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Mott

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[54] **AUTOMATIC SUBSURFACE BLOWOUT PREVENTION**

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[21] Appl. No.: **352,808**

Related U.S. Application Data

[63] Continuation of Ser. No. 12,823, Feb. 19, 1970, abandoned.

[52] **U.S. Cl.** **166/244,** 166/184, 166/187, 175/243, 175/317

[51] **Int. Cl.** **E21b 23/06,** E21b 33/127

[58] **Field of Search** 166/121, 184, 187, 244; 175/315, 243, 317

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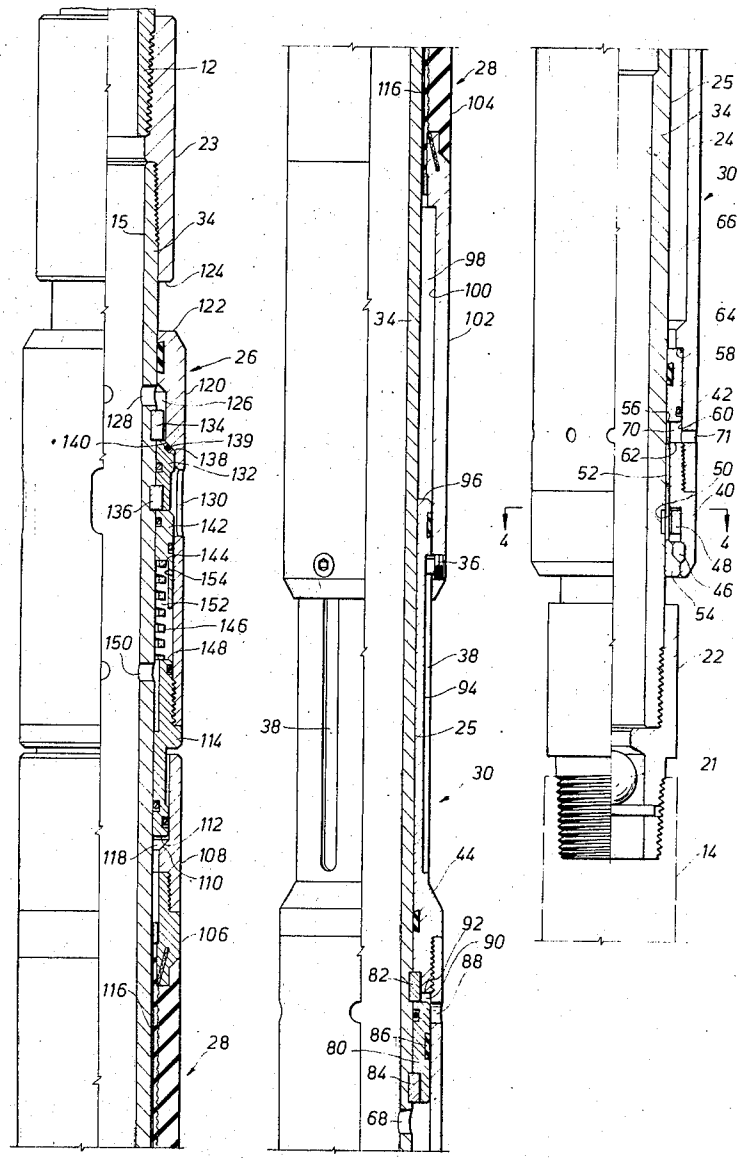
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[57] **ABSTRACT**

A tool and method for automatic subsurface closure of a well to prevent the uncontrolled flow of high-pressure formation fluids upward to the atmosphere while a well is being drilled or completed. The tool includes at least two main parts: A movable sealing means and a fluid flow control means positioned above the sealing means. The movable sealing means is used to shut in the well in response to a subsurface pressure condition. The fluid flow control means automatically provides an opening between the interior and exterior walls of the tool, when the pressure below the sealed off area is greater than the pressure above the sealed off area. The tool's functions are automatic, reversible and repetitive.

