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Jeter

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[45] **July 29, 1975**

[54] **METHOD AND APPARATUS FOR ACTUATING DOWNHOLE DEVICES**

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[73] Assignee: **Texas Dynamatics, Inc.,** Dallas, Tex.

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[21] Appl. No.: **409,910**

[52] **U.S. Cl.** **73/151;** 175/40

[51] **Int. Cl.** **E21b 47/00**

[58] **Field of Search** ..... 73/151; 175/40, 50; 340/18 NC, 18 LD, 18 CM

[56] **References Cited**

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Primary Examiner—Jerry W. Myracle

Attorney, Agent, or Firm—Bargfrede and Thompson

[57] **ABSTRACT**

To actuate downhole devices in accordance with the disclosure, fluid is pumped through the drill string at a rate that creates a preselected pressure condition in the drill string. At such preselected pressure condition, a timer is actuated that continues to run as long as the preselected pressure condition exists. If the pressure condition is maintained for a length of time sufficient for the timer to time out, the downhole device will be actuated. The device is deactuated by circulating fluid through the drill string to create a second pressure condition that actuates a timer that runs as long as the preselected pressure condition is maintained. When the timer times out, it deactivates the device. In another embodiment, the particular device to be actuated is selected by rotation of the drill string after the timer times out. It is deactuated by creating a particular flow condition until the timer times out. A third embodiment permits selection of simultaneous functions by the flow-time method and deactuation by stopping fluid circulation.

18 Claims, 11 Drawing Figures

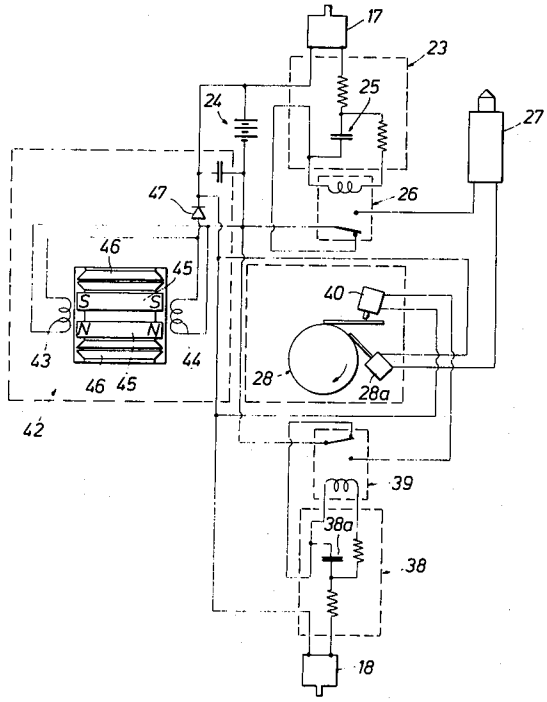


FIG. 1A

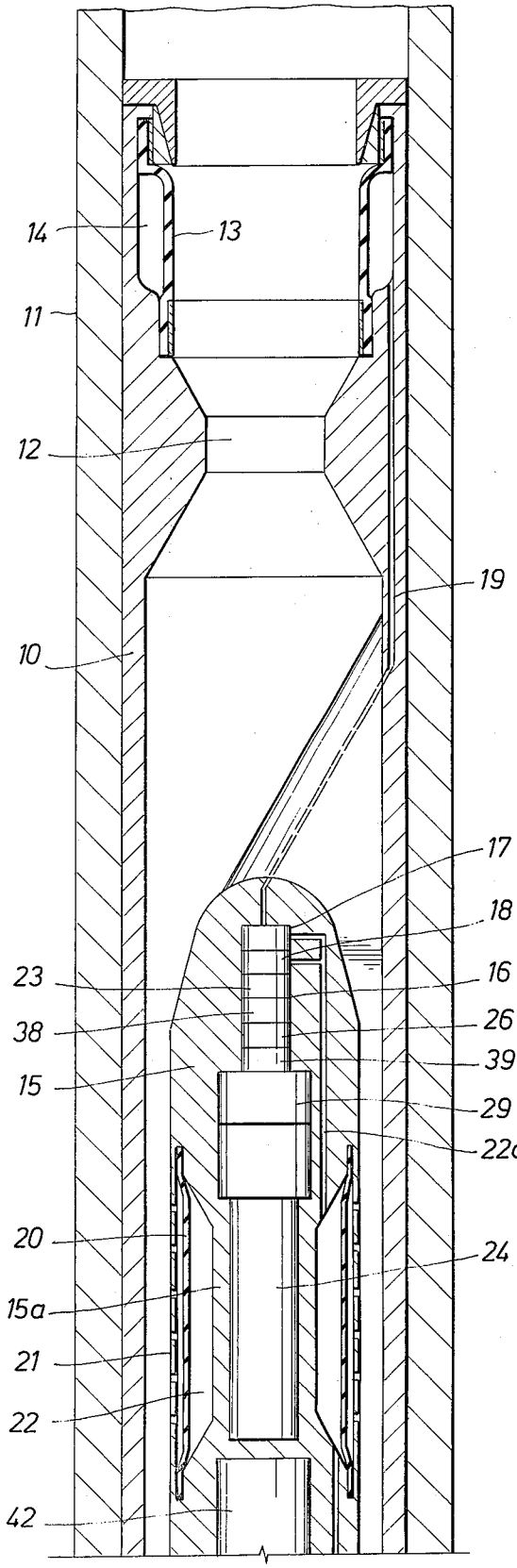

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22a
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FIG. 1B

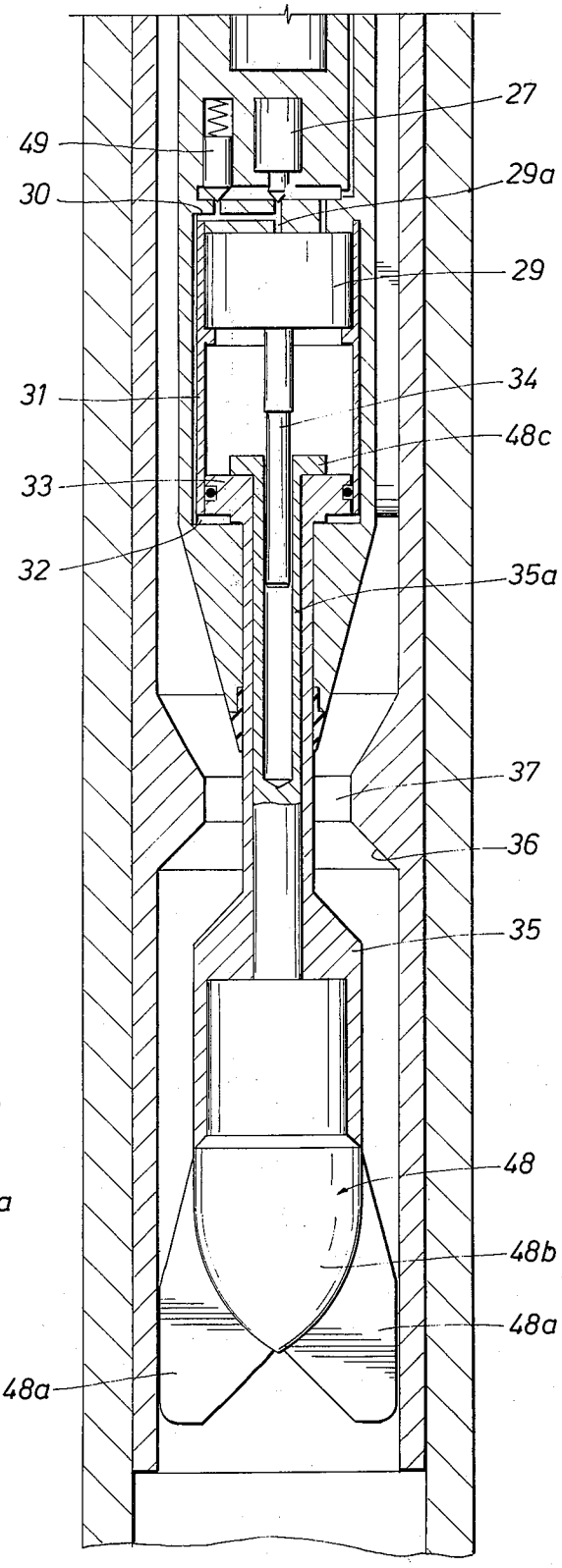

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29a
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35a
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48b
48a
48a

