United States Patent

Baker

[15] **3,677,353**

[45] **July 18, 1972**

[54] APPARATUS FOR CONTROLLING WELL PRESSURE

[72] Inventor: **Gerald S. Baker**, Houston, Tex.

[73] Assignee: **Cameron Iron Works, Inc.**, Houston, Tex.

[22] Filed: **July 15, 1970**

[21] Appl. No.: **55,105**

[52] **U.S. Cl.** **175/25**, 175/38

[51] **Int. Cl.** **E21b 7/00**

[58] **Field of Search** 175/25, 38, 218; 166/91

[56] **References Cited**

UNITED STATES PATENTS

3,477,526	11/1969	Jones et al.	175/25
3,362,487	1/1968	Lindsey	175/38
3,372,761	3/1968	Van Gils	175/25
3,429,385	2/1969	Jones et al.	175/25
3,443,643	5/1969	Jones et al.	175/25
3,470,971	10/1969	Dower	175/25
3,470,972	10/1969	Dower	175/25
3,550,696	12/1970	Kenneday	175/25
3,552,502	1/1971	Wilson	175/25

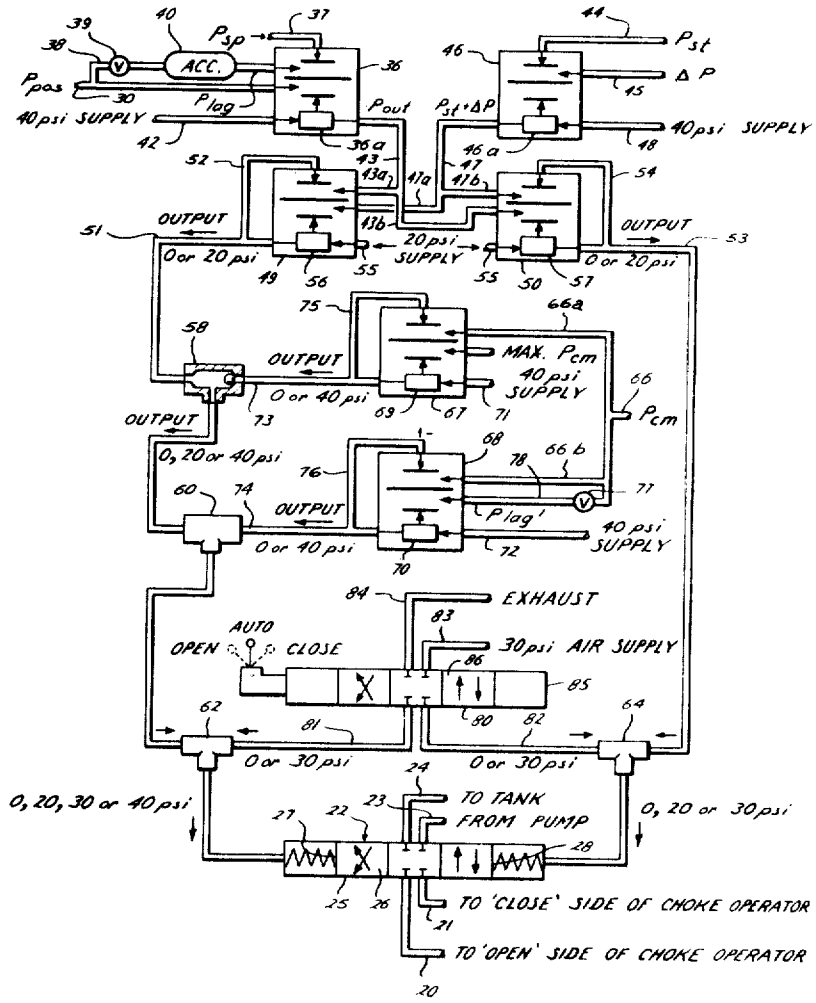
Primary Examiner—David H. Brown

Attorney—Hyer, Eickenroht, Thompson & Turner

[57] **ABSTRACT**

There is disclosed apparatus which includes a choke for connection to the annulus between a well bore and a drill string extending into the bore, and a means for operating the choke to impose a back pressure on drilling fluid in the annulus either manually or automatically in response to certain well characteristics so as to maintain a predetermined pressure differential between it and formation fluid at the bottom of the well bore.

