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Ayers, Jr. et al.

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[45] **Dec. 25, 1973**

[54] **METHOD AND APPARATUS FOR CONTROLLING WELLS**

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[21] Appl. No.: **243,360**

[52] **U.S. Cl.** **166/314,** 137/624.11, 166/53, 166/224

[51] **Int. Cl.** **E21b 43/00**

[58] **Field of Search** 166/64, 53, 65, 314, 166/224

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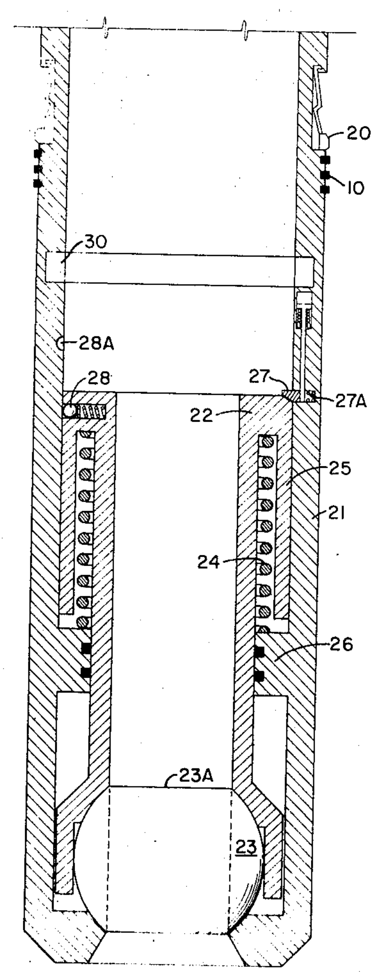
Assistant Examiner—Lawrence J. Staab
Attorney—James A. Reilly et al.

[57] **ABSTRACT**

An improved method and apparatus are disclosed for controlling flow of fluid through a conduit disposed within a well extending beneath the surface of the earth. The apparatus includes a subsurface valve situated on the conduit and provided with means for actuating the valve between an open and closed position to control the flow of fluid through the conduit. The valve automatically closes at the end of a preset flow period unless reset in response to an external signal to reinitiate the predetermined period to closure. Normally a surface generated signal, as for example a pressure pulse, is periodically directed to the actuating means to reinitiate the flow period. The frequency of the pulses is adjusted as required to assure that the actuating means will receive a pulse prior to the end of the flow period so flow will not be interrupted. If the pulses are interrupted, as for example by a rupture in the well conduit, the valve will close automatically at the end of the flow period.