FIG. 2

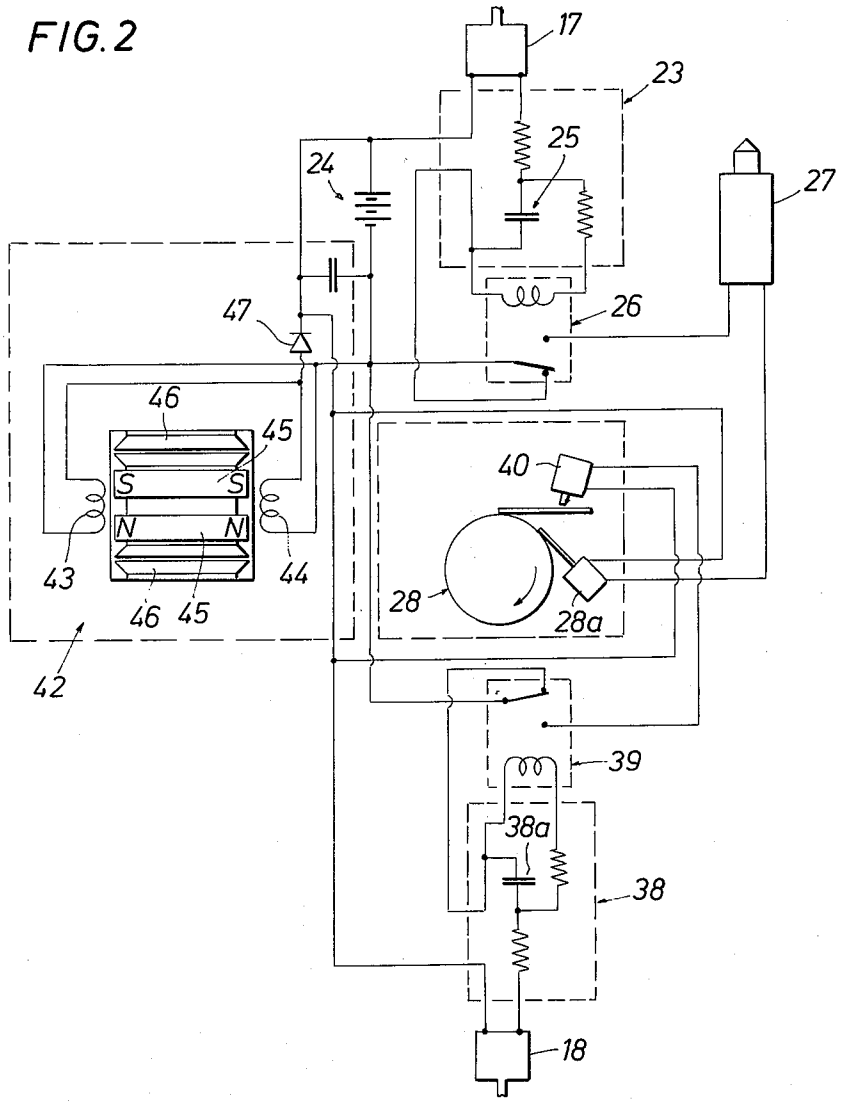


FIG. 3

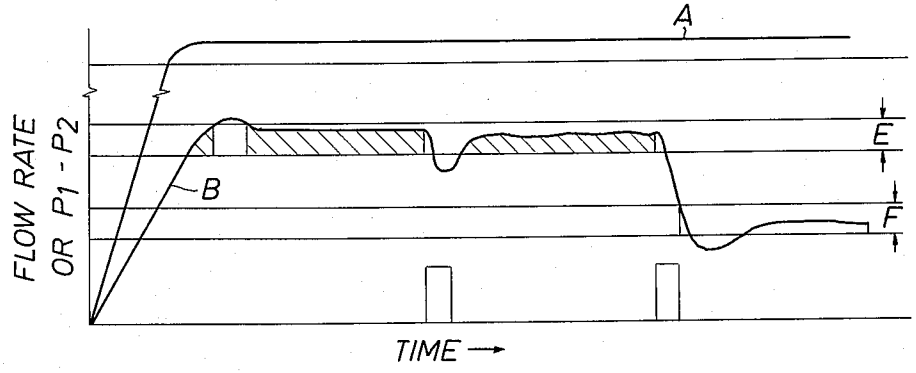


FIG. 4

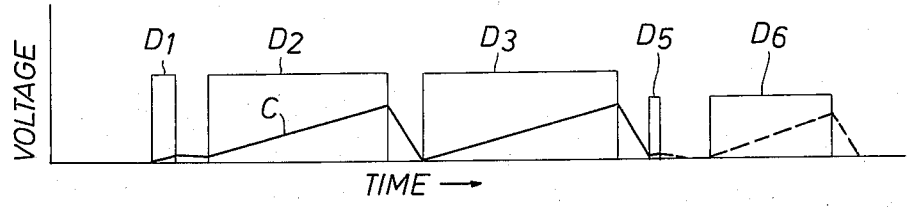
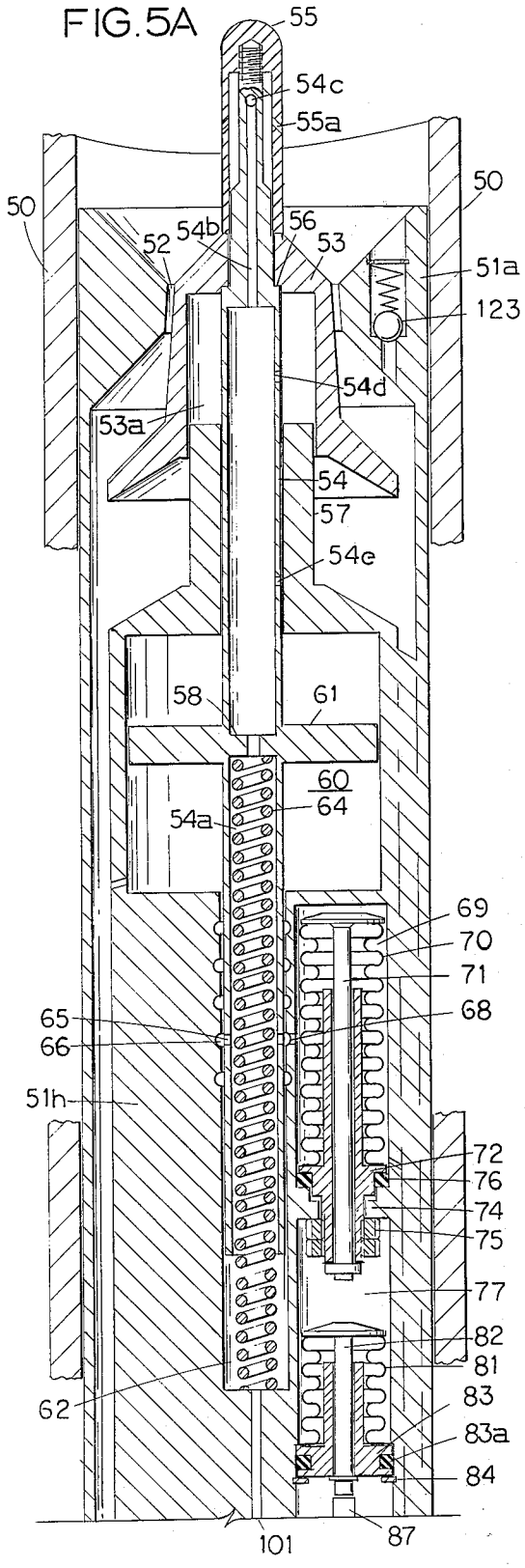


