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(54) **WELL PRESSURE CONTROL SYSTEM**

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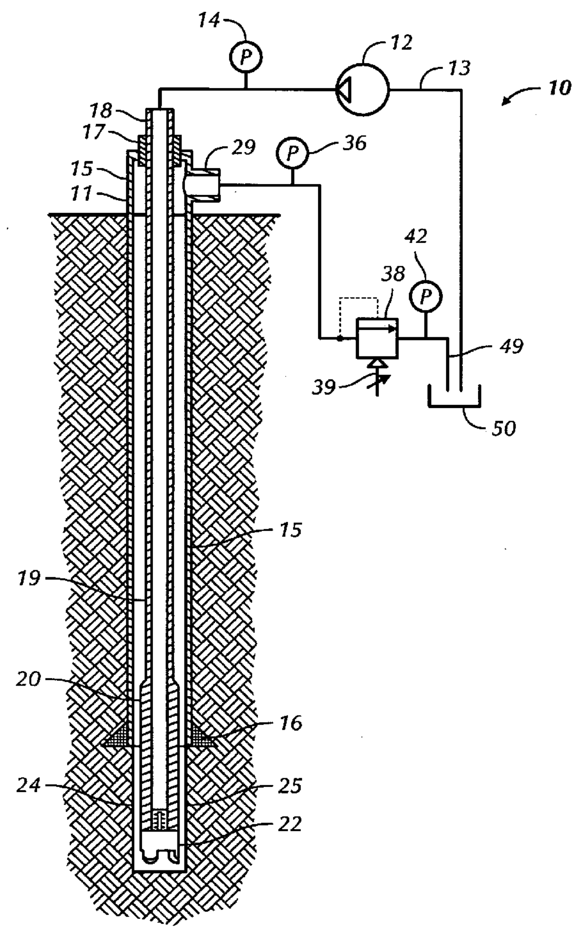
(57) **ABSTRACT**

The present invention contemplates a choke control system that provides for local and off-site monitoring and control of the annulus flow pressure of a well. The choke control system includes a choke manifold connected to at least one choke and its associated actuator; a variety of instrumental drilling sensors, pump stroke counter switches, and choke position indicators; a local choke and hydraulic pressure control console; and a programmable controller in communication with the local choke and hydraulic pressure control console. The programmable controller handles the logical operations of the choke control system, including processing instrument measurements and operator input data to produce control signals for operating the choke, the choke actuator and the various valves associated with the choke manifold. The programmable controller is typically either an electronic digital computer and/or a programmable logic controller (PLC). The present invention further contemplates the two-way communication between the choke control system and the Internet via a satellite linkage.



