes of shifting the flip-flop circuit **65** to its reset condition. The logic is such that if a one-to-zero transition occurs at the input of the NOT circuit **70**, then a one-to-zero transition is produced at the output of the AND circuit **72**. The P input of AND circuit **72** is normally at the one level. The resetting of the flip-flop circuit **65** returns the output line **66** to the zero level. This does two things. It resets the timer circuits **61** and it thereafter keeps these timer circuits **61** disabled until such time as another one level signal may appear on the output line **66**.

If, after the control apparatus **10** has been moved upwardly past at least three casing collars and not more than seven casing collars, the control apparatus **10** is thereafter moved downwardly one or more casing collars past the first casing collar detected during the upward movement, then the timer circuits **61** are disabled. This happens because the up-down counter **48** returns to the **0000** condition when the collar locator **18** passes the next collar below the first collar counted during the upward movement, it being remembered that one count is lost when the collar locator **18** changes from upward to downward movement. The resulting one-to-zero transition at the output of NAND circuit **62** is supplied by way of NOT circuit **73**, AND circuit **74**, NOR circuit **71** and AND circuit

72 to the flip-flop circuit 65 for shifting same to its reset condition. The logic is such that a negative-going one-to-zero transition at the input of the NOT circuit 73 produces a negative-going one-to-zero transition at the output of the AND circuit 72.

The timer circuit means 61 of FIG. 3 includes a pulse generator 75 which produces pulses at a constant rate and supplies same to the pulse counting input of a seven-stage binary pulse counter 76. Initially, the counter 76 has a zero setting. This zero setting is maintained until the one level activating signal appears on the output line 66 of the flip-flop circuit 65. Thereupon, counter 76 begins counting the pulses from the generator 75. Coupled to selected stages of the counter 76 is a multiple input AND circuit 77. After the counter 76 has counted a selected number of pulses, then AND circuit 77 produces a one level output signal which is supplied by way of a switch 78 to the ungrounded one of output terminals 79 for the control apparatus 10. These output terminals 79 are connected to lead wires which run to the setting tool portion 31 of the packer device 11. This one level output signal at the output of AND circuit 77 is the control signal which initiates the setting operation of the packer device 11.

By way of example, the pulse generator 75 may be constructed to produce pulses at the rate of 6 pulses per minute. Being a seven-stage counter, the counter 76 is capable of counting up to a total of 127 pulses before it cycles back around to zero. By way of example, the AND circuit 77 is connected to the four highest order stages in the counter 76. As a consequence, AND circuit 77 will produce a one level output signal when the one hundred twentieth pulse is counted by the counter 76. Since these pulse generator pulses are occurring at the rate of 6 per minute, this means that the AND circuit 77 one level output signal will be produced 20 minutes after the counter 76 is first turned on by the activating signal on flip-flop output line 66. Thus, in this example, the timer circuits 61 provide a time delay of 20 minutes. The particular value of time delay which is used can be changed by changing either the rate of generation of the pulses in the generator 75 or by changing the stages of the counter 76 to which the AND circuit 77 is connected. Preferably, this time delay is in the range of 10 to 30 minutes.

If a longer duration steady-type output signal, as opposed to a pulse-type output signal, is desired at the output terminals 79, this can be provided by inserting a flip-flop circuit between the output of the AND circuit 77 and the switch 78 such that this flip-flop circuit will be shifted to the one-level output condition upon the appearance of a one level at the output of AND circuit 77.

The logic circuits of FIG. 3 further include a battery pack 80 for providing the operating voltage for the various circuits shown in FIG. 3. One side of the battery pack 80 is connected by way of an on-off switch 81 to a voltage supply terminal 82, the other side of the battery pack 80 being grounded. The voltage supply terminal 82 is connected by way of appropriate voltage supply lines (not shown) to each of the other circuits shown in FIG. 3. Also, though not shown for sake of simplicity, each of the other circuits in FIG. 3 includes a ground connection which connects back to the ground connection of the battery pack 80.

The FIG. 3 circuits further include a single-shot or monostable multivibrator circuit 83 having a manual firing switch 84 which, when closed, causes the single-shot circuit 83 to produce a preliminary setup pulse at its output terminal 85. This output terminal 85 is connected by way of appropriate conductors (not shown) to the P input terminals of the up-down counter 48, the AND circuit 69 and the AND circuit 72. The single-shot circuit 83 is constructed so that the output terminal 85 is at the binary one level except during the occurrence of the preliminary setup pulse, during which time it goes to the binary zero level.