FIG. 5A



UP

DOWN

FIG. 5B

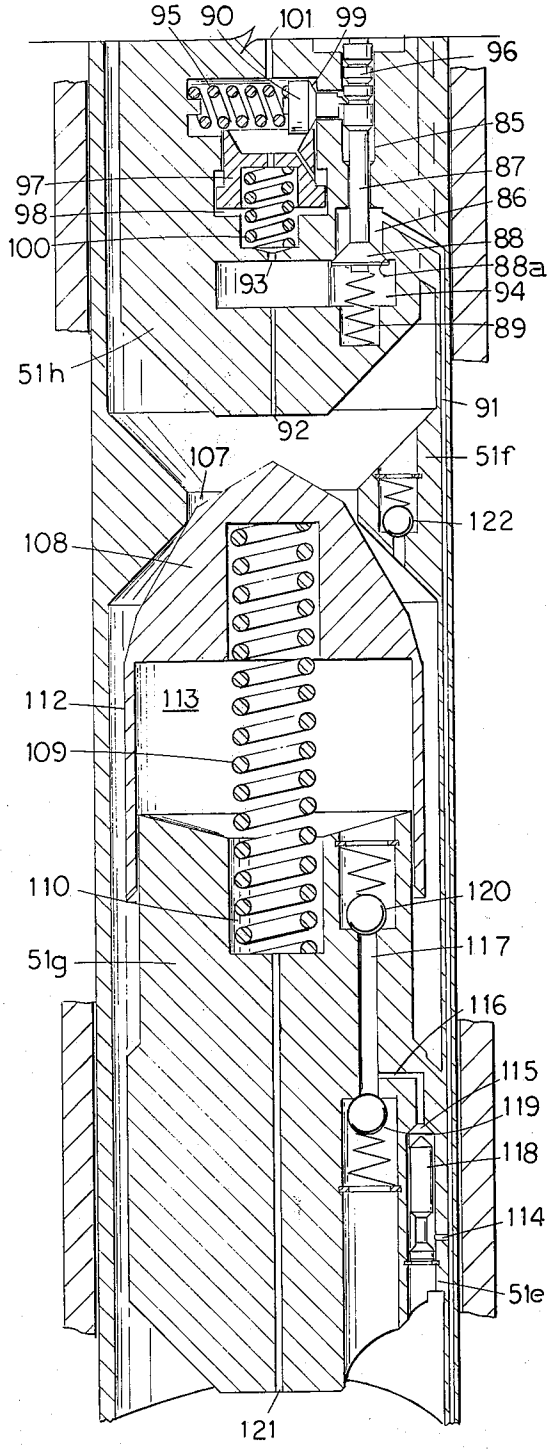


FIG. 6A

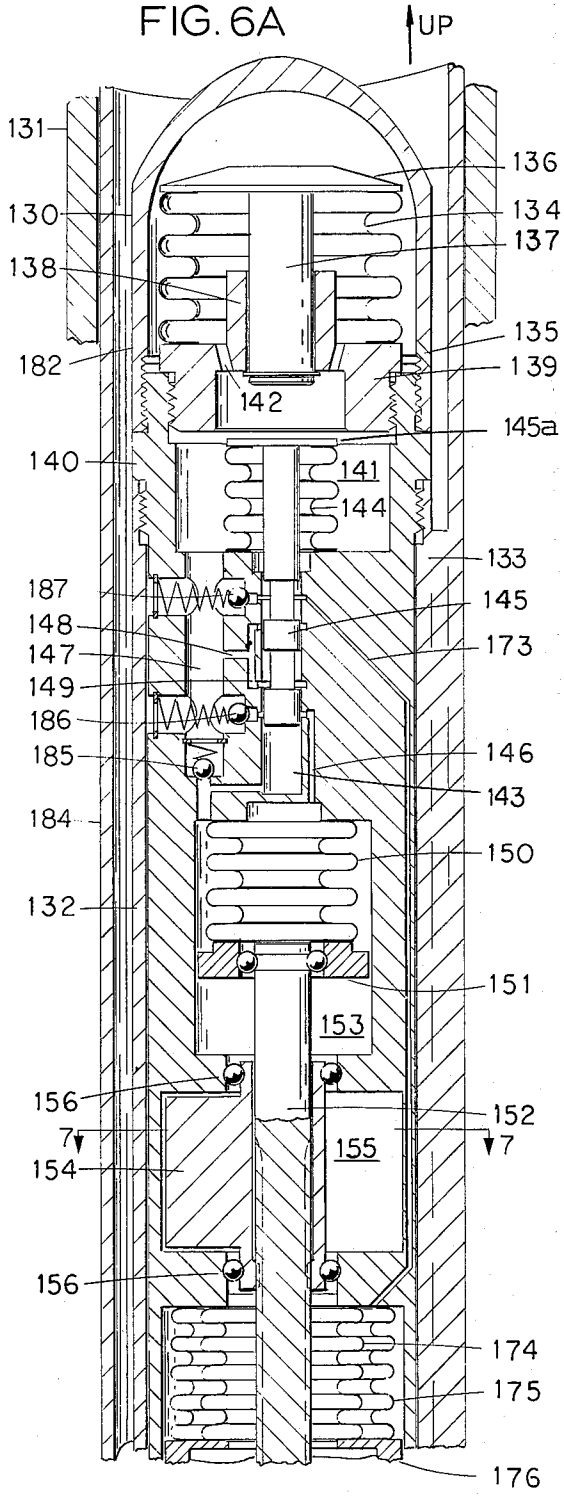

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FIG. 6B

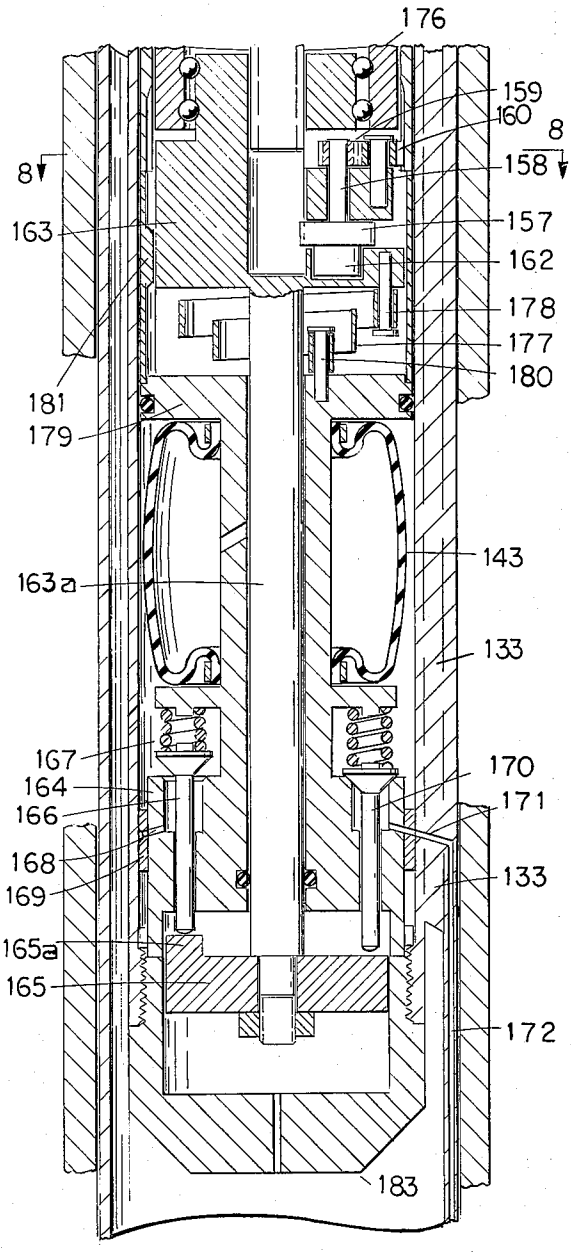

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FIG. 7

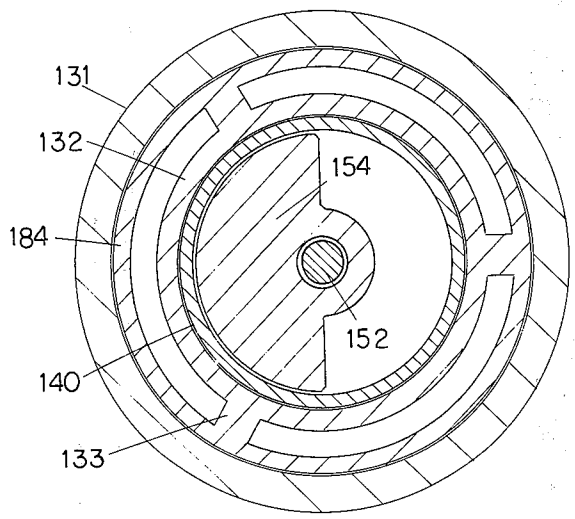
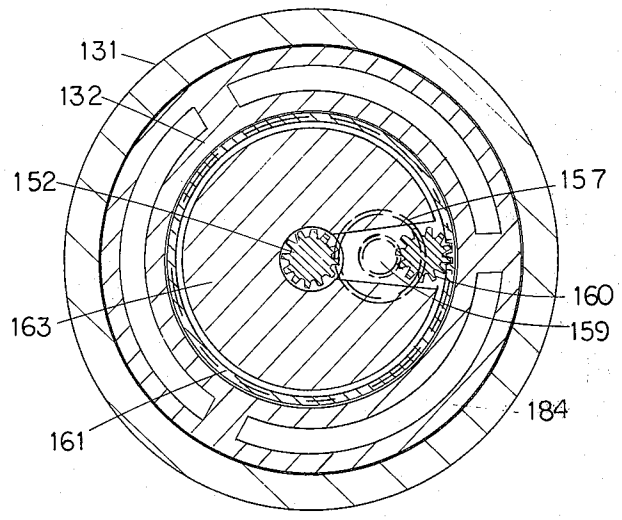


FIG. 8



METHOD AND APPARATUS FOR ACTUATING DOWNHOLE DEVICES

This invention relates to a method of and apparatus for actuating one or more downhole devices carried by a drill string.

There is a need from time to time in rotary drilling operations to cause a downhole device carried by the drill string to do something or to stop doing something. For example, if the drill string includes a fluid motor it may be desirable from time to time to lock the rotor of the motor to the stator so the assembly attached to the rotor can be rotated by the drill string and to later unlock the rotor for continued drilling without having to pull the pipe string out of the hole. Another example is the periodic measurement of hole inclination and azimuthal direction. This is done by lowering the measuring devices to the bottom of the drill string from the surface. If these devices could be carried by the drill string and turned on and off quickly, considerable down time would be saved.

In Arps U.S. Pat. No. 2,924,432, entitled "Earth Borehole Logging System", that issued Feb. 9, 1962, a system for actuating a downhole device is disclosed. With this system, the device is actuated by cycling the pressure in the drill string between a low and a high value. Thus, the actuating apparatus is operated each time the circulation pressure fluctuates between the two values, as for example, when pumping is stopped to make a connection.

It is an object of this invention to provide a method of and apparatus for actuating one or more downhole devices carried by the pipe string that requires a particular pressure condition to exist in the pipe string for a finite period of time before the device is actuated.

It is another object of this invention to provide a method of and apparatus for deactivating a downhole device carried by a pipe string by creating a preselected pressure condition in the pipe string and maintaining this pressure condition for a finite preselected period of time whereby the device will not inadvertently be deactivated when the pressure is reduced to make a connection or raised back to normal drilling pressure conditions.

It is a further object of this invention to provide a method of and apparatus for actuating a downhole device carried by a drill string that can be used to actuate the device when desired, but that otherwise is unaffected by normal drilling operations.

It is another object of this invention to provide a method of and apparatus for actuating a selected one of a plurality of downhole devices carried by a drill string by maintaining preselected pressure conditions in the drill string for a finite preselected period of time.

These and other objects, advantages, and features of this invention will be apparent to those skilled in the art from a consideration of the specification, including the attached drawings and appended claims.

In the drawings:

FIGS. 1A and 1B are vertical sectional views through a preferred embodiment of the apparatus of this invention;