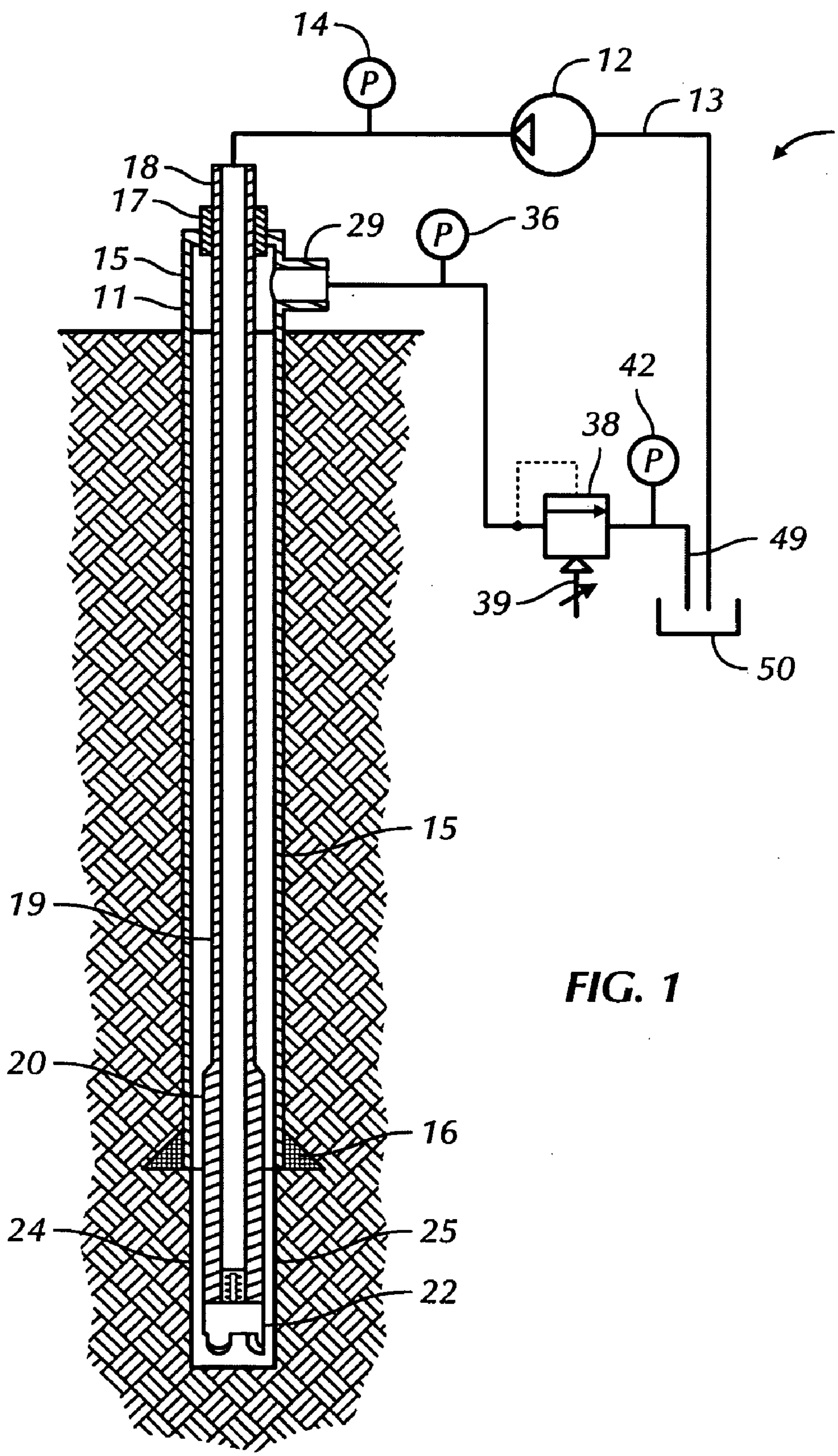



FIG. 1

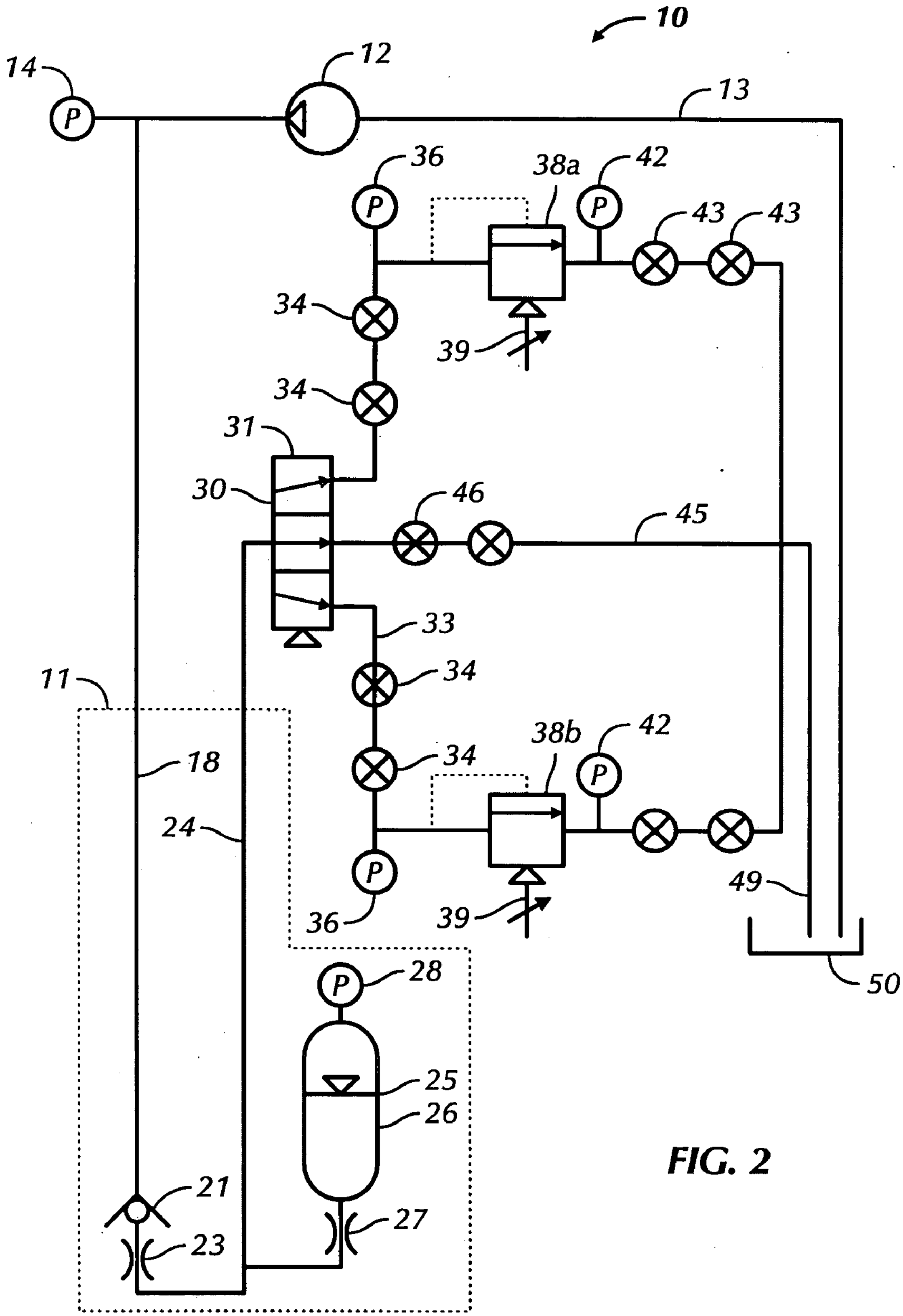

10
14
P
12
13
36
P
38a
42
P
43
43
34
39
34
31
30
46
45
33
34
11
34
38b
42
P
18
24
P
36
39
49
50
28
P
25
26
21
23
27

FIG. 2

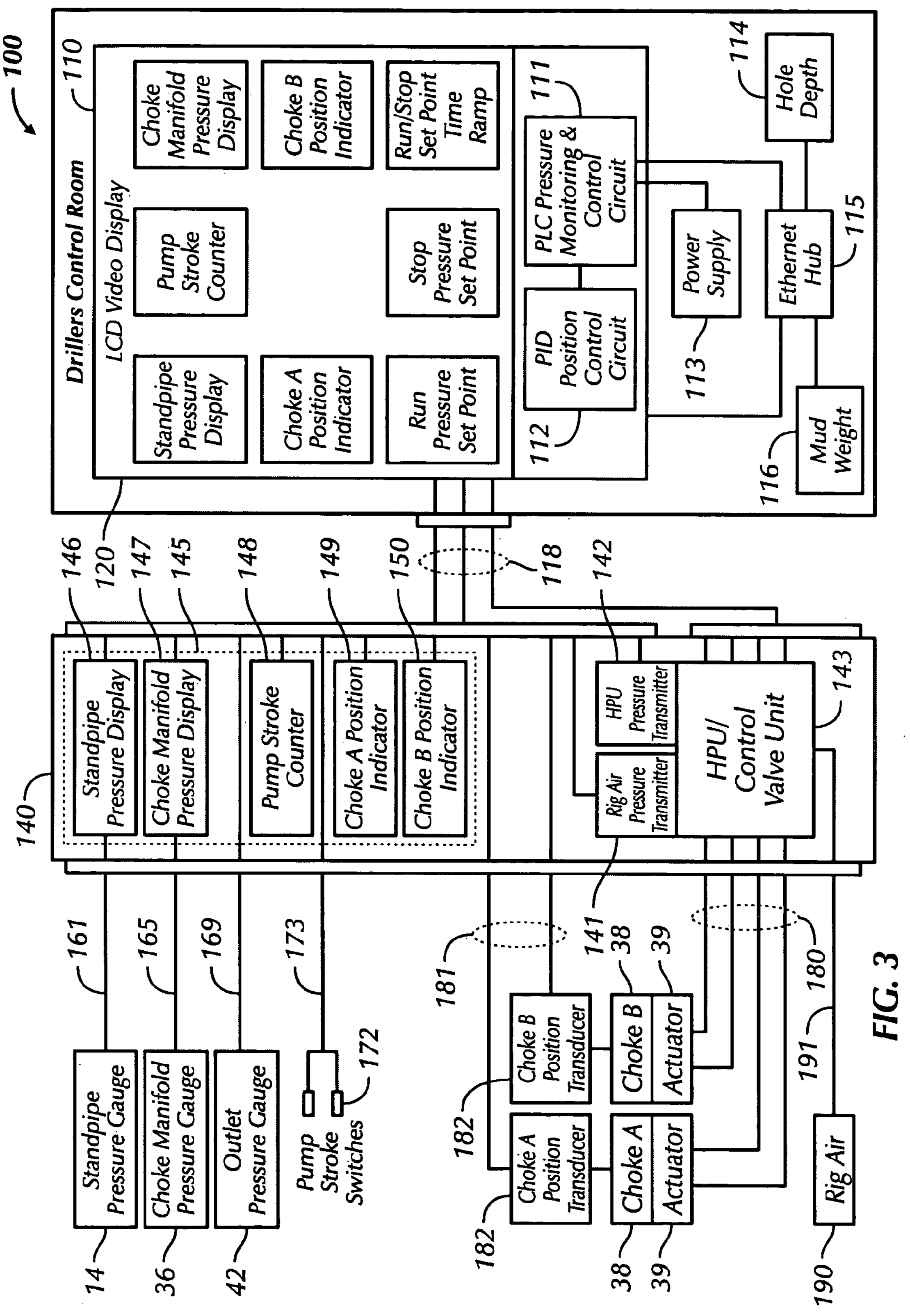

100
Drillers Control Room
110
LCD Video Display
Standpipe Pressure Display
Pump Stroke Counter
Choke Manifold Pressure Display
Choke A Position Indicator
Choke B Position Indicator
Run Pressure Set Point
Stop Pressure Set Point
Run/Stop Set Point Time Ramp
111
PLC Pressure Monitoring & Control Circuit
PID Position Control Circuit
112
Power Supply
113
Ethernet Hub
115
Hole Depth
114
Mud Weight
116
120
118
146
147
145
148
149
150
142
140
Standpipe Pressure Display
Choke Manifold Pressure Display
Pump Stroke Counter
Choke A Position Indicator
Choke B Position Indicator
Rig Air Pressure Transmitter
HPU Pressure Transmitter
HPU/ Control Valve Unit
143
141
161
165
169
173
172
181
38
39
180
191
Standpipe Pressure Gauge
Choke Manifold Pressure Gauge
Outlet Pressure Gauge
Pump Stroke Switches
Choke B Position Transducer
Choke B
Actuator
Choke A Position Transducer
Choke A
Actuator
Rig Air
182
14
36
42
190