14 Claims, 2 Drawing Figures



Patented July 18, 1972 3,677,353

2 Sheets-Sheet 1

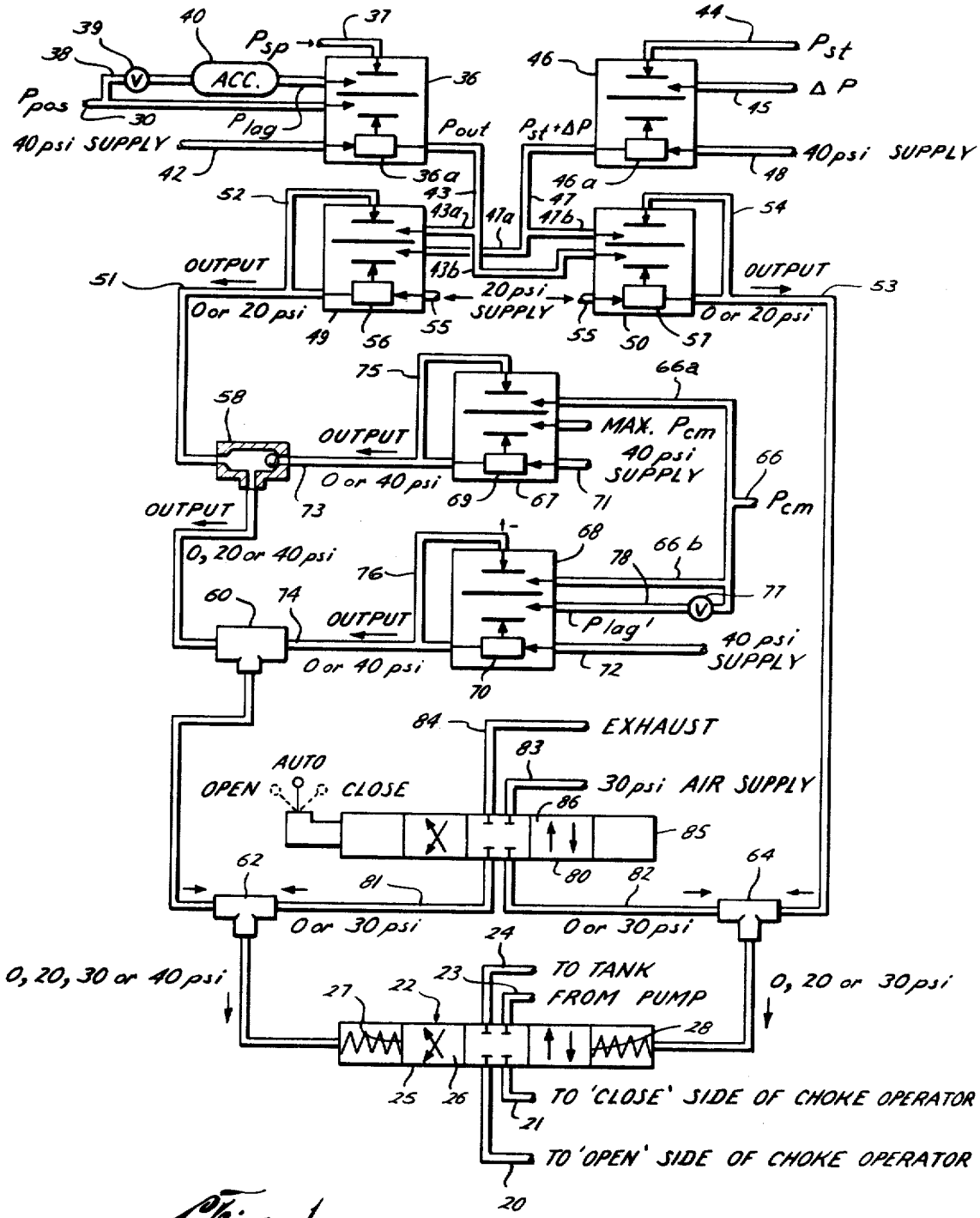


Fig. 1

Gerald S. Baker
INVENTOR.

BY
Hyer, Eickenroht, Thompson & Turner
ATTORNEYS

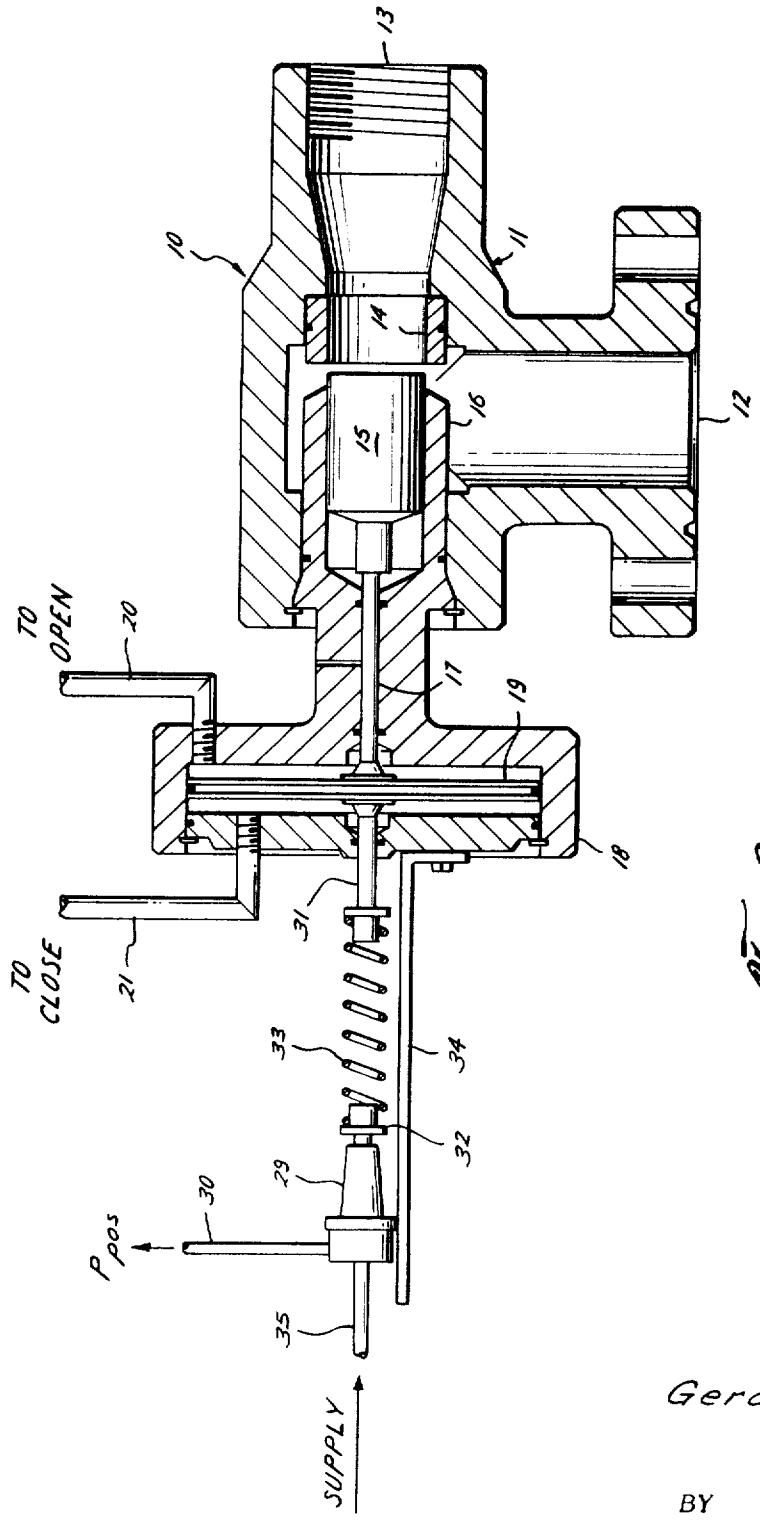


Fig. 2

Gerald S. Baker
INVENTOR.