21 Claims, 8 Drawing Figures



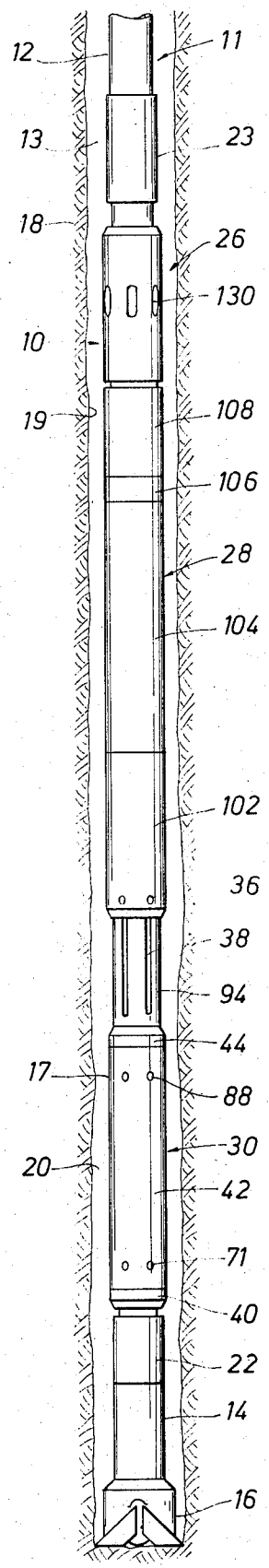


FIG. 1

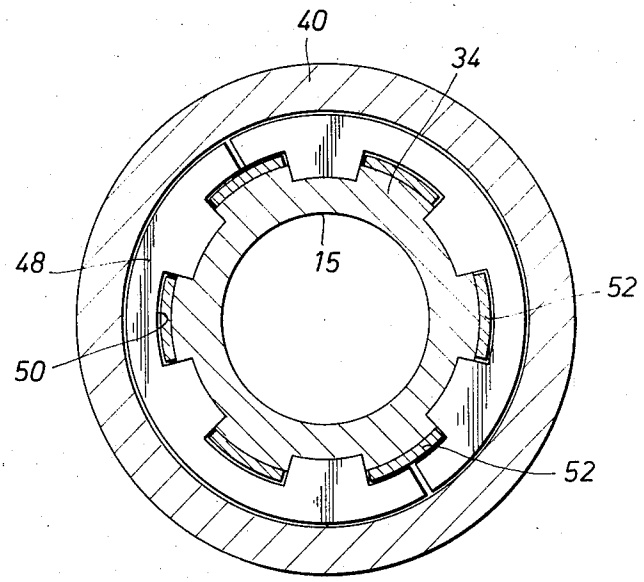


FIG. 4

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FIG. 2A

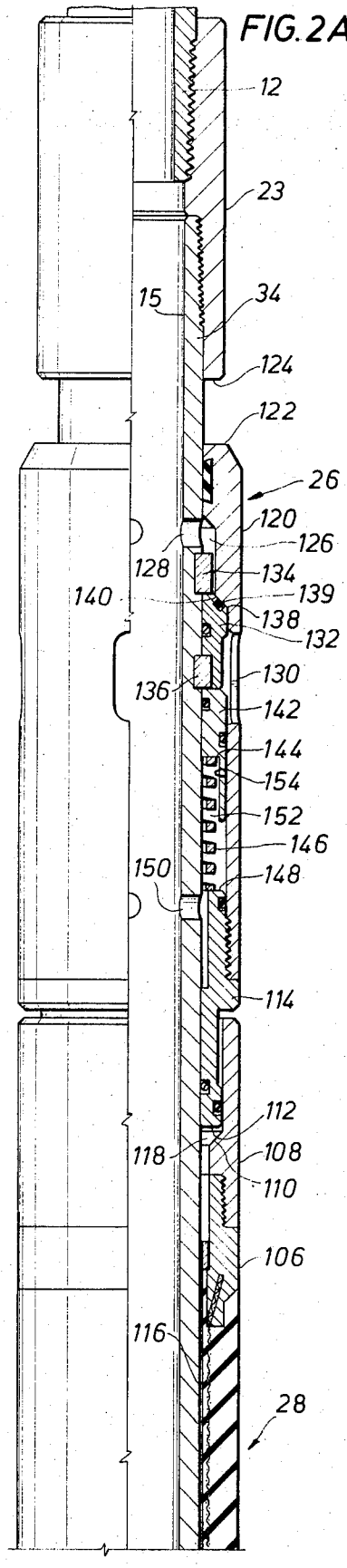


FIG. 2B

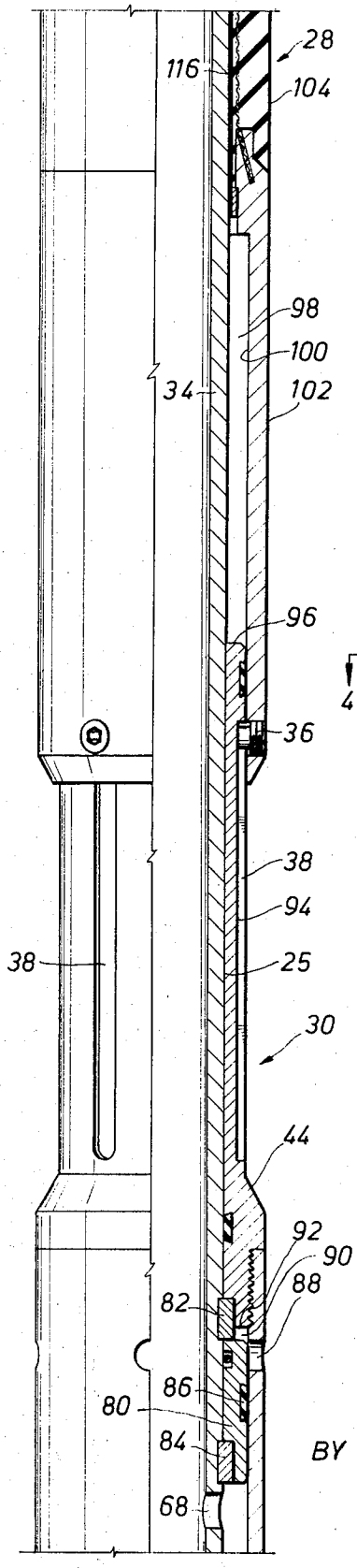
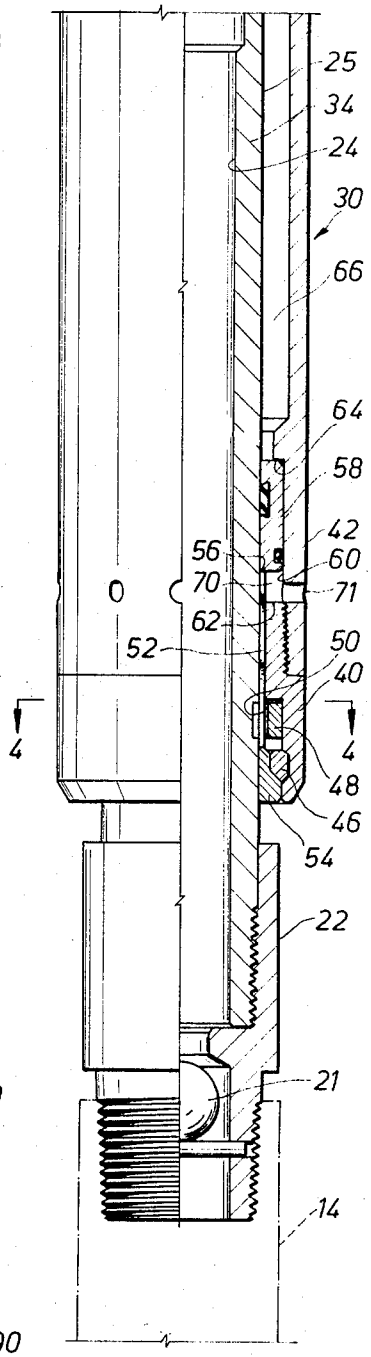