FIG. 3

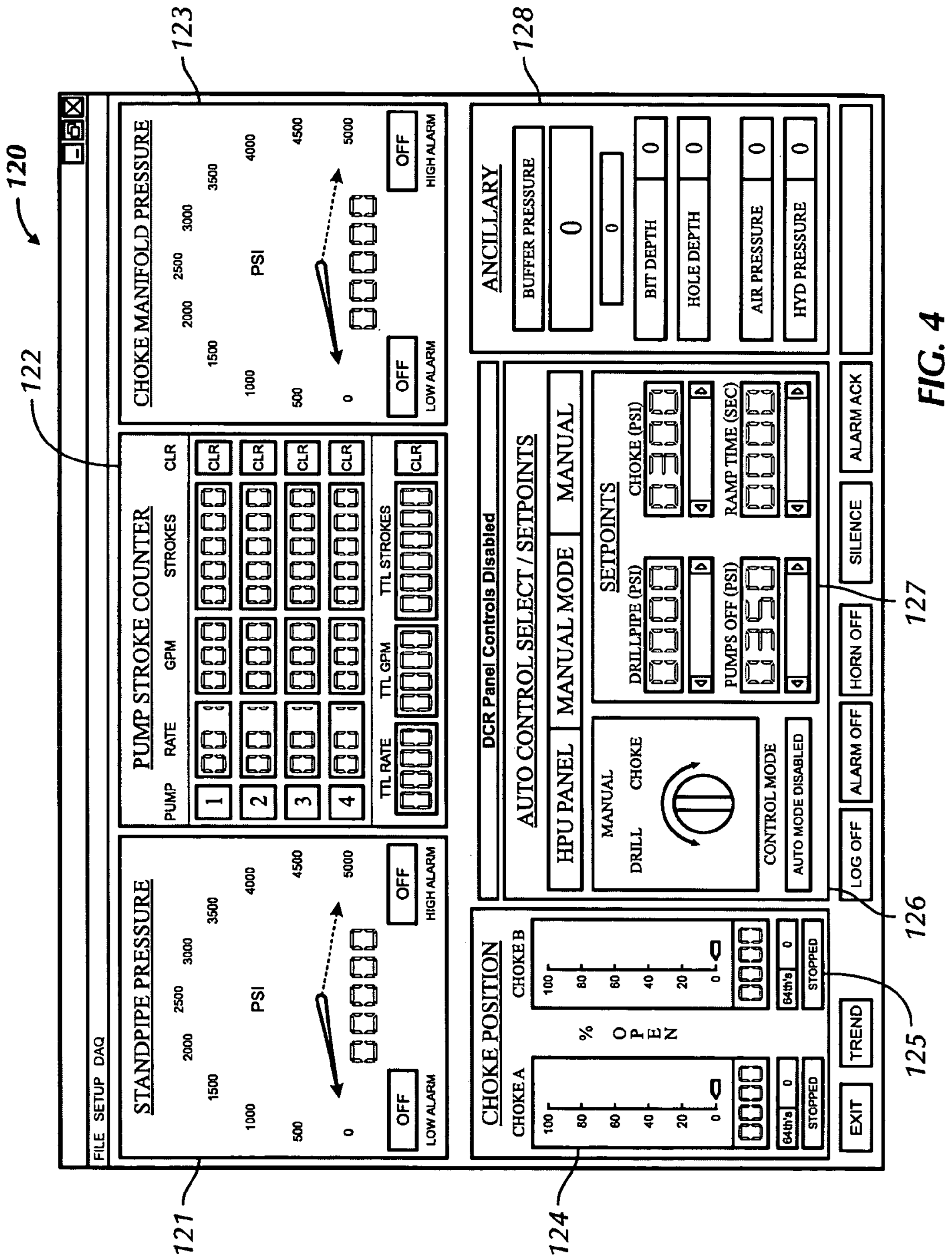

120
121
122
123
124
125
126
127
128
FILE SETUP DAQ
STANDPIPE PRESSURE
PSI
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
OFF
LOW ALARM
OFF
HIGH ALARM
PUMP STROKE COUNTER
PUMP
RATE
GPM
STROKES
CLR
1
2
3
4
TTL RATE
TTL GPM
TTL STROKES
CHOKE MANIFOLD PRESSURE
CHOKE POSITION
CHOKE A
CHOKE B
% OPEN
100
80
60
40
20
0
64th's
STOPPED
DCR Panel Controls Disabled
AUTO CONTROL SELECT / SETPOINTS
HPU PANEL
MANUAL MODE
MANUAL
DRILL
CHOKE
CONTROL MODE
AUTO MODE DISABLED
SETPOINTS
DRILLPIPE (PSI)
CHOKE (PSI)
PUMPS OFF (PSI)
RAMP TIME (SEC)
ANCILLARY
BUFFER PRESSURE
BIT DEPTH
HOLE DEPTH
AIR PRESSURE
HYD PRESSURE
EXIT
TREND
LOG OFF
ALARM OFF
HORN OFF
SILENCE
ALARM ACK