FIG. 2 is a circuit diagram showing the electrical system used in the embodiment of FIGS. 1A and 1B;

FIG. 3 is a graph of time versus flow rate or pressure;

FIG. 4 is a graph of time versus voltage;

FIGS. 5A and 5B are vertical sectional views through an alternate embodiment of the apparatus of this invention;

FIG. 6 is a vertical sectional view through another alternate embodiment of this invention;

FIG. 7 is a cross-sectional view taken along line 7—of FIG. 6; and

FIG. 8 is a cross-sectional view taken along line 8—8 of FIG. 6.

In the embodiment shown in FIGS. 1A and 1B, tubular body or housing **10** is located in pipe string **11** at the desired position, which will usually be adjacent the lower end of the string. It can be held in position in any convenient manner. Located adjacent the upper end of body **10** is orifice **12** to cause a pressure drop in fluid flowing through the orifice. Upstream of orifice **12**, when fluid is pumped down the pipe string in the conventional manner, is tubular diaphragm **13**. The opposite ends of the diaphragm are in sealing engagement with body **10** with the portion in between spaced from the body to form annular cavity **14**.

Mounted below orifice **12** in body **10** is instrument housing **15**. A plurality of electrical components are located in cavity **16** of the instrument housing, including pressure sensitive switch assemblies **17** and **18**. Cavity **16** of the instrument housing is connected to annular cavity **14** above orifice **12** by passageway **19**. By filling annular cavity **14** of the passageway with a liquid, such as oil, the pressure above orifice **12** will be transmitted to the upper end of cavity **16** and directed to act against pressure switch assemblies **17** and **18**. These pressure sensitive switches could be of the type that are actuated by a given static pressure coming from one source, such as annular space **14**. Preferably, however, the switches are actuated by the differential pressure created by the pressure drop in the fluid flowing through orifice **12**. The switches then are independent of hydrostatic pressure, which will vary depending on the position of the switches in the well bore. Each assembly includes two switches connected in series. One is normally open and closes at a first preselected pressure differential. The other is normally closed and opens at a second preselected pressure differential. When the pressure differential is between the first and second pressure differentials, the switch assembly is closed and current can flow therethrough.

Therefore, instrument housing **15** has section **15***a* of reduced diamter located inside of cylindrical screen **21** that is surrounded by tubular diaphragm **20**. The opposite ends of the diaphragm are sealed to the instrument housing with the portion in between spaced from the housing to provide annular chamber **22**. With this chamber filled with a liquid, such as oil, the pressure in pipe string **11** adjacent the instrument housing is transmitted to space **16** through passageway **22***a*. Pressure switch assemblies **17** and **18** are arranged to sense the difference in the pressure in passageways **19** and **22***a* that is created by the pressure drop across orifice **12** when fluid is pumped down drill string **11**. The amount of pressure drop is dependent upon the rate of flow and other factors, such as the viscosity of the fluid being pumped.