FIG. 2C



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FIG. 3A

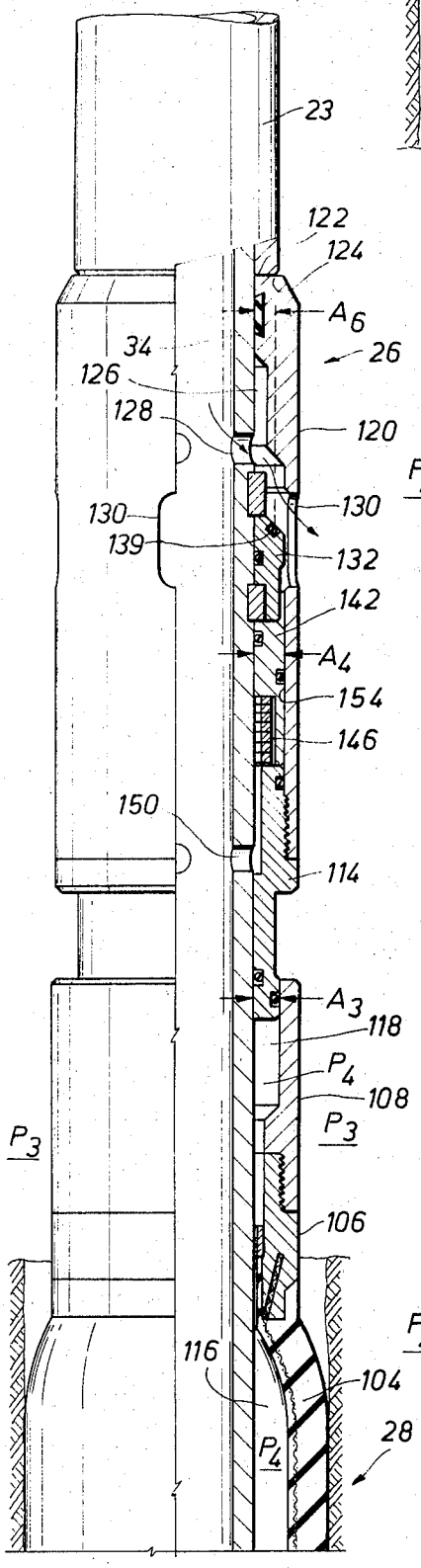


FIG. 3B

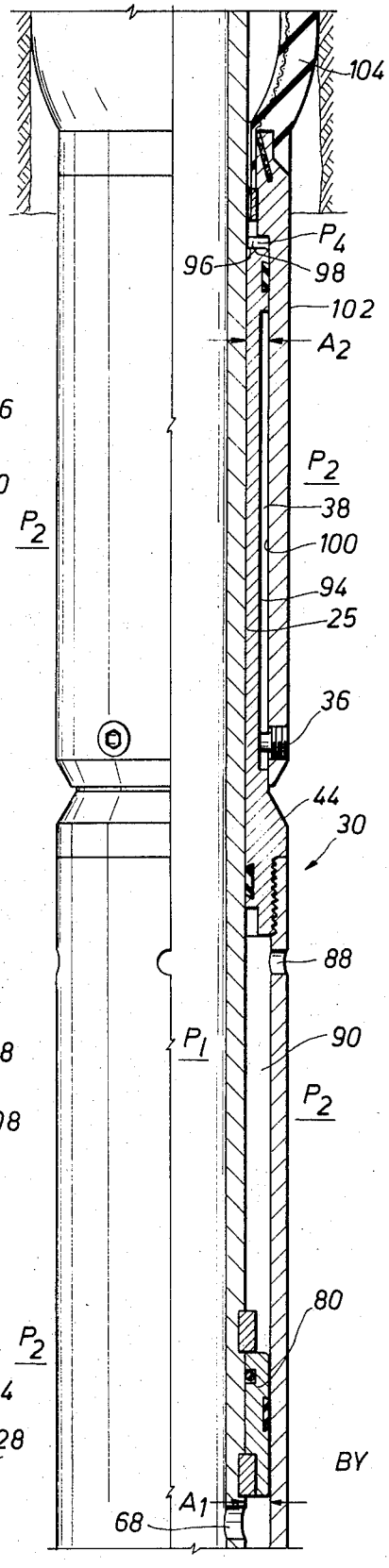
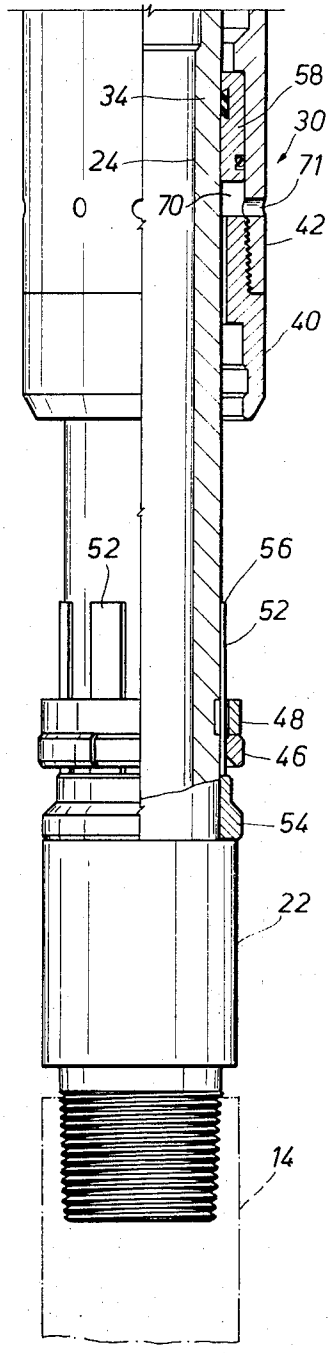


FIG. 3C



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AUTOMATIC SUBSURFACE BLOWOUT PREVENTION

REFERENCE TO PRIOR APPLICATION

This application is a continuation of application Ser. No. 12,823 filed Feb. 19, 1970, and now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention generally relates to the field of pressure control in the drilling of oil and gas wells or other type wells. More particularly it relates to the automatic subsurface closure of a drilled hole to prevent the upward flow of high-pressure formation fluids when the pressure of the formation's fluid exceeds the hydrostatic pressure of the drilling fluid adjacent to the formation. It also provides an automatic fluid flow control means to allow for the circulation of higher weight drilling fluid, thereby containing the formation's pressure.

2. Description of the Prior Art

A well blowout condition refers to the uncontrolled flow of fluids from a well to the atmosphere. The outward manifestations of a blowout condition can be very damaging both to property and life. Great efforts have been made to solve the blowout problem.

One common method involves the use of a surface blowout preventer around the drill string. Such a surface preventer can cause a subsurface blowout condition. More recently, a subsurface blowout preventer was proposed which consists of a fluid-operated packer to shut in the well, and a valve means to allow for the circulation of drilling fluid above the sealed off area. Such an apparatus is described in U.S. Pat. No. 3,427,651. In the patented