FIG. 4

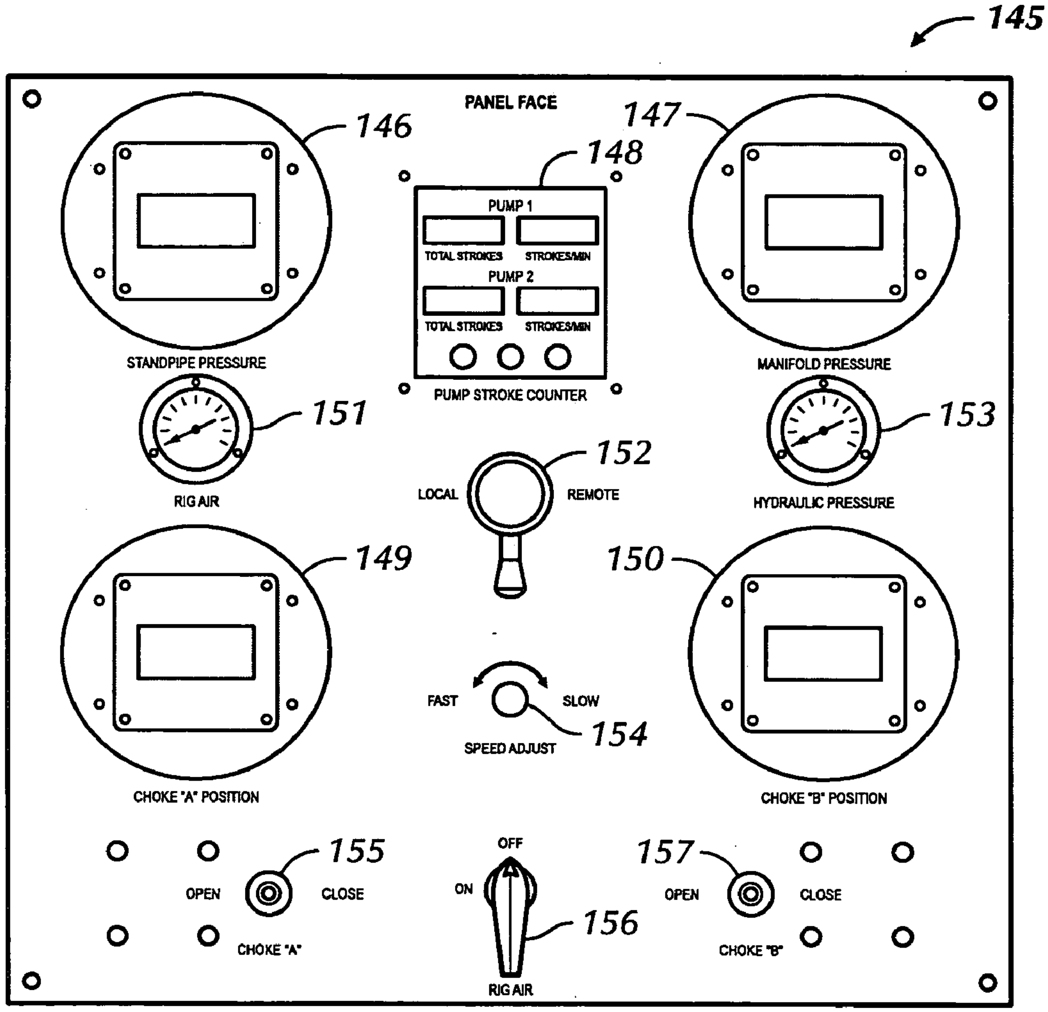

145
PANEL FACE
146
147
148
PUMP 1
TOTAL STROKES
STROKES/MIN
PUMP 2
TOTAL STROKES
STROKES/MIN
PUMP STROKE COUNTER
STANDPIPE PRESSURE
MANIFOLD PRESSURE
151
153
RIG AIR
HYDRAULIC PRESSURE
152
LOCAL
REMOTE
149
150
FAST
SLOW
154
SPEED ADJUST
CHOKE "A" POSITION
CHOKE "B" POSITION
155
OPEN
CLOSE
CHOKE "A"
OFF
ON
156
RIG AIR
157
OPEN
CLOSE
CHOKE "B"

FIG. 5

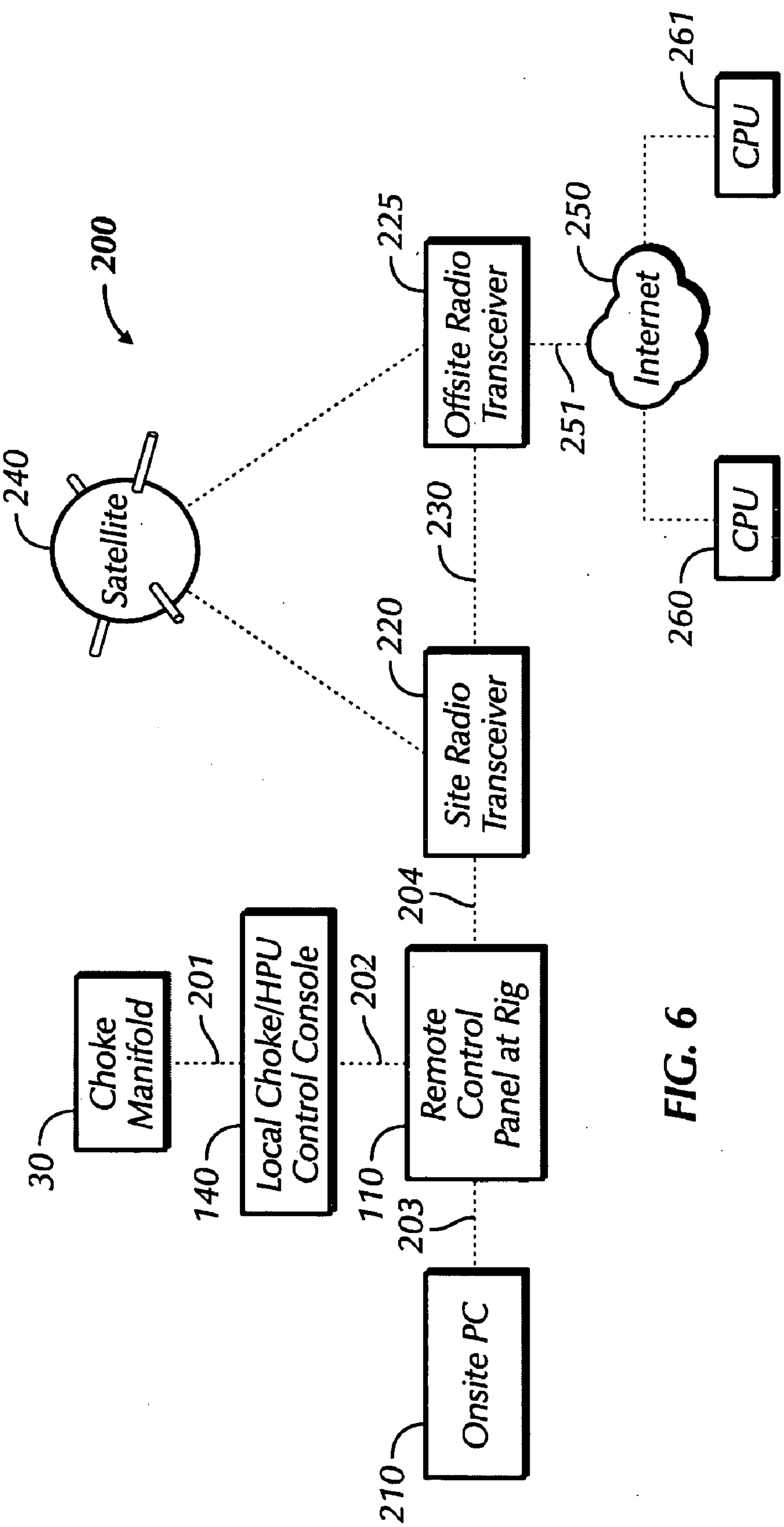

200
Satellite
240
Offsite Radio Transceiver
225
Internet
250
251
CPU
261
CPU
260
230
Site Radio Transceiver
220
204
Choke Manifold
30
201
Local Choke/HPU Control Console
140
202
Remote Control Panel at Rig
110
203
Onsite PC
210

FIG. 6

# WELL PRESSURE CONTROL SYSTEM

## CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to pending U.S. Patent Application Serial No. 60/515,875 (Attorney Docket Number PC-P007V, filed Oct. 30, 2003 by John McCaskill, et al. and entitled "Hydraulic Choke Control System for Underbalanced Drilling."