17 Claims, 7 Drawing Figures



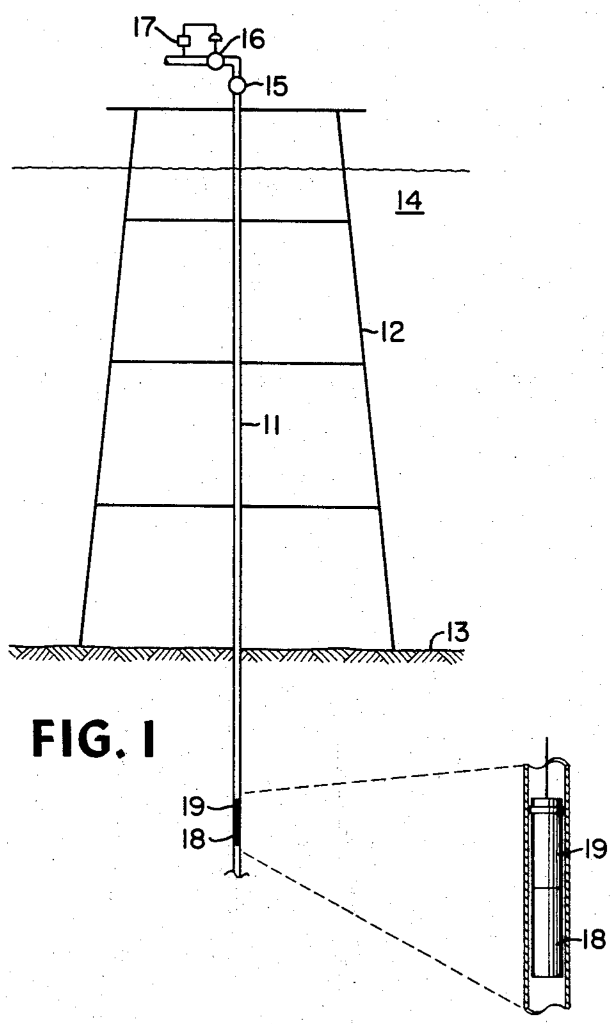


FIG. 1

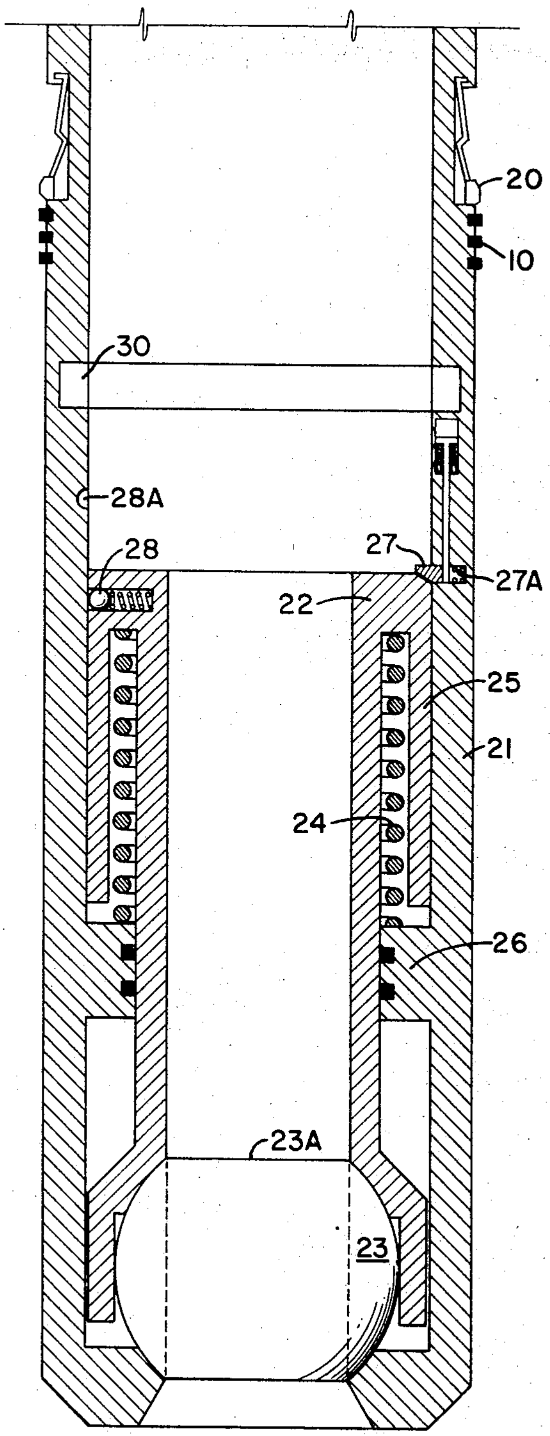

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FIG. 2

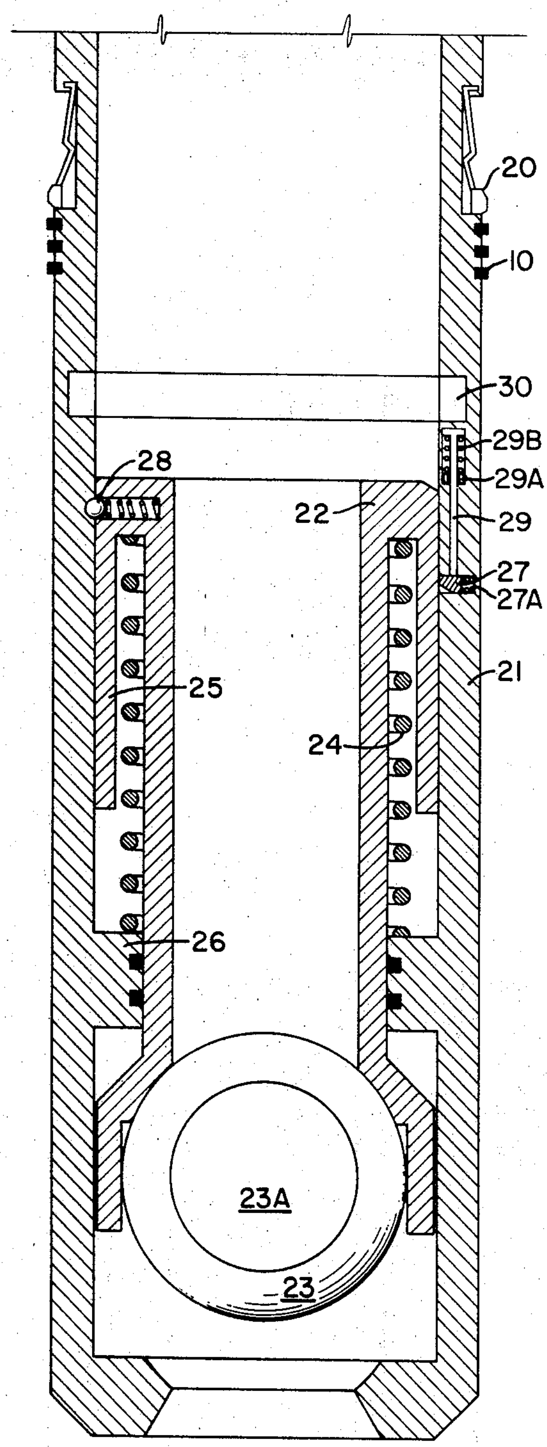
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FIG. 3