apparatus, (using the reference characters of the patent) when a high-pressure formation **12** is penetrated by a drill bit **11** and it is desired to inflate the packer **16,** drilling is halted and the hydraulic pressure of the drilling fluid is increased to a predetermined pressure above the normal circulation pressure. Then the hydraulic pressure is further increased to shear pin **33** and to move plug **30.** Fluid pressure then expands packer **16** and seals the annulus **45** between tubular member **15** and the wall of borehole **10.** Hydraulic pressure within the drill string is then decreased to prevent fluid pressure from escaping from packer **16.** A circulation port **17** is opened by means of a wire line. The weight of the drilling fluid is increased to compensate for the high-pressure formation fluid. To deflate packer **16,** circulation port **17** is closed by means of a wire line and the hydraulic pressure in the drill string is increased to a predetermined pressure level above the pressure required to inflate packer **16.** This increased hydraulic pressure causes shear pin **39** to shear and the packer to deflate.

Among the main shortcomings encountered with known devices are: the parts forming the subsurface blowout preventer require human effort to become operative; precious time is wasted in manually carrying out the required manipulations; educated guesses must be made concerning the relation between the subsurface pressure conditions existing inside and outside the portion of the drill string adjacent the high-pressure formation; the fluid-inflatable packer can carry out only one cycle of operation; and after one cycle of operation the apparatus must be reconditioned and at least the shear pins restored.