## FIELD OF THE INVENTION

[0002] The present invention relates to an apparatus for maintaining well pressure control in various situations such as underbalanced, overbalanced, or other managed pressure drilling of petroleum wells, or the control of petroleum wells that are out of control or likely to become out of control. More particularly, the present invention relates to the operation of hydraulic choke valves for the maintenance of a constant drilling fluid pressure on the downhole formation face despite fluctuations arising due to mud pump speed changes or other causes.

## DESCRIPTION OF THE RELATED ART

[0003] Hydraulic choke devices are commonly used in the oilfield when drilling wells for oil or natural gas in order to control or prevent undesired escape of formation fluids. Herein, the term "hydraulic choke" is taken to refer to the fact that the device is used with a variety of fluids, such as drilling mud, salt water, oil, and natural gas. "Hydraulic" does not herein refer to the choke actuation means, although the actuators are typically hydraulically powered. The hydraulic choke is utilized as a pressure-reducing valve for fluids outflowing from the well.

[0004] Optimal drilling conditions for certain formations, particularly sources of desirable fluid production, require underbalanced conditions. "Underbalance" in drilling refers to the maintenance of a lower drilling fluid pressure adjacent the formation than the pore pressure of the formation, so that drilling fluids do not invade the formation and degrade the ability of the formation to produce. "Underbalanced" drilling encourages flow from the well, so that a hydraulic choke is typically used on the outlet from the well. Similarly, maintenance of any managed pressure differential, negative, positive, or neutral, on a downhole formation requires suitable manipulation of a hydraulic choke to control the flow.

[0005] Undesirable variations in drilling fluid pressure may occur when changing the pumping rate of drilling fluid into the well unless the choke is appropriately adjusted to compensate. The present invention discloses an apparatus and method for accurately maintaining downhole pressures on the exposed formation as the pumping rate into the well is varied.

[0006] Surface mounted hydraulic choke valves have been used for downhole pressure control in the underbalanced drilling of petroleum wells. Normally, the chokes have been adjusted during the drilling process by direct action of a human operator. However, it is difficult for a human operator to compensate for variations in dynamic flow pressure losses in the annulus around the drillstring as the pump rate into the well changes.

[0007] For example, U.S. Pat. No. 6,352,129 B1 discloses a means of maintaining the downhole pressure within a desirable range by using a separate pump to inject fluid down the annulus with the choke closed after the pumps are turned off or are slowed. This approach takes time to balance the pressure. Furthermore, this approach complicates the rig flow circuitry, as well as the well cost and maintenance, while not necessarily proving easy to control within the desired accuracy.

[0008] Another problem is that most underbalanced control systems respond to pressure reductions in the outflow pressure of a well. Unfortunately when the pump rate into the well changes quickly and significantly, there is a time lag before the resultant reduced pressure is measured in the outflow pressure. Damage to the well can occur if the downhole pressure is allowed to vary too much before it is corrected. Thus, correcting reductions in the outflow pressure may not provide optimal timely control of the downhole pressure. Koderitz discloses one approach to this problem in U.S. Pat. No. 6,484,816 B1. Koderitz's approach is to provide a programmable controller that is responsive to a drill pipe sensor that directly detects the downhole pressure. Chang et al. describe a similar system in U.S. Pat. No. 6,575,244 B2. Chang et al. sense the actual downhole pressure, compare that pressure to a desired downhole pressure, generate an error signal reflecting the difference between the downhole pressure and the desired downhole pressure, and use that error signal to control the operation of the choke. Chang et al., unlike Koderitz, recognized that there is a lag time between the measurement of an undesirable downhole pressure and a corresponding correction of the choke and attempted to compensate for that lag time. However, even this approach addresses the situation after the downhole pressure has changed.

[0009] A need exists for an automatic, reliable, and robust oilfield service system for controlling hydraulic choke valves in a manner that accounts for variations in fluid flow and maintains a substantially constant total pressure on the open formation downhole.

## SUMMARY OF THE INVENTION

[0010] The present invention contemplates a choke control system that provides for local and off-site monitoring and control of the annulus flow pressure. The choke control system includes a choke manifold connected to at least one choke and its associated actuator; a variety of instrumental drilling sensors, pump stroke counter switches, and choke position indicators; a local choke and hydraulic pressure control console; and a programmable controller in communication with the local choke and hydraulic pressure control console. The programmable controller handles the logical operations of the choke control system, including processing instrument measurements and operator input data to produce control signals for operating the choke, the choke actuator and the various valves associated with the choke manifold. The programmable controller is typically either an electronic digital computer and/or a programmable logic controller (PLC). The present invention further contemplates the two-way communication between the choke control system and the Internet via a satellite linkage.

[0011] One aspect of the present invention is a choke control system for the control of an oilfield hydraulic drilling choke comprising: a choke axially reciprocable between a first position and a second position; a choke actuator for applying reciprocatory motion to the choke; a programmable controller in communication with the choke actuator, wherein the programmable controller provides operational control of the axial reciprocation of the choke; a site radio transceiver in communication with the programmable controller; a central processing unit; and an offsite radio transceiver in communication with the site radio transceiver and the central processing unit, wherein the central processing unit communicates with the programmable controller to selectably determine the position of the choke between the first and the second position.

**[0012]** Another aspect of the present invention is a choke control system for the control of an oilfield hydraulic drilling choke comprising: a drilling choke manifold system having at least two drilling chokes attached to the choke manifold and a choke actuator in communication with each drilling choke; a programmable controller having a memory, a power supply, and a plurality of data interfaces; a proportional-integral-differential control circuit interfacing between said logic controller and the drilling choke manifold system; a plurality of drilling sensors, wherein each sensor communicates with the programmable controller via one of the data interfaces; a site radio transceiver in communication with the programmable controller; an offsite central processing unit; and an offsite radio transceiver in communication with the site radio transceiver through a satellite communication linkage.

**[0013]** Yet another aspect of the present invention is a system for maintaining a fluid pressure within a well bore comprising: a mud pump for pumping fluid into the well bore, wherein a flow rate of the pump is proportional to the fluid pressure within the well bore; an axially reciprocable choke in fluid communication with an annulus of the well bore; a choke inlet pressure gauge for measuring a choke inlet pressure; a programmable controller providing operational control of the flow rate of the pump and the axial position of the choke; and an offsite central processing unit in communication with the programmable controller via a communication satellite.

**[0014]** A further aspect of the present invention is a method of maintaining fluid pressure control of a well bore, the method comprising: determining the flow rate of the pump; determining the choke inlet pressure; reporting the flow rate of the pump and the choke inlet pressure to the offsite central processing unit; calculating the fluid pressure in the annulus of the well bore; comparing the calculated fluid pressure with a desired annular fluid pressure; calculating adjustments needed in the flow rate of the pump or the axial position of the choke to achieve the desired annular fluid pressure; and transmitting the calculated adjustments to the programmable controller for implementation.