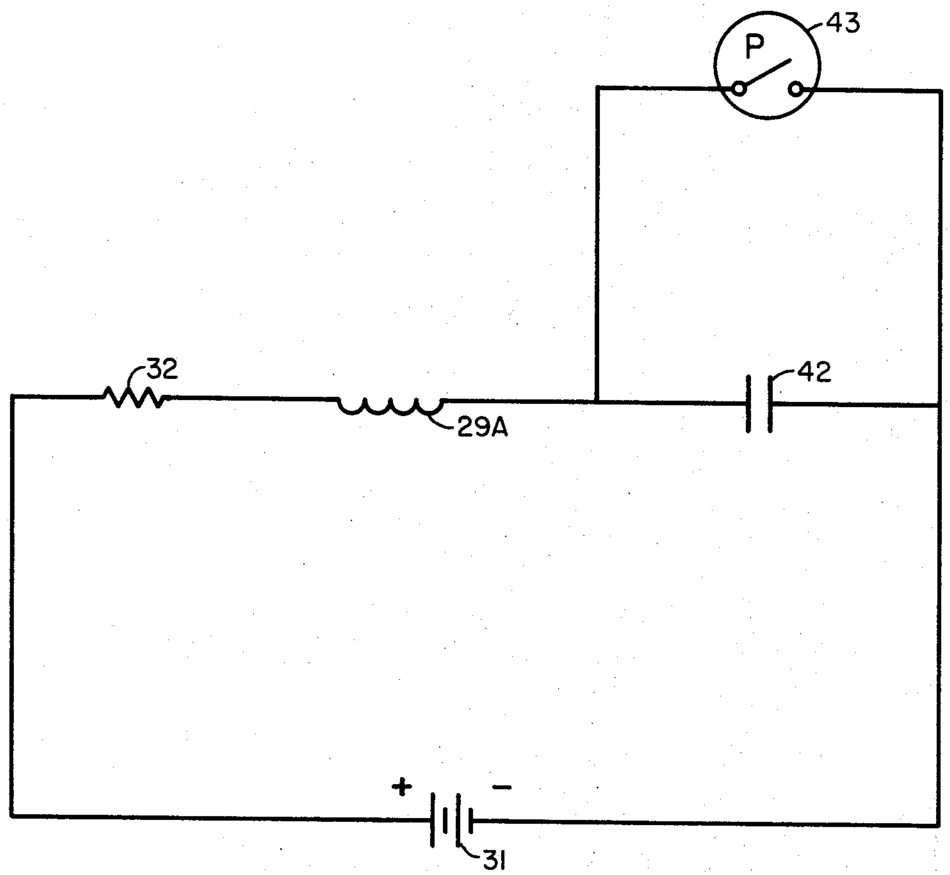

FIG. 4

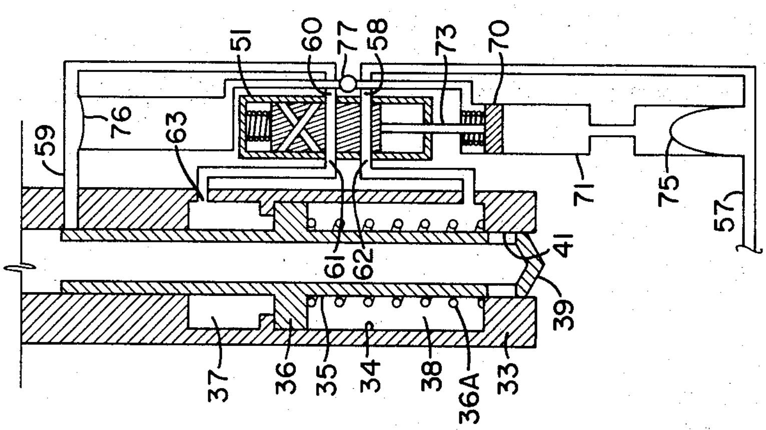

FIG. 7

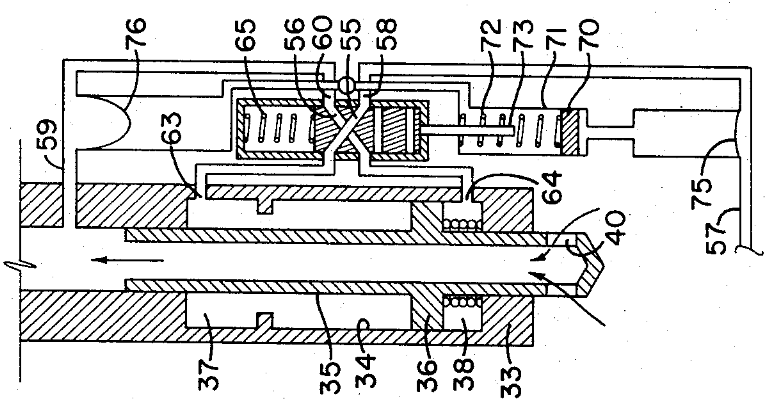

FIG. 6

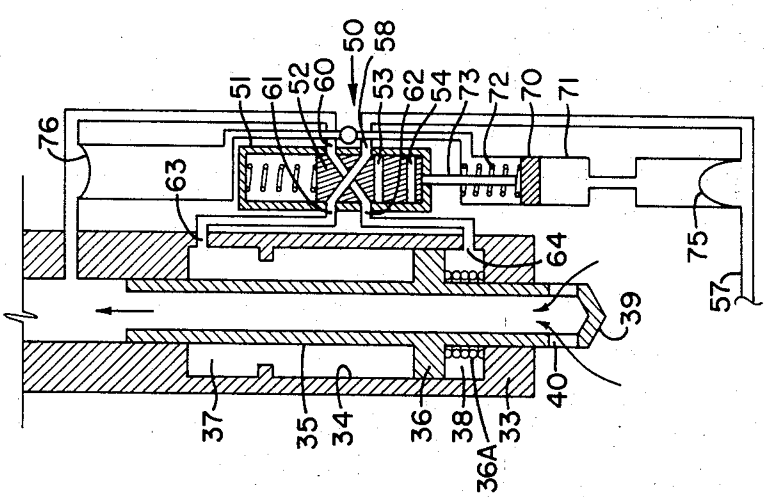

FIG. 5

METHOD AND APPARATUS FOR CONTROLLING WELLS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an improved downhole valve particularly useful as a safety valve in wells drilled for the production of crude oil and natural gas.

2. Description of the Prior Art

Wells drilled offshore for the production of crude oil and natural gas are subject to a number of hazards which may lead to their casings being accidentally ruptured. Among these are platform failures due to severe storms or collisions, equipment failures caused by erosive well fluids, and explosions or fires stemming from accidents during workovers or other surface operations. The provision of well safety equipment to close in the well in the event of an emergency is therefore an important aspect in designing such wells.

In the past, the primary approach to well protection has been the provision of a fluid-velocity actuated valve in the producing string. These safety valves have a number of inherent drawbacks. For instance, since they are actuated only by an abnormal flow velocity, it is necessary to produce the wells at reduced rates to maintain sufficient reserve producing capacity to assure emergency valve actuation. In addition, there is a lack of any positive means of controlling the valve from the surface. Finally, testing a velocity actuated valve requres a rapid change in producing rate to a level substantially abve normal, which may in turn damage the producing formation.

The problems with velocity-actuated safety valves can in many cases be mitigated by using surface-controlled, hydraulically actuated subsurface valves. In these installations a valve together with a hydraulic actuator is installed downhole in the well conduit. A hydraulic control conduit extends from the valve actuator to the surface along the exterior of the well conduit so that it will not impair movement of tools through the inner bore. These valves are generally maintained