In accordance with this invention, timing means are provided that will operate while certain pressure conditions exist in the pipe string. In the embodiment shown, such timing means include R-C timing circuit **23** (enclosed by dashed line box), as shown in FIG. **2**. The

timing circuit is actuated when the pressure differential across orifice **12** is within the preselected range that closes pressure switch assembly **17** and connects R-C circuit **23** to battery **24.** As long as the pressure differential stays within the preselected range, the battery will supply electrical energy to the timing circuit until such time as the charge on capacitor **25** has reached the point that it will actuate relay **26.** The time required for this to occur is determined by the circuit components, but it should be long enough to allow the pressure differential across orifice **12** to move back and forth through the range, as occurs during normal drilling operations, without causing the circuit to time out, i.e., actuate relay **26.**

The relay drops the timing circuit out and energizes solenoid **27** and stepping switch solenoid **28***a*. The stepping switch solenoid moves stepping switch **28** into position to actuate a downhole device. A plurality of such devices could be used with the stepping switch, with each position of the switch designed to actuate a different device.

At the same time that the downhole device is being actuated, solenoid **27** closes outlet **29***a* of hydraulic pump **29.** This causes fluid from the pump to travel through passageway **30,** down the annular space between the pump housing and cylinder **31** and through ports **32** into the bottom of the cylinder below piston **33.** The fluid raises piston **33,** and in doing so raises valve member **35** toward valve seat **36,** which is actually the tapered downstream side of orifice **37.** By narrowing the distance between valve member **35** and valve seat **36,** a pressure pulse will be created in the fluid being pumped down the pipe string. The pressure pulse can be detected at the surface and provides an indication that the downhole device is now actuated.

Power is supplied to pump **29** by impeller **48.** The impeller has vanes **48***a* that cause hub **48***b* to rotate when drilling fluid is pumped down the drill string. Output shaft **48***c* is connected to the hub and supported by piston **33.** Drive shaft **34** of the pump extends into and has a splined connection with output shaft **48***c*. It can telescope into the output shaft as the piston moves, but is connected for rotation therewith by the splines. Thus, rotation of the impeller by the flowing drilling fluid drives pump **29.**

The charge in capacitor **25** will hold relay **26** actuated long enough for the solenoid and stepper switch to so function, after which the charge will have bled down to the point that the relay will fall out. If pressure switch **17** is still closed by the pressure existing across it, R-C timing circuit **23** will be connected again to battery **24.** If it is desired to simply step stepper switch **28** one step and actuate that device, then as soon as the signal of the pressure pulse reaches the surface, the pressure differential across the switch should be changed so that switch **17** will open, otherwise the cycle will repeat itself and the stepper switch will be stepped again, which could deactivate the device actuated by the first step of the switch. This would depend on the arrangement of the stepper switch. Stepping the switch twice could stop the first device actuated or not as desired. On the other hand, if the device that is to be actuated is at the third or fourth position of the switch, then by simply holding the pressure differential across switch **17** such that switch **17** remains closed, then the circuit will simply time out three or four times stepping the stepper switch three or four times, after which when the third or fourth pressure pulse reaches the surface, the operator can change the pressure conditions and open the switch.

Means are provided to stop the actuated downhole device or devices when a preselected pressure condition exists in the drill pipe. This is the function of pressure switch **18,** second R-C timing circuit **38,** and relay **39** of FIG. **2.** A pressure drop within a preselected range is created across orifice **12.** This closes switch assembly **18** connecting R-C timing circuit **38** to battery **24.** When the charge has built-up on the condenser of the circuit sufficiently to actuate relay **39,** erasing solenoid **40** will be actuated, releasing stepper switch **28** to be returned by springs or the like to its original position. This deactivates all devices.

The electrical components described above are supplied with power by battery **24** in this embodiment. Generator **42** supplies charging current to the battery to keep it charged. The generator is operated by vertical vibrations of the pipe string, which will be substantial if the pipe string, for example, is being employed in a drilling operation. The generator is shown schematically and includes coils **43** and **44.** They are located in the magnetic field of magnets **45** so that relative movement of the coils and the magnets will induce a current in the coils that can be used to charge battery **24.** In the embodiment shown, the magnets are mounted on springs **46** so that their inertia will cause them to tend to remain stationary while the pipe moves the coils thereby producing the desired relative movement of the magnetic field and the coils to induce a current. Diode **47** rectifies the induced current to provide a DC charging current to the battery.

FIG. **3** shows graphically the relationship of flow rate or pressure drop across orifice **12** versus time. FIG. **4** shows graphically the voltage build up on capacitor **25** or **38***a*, as the case may be, versus time. In FIG. **3,** curve A shows the pressure drop across orifice **12** as the driller brings his circulation rate from zero up to normal drilling rates. In doing so, the pressure drop across the orifice will for short periods be in pressure ranges E and F, during which times pressure switch assemblies **17** and **18** will be closed. The length of time that each is closed, however, is insufficient to allow time delay circuits **23** and **38,** respectively, to actuate relays **26** and **39,** so nothing happens. Thus, the driller can bring his flow rate up to that of normal drilling or circulate drilling fluid for any purpose and as long as he passes through pressure ranges E and F before the timing circuits time out, the stepper switch will be unaffected. When such circulation is stopped, the pressure will drop through these ranges, of course, but again will not be in the ranges long enough to actuate the stepper switch.

Should the driller desire to step switch **28** to actuate one or more downhole devices in his drill string, he adjusts the flow rate to produce a pressure drop within pressure range E. This closes switch **17** and energizes timing circuit **23.** For example, curve B of FIG. **3** illustrates such an operation. The driller brings the flow rate up from zero. He enters pressure range E, then exceeds it slightly. During the time that the pressure drop is out of the range, switch **17** will be turned off. The pressure drop then stabilizes within the range and switch assembly **17** remains closed and a charge builds up on capacitor **25.**

FIG. 4 illustrates the build up of voltage on the capacitor versus time. This is shown with curve C. The square-shaped curve D is representative of the periods of time that the pressure switch **17** is closed. Thus, during the first brief period D_1 that switch **17** is closed, a small amount of voltage builds up on the capacitor. Then, the switch is off again for a short period of time and some of the charge drains off. During time interval D_2, voltage builds up to the point where relay **26** is actuated. As explained above, this cuts off the source of power to the timing circuit, as shown by the gap between D_2 and D_3, and the voltage on the capacitor begins to drain off. When solenoid **27** causes pump **29** to move valve element **35** up far enough to cause a pressure pulse, this will, of course, affect the rate of flow of fluid through the drill pipe and may cause the pressure drop across orifice **12** to drop to a point out of the pressure range E, as indicated in FIG. **3** by curve B. This is a very short interval and is just a momentary change in the pressure drop. If the flow rate is maintained, the pressure drop will move again into range E and the cycle will be repeated.

Curve B is shown moving from range E to range F_1 which is the pressure range that closes pressure switch assembly **18.** Here again, for illustration purposes, the curve of Delta P is shown dropping through the range closing the switch momentarily (time period D_5), but long enough to start a build up of charge on capacitor **38***a*, *then returning into the pressure zone and holding switch 18 closed long enough* (*time period* D_6), for time delay circuit **38** to time out. When this occurs, as explained above, relay **39** will return stepper switch **28** to its original starting point, deactuating all of the devices previously actuated, which, in the example shown, would be the two or more that are actuated by the first and second positions of the stepper switch.

In the example described, the flow rates are adjusted to cause timing circuit **23** to time out in sequence and step switch **28** twice. By maintaining this flow rate, the switch can be stepped as many times as desired. Also, after the downhole device is actuated, the driller may want to return to normal flow rates. This he can do and even stop pumping altogether to make a connection or whatever without affecting switch **28.** At a later time, he can return the flow rate to provide a pressure drop within range F and deactuate the device.