**[0015]** The foregoing has outlined rather broadly several aspects of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiment disclosed might be readily utilized as a basis for modifying or redesigning the structures for carrying out the same purposes as the invention. It should be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0016]** For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

**[0017]** **FIG. 1** is a schematic representation of a well pressure control system, showing the arrangement of the well, the drill string, and a simplified arrangement of the fluid circulating system;

**[0018]** **FIG. 2** is a hydraulic circuit schematic showing the equivalent circuit elements of the well and the fluid circulating system;

**[0019]** **FIG. 3** is a schematic diagram showing the controls system for the drilling choke manifold;

**[0020]** **FIG. 4** shows a front profile view of the local choke console and the hydraulic power unit package;

**[0021]** **FIG. 5** shows the panel face of the local choke console;

**[0022]** **FIG. 6** is a schematic diagram of the choke system in communication with the Internet via a satellite link.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0023]** The present invention relates to an apparatus for maintaining well pressure control in various situations such as underbalanced, overbalanced, or other managed pressure drilling of petroleum wells, or the control of petroleum wells that are out of control or likely to become out of control. More particularly, the present invention relates to the operation of hydraulic choke valves for the maintenance of a constant drilling fluid pressure on the downhole formation face despite fluctuations arising due to mud pump speed changes or other causes.

**[0024]** The present invention contemplates a choke control system that provides local and off-site monitoring and control of the annulus flow pressure. The choke control system includes a choke manifold connected to at least one choke and its associated actuator; a variety of instrumental drilling sensors, pump stroke counter switches, and choke position indicators; a local choke and hydraulic pressure control console; and a programmable controller in communication with the local choke and hydraulic pressure control console. The programmable controller handles the logical operations of the choke control system, including processing instrument measurements and operator input data to produce control signals for operating the choke, the choke actuator and the various valves associated with the choke manifold. The programmable controller is typically either an electronic digital computer and/or a programmable logic controller (PLC). The present invention further contemplates the two-way communication between the choke control system and the Internet via a satellite linkage.

**[0025]** Referring to **FIGS. 1 and 2**, the drilling system **10** for a petroleum well, exclusive of the derrick and other items not pertinent to this system, is shown. The well **11** as shown is not completed for production, but is in a representative drilling arrangement for penetrating a potential productive geological formation. The well **11** is a cylindrical hole, not necessarily vertical or straight, which is lined at its upper end by well casing **15**. The casing **15** is normally cemented into the ground, with the lower end of the casing and its annular cement layer indicated by the symbolic casing shoe **16**. As shown in **FIG. 1**, the drill bit **22** has penetrated the geologic formation below the casing shoe **16** and is assumed to be in a potential pay formation **25** which is sensitive to damage from exposure to wellbore pressures higher than its pore pressures.

[**0026**] The drillstring **18** consists of, from the upper end, the drill pipe **19**, the drill collars **20**, a float valve **21** (located between the drill collars **20** and the bit **22**), and the drill bit **22**. The drill bit **22** when cutting normally is in rotational contact with the bottom of the well **11**, with drill cuttings being circulated away from the bit and uphole in the annulus **24** between the drillstring **18** and the hole by means of drilling fluids flowing through nozzles **23** in the bit. Drilling fluid is taken from the sump **50** through suction line **13** to supply mud pump **12**, which in turn pumps drilling fluid down the bore of the drillstring. The outlet pressure of the mudpump, termed the standpipe pressure, is measured by standpipe pressure gauge **14**. Rotating head **17** provides a rotary seal between the top of the casing **15** and the drill pipe **19** of the drillstring **18**.

[**0027**] The formation **25** is typically competent but porous rock, but it may also be an unconsolidated bed of granular material. Because the formation **25** has pressurized somewhat compressible fluids in its communicating pore spaces, flow can occur either into or out of the formation. Underbalanced or managed pressure drilling is used in an attempt to avoid causing flow into the formation **25**, which can damage the productive capacity of the formation.

[**0028**] The formation **25**, in the schematic representation of **FIG. 2**, is modeled as a very large accumulator having an undisturbed formation pressure that could be measured with an in situ gauge **28**. Although such a gauge **28** is normally unavailable, it is shown in **FIG. 2** as a virtual entity. The capability of the formation **25** to communicate with the annulus **24** is somewhat restricted by formation permeability and alteration of the formation wall by the drilling process, as is indicated by the presence of the virtual flow restrictor **27**.

[**0029**] Flow from the annulus **24** passes upward through the casing **15**, closed above by the rotating head **17**, and exits the casing through laterally opening bell nipple **29**. The exiting flow is conducted through a flowline to a choke **38** or a choke manifold **30**. The choke valves **38** are basically a selectively variable ruggedized pressure reducing valve configured for drilling service. The choke manifold **30** normally has one choke working at a time, so for reasons of clarity, only one choke is shown in **FIG. 1**. However, the typical choke manifold consists of multiple chokes **38** with associated interconnecting piping and control valves. **FIG. 2** illustrates the most common scenario where two chokes **38**A and **38**B are associated with the choke manifold **30**.

[**0030**] Flow from the annulus **24** enters the four-way cross connection **31**, where it is selectively directed to either a first choke **38**A by way of first flow branch **32** or a second choke **38**B by way of second flow branch **33** or it flows into the choke bypass line **45**. Flow is able to enter both chokes **38**A and **38**B simultaneously as well as individually. Upstream of each of the chokes **38**A and **38**B is a pair of on/off choke inlet control valves **34**, typically of the gate variety, for isolating the chokes from the upstream side. Likewise, downstream of each of the chokes **38**A and **38**B is a pair of on/off choke outlet control valves **43**, typically of the gate variety, for isolating the chokes from the downstream side. Immediately upstream of each choke **38**A and **38**B is located a choke manifold pressure gauge **36** for measuring the pressure on the choke inlet. Likewise, immediately downstream of each choke **38** is located a choke outlet or buffer pressure gauge **42** for measuring the pressure on the choke outlet. Alternatively, a single choke inlet pressure gauge **36** installed at cross fitting **31** and/or a single choke outlet gauge **42** installed at the intersection of the outlet lines of the choke manifold **30** could be used.

[**0031**] Bypass line **45** has two intermediately located bypass line shutoff valves **46** similar to valves **34** and **43** for controlling flow in the bypass line. The first flow branch **32** and the second flow branch **33** reconnect to the choke bypass line **45**, with flow exiting from the choke manifold **30** by way of return line **49** and thence passing to the sump (mud pit) **50**.

[**0032**] The chokes **38**A and **38**B are operated by hydraulic actuators **39**, which are in turn driven by a pneumatically powered pump integral with the hydraulic power (HPU)/control valve unit **143** of the local choke console and hydraulic power package or local choke/HPU control console **140**. As an alternative, the chokes **38**A and **38**B could be operated pneumatically or electrically, and the drive for the HPU/control valve unit **143** could be electric. The chokes **38**A and **38**B are provided with a choke control system **100**, which is able to operate both chokes autonomously with sensor inputs or manually with operator overrides.

[**0033**] The schematic diagram of **FIG. 3** shows the arrangement of the control system **100** for the choke manifold **30** of the present invention. The control system **100** consists of the four primary subassemblies: (1) the virtual choke console **110**; (2) the local choke/HPU control console **140**; (3) the drilling sensors **14**, **36**, **42**, and the pump stroke counter switches **172**; and (4) the chokes and the associated actuators **39** with their feedback choke position sensors **182**.