open hydraulically and close in response to a drop in hydraulic pressure in a control line or similar conduit. This type system has the advantage that the valve can be positively controlled from the surface, may be tested safely, and requires no reserve producing capacity. Because of the external hydraulic fluid line, however, it has the disadvantage of requiring more space than a velocity-actuated valve. By advance planning space can be provided for these systems in new wells, but in many existing wells there is insufficient room. In the latter situation the only way to install such a system is in an internal concentric string of pipe. This in turn reduces the diameter of the flow path and frequently creates an undesirably high flow restriction, rendering deployment of the system impractical.

There therefore exists a need for an improved subsurface safety valve which can be positively controlled from the surface, can safely be tested, requires no mechanical connection with the surface, and does not require reserve producing capability. Such an improved valve would not have the space limitations attendant with surface controlled, hydraulically actuated subsurface valves.

SUMMARY OF THE INVENTION

The present invention provides a subsurface safety valve which requires no mechanical connection to the surface and alleviates the problems outlined above. The improved subsurface safety valve of the invention is useful primarily in controlling the flow of fluid through a conduit within a well for the production of crude oil or natural gas. The improvement comprises a means for actuating the valve which maintains the valve open throughout the duration of a preset flow period and automatically closes the valve at the end thereof unless the actuating means is set by an intervening external signal to reinitiate the preset flow period prior to closure. The span of the predetermined flow period may, for example, be defined by a specific time interval or by a particular volume of fluid. The external signal used to reset the device is preferably a surface generated pressure pulse which is transmitted through a well fluid.