Accordingly, it is a main object of this invention to overcome the above and other shortcomings of known devices. In accordance with this invention, a well can be controlled automatically in response to the occurrence of a sudden change in the pressure of a subsurface formation. A sealing wall will automatically expand in response to such changed pressure condition, and automatically contract after the pressure of the drilling fluid is properly compensated. The operation is therefore automatic, reversible, and repetitive.

SUMMARY OF THE INVENTION

An automatic tool and method for shutting in a well when a subsurface formation pressure becomes excessive, thereby preventing the lifting of the drilling fluid in the portion of the borehole above the tool. The tool includes at least two distinct and cooperating parts. The first is a fluid-inflatable packer and the second a fluid flow control valve positioned above the packer. After the packer provides a seal and effectively shuts in the well, the valve automatically opens to provide a flow channel for the circulation of drilling fluid. When the pressure of the drilling fluid above the sealed off area exceeds the pressure below the sealed off area, the packer will automatically deflate and return to its deactivated condition. Thereafter, normal drilling operations can be resumed. When another high-pressure formation is encountered, the packer will again inflate to shut in the well.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a view in perspective of a preferred embodiment of the present invention;

FIGS. **2A, 2B,** and **2C** are more detailed views partly in section of the embodiment shown in FIG. **1;**

FIGS. **3A, 3B,** and **3C** are similar to FIGS. **2A, 2B,** and **2C** but with the movable parts arranged in activated positions, and

FIG. **4** is a cross-section on line **4—4** in FIG. **2C.**

Referring to the drawings there is shown a subsurface apparatus **10** for controlling wells during drilling operations. Apparatus **10** is herein, generally, called a tool and, particularly, a subsurface blowout preventer. Normally, tool **10** forms part of and is positioned at a selected, desired elevation along a drill string assembly, generally designated as **11.** String **11** includes drill pipes **12,** collars **14,** and a bit **16.**

Experience indicates that if one tool is used, the preferred location is near the top drill collar **14.** Several vertically-spaced tools **10** can be inserted within string **11** for greater protection. Drill string **11** has an inner wall **15** and an outer wall **17** and extends into a borehole **13** which may or may not have a casing. Borehole **13** traverses a formation **18** whose wall **19** is typically made up of distinct, vertically-spaced zones, each zone being characterized by an internal fluid (water, oil, or gas) pressure P_f.

Under normal drilling operations, a drilling fluid (liquid or gas) is pumped from the surface down string **11,** through restricted orifices (not shown) in bit **16,** and up through an annular area or annulus **20** between walls **17** and **19.** After circulation of the drilling fluid is established, for the same elevation, the hydraulic pressure inside string **11** on the inner wall **15** is greater than the pressure on the outer wall **17.** Conversely,

with no fluid circulation, the interior and exterior hydrostatic fluid pressure, at any level, is substantially the same.

As bit **16** continues to drill, a formation may be encountered whose pressure P_f is greater than the pressure of the circulating fluid in the adjacent annulus **20.** This condition may cause the well to "blow out" unless preventive measures are immediately taken, preferably automatically. The outward manifestations of a blow-out condition are well-known and need not be described. A check valve **21** positioned at the lowermost end of tool **10** will prevent the formation's pressure P_f from fluidly communicating with the interior of drill string **11.**

Referring more specifically to the construction of tool **10,** it includes a preferably tubular member or mandrel **34** which extends throughout the entire length of tool **10.** The mandrel's lower end is threadedly connected to a bottom connector **22,** and its upper end is threadedly connected to a top connector **23.** Mandrel **34** has an inner wall **24** and an outer wall **25.** Mounted on wall **25** are fixed and movable members which can be grouped into two main parts: a valve **26,** and a fluid-inflatable sealing means or packer **28** which includes a packer setting mechanism **30.**

THE PACKER SETTING MECHANISM 30

Guide pins **36** of mechanism **30** extend into spaced, longitudinal slots **38** to allow for the up-and down movement of mechanism **30.** A locking sleeve **40** is threadedly connected to a cylinder **42,** which in turn is threadedly connected to a packer piston **44.** Sleeve **40** is releasably secured by a snap ring **46** and a fixed, splined, retainer ring **48.** Ring **48** defines several (six) openings **50.** Through each opening **50** vertically extends a finger **52** of a movable expander ring **54.** The tip **56** of each finger **52** is in contact with a power piston **58.** Piston **58** is slidably mounted between wall **25** and the cylindrical inner wall **60** of cylinder **42.** Piston **58** can move between a shoulder **62** of sleeve **40** and a shoulder **64** of cylinder **42.** Between the internal wall **60** of cylinder **42** and the external wall **25** of mandrel **34** is formed a long chamber **66** which communicates with the internal pressure in mandrel **34,** through a port **68.** Below piston **58** is a chamber **70** which fluidly communicates with the pressure in the annular area **20,** through ports **71.** Above piston **58** is the chamber **66.**

A sleeve **80** is fixedly secured on wall **25** by rings **82** and **84.** Wall **60** of cylinder **42** slides on a seal **86** in the outer wall of sleeve **80.** A port **88** communicates the annulus pressure to a chamber **90.** This pressure is exerted on the lower surface **92** of the packer piston **44.** The outer cylindrical wall portion **94** of cylinder **44** defines the previously-mentioned, vertically-extending, spaced slots **38.** The top surface **96** of packer piston **44** is exposed to the pressure of an enclosed fluid within packer chamber **98.** The packer fluid is typically a heavy oil having a low vapor pressure.