[**0034**] The virtual choke console **110** is located in the driller's control room of the drilling rig (not shown) so that the driller can more readily ascertain system status and better control the rig. The console **110** is provided with a programmable controller having a memory, operational software, a power supply **113**, and data interfaces with a local choke/HPU control console **140** that is in communication with the choke manifold system. The programmable controller is typically an electronic digital computer and/or a programmable logic controller (PLC) **111**, as shown in **FIG. 3**, to handle the logical operations of the system, including processing instrument measurements and operator input data to produce control signals for operating the chokes **38**A and **38**B, the choke actuators **39** and the various valves **31**, **34**, **36**, and **46** associated with the choke manifold **30**.

[**0035**] For example, changes (including predictive changes) in annulus pressure may be measured or calculated from either the pressure in the drillpipe and the mud weight, or from a hydraulic model of the well using simulation software. The proper control signals for making positional changes in one or more chokes and/or one or more valves as needed to maintain control of the desired annulus pressure are communicated from the programmable controller to the local choke/HPU control console **140** that is in communication with the choke manifold system, as well as to the virtual choke display panel **120**. More specifically, the PLC **111** typically communicates data with a proportional-integral-differential (PID) position control circuit **112** that is in communication with the HPU/control valve unit **143** for operation of the chokes **38**A and **38**B and the control valves.

[**0036**] Power from the rig is converted by an onboard power supply **113** in the console **110** to a power compatible with the electronics of the control system **100**.

[**0037**] The hole depth measurement is either input by the driller or instrumentally provided by a sensor **114**, likewise the annulus mud weight is provided by either input from the driller or by a sensor **116**. These inputs are communicated to the programmable controller of the console **110** by the rig Ethernet data network through the Ethernet hub **115** of the rig. Communication with the other major subsystems of the control system **100** is by means of interconnecting cables **118**.

[**0038**] The virtual choke display panel **120**, shown in more detail in **FIG. 4**, displays the critical instrument readouts which permit the driller to be properly informed about the well pressure status. The arrangement of the display panel **120** gives the driller the capability to select either automatic control using the PLC **111** and its associated hardware and software to control choke operation or, alternatively, manual control. The panel **120** shows on a liquid crystal display (LCD) screen virtual gauges for the control parameters. The virtual gauges are digitally generated images that have the appearance of actual mechanical gauges and serve to provide a very flexible readout of the appropriate readings. Among the virtual gauges shown in the arrangement of **FIG. 4** are the standpipe pressure gauge readout **121**, the pump stroke counter **122**, the choke inlet pressure gauge readout **123**, the choke A position readout **124**, the choke B position readout **125**, a selector for automatic or manual choke control **126**, setpoint displays **127**, and ancillary information displays **128**.

[**0039**] The pump stroke counter **122** displays for each rig pump the pump rate, the flow rate, the stroke rate, and cumulative totals for those same parameters. The setpoint displays show the desired drill pipe pressure, the desired choke inlet pressure, the desired pumps-off pressure, and the ramp up and ramp down times for changing between pump on and off states for the choke manifold **30**. The ancillary data includes the choke outlet (buffer) pressure, the bit depth, the hole depth, and the air and hydraulic pressures for the HPU/control valve unit **143**. Virtual switches activated by screen contact by the driller serve to provide operator selectablity over the array of manual control functions for the choke control system **100**.

[**0040**] The local choke/HPU control console **140** consists of the HPU/control valve unit **143** with its associated rig air pressure transmitter **141** and hydraulic power unit (HPU) pressure transmitter **142**, along with the local choke console display panel **145**.

[**0041**] The local choke console display panel **145** is shown in **FIG. 5** with its conventional indicators and operator controls. The panel **145** includes a standpipe pressure display **146** reporting the data from the gauge **14**, a choke manifold inlet pressure display **147** showing the pressure data from gauge **36**, a conventional pump stroke counter **148**, and conventional choke position indicators **149** and **150** for choke **38**A and choke **38**B respectively. Additionally, a rig air pressure gauge **151**, an actuator hydraulic pressure gauge **153**, and a selector **152** for either local or remote control are on the local choke display panel **145**. Finally, manual system controls on the display panel **145** include a choke speed adjustment **154**, a rig air on/off control switch **156**, and separate choke **38**A and choke **38**B controls for choke position **155** and **157**, respectively.

[**0042**] The standpipe pressure gauge **14** is connected to its display **146** by cable **161**, the choke manifold pressure gauge **36** is connected to its display **147** by cable **165**, and the choke outlet (buffer) pressure gauge **42** is connected to the display panel **145** by a cable **169**. Additionally, a pump stroke switch **172** is mounted on each mud pump **12** of the drilling system **10** and communicates its data to the local choke/HPU control console **140** by a cable **173**.

[**0043**] Each choke **38** with its attached actuator **39** has a choke position sensor **182** mounted thereon and reporting to the local choke/HPU control console **140** over cable pair **181**. The actuators **39** of the chokes **38**A and **38**B are powered by connecting hydraulic hoses **180**, which are in turn connected to the hydraulic power unit and its control valves **143**. Rig air from the rig air source tank **190** is attached to the HPU/control valve unit **143** by means of rig air line **191**.

[**0044**] **FIG. 6** schematically illustrates an alternative arrangement of the choke control system **200** connected to the Internet through a satellite link, such that the system may be monitored and controlled remotely from the rig. This satellite linkage to the control system **200** permits two way communication between the well and one or more central processing units (CPUs). Access to well data at distant sites allows for well monitoring from an operator's headquarters or other site. If desired, the entire choke control system at the rig can be controlled from a remote location using the radio links described herein and illustrated in **FIG. 6**.

[**0045**] In the choke control system **200** shown in **FIG. 6**, the choke manifold **30** is attached by means of a cable **201** to the local choke/HPU control console **140** and attendant mechanism located at the choke manifold. A second cable **202** interconnects the remote control panel **110** and its attendant mechanism with the local choke/HPU control console **140** located at the choke manifold. A first data port in the remote control panel **110** at the rig is provided whereby a separate, autonomous onsite personal computer (PC) **210** can be connected to the rig remote control panel **110** by means of a suitable cable **203**. This first data port permits two-way communication of data and control of the rig choke control system by an onsite personal computer **210**.

[**0046**] The remote control panel of the rig **110** is also provided with a second data port for two-way communication. A cable connection **204** from the second data port allows communication between the remote choke control panel and a site radio transceiver **220**. When utilized, the radio transceiver sends and receives signals to a second, off-site radio transceiver **225**. The signals may be communicated either directly through communication cabling **230** or they may be relayed by a commercially available satellite **240**. The satellite **240** is used to permit two-way communication with an off-site radio transceiver over substantial distances. This is particularly advantageous for high frequency radio communications, since such connections are basically line of sight and hence limited in range unless a satellite relay is used.

[**0047**] If the offsite radio transceiver **225** is attached for two-way communication to one or more CPUs, such as CPU **260** or CPU **261**, via the Internet **250** via cabling **251**, then the local rig choke control system may be accessed remotely by means of the Internet combined with the two-way satellite radio link. This enables the control of the rig choke control system **110** by a very broad array of possible access points. Such control communication may prove desirable in the event that offsite expertise and/or supplemental algorithms are needed in a well control situation.