The present method involves producing a well through a conduit including a safety valve constructed in accordance with the invention and periodically generating a signal at the earth's surface which is detectable at the valve and serves to reinitiate the flow period of the valve acutator. The frequency of the pulses is adjusted as required to pulse the valve prior to termination of the flow interval, and thereby prevent the valve from closing. To test the valve or close it from the surface, the periodic signals are interrupted so that the valve closes at the end of the flow period. Preferably the valve is reopened by increasing the pressure within the conduit above the valve to a level in excess of that below it.

The method and apparatus of the invention require no mechanical linkage between the valve and the surface, can be run and removed with wireline tools, can be tested on a rountine basis, and can automatically shut in wells in the absence of intermittent signals from the surface. It will therefore be apparent that the present invention offers significant advantages over systems available heretofore.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of the subsurface safety valve system of the invention.

FIG. 2 is a cross-sectional elevation view of a valve assembly constructed in accordance with the present invention in its open position.

FIG. 3 shows the apparatus of FIG. 2 with the valve in its closed position.

FIG. 4 is a schematic of electric componentry which can be used with the valve assembly shown in FIGS. 2 and 3.

FIG. 5 is a schematic of another embodiment of a safety valve constructed in accordance with the present invention in its open position.

FIG. 6 is a schematic of the system of FIG. 5 showing the flow interval timer being reset to its initial position.

FIG. 7 schematically depicts the system of FIG. 5 with the valve in the closed position.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a schematic elevation of the subsurface safety valve system of the present invention. The system shown includes a well conduit **11** extending from the top of offshore platform **12** into a borehole in the floor **13** of the body of water **14**. Although not shown in the drawing, the lower end of the conduit is in communication with a producing formation. Surface equipment for controlling flow of produced fluid includes a manually controlled master valve **15** and a flow control device **16,** as for example a pressure actuated motor valve, situated on the well conduit. A controller **17** for regulating the position of the flow control device is also shown. This may comprise a source of high pressure gas together with a timing device. Downhole equipment includes safety valve **18** coupled with an actuator **19.** The actuator and valve are normally enclosed within an outer housing provided with external seals and adapted for installation and removal with wireline operated tools.

The actuator maintains the downhole valve in the open position throughout the span of a flow period having a preset duration and closes the valve without intervention from the surface at the termination of the flow period. The actuator is resettable in response to an external signal to reinitiate the preset flow period prior to valve closure. In the system shown in FIG. **1,** controller **17** can be set to periodically actuate a valve or other flow control device to restrict flow and thus create a pressure pulse in the well conduit. A pressure responsive means situated downhole on the valve actuator will respond to this pulse by resetting the flow interval to zero and restarting the flow period to closure so that flow continues uninterrupted.

If positive downhole closure is required, or if it is desired to test the downhole valve, the controller at the surface is adjusted to omit the periodic pressure pulse. This results in the downhole actuator receiving no signal and closing the valve after the duration of the predetermined flow interval. Similarly, in the event the well casing is severed or severely damaged, the actuator will receive no reset signal and the valve will automatically close, shutting in the well.

The safety valve is preferably a normally closed device. A full opening ball valve is preferred, but numerous other closure devices would be satisfactory for use with the system. It will generally be most convenient to employ surface generated pressure fluctuations in the flow stream to signal the downhole actuator; however, other systems, as for example, acousitc, electrical or radio signal could be used.

The longevity of the flow period prior to closure is variable within wide limits consistent with the present invention. It is preferred, however, that a relatively short flow interval be employed. When the flow period is defined in terms of time or fluid volume, this has the advantage of reducing substantially the volume of flow through the conduit between loss of well control due to damage and subsequent closure of the valve. A number of devices for controlling the duration of the flow interval will be readily apparent. The preferred systems are, however, responsive to either elapsed time or to the cumulative volume of fluid flowing through the safety valve.

FIG. **2** and **3** are cross-sectional elevation views of one configuration of safety valve exemplary of the apparatus of the present invention. The apparatus shown includes an outer housing **21** having seals **10** and expansible dogs **20** situated on the upper exterior to permit it to be anchored within the well conduit against vertical movement and sealed against circumferential flow. A slidable cylindrical mandrel **22** is disposed within the outer housing. A ball **23** having an aperture **23A** therethrough is rotatably mounted within the lower interior of the mandrel. The ball engages the outer housing by means not shown so that as the mandrel slides from the lower position, FIG. **2,** to the upper, FIG. **3,** the ball rotates from the open to the closed position. The mandrel is biased toward the upper position by compressed spring **24** situated between the outer flange **25** of the mandrel and the inner shoulder **26** of the outer housing. Spring-biased latch **27** extends inwardly whenever its compressed spring is permitted to expand, FIG. **2,** and is locked in place above the mandrel by solenoid actuated locking member **29** to block it against movement so that the valve remains open. When the locking member is withdrawn to free the latch, the spring-loaded mandrel slides upwardly forcing the latch into its receptacle within the outer housing and closing the valve, as shown in FIG. **3.** Valve closure is assisted by differential pressure exerted by the flowing well stream. Spring-biased ball detent **28** engages a recess **28A** in the outer housing when the mandrel is fully extended. To reopen the valve, pressure within the well conduit above the closed valve is increased to a level in excess of pressure below it. The differential pressure required to generate a force sufficient to overcome the ball detent should also be sufficient to overcome the force of the spring **24** so that the mandrel will snap back to its original position, opening the ball valve.