THE PACKER 28

Chamber **98** is formed between the outer wall **25** of mandrel **34** and the inner wall **100** of a cylinder **102.** Pins **36** of cylinder **102** extend into slots **38.** Cylinder **102** forms integral part with a movable flexible member, or fluid-expandable packer wall **104.** Wall **104,** in turn, forms integral part with a sleeve **106** which is threadedly connected to a sleeve **108.** Sleeve **108** defines a stop shoulder **110** for arresting the further movement of the bottom surface **112** of a piston **114.** A fluid passageway **116** establishes fluid communication between chambers **98** and **118.**

THE VALVE 26

A valve cylinder **120** is threadedly connected to piston **114.** The top surface **122** of cylinder **120,** when in its raised position, will abuttingly engage the bottom surface **124** of top connector **23.** When valve **26** is open, a chamber **126** is in fluid communication with the mandrel's interior pressure through openings **128** and with the annulus pressure through ports **130.** A cylinder **132** is fixedly mounted on the outer wall **25** by two retaining rings **134** and **136.** Cylinder **132** defines an inclined valve surface **138** which snugly engages surface **140** of cylinder **120.** A seal **139** is provided on surface **138.** A floating piston **142** provides a shoulder **144** for engaging a coiled spring **146** which also rests on the top surface **148** of piston **114.** Ports **150** fluidly communicate with a chamber **152** formed between wall **25** and the inner wall **154** of cylinder **120.**

GENERAL DESCRIPTION OF OPERATION

To facilitate the understanding of the operation of tool **10,** and with particular reference to FIGS. 3A, 3B and 3C, let

P_1 = pressure inside mandrel **34,**
P_2 = pressure outside tool **10** and below packer seal **104,**
P_3 = pressure outside tool **10** and above packer seal **104,**
P_4 = pressure inside packer seal and in chamber **98,**

A_1 = cross-sectional area of chamber **66,**
A_2 = cross-sectional area of piston surface **96** = A_1
A_3 = cross-sectional area of piston surface **112** = $0.5A_1$
A_4 = cross-sectional area of sliding piston **142** = A_1
$A_5 = A_4 - A_3$
A_6 = cross-sectional area from seal **139** to wall **25** = $0.7A_1$

For simplicity assume that,

$A_1 = A_2 = A_4 = 1$ (unit area), and
$A_3 = A_5 = 0.5$

In operation, tool **10** is connected to a drill collar **14** and to a drill pipe **12** by connectors **22** and **23,** respectively. As the drill string **11** is being lowered into the annular area **20,** tool **10** is in its deactivated and locked condition. Check valve **21** prevents the drilling fluid which is in borehole **13** from entering into mandrel **34.** Accordingly, before fluid circulation begins, the exterior hydrostatic pressure is greater than the interior pressure and an upward force becomes exerted on the power piston **58.** The movement of piston **58** is arrested by shoulder **64** of cylinder **42.** Snap ring **46** locks sleeve **40** and hence cylinder **42.**

Thereafter, in conventional manner, the drill pipe **12** is filled with a drilling fluid and circulation is established through the drill string **11,** bit **16,** and up the annular area **20.** The interior pressure then becomes greater than the exterior pressure. A downwardly directed force now becomes exerted on power piston **58.** Piston **58** pushes against the tips **56** of fingers **52,** causing ring **54** to move downwardly against connector **22.** Snap ring **46** reduces its diameter and frees sleeve **40,**

and hence cylinder **42**, for upward movement. The packer setting mechanism **30** is now in its deactivated and unlocked condition, and cylinder **42** does not move upward, since piston **58** now exerts a downward force against shoulder **62** of sleeve **40**.

OPERATION OF PACKER SETTING MECHANISM 30

When the drill bit **16** encounters a high-pressure formation sufficient to cause a blowout condition, the formation's fluid pressure P_f will communicate through ports **71** with chamber **70**. The check valve **21** will prevent the formation's pressure from lifting the drilling fluid inside mandrel **34**. P_2 is then greater than F_1, P_1 is applied against the top surface and P_2 against the bottom surface of power piston **58**, and power piston **58** will move upwardly. An upward force also becomes exerted by P_2 on the lower surface **92** of packer piston **44**. Since piston **58** pushes cylinder **42** upwardly and an upward force is also exerted on the packer piston **44**, the packer **28** will now become inflated.

OPERATION OF PACKER 28

As the packer piston **44** moves up into chamber **98**, the constant volume fluid in chamber **98** moves up through passageway **116** and causes the flexible wall **104** to move radially outwardly. If possible, a seal will be established between packer wall **104** and wall **19** of borehole **13**. If packer wall **104** does not effectuate a seal, cylinder **120** will not move up and valve **26** will remain closed. Conversely, if a wall is encountered and a seal established, valve **26** can open.