BY
Hyer, Eickenroht, Thompson & Turner
ATTORNEYS

APPARATUS FOR CONTROLLING WELL PRESSURE

This invention relates to apparatus for use in controlling the pressure of fluid within a wellbore into which a drill string extends by means of a back pressure imposed upon the annulus between the well bore and drill string. More particularly, this invention relates to improved apparatus of the type shown and described in U.S. Pat. Nos. 3,443,643, 3,429,385 and 3,477,526.

It has been customary to provide a choke in a manifold connecting with the annulus beneath a blowout preventer closable about the drill string in order to establish and maintain a back pressure on fluid in the annulus which, together with its hydrostatic pressure, is sufficient to contain the fluids within formations penetrated by the wellbore - i.e., prevent them from flowing into the wellbore. In the case of a "kick", the choke must continue to contain the formation fluid as heavier mud is circulated down the drill string and up the annulus to "kill" the well. The choke is preferably adjustable so that, in controlling the well pressure, an attempt may be made to avoid excessive back pressure which might cause the drill string to stick, or damage a formation, the well casing, or the wellhead equipment.

Each of the prior patents discloses apparatus in which the choke is adjusted in an essentially automatic fashion. Thus, in each case, pneumatic signals representing the inlet or standpipe pressure and the circulating pressure loss in the drill string plus the static pressure adjusted by an amount which represents the desired pressure differential between drilling fluid pressure and formation pressure are produced and compared to cause the choke member to move to an equilibrium position, whereby the deviation of the pressure differential from the predetermined value thereof is maintained substantially at zero.

An object of this invention is to provide apparatus of the type above described in which there is ample force for operating a four-way valve which directs hydraulic fluid to and from the choke actuator, regardless of how small the imbalance of the compared signals might be, or how large the frictional resistance to movement of the shiftable parts of the valve might be.

Another object is to provide apparatus of this type which causes the choke to open quickly in response to predetermined conditions of pressure of the fluid within the outlet or choke manifold; and, more particularly, in a desired heirarchy with respect to control of the choke in response to the above-described imbalance.

A further object is to provide apparatus of this type in which the choke may be opened manually, also in a desired heirarchy with respect to the other choke controls.

Still another object is to provide such apparatus in which hunting or overcontrol of the choke is minimized, without delay in choke response and also in such a manner as to avoid continuous modulation of the choke.

These and other objects are accomplished, in accordance with the illustrated embodiment of the present invention, by apparatus including a hydraulic four-way valve operating the choke and pneumatic relays for operating the valve. The relays supply pressure to oppositely reacting pressure responsive surfaces of the valve in response to, but independently of the amount of, an imbalance between certain of the characteristics of the well, and particularly between standpipe pressure and static pressure plus circulating pressure loss. Thus, ample force is available to operate the valve regardless of how small such imbalance may be, or how large the frictional resistance of the valve may be.

This apparatus also includes means for producing signals which automatically cause the choke to open in response to a predetermined maximum choke manifold pressure and/or a predetermined rate of increase in such pressure. More specifically, these controls are designed to override other signals and thus protect against undesirable pressure conditions in the manifold regardless of other well characteristics.

In order to minimize hunting and overcontrol, means are provided for producing a first signal representing the position of the flow-restricting member of the choke relative to its seat, and a second signal representing a lagged position-representing signal. These signals are combined with the signal representing standpipe pressure to produce a signal which cooperates with the signal representing adjusted static pressure plus circulating pressure loss to limit the rate at which the flow-restricting member changes position with respect to time. Thus, the choke is immediately responsive to an adjusted imbalance between signals representing standpipe pressure and adjusted static pressure plus circulating pressure loss, and moves in a correcting direction in timed steps only to the extent necessary to correct the imbalance.

In the drawings, wherein like reference characters are used throughout to designate like parts:

FIG. 1 is a diagrammatic illustration of the circuitry for transmitting various signals to the choke of the apparatus; and

FIG. 2 is a sectional view of the choke and a relay for producing a signal representing the position of the flow-restricting member of the choke relative to its seat.

With reference now to the details of the above-described drawings, the choke shown in FIG. 2, and designated in its entirety by reference character 10, is similar in construction to that shown in each of U. S. Pat. Nos. 3,429,385 and 3,443,643. Thus, it includes a body 11 having a flowway therethrough connecting at one end to an inlet 12 and at the opposite end to an outlet 13. As described and shown in each of the aforementioned patents, the inlet 12 connects with a manifold connecting with the annulus between a wellbore and a drill string extending into the wellbore, and the outlet 13 connects with suitable piping for conveying drilling fluid from the choke to the mud pits or other suitable places for disposal.

The flowway includes inlet and outlet portions arranged at right angles and a ring 14 disposed at the intersection of these angularly arranged flowway portions to provide a seat surrounding the flowway. A cylindrical flow-restricting member 15 is reciprocable within a sleeve 16, which is held within the valve body 11 by a snap ring, for movement toward and away from maximum flow-restricting position with respect to the seat 14.