The actuator is adpated to close the valve at the end of a preset flow period unless an intervening external signal is received which resets the actuator and causes it to reinitiate the flow period, thereby deferring closure for the span of an additional flow interval. In the embodiment shown in FIGS. **2** and **3,** the actuator closes the subsurface valve by unlocking latch **27** which when extended and locked into place restrains spring-biased mandrel **22** in its lower position to keep the valve open. Position of the lock on latch **27** may for example be controlled by a solenoid designed to fail safe. Solenoid **20** when energized, forces locking member **29** downward, overcoming spring **29B** to hold latch **27** in place. Whenever the solenoid is deenergized, spring **29B** forces the locking member upward, causing the valve to close.

Electrical or electronic componentry associated with the valve may be mounted within the wall of outer housing **21,** as for example within the circumferential housing designated by numeral **30** in the drawings. This will normally include a source of electric power, as for example, a battery or turbine generator, to provide energy for the solenoid and associated control circuitry. The latter includes a pressure sensitive device in communication with the inner bore of the valve housing. This device, which may for example be a pressure transducer or pressure switch, is actuated in response to a pressure condition within the section of the well conduit above the valve, as might be created by restricting flow or by shutting the well in at the surface for a brief interval. The pressure-sensitive device acts in combination with a timer or similar device for indicating the termination of the predetermined flow period. The signal from the pressure sensitive device serves to reset the timer and reinitiate the timed interval, permitting deferral of termination of the flow period and thereby maintaining the valve open for an additional flow period.

FIG. **4** is a schematic diagram of componentry which can be used for this purpose. Shown is a battery **31** which provides a source of power for a circuit including resistor **32**, solenoid **29A**, and capacitor **42**. As capacitor **42** charges, the voltage across resistor **32** and solenoid **29A** decreases until a point is eventually reached at which the voltage drop across the solenoid is insufficient to hold locking pin **29** against spring **29B**. This permits the spring to lift the locking pin which in turn results in closure of the valve. The flow period to closure is governed by the time period required to charge the capacitor to the critical level and can be varied by changing the resistance of resistor **32**. A normally open pressure switch **43**, which closes in response to a pressure increase, is situated in a second circuit which also includes capacitor **42**. In response to a pressure signal the switch closes, discharging the capacitor through the pressure switch circuit. When the pressure switch reopens, its circuit is again broken, permitting the capacitor to begin charging. The flow period is thus reinitiated, deferring closure of the valve for the duration of another flow period.

As pointed out above, after closure, the valve is normally reopened by increasing pressure within the well conduit to a level above that which exists within the portion of the conduit situated beneath the valve. This increase actuates the pressure sensor which closes the pressure switch discharging the capacitor and reinitiating the timed flow cycle. Discharging the capacitor permits sufficient current to again flow through the solenoid to cause it to force locking pin **29** downward. The locking member will, however, be temporarily restrained from movement by spring-biased latch **27**, which is temporarily blocked against movement by the exterior of the mandrel until such time as the differential pressure across the valve depresses the mandrel to its open position. With the mandrel depressed the latch extends inwardly and is locked in place to hold the valve open.

FIGS. **5**, **6** and **7** depict schematically another embodiment of the apparatus of the present invention. It will be understood that the arrangement of the structural elements shown in the drawing is for convenience of illustration only and that the entire system shown would normally be arranged such that it could be conveniently enclosed within a wireline retrievable outer housing. The apparatus includes a valve body **33** having an inner extending cylindrical bore **34**. A conduit **35** with an external circumferential shoulder **36** is slidably disposed within the bore of the valve body, dividing it into an upper chamber **37** and lower chamber **38** separated by the slidable piston formed by shoulder **36**. The lower end of the conduit is closed, as by means of a cap **39**, but the conduit has two lateral ports designated by numeral **40** for admitting fluid. The upper end of the conduit is open, completing the flow path through the valve body. When the piston is in its uppermost position within the valve body, as shown in FIG. **7**, the two lateral ports in the lower end of the conduit are flush with inner shoulder **41** at the lower end of the bore through the valve body and thereby seal the conduit against flow. Thus, with the piston in its upper position the valve is closed, whereas in the lower position the valve is open to flow.