As explained above, solenoid **27** closes outlet **29**a of pump **29** directing the discharge of the pump under piston **33** to raise valve element **35** and create a pressure signal in the fluid stream. The closer the valve element comes to valve seat **36,** the greater the pressure drop for a given flow rate. This increases the upward force required of piston **33** and the pressure of the fluid under the piston. Usually, solenoid **27** will be deenergized before the pressure drop builds up too much or the passageway is closed off. However, to be safe, check valve **49** is designed to release the fluid pressure under the piston when it reaches a preselected amount.

The alternate embodiment of the invention, shown in FIGS. **5**A and **5**B, is designed to also actuate a device when a differential pressure within a preselected range is applied to the apparatus and maintained for a predetermined finite period of time. The apparatus is all carried by pipe section **50** in which is located instrument housing **51.** Housing **51** is shown in one piece for simplicity, although in practice it would probably consist of many separate parts. The upper end portion **51***a* of tubular member **51** has opening **52** of reduced diameter to provide a flow restriction for the fluid being pumped through the pipe string. Pipe joint **50** is connected into a pipe string in the conventional manner. Housing **51** may be held in axial position within pipe joint **50** by tool joints or any suitable method.

Combining with orifice **52** to restrict the flow of fluid through the orifice is valve element **53** that is supported by rod **54.** The rod extends through the valve element and is connected to cap **55** that holds the valve element in position on the rod against upwardly facing shoulder **56.** The valve element telescopes over annular guide **57** which is an integral part of housing **51.**

Valve rod **54** extends through guide **57** and into cylinder **60.** Piston **61** is located in the cylinder and attached to the rod to cause the rod to move when the piston is subjected to a different pressure in the cylinder. The rod extends downwardly into elongated opening **62** in selector valve body **51***h*. Valve rod **54** has central opening **54***a* of relatively large diameter that extends from the lower end to where it connects with central opening **54***b* of smaller diameter in the upper portion of the rod. Coil spring **64** is located in opening **54***a* with one end engaging partition **58.** The other end engages the bottom of opening **62** to resiliently urge the rod and valve element **53** upwardly into position to restrict the flow of fluid through orifice **52.** When fluid is being pumped down the pipe string, the pressure of the fluid upstream of orifice **52** will act against valve element **53** and urge it downwardly against the upward force of spring **64.** The fluid upstream can also enter cap **55** through ports **55***a* and pass through lateral ports **54***c* into central opening **54***b* of the valve rod. From opening **54***b*, the fluid can flow into cylindrical cavity **53***a* of valve element **53** through passageway or opening **54***a* and port **54***d*. The fluid entering cavity **53***a* will be at substantially the same pressure as the fluid upstream of orifice **52** and will act upwardly against the upper end of cavity **53***a* to resist downward movement of valve element **53.** The clearance between guide **57** and valve element **53** is such that it will sufficiently restrict the flow of fluid from cylindrical cavity **53***a* that pressure will build up in the cavity and exert such an upward force.

For a given flow rate then, valve element **53** will move valve rod **54** downwardly to a given position, such as the one shown in FIG. **5**A. In this position, port **65** in the lower end of the rod will be in alignment with annular groove **66** on the wall of opening **62.** This allows fluid from upstream of orifice **52** to flow into chamber **69** through lateral port **68.** Within the physical space limitations available, any given number of ports **68** and chambers **69** can be provided, each one designed to actuate a different downhole device, as will be described below. As to which device is to be actuated, of course, it will depend upon the position of rod **54** and this, in turn, is dependent upon the rate of flow of fluid through orifice **52.**

Located in chamber **69** is bellows **70.** The upper end of the bellows is connected to rod **71,** which extends through bellows base **72.** Cylindrical body portion **51**h of housing **51,** in which cavity **69** is located, includes annular flange **74** to support the base of the bellows in the cavity. Nuts **75,** in engagement with threads on the lower end of the base, clamp the bellows base to the annular flange. Seal ring **76** prevents the flow of fluid from chamber **69** past the bellows base. In this embodi-

ment of the invention, this bellows assembly provides the timer for the apparatus.

The fluid in chamber **69** is at or a little below upstream pressure. The fluid inside bellows **70** and in chamber **77** below the bellows is maintained at the pressure adjacent this portion of the apparatus, which is downstream of the orifice and a lower pressure than that upstream. The pressure differential across bellows **70** will cause it to collapse or contract moving rod **71** downward through the central opening in base **72.** This will displace fluid from inside the bellows into chamber **77** through the annular space between the rod and the opening in the base.

For pressure differentials within a preselected range, the annular space can be designed to require a finite minimum period of time for a sufficient volume of the fluid in bellows **70** to be displaced for rod **71** to move into engagement with rod **82.** The upper end of bellows **81** is attached to rod **82** and the lower end is attached to bellows base **83** to provide a seal between the rod and bellows base **83** while allowing the rod to reciprocate. Snap ring **84** supports the base and bellows in the lower end of chamber **77.** Seal ring **83***a* is carried by the base to maintain a seal between the bellows base and body **73.**

Valve stem **87** extends into chamber **77** in axial alignment with rod **82** and with its upper end adjacent the lower end of the rod. The valve stem extends downwardly through openings **85** and **86** into chamber **94.** The lower end of the stem is connected to valve head **88** which engages seat **88***a* and isolates opening **86** from chamber **94.** Valve head **88** is held against its seat by coil spring **89.**

The apparatus just described is designed for bellows rod **82** to be moved downwardly by rod **71** after a predetermined period of time and move valve element **88** away from seat **88***a*. This allows fluid to flow from chamber **94** to passageway **91** which causes fluid pressure to be supplied to the device to be actuated in a manner described below. Chamber **94** is supplied with fluid at upstream pressure from chamber **98** by port **93.** Passageway **101** conducts fluid at upstream pressure from chamber **62** to chamber **98.** Piston **97** is located in chamber **98** for purposes to be described below, but port **97***a* in the piston allows fluid to flow to port **93** with only a small pressure drop. Passageway **92** connects chamber **94** to ambient pressure at all times to help keep a pressure differential from building up between the inside cavities of the housing and the outside when the apparatus is not being operated. The diameter of passageway **92** is such that the flow of fluid through it will not appreciably drop the pressure in chamber **94.** Appropriate seals (not shown) are provided to isolate passageway **91** from the pressure in chamber **94** except when valve **88** is open. Thus, with the apparatus described, for a given flow rate and pressure drop across orifice **52** that is held for a predetermined finite period of time, the downhole device can be actuated.

As bellows **70** moves rod **71** downward into engagement with rod **82,** fluid is displaced from bellows **70** into chamber **77.** To keep the pressure in chamber **77** from increasing above ambient, an arrangement (not shown) like sleeve **20** described above and shown in FIG. 1A can be used.

Means are provided to hold valve element **88** open after upstream pressure is removed from above bellows **70** so that the device will continue to be actuated, while other flow rates are selected to actuate additional devices or to return to drilling operations or the like. In the embodiment shown, pin or pawl **90** is urged to the right by coil spring **95** so that the sharp edge on the end of the pawl will engage the circumferential grooves **96** in the valve stem. Grooves **96** have flat walls on their low side and tapered walls on the upper side. These tapered walls will cam the pawl to the left and out of the way as the valve stem moves down to open the valve. The flat walls, however, will not exert a lateral force on the pawl and the pawl will prevent upward movement of the valve stem and hold the valve open.

Some means should be provided to close the valve when it is desired to cancel the operation of the device. In the embodiment shown, piston **97** is located in chamber **98** of housing area **51***h* and its upper end has a sharp circular edge to engage bevel **99** on the pawl. Coil spring **100** urges piston **97** upward from the position shown which movement will cause its upper end to cam pawl **94** to the left. Such movement will release valve stem **87** for upward movement, allowing spring **89** to close the valve and deactivate the device. In this embodiment, the device will be deactivated when there is no flow through the pipe string. When there is flow, fluid from the inside of chamber **62,** which is at the pressure of the fluid upstream of orifice **52,** can flow downwardly through passageway **101** and act against piston **97** urging it downwardly to the position shown where pawl **94** is free to move to the right to hold the valve open. When flow is stopped, the pressure across piston **97** equalizes and spring **98** will move it upwardly causing it to cam the pawl to the left and release the valve stem, thereby deactivating the downhole device.