OPERATION OF THE CIRCULATING VALVE 26

Surface **112** of piston **114** is exposed to the pressure P_4. Therefore, when P_2 is greater than P_1, the upward force F_u on threadedly connected members **114** and **120** is,

$$F_u = P_4A_3 + P_1A_6 + P_3A_5, \text{ and}$$

the downward force F_d on members **114** and **120** is,

$$F_d = P_3\ A_4 + P_3A_6$$

A balanced condition of the valve **26** exists, and valve **26** is closed, when the upward forces equal the downward forces, i.e., $F_u = F_d$.

By substituting the above numbers for A_3, A_4, A_5, and A_6, and since,

$$P_4 = 2P_2 - P_1$$

then one obtains

$$P_3 = 5P_2 + P_1/6 = Q_1$$

Thus for all conditions when P_3 is greater than Q_1, valve **26** will be closed, and for all conditions where P_3 is less than Q_1, valve **26** will be open.

It follows then that for valve **26** to open P_3 must be less than P_2. This condition is met only when packer **28** has sealingly engaged wall **19** of borehole **13**, and a differential pressure is established across the packer **28**.

Under normal drilling operations when the interior pressure P_1 is greater than the exterior pressure P_2, the floating piston **142** is at its upper position and engages stop ring **136**. The forces involved are P_1A_4 acting downwardly through port **150** against piston **114** and P_1A_6 acting upwardly through port **128** on cylinder **120**. Since P_1A_4 is greater than P_1A_6, cylinder **120** is forced downwardly and its shoulder **140** tightly engages seal **139** to prevent fluid from communicating between the valve's internal port **128** and its external port **130**.

Upon the occurrence of a blowout condition, P_2 becomes greater than P_1, and an upward force is exerted on cylinder **42** and hence on packer piston **44**, as previously described. The packer's fluid in chamber **98** becomes compressed and its wall **104** inflated. For valve **26** to open, P_3 must be less than P_2, hence either P_2 must increase or P_3 must decrease. P_2 may become greater than P_3 when an effective seal is established between wall **104** and wall **19** of borehole **13**. It may be possible from the surface to decrease P_3.

In any event, when P_2 is greater than P_1, P_2 exerts a downward force P_2A_4 through port **130** on the top surface of floating piston **142** moving it downwardly, compressing spring **146**, and pushing against surface **148** of piston **114**. A downward force is thus exerted on cylinder **120**. On cylinder **120** are also exerted a downward force P_2A_6, and an upward force P_2A_5. The net force is however a downward force. Valve **26** will remain effectively closed and will not accidentally open.

Now, under all conditions the packer fluid in chamber **98** fluidly communicates with chamber **118** through passageway **116**. Hence, either a low or relatively high upwardly directed force P_4A_3 is exerted on surface **112** of piston **114**. When pressure conditions in and around tool **10** are such that P_3 is less than Q_1 (see Equation I), valve **26** will open.

To open valve **26**, piston **114** and cylinder **120** must move upwardly until surface **122** of cylinder **120** is stopped by surface **124** of top connector **23**. Fluid communication is now established between the valves internal port **128** and external port **130**, i.e., between the inside and outside of drill string **11** above the sealed-off area. Moving up with piston **114** is piston **142** thereby carrying compressed spring **146**.

After valve **26** opens, the circulation of drilling fluid can be re-established and the weight of the fluid increased so that the internal pressure P_1 is greater than the external pressure P_2 below packer **28**. Again a downwardly directed force is exerted on piston **58** through port **68**. Piston **58** pushes locking sleeve **40** and piston **44** downwardly to their lowermost deactivated position. The fluid pressure in chambers **98** and **118** becomes reduced and wall **104** deflated. Valve **26** closes thereby breaking fluid communication between the valve's ports **128** and **130**.

Tool **10** has now completed a full cycle: Packer **28** was activated and reversibly deactivated. Tool **10** is now ready to repeat another full cycle in response to another high-pressure formation fluid.

Thus, it will be evident from the above description that the various movable parts of tool **10** become automatically actuated without human intervention. Also, the function of each part is executed without having to guess at the subsurface pressure values in and around tool **10**. Since no human effort is required, little precious time is wasted and serious damage to both life and property can be averted.

It will be appreciated that while a preferred embodiment of this invention has been described in great detail and with reference to certain illustrative values, the invention is not limited thereto and modifications will readily suggest themselves to those skilled in the art,

and all such modifications are intended to fall within the scope of the following claims.