The position occupied by the piston, and thus the operating position of the valve, is controlled by the pressure differential between the upper and lower chambers positioned above and below the piston, respectively. It will normally be desired to include a biasing

means, for example compressed spring **36A** on the underside of the piston, to assure that the valve will close in the event of failure of hydraulic circuitry. Well pressures routed by a pilot valve designated generally by numeral **50** provide the pressure differentials required to operate the valve. In this connection it will be noted that during normal producing operations, fluid flows upwardly through the valve creating a pressure differential across the valve, the pressure below being higher than that above.

The pilot valve typically includes a cylindrical housing **51** within which a pilot piston **52** is slidably disposed. The pilot piston has two pairs of unconnected flow paths extending therethrough. The lower pair, numbered **53** and **54**, are arranged horizontally for straight-through flow. The upper pair, numbered **55** and **56**, have crossed paths of flow which are independent of one another. The cylindrical housing enclosing the pilot valve includes two corresponding pairs of ports extending therethrough. One pair is situated on each side and they are arranged for alignment with the ends of either the crossed or the horizontal pair of flow paths, depending on the position of the pilot piston within the cylinder. A high pressure fluid conduit, designated by numeral **57**, leads form a well conduit port situated below the valve to high pressure source port **58** of the pilot valve cylinder. Low pressure conduit **59** extends from a well conduit port positioned above the valve to low pressure source port **60** on the pilot cylinder. Upper chamber conduit **61** and lower chamber conduit **62** connect the chambers above and below the valve piston to upper and lower chamber ports on the pilot cylinder designated by numerals **63** and **64** respectively.

With the upper end of the pilot piston containing the crossed flow paths aligned with the ports through the pilot valve cylinder, FIGS. **4** and **5**, the low pressure conduit is in communication with the lower chamber and the high pressure conduit with the upper chamber. In this pilot position the differential pressure across the valve piston forces it downward, maintaining the valve in the open position. When the pilot piston is in its upper position, FIG. **6**, the horizontal, straight-through flow paths are aligned with the ports through the pilot cylinder housing. Thus, in this pilot position the low pressure conduit is in communication with the upper chamber whereas the high pressure conduit is in communication with the lower chamber. The resultant differential pressure in combination with spring **36A** forces the valve piston upwardly, closing the valve to flow.

A spring **65** or other biasing means acts to bias the pilot piston downwardly so that it tends to stay in the crossed configuration. The position of the pilot piston (and the valve) is governed by displacement of a spring-biased actuator piston. This pilot actuating piston is designated by numeral **70** in the drawing and is shown slidably disposed within a cylinder **71**. A spring **72** is disposed within the actuator cylinder above the piston and compresses to bias it against upward movement. The actuator piston is otherwise free to travel up or down within its cylinder, depending on the differential pressure acting across it. A rod **73** attached to the lower end of pilot piston **52** extends from thee pilot cylinder through openings provided with suitable seals into the upper end of the actuator cylinder. As the spring-biased actuator piston approaches the upper extremity of its cylinder, it drives the piston rod upwardly, shifting the pilot piston into the horizontal straight-through flow configuration and causing the valve to close.

As pointed out above, the position occupied by the actuator piston is governed by the disposition of a control fluid. This control fluid, which may for example, be a hydraulic fluid, is disposed within the chamber situated above and below the actuator piston. The chamber beneath the piston is in communication with a lower chamber having a distensible member **75** therein, separating the control fluid from the fluid contained within high pressure fluid conduit **61**. The chamber above the actuator piston is in communication with a similar upper chamber also having a distensible member therein, designated by numeral **76**, but separating the control fluid therein from the fluid within the low pressure fluid conduit **62**. Thus the differential pressure between the high pressure fluid conduit and the low pressure fluid conduit is exerted through the control fluid. A directional flow restriction **77** is included in the flow path between the two distensible members and is arranged to severely restrict flow from the chamber in pressure communication with the high pressure conduit to the chamber in pressure communication with the low pressure conduit. Thus, in the normal flow situation in which the valve is open (FIGS. **5** and **5**) and pressure below it exceeds that above it, the flow of control fluid is impeded, retarding substantially the rate of ascent of the actuator piston. The directional flow restriction permits unimpeded flow in the opposite direction. As a result, when the flow of the well is restricted at the earth's surface and the differential pressure across the valve is reduced to the point that the force generated by the spring biasing the actuator piston is greater than the force on the piston resulting from differential pressure, the control fluid flows freely, permitting rapid return of the actuator piston to its initial position. This directional flow restriction acts as a dash pot type timer, permitting the actuator piston to be displaced upwardly through a preset flow interval, which can be varied by adjusting the resistance to flow and yet be rapidly returned by means of a surface generated pressure signal to reinitiate the cycle. If the pressure transient reducing the differential pressure across the valve is not received prior to termination of the preset flow interval, the actuator piston will reach the upper end of its cylinder and drive the pilot piston upwardly resulting in closure of the valve. It will be noted that this flow interval timer is responsive to the product of pressure differential and elapsed time which is in turn proportional to cumulative fluid flow through the valve. The closed valve may subsequently be reopened by increasing the pressure within the well conduit above the valve. Once the pressure above approaches that below the valve, the springs biasing the actuator piston and the pilot piston will force them downward, depressing the pilot piston to the crossed flow path configuration. Thereafter, reduction of the pressure above the valve to a level below that existing under the valve will then cause the differential pressure across the valve piston to open the valve.