The flow-restricting member 15 is so moved by a rod 17 which extends through an outward extension of sleeve 16 into a cylinder 18 mounted thereon. The free end of the rod 17 connects with a piston 19 which is sealably reciprocable within the cylinder for moving the rod and thus the flow-restricting member toward and away from the seat. More particularly, the piston is urged to the left, or in a direction to move the flow-restricting member to minimum flow-restricting position, by means of hydraulic fluid supplied to the cylinder through a conduit 20. The piston is moved to the right, or in a direction to move the flow-restricting member to maximum flow-restricting position, by means of hydraulic fluid supplied to the cylinder on the lefthand side of the piston through a conduit 21.

The conduits 20 and 21 are shown in FIG. 1 to connect with a four-way valve 22 for selectively supplying hydraulic fluid to one side of the piston 19 and exhausting it from the other, thereby controlling movement of flow-restricting member 15. As indicated in FIG. 1, a conduit 23 leads from a pump for supplying hydraulic fluid from a suitable source to the four-way valve, and a conduit 24 leads from the valve to return the fluid to the source.

As shown diagrammatically in FIG. 1, the valve 22 includes a housing or casing 25 to which the conduits 20, 21, 23 and 24 connect and a spool 26 reciprocable within the housing between a neutral position, as shown in FIG. 1, in which the conduits 20 and 21 are disconnected from the conduits 23 and 24, and alternate positions in which ports within the spool connect the conduits to direct hydraulic fluid in the desired manner. Thus, as will be apparent from the arrows on the spool, it may be shifted to the left so as to supply hydraulic fluid to the lefthand side of the piston 19 and exhaust it from the righthand side thereof, and thus urge the flow-restricting member toward maximum flow-restricting position, or to the

right in order to supply hydraulic fluid to the righthand side of the piston and exhaust it from the lefthand side thereof so as to urge the flow-restricting member toward minimum flow-restricting position.

The spool **26** may be sealed with respect to the valve casing or housing by means of O-rings or the like (not shown) so as to confine the passage of hydraulic fluid through ports in the spool in the manner above described. The spool is shifted between its alternate positions by means of pneumatic fluid supplied to pressure responsive surfaces **27** and **28** within the valve housing and on opposite ends of the spool in response to signals emanating from the circuitry shown in FIG. **1**. Springs are disposed on opposite ends of the spool to urge it to the neutral position shown in FIG. **1** when fluid pressure on its ends are equal.

One such signal (P_{pos}) represents the position of the flow-restricting member **15** with respect to the seat **14** and is produced by means of a relay **29** (FIG. **2**) adapted to sense the position of the flow-restricting member and transmit a signal representing same to the circuitry through a conduit **30**. For this purpose, a tailrod **31** extends from the left side of the piston **19** and through the cylinder to the exterior thereof. The end of the tailrod faces a rod **32** extending from the relay, and a compression coil spring **33** is disposed between the two rods. Thus, movement of the tailrod **31** toward and away from the relay, and thus the position of the flow-restricting member **15** relative to the seat **14**, is reflected by an increase or decrease in the force of the spring and thus the force on rod **32**.

The relay may be of conventional construction, such as a "Model **405**" pneumatic force transmitter manufactured and sold by Moore Products Co., of Spring House, Pa., and adapted to receive pneumatic fluid through a conduit **35** for supplying the signal. As will be apparent, when the flow-restricting member moves away from maximum flow-restricting position, it compresses the spring **33** so as to increase P_{pos} and, conversely, when the flow-restricting member moves toward maximum flow-restricting position, it permits the spring **33** to expand to reduce P_{pos}.

Preferably, P_{pos} is indicated on a control panel of the general nature described in the above-mentioned patents, whereby this information may be used by personnel in charge of operation of the apparatus.

The apparatus also includes a means for producing a signal (P_{sp}) representing the pressure of fluid within the standpipe, means for producing a signal (P_{st}) representing the pressure of the fluid in the standpipe in a static state, as adjusted to reflect a desired pressure differential, and means for producing a signal (ΔP) representing the pressure loss due to fluid circulation. These well characteristics are sensed and signals representing same are produced and preferably indicated on the control panel in the manner shown and described in U. S. Pat. Nos. 3,443,643 and 3,429,385.

As shown in FIG. **1**, p_{pos} is transmitted through conduit **30**, and P_{sp} is transmitted through a conduit **37** to a relay **36**. Additionally, a conduit **38** connects the conduit **30** with the relay and has a lag element **39** therein as well as an accumulator **40** intermediate the lag element and the relay **36**. Thus, a signal (P_{lag}) representing a lagged P_{pos} is transmitted through the conduit **38** to the relay **36**.

The relay **36** may be any commercially available summing relay, such as the "Model **68–1**" which is manufactured and sold by the aforementioned Moore Products Co., for combining the aforementioned signals in a manner to produce an output signal (P_{out}) in accordance with the following equation:

$$P_{out} = P_{sp} + P_{lag} - P_{pos}.$$

Thus, as indicated diagrammatically in FIG. **1**, P_{sp} is introduced into the top port, and P_{lag} and P_{pos} into the upper and lower side ports, respectively, of the relay, and the relay includes a pilot valve **36***a* adapted to receive supply pressure at 40 p.s.i. through a conduit **42** and to produce and transmit P_{out} through a conduit **43**.

P_{st} and ΔP are transmitted through conduits **44** and **45**, respectively, to the upper port and upper side port of a relay **46** similar to the relay **36**, where they are combined to produce and transmit through the conduit **47** a signal representing the sum of P_{st} and ΔP. As in the case of the relay **36**, the relay **46** includes a pilot valve **46***a* to which pneumatic fluid at 40 p.s.i. is supplied through a conduit **48**.