Switches 78, 81 and 84 are mechanically linked with the control shaft 29 which, as indicated in FIG. 1, can be manipulated from outside of the control apparatus housing 17. The various electronic circuits shown in FIG. 3 are preferably of the integrated circuit type. As such, they require very little space inside of the control apparatus housing 17. Also, since circuits of this type are solid state type circuits, the current drain on the battery pack 80 is a minimum.

OPERATION OF THE PREFERRED EMBODIMENT

Considering now the operation of the above described subsurface control apparatus, the switch control shaft 29 is initially set so that all of the switches 78, 81 and 84 are in their open positions. The control apparatus 10 is then connected to the downhole device which is to be operated, in this case, the packer device 11. The wire line 12 is connected to the control apparatus 10 and the apparatus is moved into position for lowering into the oil or gas well. At this point, the switch control shaft 29 is manipulated to close the battery pack switch 81. This energizes the various circuits shown in FIG. 3. The switch control shaft 29 is then again manipulated to close the preliminary setup switch 84. The resulting preliminary setup pulse P sets the up-down counter 48 to an initial binary 1111 condition. By means of the AND circuits 69 and 72, it also places the flip-flop circuits 63 and 65 in their reset conditions. Thereafter, the switch control shaft 29 is again manipulated to close the control apparatus output switch 78. This manipulation also opens the preliminary setup switch 84. The battery pack on-off switch 81 remains closed during these latter two manipulations. The control apparatus 10 is now ready to be lowered into the string of casing pipe 15 lining the wall of the oil or gas well.

For sake of an example, it will be assumed that it is desired to set the packer device 11 at a depth of some 2,000 feet or more in the oil or gas well. As the control apparatus 10 and packer device 11 are lowered to this depth, the up-down counter 48 commences to count the signals which are periodically produced by the collar locator 18 as it periodically passes one of the casing collars between successive pipe sections. The counter 48 counts the first 15 collar locator signals, whereupon the counting action ceases and the counter 48 holds its then existent count condition, which is the 0000 condition. In other words, for these first 15 collars the counter 48 counts downward from its initial 1111 setting to the lower limit 0000 condition. At this point, the NAND circuit 62 output goes to the zero level, which disables the down gate AND circuit 58 and thus prevents further counting for the subsequent downward movement.

The downward movement of the control apparatus 10 and packer device 11 continues until the packer device 11 reaches the depth at which it is to be set or, at most, a depth not more than seven pipe sections below the desired setting depth. At this point, the movement of the control apparatus 10 and packer device 11 is halted. The depth of the packer device 11 is known from the amount of the wire line 12 which has been reeled out in lowering the packer device 11 into the well.

After the downward movement of the control apparatus 10 and packer device 11 has been halted, the control apparatus 10 and packer device 11 are then moved in an upwardly direction past at least three but not more than seven casing collars. Immediately after the third casing collar is passed in this upward movement, the counter 76 in the timer circuits 61 is activated to commence the preset timing cycle (e.g., 20 minutes). The packer device 11 is then moved a short distance to its final resting position, namely, the desired packer setting depth. The packer device 11 is then held in this position and is thereafter set into place in the casing string 15 when the timer circuits 61 produce the control signal at the output terminal 79.

After the initial activation of the timing circuit counter 76 (passage of third casing collar when moving in upward direction), the position of the control apparatus 10 and packer device 11 can be thereafter adjusted in either an upwardly or downwardly direction so long as a net total of not more than

three collars is passed in the downward direction or a net total of not more than four collars is passed in the upward direction. If either of these limits is exceeded, the flip-flop circuit **65** is reset and, hence, the timer counter **76** is also reset and maintained in a disabled condition. If the casing collars are spaced 30 feet apart, this allows for a downward adjustment of 90 feet and an upward adjustment of 120 feet without disabling the timer circuits **61**.

The ability to turn off the timer circuits **61** and hence to prevent the operation of the downhole device represents a safety feature in case anything should go wrong and it should become necessary not to set the downhole device. Also, it means that the downhole device cannot be completely withdrawn from the oil well without causing an automatic disabling of the timer circuits **61**.

In the event that the timer circuits **61** should be disabled and it should thereafter be desired to restart such timer circuits **61**, then this can be accomplished by manipulating the movement of the control apparatus **10** such that the up-down counter **48** is returned to its lower limit **0000** condition and the control apparatus **10** thereafter moved in an upwardly direction a distance corresponding to a minimum of three casing collars.

As seen from the foregoing, the electronic logic circuits of FIG. **3** are constructed so that the operation of the downhole device is not initiated until after a predetermined pattern of downward and upward movements of the control apparatus **10** has been caused to occur. The particular movement pattern which was described above is only one of many movement patterns which the logic circuits can be constructed to detect. Thus, the described movement pattern should be taken by way of example and not by way of limitation on the scope of the invention.