It may be preferable to provide a time delay between the stopping of flow and the release of the valve stem to allow circulation to be stopped momentarily, as when adding another joint to the pipe string, without deactuating the device. This can be done, for example, by using a double bellows arrangement like bellows **70** and **81** to move a beveled surface to cam pawl **90** to the left after a predetermined period of time.

As explained above, the position of control rod **54** determined which of the plurality of grooves **66** is supplied with actuating pressure and which of the plurality of downhole devices is actuated. The position of the control rod is determined by the pressure drop through orifice **52,** which is a function of the rate that fluid is pumped through the pipe string. Thus, for each position of the control rod, the pressure upstream of orifice **52** will be different and the pressure of the actuating fluid supplied to passageway **91** will be different.

It may be desirable or necessary to supply each downhole device with actuating fluid having a pressure different from the pressure of the fluid in passageway **91.** Therefore, it is one of the features of this invention to provide means for controlling the pressure of the actuating fluid supplied to each of a plurality of devices. In the embodiment shown, passageway **91** extends downwardly through the cylindrical portion of the housing where it is connected to portion **51g** of the housing that is supported in the center of the housing by rib **51e.** Portion **51f** of the housing provides orifice **107** through which the fluid flowing in the pipe string must pass. Valve element **108** is urged upwardly toward a position to close orifice **107** by coil spring **109** that extends from the bottom of bore **110** in housing portion

51g over which the valve member telescopes. The telescoping portion of the valve member is cylindrical skirt **112** that forms cavity **113** between the upper end of housing portion **51g** and valve member **108.** Fluid flowing through passageway **91** enters cavity **113** through passageways **114, 115, 116,** and **117.**

Located in passageway or cavity **115** is flow restriction **118** that limits the rate fluid can flow into chamber **113.** The cross-sectional area against which the fluid acts in chamber **113** is greater than that of orifice **107** so that with sufficient pressure in chamber **113,** the valve element can be closed. As it is urged toward the closed position, the upstream pressure, of course, will increase providing passageway **91** with the increased pressure upstream of the orifice. Consequently, by arranging check valve **119** to open at the preselected pressure desired, valve element **108** will be positioned by the upstream pressure fluid to produce this pressure after which check valve **119** will open and this pressure will be maintained. The increase in upstream pressure and the pressure in passageway **91** caused by orifice **107** does not change the position of control or selector rod **54** since the pressure differential across orifice **52** does not change, as both upstream and downstream pressure across this orifice are affected equally.

A plurality of devices may be supplied with fluid of different pressure with this apparatus. Each device is connected to a passageway, such as passageway **91,** through which actuating fluid is supplied to the device. Each passageway is connected into chamber **113** through its own set of check valves **119** and **120.** As explained above, check valve **119** controls the pressure supplied to the device, whereas check valve **120** allows the other devices to be supplied with different pressures by keeping the pressure in chamber **113** from entering passageway **117** when this particular set of passageways is inoperative. Fluid continuously bleeds from chamber **113** through port **121** to insure that the valve element doesn't become locked in some position. The rate of flow of fluid through port **121,** however, is sufficiently low not to affect the overall operation of the apparatus.

When not operating the apparatus, it is generally desirable to allow fluid to flow through the pipe string as freely as possible and with a minimum of restriction. Consequently, it's another feature of this invention to provide means for moving valve element **53** substantially out of position to restrict the flow through orifice **52.** In the embodiment shown, as the rate fluid is pumped increases toward normal circulation rates, the upstream pressure will increase and valve element **53** will move control rod **54** downwardly until port **54***d* enters the bore of rod guide **57.** The clearance between the rod and the bore of the rod guide is such that the flow of fluid from port **54***d* is reduced to the point where it cannot build up pressure in chamber **53***a.* At the same time, port **54***e* moves into the upper end of chamber **60** and now the fluid upstream of orifice **52** acts against piston **61** which will force valve element **53** and rod **54** downwardly to the limit of their downward travel away from orifice **52.** This opens up the orifice to reduce to a minimum the pressure drop therethrough during times that the apparatus is inoperative. Check valves **122** and **123** in housing portions **51***f* and **51***a,* respectively, allow reverse circulation and also allow the pipe string to fill up while it is being run into the hole.

In the other embodiment of the invention shown in FIGS. **6–8,** all of the apparatus is located in housing **130,** which consists essentially of upper cap **182,** body **140,** enclosure **132** and lower cap **183.** As shown in FIGS. 7 and **8,** the housing is supported in the center of pipe string **131** by arms **133** radially extending between the housing and cylindrical support **184.** The natural pressure drop in the fluid flowing past the restriction to flow offered by the housing and support arms is employed to actuate this device when given preselected pressure differentials are held for predetermined finite periods of time.

Located in upper cap **182** of the housing is bellows **134.** It is exposed externally to the pressure of the fluid in the pipe string adjacent the upper end of the housing through one or more ports **135** extending through the cap. The upper end of the bellows is connected to disc **136.** Rod **137** is attached to the disc and extends through rod guide **138.** The lower end of the bellows is attached to bellows base **139,** which is integrally attached to rod guide **138.** The base of the bellows is connected to the upper end of body **140,** and forms one wall of cavity **141** in the body. The fluid in bellows **134** is discharged through ports **142** into cavity **141,** when the pressure on the outside of the bellows exceeds that on the inside.

A pressure differential is created across the bellows when fluid is pumped down the drill pipe. The pressure on the outside of the bellows is that of the fluid adjacent ports **135.** Everything in body **140** below valve **145** and above annular diaphragm **143** (FIG. **6B**) is filled with fluid and sealed from the effect of outside pressure except through bellows **134,** valve **145,** and flexible diaphragm **143.** These two pressure sensing elements, bellows **134** and diaphragm **143,** are spaced apart longitudinally in the housing so that the ambient pressure at the upper end of the housing is greater than that adjacent diaphragm **143,** and it is this difference in pressure that is used to operate the apparatus by causing bellows **134** to collapse forcing fluid out of the bellows into chamber **141.**

Bellows **144** is located in cavity **141** with its lower end attached to body **140.** Its upper end is attached to disc **145***a* of valve spool **145.** The bellows seals the upper end of elongated chamber **143** in which valve spool **145** is located. Cavity **141** has lower extension **147** that is connected to valve chamber **143** by passageway **148** that divides into two branches, an upper and a lower. The valve spool is in sealing engagement with the wall of cavity **143** except for the two spaced portions of reduced diameter. Passageway **146** connects valve chamber **143** to the inside of bellows **150** in cavity **153.**

As shown, the valve spool is positioned to prevent the flow of fluid from cavity **147** to passageway **146.** At a preselected differential pressure across bellows **134** produced by a preselected flow rate, the pressure will build up in chamber **141** sufficiently to collapse bellows **144** far enough to move the valve spool downwardly far enough to position the lower portion of reduced diameter of the spool adjacent the lower branch of passageway **147** and the upper end of passageway **146.** The higher pressure fluid in cavities **144** and **147** will then flow to the inside of bellows **150** through passageway **146.** This will cause bellows base **151** and splined rod **152** to move downwardly in chamber **153.** Splined rod **152** engages matching splines on eccentric weight **154.**

The weight is mounted in cavity **155** by bearings **156** for free rotation around the longitudinal axis of the housing. The lower end of splined rod **152**, when moved downwardly by bellows **150**, moves into engagement with gear **157** (FIG. **8**). This gear is mounted on shaft **158**. Pinion **159** is mounted on the shaft and is in engagement with gear **160**, which in turn engages ring gear **161** mounted on the inside of the housing. One-way clutch **162** prevents gear **157** and shaft **158** from rotating except in one direction. The eccentric weight will seek the low side of the hole and tend to remain stationary as the pipe string is rotated. There will usually always be a low side. If the well bore is substantially vertical, the tendency of the eccentric weight to remain stationary may not be sufficient for the operation of the apparatus. If this is anticipated to be a problem, a gyroscope can be substituted for the eccentric weight in the manner described in my copending application, Ser. No. 409,176, filed Oct. 24, 1973.