P_{out} is transmitted through branches **43***a* and **43***b* of conduits **43**, and the signal from relay **46** is transmitted through branches **47***a* and **47***b* of the conduit **47**, to the relays **49** and **50**. The relays **49** and **50** function as on-off switches and, for this purpose, each may comprise a "Model **68–5**" relay manufactured and sold by the aforesaid Moore Products Co. and internally ported to provide a feedback of the output signal therefrom. Thus, as shown in FIG. **1**, the output signal from the relay **49** transmitted through conduit **51** is fed back to the relay through conduit **52**, and the output signal from the relay **50** transmitted through conduit **53** is fed back to the relay through conduit **54**.

As shown in FIG. **1**, P_{out} is transmitted to an upper side port of the relay **49** and to a lower side port of the relay **50**. Conversely, the signal from relay **46** is transmitted to a lower side port of the relay **49** and an upper side port of the relay **50**. A supply of pneumatic fluid of 20 p.s.i. is fed to each of the relays **49** and **50** through a conduit **55** for use in operating the pilot valve **56** of the relay **49** and the pilot valve **57** of the relay **50**.

In a relay of this type, when the sum of the signals into the upper side port and the upper feedback port is greater than the signal into the lower side port, the pilot valve opens to produce an output signal equal to full supply pressure. When said sum is less, the pilot valve vents supply pressure.

Thus, with reference to the particular circuit shown in FIG. **1**, when P_{out} from relay **36** is greater than the sum of P_{st} and ΔP, relay **49** will supply a signal to the conduit **51** equal to 20 p.s.i., and relay **50** will supply a signal to conduit **53** which is zero. On the other hand, when the sum of signals P_{st} and ΔP is greater than P_{out}, the relay **50** will supply a signal of 20 p.s.i. to conduit **53**, and relay **49** will supply a signal to conduit **51** which is zero.

As shown in FIG. **1**, conduit **51** is connected to the left end of valve **22**, and conduit **53** is connected to the right end thereof. Consequently, the signal in **51** acts over surface **27** on the spool to urge it to the right, and the signal in **53** acts over surface **28** on the spool to urge it to the left.

Thus, assuming the apparatus is set for automatic control and choke manifold pressure is within preset limits, an imbalance of the well characteristics due to a standpipe pressure greater than the sum of adjusted static pressure and circulating pressure loss causes the spool **26** of valve **22** to move to the right and thereby reduce choke manifold pressure, and thus eventually standpipe pressure. Conversely, an imbalance due to standpipe pressure less than said sum causes the spool to move to the left to increase choke manifold fluid pressure and thus standpipe pressure.

When P_{sp} equals P_{st} plus ΔP, the flow-restricting member of the choke is stationary. At this time, P_{out} equals P_{sp}, because P_{pos} equals P_{lag} to the equation above. Thus, the signals from relays **49** and **50** are equal, and the spool will assume the neutral position shown in FIG. **1**.

In the event P_{sp} increases, p_{out} will also increase, which, for reasons above described, will cause the choke to move in an opening direction toward minimum flow-restricting position. As the flow-restricting member of the choke begins to open, the spring **33** will be compressed so as to increase P_{pos}. This increase in P_{pos} will offset the increase in P_{sp} so as to return P_{out} to its original value equal to the sum of P_{st} and ΔP, as a result of which the choke will stop movement.

Since the choke and thus the flow-restricting member are now stationary, P_{pos} will remain constant. However, P_{lag} will continue to increase slowly until it reaches the value of P_{pos}. When P_{lag} reaches the value of P_{pos}, P_{out} will again increase to the increased value of P_{sp}. As a result, the flow-restricting

member will move another step in an opening direction, and this process will be repeated until the value of P_{sp} reaches the proper value to null the system - i.e., until it equals the sum of P_{st} and ΔP. Thus, the rate of change of position of the flow-restricting member is limited to an extent dependent upon the setting of lag element **39**.

In the event P_{sp} decreases, the flow-restricting member of the choke will be caused to move step-by-step at a limited rate in a closing direction - i.e., toward maximum flow-restricting position.

As shown in FIG. **1**, shuttle valves **58**, **60** and **62** are disposed in conduit **51**, and a shuttle valve **64** is disposed in conduit **53**. As also shown in FIG. **1**, each of the shuttle valves is connected to a conduit for receiving, under circumstances to be described, a pneumatic signal which overrides the signals transmitted from the relays **49** and **50** during the above-described automatic control of a well. Thus, as will be apparent from the cross-sectional view of the shuttle valve **58**, which is typical of shuttle valves **58**, **60**, **62** and **64**, a ball-shaped valve element is adapted to shift in a direction to admit the stronger of the two signals it receives to the downstream portion of the conduit **51** or **53**.

As previously described, the apparatus includes means for producing overriding signals representing a pressure within the choke manifold greater than a predetermined maximum, as well as a rate of change of pressure in the choke manifold greater than a predetermined rate. For this purpose, the apparatus includes a means for sensing manifold pressure and producing a signal (P_{cm}) representing same, as described in either of the aforementioned U.S. Pat. Nos. 3,443,643 or 3,429,385. Also, as in the prior apparatus, the value of choke manifold pressure may be indicated on the control panel.

As shown in FIG. **1**, P_{cm} is transmitted through branches **66***a* and **66***b* of a conduit **66** to each of relays **67** and **68**, which are similar to the relays **49** and **50** in that each functions as an on-off switch. Thus, as in the case of the relays **49** and **50**, each such relay **67** and **68** may comprise the aforementioned "-Model **68-5**" computing relay, and thus includes upper and lower side ports for receiving signals to be compared as well as an upper port for receiving a feedback signal through conduit **75** or **76**. Additionally, relay **68** includes a negative bias, as indicated diagrammatically in FIG. **1**.