What is claimed is:

1. In a subsurface valve for controlling the flow of fluid through a well conduit, the improvement comprising means for actuating the valve between open and closed positions at the end of a preset flow period and means responsive to an external signal received prior to the end of said flow period for resetting said actuating means to reinitiate said preset flow period prior to actuation.

2. The apparatus of claim **1** wherein said actuating means includes a timer for determining the span of said flow period.

3. The apparatus of claim **1** wherein said actuating means includes a differential pressure actuated means for determining the span of said flow period prior to actuation.

4. The apparatus of claim **1** wherein the span of said flow period is determined from the cumulative volume of fluid flowing through said conduit.

5. The apparatus of claim **1** wherein said actuating means includes a means responsive to pressure within said well conduit for resetting same.

6. A safety device for controlling flow of a well fluid through a vertical conduit within a well extending beneath the surface of the earth which comprises a subsurface valve adapted to be disposed within said conduit and provided with means for urging the valve towards a closed position, means for holding said valve open until the end of a preselected flow period, and means responsive to an external signal received prior to the end of said flow period for reinitiating said preset flow period prior to valve closure.

7. The apparatus of claim **6** wherein said means urging said valve towards said closed position includes a spring.

8. The apparatus of claim **6** including a timer for determining the span of said flow period.

9. The apparatus of claim **6** including a differential pressure-actuated means for determining the span of said flow period.

10. The apparatus of claim **6** wherein said means is responsive to pressure within said well conduit.

11. A safety device for controlling flow of a well fluid being produced through a conduit within a well extending beneath the surface of the earth which comprises:

a. a subsurface valve configured to be disposed within said conduit and adapted in a closed position to stop said flow of well fluid;
b. means for urging said valve towards the closed position; and
c. means for holding said valve in the open position against the urging of said means throughout the duration of a preselected flow period, said means permitting said valve to close at the end of said flow period; and
d. means responsive to an external signal received prior to the end of said flow period for reinitiating said preset flow period prior to valve closure.

12. The apparatus of claim **11** wherein said actuator means includes a timer for determining the span of said flow period prior to actuation.

13. The apparatus of claim **11** wherein said actuator means includes a differential pressure actuated means for determining the span of said flow period prior to actuation.

14. The apparatus of claim **11** wherein said actuator means inlcudes a means responsive to pressure within said well conduit for resetting same.

15. A safety device for controlling flow of a well fluid being produced through a conduit within a well extending beneath the surface of the earth which comprises:

a. a subsurface valve adapted to be disposed within said conduit and provided with biasing means for urging said valve towards the closed position;
b. means for holding said valve in the open position against said biasing means;
c. means associated with said valve for indicating the termination of a predetermined flow period;
d. means associated with said holding means and responsive to said indicating means for releasing said holding means to close said valve upon termination of said flow period; and
e. means associated with said indicating means and responsive to a signal generated at the earth's surface for resetting said indicating means and reinitiating said flow period to permit deferral of termination of said flow period.

16. A method for regulating the flow of fluid within a well conduit extending beneath the earth's surface comprising:

a. controlling the flow of fluid within said conduit at a subsurface control point so as to terminate flow of fluid thereby at the end of a predetermined flow period in the absence of a control signal during said flow period, and
b. transmitting a signal from the earth's surface at a frequency such that said signal arrives at said control point prior to the end of each said flow period whereby flow continues uninterrupted.

17. The method of claim **16** wherein said signal is a pressure pulse and is transmitted through fluid in said conduit.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,780,809 Dated December 25, 1973

Inventor(s) R. C. Ayers, Jr., J. F. Bayless, J. W. Graham, J. R. Lloyd, W. D. Loth, and R. E. Williams

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 10, delete "set" and insert --reset--.
Column 4, line 28, delete "adpated" and insert --adapted--.

Signed and sealed this 23rd day of April 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

)RM PO-1050 (10-69)

USCOMM-DC 60376-P69
★ U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334