With the gears in engagement with each other and with splined rod **152**, rotation of the drill pipe will rotate ring gear **161** with it. Splined rod **152** will remain stationary and gears **157** and **159** will walk around the ring gear and splined rod, respectively, and in doing so, cause valve selector assembly **163** to rotate around its longitudinal axis, which also is the longitudinal axis of the pipe string.

The valve selector assembly includes shaft section **163***a* which extends through valve body **164**. Cam plate **165** is attached to the lower end of shaft **163***a*. As shaft **163***a* rotates cam plate **165** relative to valve body **164**, cam **165***a* engages successively the stems of the valve elements carried by valve body **164**. As shown in FIG. **6**, cam **165***a* is in engagement with the stem of valve **166** and has raised it off its seat to allow fluid to flow from chamber **167** to passageway **168** which continues into spacer member **169**. From there, the passageway passes through one of ribs **133** of the housing and downwardly to the device that this valve controls. Further rotation of the drill pipe will cause cam plate **165** to allow valve **166** to close. Continued rotation will open valve **170** allowing fluid to move from cavity **167** to passageway **171** which, as shown in the drawings, is connected to passageway **172** through spacer **169** and rib **133**. Passageway **172** is connected to a downhole device to be actuated when fluid under pressure is supplied to it through passageway **172**.

The number of rotations of the drill pipe required to rotate cam plate **165** to open valves **166** and **170** is known and is a function of the gear ratio of the gear train between the ring gear rotated by the drill pipe and the splined rod. When cam plate **165** is in position to actuate the desired device, normal operations can be resumed. Increased circulation will provide an increase in the pressure drop across housing **130** and increase the pressure drop across bellows **144**. For normal drilling operations, this is sufficient to move valve spool **145** to a position to cut off any further flow of fluid to any of the parts of the device below the control valve. The spring action of bellows **150** will move splined rod **152** upwardly out of engagement with gear **157** and rotation of the drill pipe will not affect the position of cam **165***a*. This allows the device selected to continue to operate while further operations are being performed, such as drilling.

To deactivate the device and return the apparatus to its starting position, a particular flow rate is used to provide a pressure differential across bellows **144** that will position valve spool **145** to connect chamber **141** to passageway **173** through the upper branch of passageway **148**. This introduces fluid at upstream pressure to the annular space between bellows **174** and **175** which moves bearing housing **176** downwardly carrying valve selector assembly **163** with it. Such movement moves gear **160** out of engagement with annular ring gear **161**. Clock spring **177** has one end attached to selector assembly **163** by pin **178** and the other end connected to stationary housing member **179** by pin **180**. When gear **160** moves clear of the ring gear, spring **177** will rotate the valve selector assembly, including cam plate **165**, back to the position where pin **178** is in engagement with stop **181**. This places the cam plate in a known position relative to the valves that control the downhole devices, and when it is desired to actuate a particular downhole device, the number of rotations of the drill pipe that are required to open the desired valve will be known.

To avoid deactuating a device inadvertently while passing through the pumping rate that would position the valve spool to do this, passageway **173** is of a diameter such that the flow of fluid through it, plus the capacity of the space between bellows **174** and **175** and the distance the selector assembly must move to disengage the gears, takes some time, the amount of which can be selected. Thus, there is a built-in time delay before a device can be deactuated.

From the foregoing, it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the method and apparatus.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the method and apparatus of this invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

The invention having been described, what is claimed is:

1. A method of actuating a downhole device in a drill string comprising pumping fluid down the drill string at a rate to provide a pressure drop across a flow restriction within a preselected range that is different from the range of pressure drops produced during normal drilling operations, maintaining said pumping rate for a predetermined, finite, period of time and actuating said downhole device at the end of the time period.

2. The method of claim **1** with the further step of creating a pressure pulse in the fluid in the drill string that is detectable at the surface when the device is actuated.

3. The method of claim **1** with the further step of pumping fluid down the drill string at a second rate to provide a pressure drop across a flow restriction within a second different preselected range and maintaining said second rate for a predetermined, finite, period of time to deactuate said downhole device.

4. The method of claim **1** with the further step of stopping the pumping of fluid to deactivate the downhole device.

5. A method of actuating one of a plurality of downhole devices carried by a drill string comprising pumping fluid through the drill string to create a pressure drop across a flow restriction within one of several preselected ranges that are different from the range of pressure drops produced when pumping fluid during normal drilling operations, maintaining said pressure drop for a predetermined, finite period of time and actuating one of said downhole devices at the end of the time period.

6. A method of actuating a plurality of downhole devices carried by a drill string comprising pumping fluid through the drill string at a rate to create a pressure drop across a flow restriction within a preselected range that is different from the range of pressure drops produced during normal drilling operations, maintaining the pumping rate for a predetermined, finite period of time to actuate one of said devices after the time period has elapsed, and maintaining the pumping rate for additional predetermined, finite periods of time to actuate another of said devices for each additional elapsed time period the pumping rate is maintained.

7. The method of claim 6 with the further steps of pumping at a second rate to produce a second pressure drop across the flow restrictions and maintaining said second pumping rate for a predetermined, finite period of time to deactuate said devices.

8. A method of actuating one of a plurality of devices carried by a drill string comprising pumping fluid through the drill string to provide a pressure differential, maintaining the pressure differential for a predetermined, finite, period of time, and rotating the drill string a predetermined number of revolutions to actuate said device.

9. The method of claim 8 with the further step of pumping fluid through the drill string at a rate to produce a second pressure drop and maintaining said pumping rate for a predetermined, finite minimum period of time to deactuate said device.

10. Apparatus for actuating a downhole device carried by a drill string comprising timing means carried by the drill string, means responsive to a preselected pressure condition in the drill string to cause the timing means to operate while said pressure condition exists, and means to actuate said downhole device when the timing means times out.

11. The apparatus of claim 10 further provided with means to deactuate the device including a second timer, means to cause the second timer to operate through a timing cycle when a second preselected pressure condition exists, and means to deactivate the device when the second timer times out.

12. Apparatus for actuating a downhole device carried by a drill string comprising means for creating a pressure drop when fluid is pumped down the drill string, a timer carried by the drill string, means responsive to said pressure drop when it is within a preselected range to actuate the timer and to allow it to operate as long as the pressure drop is within said range, and means to actuate said device when the timer times out after a predetermined finite period of time.

13. The apparatus of claim 12 further provided with means to deactuate the device including a second timer and means to actuate the timer and to allow it to operate as long as the pressure drop is within a preselected second range, and means to deactivate the device when the timer times out after a predetermined finite period of time.

14. Apparatus for actuating a plurality of downhole devices carried by a drill string extending into a well bore, comprising timing means carried by the drill string, means responsive to a preselected pressure condition in the drill string to cause the timing means to operate while said pressure condition exists, and means to actuate one of said devices each time the timing means times out.

15. The apparatus of claim 14 further provided with means for creating a surface detectable signal as each device is actuated.

16. The apparatus of claim 14 further provided with second timing means, means responsive to a preselected pressure condition in the drill string to cause the second timing means to operate while said pressure condition exists, and means for deactivating said devices when the second timer times out.

17. The apparatus of claim 14 in which the means to actuate one of said devices includes means responsive to rotation of the drill string to actuate additional devices.

18. The apparatus of claim 14 further provided with means to provide a preselected pressure differential for each of the devices when actuated.

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