As shown in FIG. **1**, pressure at 40 p.s.i. is supplied through conduits **71** and **72** to each of pilot valve **69** of relay **67** and the pilot valve **70** of relay **68**. Thus, upon opening of pilot **69**, relay **67** will transmit a 40 p.s.i. signal through conduit **73** to shuttle valve **58**, and upon opening of pilot **70**, relay **68** will transmit a 40 p.s.i. signal through conduit **74** to shuttle valve **60**.

As indicated in FIG. **1**, P_{cm} is transmitted through conduit **66***a* to the upper side port of the relay **67**, and another signal representing the maximum allowable choke manifold pressure is fed to the lower side port of the relay **67**. This latter signal is produced by setting a maximum allowable choke manifold pressure on the panel above mentioned. These two signals are so combined by the relay **67** that when actual choke manifold pressure is greater than maximum allowable choke manifold pressure, the pilot valve **69** will be opened so as to produce a signal of 40 p.s.i., which is transmitted through the conduit **73** to the shuttle valve **58**.

As will also be understood from FIG. **1**, P_{cm} is also transmitted through conduit **66***b* to the upper side port of relay **68**. It is also introduced into a conduit **78** connecting with the conduit **66** where it is lagged by means of an adjustable lag element **77** before being fed into the lower side port of the relay **68** to produce a signal $P_{lag'}$.

The aforementioned negative bias on relay **68** will effectively determine the rate of change in choke manifold pressure at which the pilot valve **70** will open to produce a 40 p.s.i. signal in conduit **74**. That is, the bias will combine with $P_{lag'}$ to produce a sum which is either greater or less than the P_{cm} transmitted to the relay. Since any change in choke manifold pressure will be lagged through the conduit **78**, there is a rate of increase at which P_{cm} will be stronger than the sum of $P_{lag'}$ plus the negative bias. When this point is reached, the pilot valve **70** will be opened so as to transmit full supply pressure at 40 p.s.i. through the conduit **74** to the shuttle valve **60**.

The signals transmitted through conduit **73** or **74**, when they occur, are stronger than the signal from relay **49**, so either will override the latter signal and thus shift the corresponding shuttle valve **58** or **60** to a position for transmitting it to the downstream portion of the conduit, regardless of the magnitude of the signal from relay **49**.

Each of the signals delivered through conduits **73** or **74** is also stronger than any signal supplied to valve **22** by relay **50**. Furthermore, these signals are stronger than and thus override any signals which would otherwise be transmitted to the conduits **51** and **53** by the manual control to be described below. Consequently, the signal transmitted to the surface **27** of the spool **26** will in any case be stronger than the signal transmitted to the surface **28**, whereby the spool is caused to shift to the right and thereby cause the choke to be moved in an opening direction.

Assuming that either of these latter signals has thus shifted the spool **26** to the right, but that the choke manifold pressure has dropped below the maximum, or has returned to a rate of change below the permissible rate of change, the four-way valve **22** will be automatically returned to automatic operation.

The manual control for the apparatus includes a four-way valve **80** for supplying pneumatic fluid to the valve **22** to selectively move the choke to opened or closed position regardless of the relationship of standpipe pressure to the sum of static pressure plus circulating pressure loss, assuming of course that manifold pressure is within preset limits. Thus, as noted above, this means for manually operating the choke is adapted to be overriden by either the maximum choke manifold pressure control or rate of change of choke manifold pressure control.

Valve **80** is connected to the shuttle valve **62** by conduit **81** and to the shuttle valve **64** by conduit **82**. It is adapted to receive pneumatic fluid at 30 p.s.i. through conduit **83**, and to exhaust pneumatic fluid through a conduit **84**. As in the case of valve **22**, it includes a casing **85** and a spool **86** reciprocable within the casing between a neutral position in which the conduits **83** and **84** are disconnected from the conduits **81** and **82**, as shown in FIG. **1**, and alternate positions to the left to supply pneumatic fluid to the conduit **82** and return it to the exhaust through conduit **81**, and to the right to supply pneumatic fluid through conduit **81** and exhaust it by means of the condit **82**.

As indicated diagrammatically in FIG. **1**, there is a lever on the lefthand end of the four-way valve **80** for manually moving it between the neutral ("auto") position, in which it is ineffective, and either "open" or "close" positions in which the spool **86** is shifted to either its right or lefthand position. When the spool is in its righthand or opening position, pneumatic fluid is transmitted to the conduit **81** and exhausted through conduit **82**. Assuming that neither maximum choke manifold pressure nor maximum rate of change of manifold pressure has been exceeded, the 30 p.s.i. signal in the conduit **81** will override any signal from relay **49** to shift the shuttle valve **62** and thus connect conduit **81** to conduit **51**.

In order to manually move the choke in a closing direction, the hand lever shown in FIG. **1** is moved to the "close" position, which shifts the spool **86** to the left so as to connect supply pressure of 30 p.s.i. with the conduit **82**. Assuming that neither choke manifold pressure maximum or rate of change choke manifold pressure permissible has been exceeded, the signal in conduit **51** will be either zero or 20 p.s.i. Consequently, the signal in conduit **82** will override any signal from relay **50** to shift shuttle valve **64** to a position connecting the conduit **82** with the conduit **53** and thus supply a signal of 30 p.s.i. to the right-hand end of the spool **26**. This, of course, causes the spool **26** to be moved to the left to cause the choke to be urged in a closing direction.

It will be understood that under any of the circumstances above mentioned - i.e., whether the system is on automatic or

manual control, or whether or not one or both maximum choke manifold pressure or maximum rate of change of choke manifold pressure has been exceeded, a pneumatic pressure signal will be supplied to one end surface of the spool **26** which is significantly greater than the pneumatic pressure signal supplied to the other end surface thereof. In some cases, the differential may be as much as 40 p.s.i., and in any case the differential will be at least 10 p.s.i. Consequently, the force available greatly exceeds the force required to shift the spool **26** of the hydraulic four-way valve **22**.