While there has been described what is at present considered to be a preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. Subsurface control apparatus for use in an oil or gas well having a string of pipe therein comprising:

housing means adapted to be lowered through the string of pipe and including means for coupling thereto and lowering therewith a downhole device which requires operation after it is lowered into the well;

magnetic detector means located in the housing means for generating an electrical signal each time the detector means moves past a pipe joint; and

electronic logic counting circuit means located in the housing means and responsive to the signals produced by the magnetic detector means for counting said signals and producing a control signal for initiating the operation of the downhole device.

2. Subsurface control apparatus in accordance with claim **1** wherein the magnetic detector means includes:

permanent magnet means for producing magnetic flux;

pole piece means for enabling the magnetic flux to link with the well pipe; and

coil means responsive to changes in the magnetic flux for producing electrical signals indicative of such changes.

3. Subsurface control apparatus in accordance with claim **1** further including; a nonelectrical wire line connected to said housing means for supporting same in the pipe string; said wire line constituting the sole support means for said housing means and said means therewith.

4. Subsurface control apparatus in accordance with claim **1** wherein the magnetic detector means produces an electrical signal having a positive and a negative fluctuation each time the detector means moves past a pipe joint, the order of occurrence of the positive and negative fluctuations being dependent on the direction of movement of the detector means past the pipe joint, and wherein the electronic logic circuit means includes:

bistable circuit means coupled to the magnetic detector means for changing states in response to the magnetic detector signals, the final state following any given magnetic detector signal depending on the order of occurrence of the positive and negative fluctuations;

pulse generator circuit means coupled to the bistable circuit means for generating a delayed pulse a predetermined time interval after each change of state of a particular polarity in such bistable circuit means;

an up-down pulse counter;

circuit means for coupling the bistable circuit means to the up-down pulse counter for controlling the direction of counting therein;

circuit means for coupling the output of the pulse generator circuit means to the pulse counting input of the up-down pulse counter;

timer circuit means for producing the control signal to be supplied to the downhole device a predetermined time interval after an activating signal is supplied to such timer circuit means; and

logic circuit means coupled to the up-down pulse counter for detecting the occurrence of a predetermined number of downward counts and thereafter a predetermined number of upward counts for thereupon supplying an activating signal to the timer circuit means, such logic circuit means also including means for thereafter disabling the timer circuit means if more than predetermined numbers of net upward or downward counts occur after the activating signal is first supplied to the timer circuit means.

5. Subsurface control apparatus in accordance with claim **4** wherein the magnetic detector means includes:

permanent magnet means for producing magnetic flux;

pole piece means for enabling the magnetic flux to link with the well pipe; and

coil means responsive to changes in the magnetic flux for producing electrical signals indicative of such changes.

6. Subsurface control apparatus in accordance with claim **1** wherein the electronic logic circuit means includes:

counting circuit means for counting magnetic detector signals produced during downward and upward movements of the detector means; and

circuit means coupled to the counting circuit means and responsive to the downward and upward counts of such counting circuit means for producing the control signal for the downhole device after the detection of a predetermined pattern of downward and upward counts.

7. Subsurface control apparatus in accordance with claim **6** wherein:

the signals produced by the magnetic detector means have a polarity characteristic which is dependent on the direction of movement of the detector means past the pipe joint; and

the counting circuit means includes up-down counter circuit means for counting in one direction in response to downward movement produced magnetic detector signals and for counting in the other direction in response to upward movement produced magnetic detector signals.

8. Subsurface control apparatus in accordance with claim **7** wherein the electronic logic circuit means further includes circuit means responsive to the magnetic detector signals for supplying pulses to the counting input of the up-down counter circuit means and for supplying direction control signals to the up-down counter circuit means for controlling the direction of counting for the pulses.

9. Subsurface control apparatus in accordance with claim **6** wherein the circuit means coupled to the counting circuit means includes:

detector circuit means for producing an activating signal upon the detection of a predetermined pattern of downward and upward counts; and

timer circuit means responsive to the activating signal for producing the control signal for the downhole device a predetermined time interval after the initial occurrence of the activating signal.

10. Subsurface control apparatus in accordance with claim 9 wherein the duration of the predetermined time interval of the timer circuit means is in the range of 10 to 30 minutes.

11. Subsurface control apparatus in accordance with claim 9 wherein the detector circuit means further includes means for disabling the timer circuit means if more than predetermined numbers of net upward or downward counts occur after the initial occurrence of the activating signal.