What is claimed is:

1. A well tool for controlling a well having a borehole filled with a drilling fluid, said borehole extending through a geological structure which is susceptible of containing a formation fluid, the tool being adapted for insertion within a very long drill string which is lowered into the well bore, said tool comprising:

a tubular member having an inner and an outer wall;

a fluid-inflatable sleeve means mounted on said outer wall and being adapted to radially expand and to close off the annular area between the drill string and the borehole wall;

fluid pressure control means mounted on said tubular member for controlling the expansion and contraction of said sleeve means, said control means defining: (1) a first fluid chamber fluidly communicating with said sleeve means, said first chamber being filled with a constant volume fluid, and (2) a second chamber fluidly communicating with the interior of said sleeve means and with said first chamber, said second chamber being positioned on said outer wall above said sleeve means;

said control means including: a first piston movably mounted in said first chamber and a second piston mounted on said outer wall for moving said first piston in and out of said first chamber; and

said sleeve means radially expanding when said first piston moves into said first chamber and radially contracting when said first piston moves out of said first chamber.

2. The tool of claim 1 and further including:

locking means mounted on said outer wall for releasably securing said first piston to said tubular member; and

said second piston unlocking said locking means when the pressure of the fluid inside said tubular member is greater than the pressure of the fluid within said annular area.

3. The tool of claim 2 and further including;

a first fluid passageway between said inner wall and said annular area above said sleeve means; and

valve means for automatically controlling fluid flow through said first passageway.

4. The tool of claim 3 and further including:

a third piston movably mounted in said second chamber, one surface of said third piston being responsive to the pressure inside said sleeve means and another surface being responsive to the pressure inside said tubular member; and

said third piston moving out of said second chamber after said annular area below said sleeve means becomes effectively sealed off.

5. The tool of claim 4 and further including:

second sleeve means connected to said third piston; and

said second sleeve means defining a valve surface which controls the fluid flow through said first passageway.

6. The tool of claim 5 and further including:

a spring-biased floating piston mounted on said outer wall; and

said floating piston assisting in moving said third piston downwardly into said second chamber when fluid communication through said passageway becomes cut off.

7. The tool of claim 6 and further defining:

a second fluid passageway between said annular area and a surface of said second piston;

a third fluid passageway between said annular area and said first piston;

a fourth fluid passageway between said tubular member and a surface of said floating piston; and

an opposite face of said floating piston being responsive to the fluid pressure in said annular area above said inflatable sleeve means.

8. The tool of claim 7 and further including:

a shoulder securely mounted on said outer wall;

a seal on said shoulder; and

said seal snugly engaging said valve surface when said valve means is closed.

9. A method for controlling a well having a borehole filled with a drilling fluid, said borehole extending through a geological structure which is susceptible of containing a formation of high-pressure fluid, and a very long drill string extending through said borehole, said method comprising:

sealing off a portion of the annular area between said drill string and the borehole wall in response to subsurface differential pressures existing between the interior and exterior of said drill string;

opening a fluid passageway between the interior of said drill string and said annular area above said sealed off portion in response to said differential pressures;

circulating drilling fluid down said drill string through said passageway and up said annular area above said sealed off portion;

increasing the weight of said drilling fluid;

closing said fluid passageway in response to said differential pressures; and

unsealing said previously sealed off portion when the weight of said drilling fluid reaches a sufficient level, thereby allowing drilling fluid to circulate down said drill string and up through said annular area.

10. An elongated tool connectable to a string of liquid conducting hollow members for insertion into a well bore, said tool comprising:

a hollow mandrel;

radially expandable sealing means carried by said mandrel, said sealing means defining a first chamber and a liquid filling said chamber;

pressure-responsive control means operatively coupled to said sealing means for normally maintaining said sealing means contracted, and

said control means controlling the pressure of the liquid in said first chamber and including a differential-pressure sensing element responsive to a change in the well bore pressure external to said tool relative to the pressure in said hollow mandrel.

11. The tool of claim 10 including,

disabling means coupled to said pressure control means adapted to disable said control means when said tool is initially inserted into said well bore, and

said disabling means changing to enabling means after said tool becomes functional in said well bore.

12. The tool of claim 10 including,

normally-closed first fluid communication means disposed above said sealing means, and

said communication means being adapted to open for establishing fluid communication between the inside and outside of said tool.

13. The tool of claim **10** wherein,

said first sensing element is a piston mounted on said mandrel for longitudinal movement.

14. The tool of claim **13** wherein,

said control means include a movable mechanism controlled by said first sensing element; and

said mechanism pressurizing or depressurizing the liquid in said first chamber.

15. The tool of claim **14** including,

locking means for initially securing said mechanism to said mandrel, and

said locking means releasing said mechanism after said tool becomes functional in said well bore.

16. The tool of claim **15** wherein the movement of said first sensing element exerts a downward force against said locking means to release said locking means.

17. The tool of claim **16** wherein said mechanism includes a piston adapted to move in or out of said first chamber.

18. The tool of claim **17** wherein said first communication means includes a circulating valve having a body portion coupled to said sealing means.

19. The tool of claim **18** wherein the first communication means includes a second differential-pressure sensing element movably mounted on said mandrel, and

said second sensing element assisting in maintaining said circulating valve normally closed.

20. The tool of claim **19** wherein:

said second sensing element is a piston movably mounted on said mandrel; and

said sealing means includes an expandable element adapted to seal off said well bore when said first chamber becomes pressurized.

21. The tool of claim **20** including a check valve positioned near the bottom end of said mandrel to prevent fluid from entering said mandrel.

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