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 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 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. For use in drilling a well into an earth formation containing fluid under pressure, wherein drilling fluid is circulated through a drill string extending into a wellbore and through the annulus therebetween, said string and annulus having upper ends, one of which is an inlet and the other an outlet, there being a pressure differential, positive or negative, by which the bottom hole pressure of the drilling fluid exceeds the formation fluid pressure, and there being a deviation, positive or negative, by which said pressure differential exceeds a predetermined value thereof; apparatus for maintaining said pressure differential at the predetermined value thereof, comprising a choke including a flow-restricting member movable toward and away from a seat for regulating the outlet fluid pressure, means for causing the flow-restricting member to move toward and away from the seat to respectively increase or decrease the outlet fluid pressure automatically in response to said deviation being respectively negative or positive, whereby the outlet pressure approaches a value at which said deviation is zero, means for producing a signal representing the position of said flow-restricting member, and means responsive to said signal for controlling the rate of change of said position.

2. Apparatus of the character defined in claim 1, including means for causing the flow-restricting member to move away from the seat for decreasing said outlet fluid pressure automatically in response to the value thereof exceeding a predetermined level and regardless of other well characteristics.

3. Apparatus of the character defined in claim 1, including means for causing the flow-restricting member to move away from the seat for decreasing the outlet fluid pressure automatically in response to the rate of increase thereof exceeding a predetermined level and regardless of other well characteristics.

4. Apparatus of the character defined in claim 6, including means for producing a sixth signal which represents outlet fluid pressure to cause the flow-restricting member to move away from the seat for decreasing said outlet fluid pressure automatically in response to the value thereof exceeding a predetermined level and regardless of other well characteristics, and means for producing a seventh signal which represents the rate of change of outlet fluid pressure to cause the flow-restricting member to move away from the seat for decreasing the outlet fluid pressure automatically in response to the rate of increase thereof exceeding a predetermined level and regardless of other well characteristics.

5. Apparatus of the character defined in claim 4, including means for manually producing an eighth signal to selectively cause the choke to increase or decrease the outlet fluid pressure regardless of said well characteristics.

6. For use in drilling a well into an earth formation containing fluid under pressure, wherein drilling fluid is circulated through a drill string extending into a wellbore and through the annulus therebetween, said string and annulus having upper ends, one of which is an inlet and the other an outlet, there being a pressure differential, positive or negative, by which the bottom hole pressure of the drilling fluid exceeds the formation fluid pressure, and there being a deviation, positive or negative, by which said pressure differential exceeds a predetermined value thereof; apparatus for maintaining said pressure differential at the predetermined value thereof, comprising a choke including a flow-restricting member movable toward and away from a seat for regulating the outlet fluid pressure in response to first and second signals, means for producing a first signal, and means for producing a second signal which represents the sum of inlet fluid pressure in a static state as adjusted to include said pressure differential and fluid pressure loss due to circulation within the well bore and which cooperates with the first signal to cause the flow-restricting member to move toward and away from the seat to respectively increase or decrease the outlet fluid pressure automatically in response to said deviation being respectively negative or positive, whereby the outlet pressure approaches a value at which said deviation is zero, said means for producing the first signal comprising means for producing a third signal representing inlet fluid pressure, means for producing a fourth signal representing the position of the flow-restricting member with respect to said seat, means for producing a fifth signal representing a damped position representing signal, and means for combining said signals in accordance with the equation:

First Signal = Third Signal − Fourth Signal + Fifth Signal,

so as to control the rate at which the flow-restricting member changes position with respect to said seat.

7. For use in drilling a well into an earth formation containing fluid under pressure, wherein drilling fluid is circulated through a drill string extending into a wellbore and through the annulus therebetween, said string and annulus having upper ends, one of which is an inlet and the other an outlet, there being a pressure differential, positive or negative, by which the bottom hole pressure of the drilling fluid exceeds the formation fluid pressure, and there being a deviation, positive or negative, by which said pressure differential exceeds a predetermined value thereof; apparatus for maintaining said pressure differential at the predetermined value thereof, comprising a choke for regulating the outlet fluid pressure in response to signals, means for producing a first signal, means for producing a second signal which varies with well characteristics and cooperates with the first signal to cause the choke to increase or decrease the outlet fluid pressure automatically in response to said deviation being respectively negative or positive, whereby the outlet pressure approaches a value at which said deviation is zero, and means for producing a third signal which represents the value of fluid pressure within the outlet and overrides the first and second signals to cause the choke to decrease the outlet fluid pressure automatically in response to the value thereof exceeding a predetermined level and regardless of said well characteristics.

8. For use in drilling a well into an earth formation containing fluid under pressure, wherein drilling fluid is circulated through a drill string extending into a wellbore and through the annulus therebetween, said string and annulus having upper ends, one of which is an inlet and the other an outlet, there being a pressure differential, positive or negative, by which the bottom hole pressure of the drilling fluid exceeds the formation fluid pressure, and there being a deviation, positive or negative, by which said pressure differential exceeds a predetermined value thereof; apparatus for maintaining said pressure differential at the predetermined value thereof, comprising a choke for regulating the outlet fluid pressure in response to signals, means for producing a first signal, means for producing a second signal which varies with well characteristics and cooperates with the first signal to cause the choke to increase or decrease the outlet fluid pressure automatically

in response to said deviation being respectively negative or positive, whereby the outlet pressure approaches a value at which said deviation is zero, and means for producing a third signal which represents the rate of change of fluid pressure within the outlet and overrides the first and second signals to cause the choke to decrease the outlet fluid pressure automatically in response to the rate of increase thereof exceeding a predetermined level.

9. For use in drilling a well into an earth formation containing fluid under pressure, wherein drilling fluid is circulated through a drill string extending into a wellbore and through the annulus therebetween, said string and annulus having upper ends, one of which is an inlet and the other an outlet, there being a pressure differential, positive or negative, by which the bottom hole pressure of the drilling fluid exceeds the formation fluid pressure, and there being a deviation, positive or negative, by which said pressure differential exceeds a predetermined value thereof; apparatus for maintaining said pressure differential at the predetermined value thereof, comprising a choke for regulating the outlet fluid pressure in response to signals, means for producing a first signal, means for producing a second signal which varies with well characteristics and cooperates with the first signal to cause the choke to increase or decrease the outlet fluid pressure automatically in response to said deviation being respectively negative or positive, whereby the outlet pressure approaches a value at which said deviation is zero, means for producing a third control signal which represents the value of fluid pressure within the outlet and overrides the first and second signals to cause the choke to decrease the outlet fluid pressure automatically in response to the value thereof exceeding a predetermined level and regardless of other well characteristics, and means for producing a fourth control signal which represents the rate of change of fluid pressure within the outlet and overrides the first and second signals to cause the choke to decrease the outlet fluid pressure automatically in response to the rate of increase thereof exceeding a predetermined level.

10. Apparatus for operating a drilling choke in response to the comparative values of characteristics within a well to the outlet of which the choke is connected, said apparatus comprising a reciprocable actuator for connection to the flow-restricting member of the choke, a source of hydraulic fluid under pressure, a four-way valve having a spool with oppositely reacting surfaces thereon responsive to fluid pressure for urging it toward alternate positions, conduits connecting the source of hydraulic fluid with the valve and the valve with the actuator for supplying hydraulic fluid to one side and exhausting it from the other side of said actuator, upon shifting of said spool to one alternate position, and means responsive to an imbalance of said values for selectively admitting pneumatic fluid to one of said surfaces which is at a higher level than that admitted to the other of said surfaces so as to move said spool to one of its positions irrespective of the magnitude of the imbalance.

11. Apparatus of the character defined in claim 10, including means for producing first and second signals representing the values of said well characteristics, and means for admitting said pneumatic fluid includes means for receiving and comparing said signals so as to determine the imbalance.

12. For use in drilling a well into an earth formation containing fluid under pressure, wherein drilling fluid is circulated through a drill string extending into a wellbore and through the annulus therebetween, said string and annulus having upper ends, one of which is an inlet and the other an outlet, there being a pressure differential, positive or negative, by which the bottom hole pressure of the drilling fluid exceeds the formation fluid pressure, and there being a deviation, positive or negative, by which said pressure differential exceeds a predetermined value thereof, apparatus for maintaining said pressure differential at the predetermined value thereof, comprising a choke for regulating the outlet fluid pressure in response to signals, means for producing a first signal, means for producing a second signal which varies with well characteristics and cooperates with the first signal to cause the choke to increase or decrease the outlet fluid pressure automatically in response to said deviation being respectively negative or positive, whereby the outlet pressure approaches a value at which said deviation is zero, means for manually producing a third signal which overrides the first and second signals to selectively cause the choke to increase or decrease the outlet fluid pressure, and means for producing a fourth signal which represents the value of fluid pressure within the outlet and which overrides the first, second and third signals to cause the choke to decrease the outlet fluid pressure automatically in response to the value thereof exceeding a predetermined level.

13. For use in drilling a well into an earth formation containing fluid under pressure, wherein drilling fluid is circulated through a drill string extending into a wellbore and through the annulus therebetween, said string and annulus having upper ends, one of which is an inlet and the other an outlet, there being a pressure differential, positive or negative, by which the bottom hole pressure of the drilling fluid exceeds the formation fluid pressure, and there being a deviation, positive or negative, by which said pressure differential exceeds a predetermined value thereof; apparatus for maintaining said pressure differential at the predetermined value thereof, comprising a choke for regulating the outlet fluid pressure in response to signals, means for producing a first signal, means for producing a second signal which varies with well characteristics and cooperates with the first signal to cause the choke to increase or decrease the outlet fluid pressure automatically in response to said deviation being respectively negative or positive, whereby the outlet pressure approaches a value at which said deviation is zero, means for manually producing a third signal which overrides the first and second signals to selectively cause the choke to increase or decrease the outlet fluid pressure, and means for producing a fourth signal which represents the rate of change of fluid pressure within the outlet and which overrides the first, second and third signals to cause the choke to decrease the outlet fluid pressure automatically in response to the rate of increase thereof exceeding a predetermined level.

14. For use in drilling a well into an earth formation containing fluid under pressure, wherein drilling fluid is circulated through a drill string extending into a wellbore and through the annulus therebetween, said string and annulus having upper ends, one of which is an inlet and the other an outlet, there being a pressure differential, positive or negative, by which the bottom hole pressure of the drilling fluid exceeds the formation fluid pressure, and there being a deviation, positive or negative, by which said pressure differential exceeds a predetermined value thereof; apparatus for maintaining said pressure differential at the predetermined value thereof, comprising a choke for regulating the outlet fluid pressure in response to signals, means for producing a first signal, means for producing a second signal which varies with well characteristics and cooperates with the first signal to cause the choke to increase or decrease the outlet fluid pressure automatically in response to said deviation being respectively negative or positive, whereby the outlet pressure approaches a value at which said deviation is zero, and means for manually producing a third signal which overrides the first and second signals to selectively cause the choke to increase or decrease the outlet fluid pressure, means for producing a fourth control signal which represents the value of fluid pressure within the outlet and which overrides the first, second and third signals to cause the choke to decrease the outlet fluid pressure automatically in response to the value thereof exceeding a predetermined level, and means for producing a fifth control signal which represents the rate of change of fluid pressure within the outlet and which overrides the first, second and third signals to cause the choke to decrease the outlet fluid pressure automatically in response to the rate of increase thereof exceeding a predetermined level.

* * * * *