[**0048**] Operation of the Invention

[**0049**] The arrangements shown in the drawings of this document can be varied from what is depicted without departing from the spirit of the present invention. Likewise, the operational sequence can be varied somewhat from what is described herein without departing from the spirit of the invention.

[**0050**] The pressure at the open annulus **24** in a well is a combination of hydrostatic pressure due to the height of the annulus fluid column and the density of the returning drilling fluid (including its cuttings), the pump action, the dynamic or static pressure drop across the choke manifold **30**, and the annular flow losses. The annular flow losses are dependent on velocities, flow Reynolds numbers, and the mud viscosities. American Petroleum Institute (API) API Bulletin **13**D: "The Rheology of Oil-Well Drilling Fluids", 1st Edition, August 1980 gives information on how these flow losses and those of the drillstring can be calculated from flow rates, well properties, and mud properties. Thus, the downhole pressure and predicted variations of the downhole pressure can be solved using algorithmic calculations. Many of the necessary calculations can be performed at the rig site using software programs entered into the choke control system **100**. The software programs typically use the data acquired by the instrumentation associated with the control system **100** supplemented with manual data inputs to calculate downhole pressure and other desired variables.

[**0051**] For example, the desired downhole annulus pressure may be preselected based on the formation pressure inferred from well stability testing and geological parameters. For a porous formation, the formation pressure at a given depth consists of a hydrostatic pressure component that varies linearly with depth in the formation and a geopressure. The geopressure can be much higher than the hydrostatic pressure component depending on the formation depth, or the geopressure can be much lower than the hydrostatic pressure component in a depleted formation.

[**0052**] Rig measurements are made of the drilling mud properties, including viscosity properties of the mud and the density of the mud return from the well. This data can be entered manually into the control system **100** or can be digitally entered by the instrumentation. The depth of the well is accurately determined from the footage of the drillstring in the well and can be entered into the control system **100**. In addition, accurate flow rates can be determined using information such as the measurement of the pump strokes by sensors **172** and the pump volumetric efficiencies. The diameters of the drill pipe **19**, the drill collars **20**, the bit nozzles **23**, the casing **15**, and the hole cut by the bit **22** are also known with reasonable accuracy and can be used to calculate the annulus flow velocities and, hence, flow losses for the different sections of the annulus **24**. All of this data can be manually or automatically entered into the control system **100** so that the annulus pressure drop as a function of pump strokes can be determined by the control system.

[**0053**] The pressure drop across the choke manifold **30** is measured as the difference between the pressure readings from gauges **36** and **42**. The choke outlet pressure from gauge **42** is normally very low unless a stoppage occurs in the outlet line. In any case, the actual choke inlet pressure **36** is required for proper adjustment of the choke manifold **30**.

[**0054**] The operation of the present invention when a single choke is in use is as follows. The system uses the data from operator inputs and instrument measurements to calculate the annular pressure drop as a function of flow. When the pressure at the choke inlet pressure gauge **36** deviates from its calculated desired level for maintaining the bottomhole annular pressure constant, then the PID position control circuit **112**, using its coded control algorithms, signals the control solenoid valves of the HPU/control valve unit **143** to adjust the position of the active choke **38**. The choke position is adjusted by appropriately applying hydraulic fluid to one side or the other of the choke actuator **39**.

[**0055**] The deviation in choke inlet pressure due to random causes is minor, with most of the deviation being due to variations in the drilling fluid flow rate. As a first order estimate, the annulus flow pressure drop is proportional to the square of the flow rate of the mud pump **12**. In the case when the mud pump **12** is shutting down to, say, make a drillstring connection, the control system **100** performs the following functions: it calculates predicted changes in the annulus flow pressure drop, it calculates a ramping program for adjusting the choke position to continuously maintain the desired pressure in the annulus **24**, and it communicates the ramping program to the local choke/HPU control console **140**.

[**0056**] Typically, the ramping program is based on the assumption that the float valve **21**, a type of check valve, is able to hold the annulus flow pressure. In the event that the float **21** is leaky and the formation **25** pressure is in excess of the pressure in the annulus **24**, some formation flow will offset the float valve leakage. In any event, with float valve **21** leakage or not, some influx from the formation **25** will occur into the annulus **24**, so that venting through the choke manifold **30** may be necessary to achieve the desired annulus pressure underbalance.

[**0057**] In other instances, the amount of flow is excessive for a single choke **38**, so that a preset limit (the choke setpoint shown in **FIG. 4** as part of the display for the setpoint readouts **127**) is exceeded. At that point, the control system **100** will automatically open the other choke **38** so that the desired bottomhole annular pressure can be reestablished. If the control system is not operating in the automatic control mode, then the driller at display panel **120** or at the local choke console **145** can do the opening of the second choke **38** manually.

[**0058**] When it is desired to switch from one choke **38** to another in the choke manifold **30** during the course of operations, the control system **100** is able to automatically perform the change. This approach can also be duplicated manually or semi-manually.

[**0059**] One approach to switching the operational choke is as follows. The position of the first choke, say choke **38**A, is recorded. The second choke **38**B is then opened to a fixed percentage, say 20%, of the opening of choke **38**A, following which the choke isolation valves **34** and **43** are opened. With the drop of choke inlet pressure resulting from the opening of the choke **38**B in parallel with the properly adjusted choke **38**A, the control system **100** compels the choke **38**A to adjust in compensation. Multiple further incremental openings of choke **38**B are made until choke **38**A reaches its fully closed position under direction of the control system **100** or the preset close limit of the choke **38**A is reached, also causing closing of choke **38**A. The preset close limit of the choke **38**A is preset on the control panel **120** in the setpoint readouts **127**. The choke isolation valves **34** and **43** for choke **38**A are then closed and choke **38**B effectively controls the annulus backpressure.

[**0060**] An alternative approach to switching the operational choke utilizes the control system **100** to calculate a ramping program for the opening of one choke and the closing of the other choke. The ramping program can make multiple incremental coordinated adjustments to the position of both choke **38**A and **38**B. In addition, the control system **100** can introduce the coordinated opening and closing of relevant choke isolation valves **34** and **43**.

[**0061**] The choke control system **200**, illustrated in **FIG. 6**, is connected to the Internet through a satellite link. This satellite linkage to the control system **200** permits two-way communication between the well and one or more CPUs. Access to well data at distant sites allows for well monitoring from an operator's headquarters or other site. If desired, the entire choke control system at the rig can be controlled from a remote location using the radio links described herein and illustrated in **FIG. 6**.

[**0062**] Advantages of the Invention

[**0063**] The present invention permits utilization of a quickly responding, accurate automatically controlled hydraulic choke system for close control of the annular pressure in a petroleum well being drilled in an underbalanced, overbalanced, or managed pressure condition, as well as for the control of situations where the well is out of control or likely to become out of control. The choke control system **100** and **200** are readily adaptable to a wide variety of well control situations. Additionally, the system is readily adjusted and serves as an adjunct to conventional drilling hardware.

[**0064**] The satellite linkage of the choke control system **200** can be particularly valuable when the operator is faced with an unusual situation requiring additional calculations and considerations for proper adjustments to maintain the desired well pressure. By providing for offsite control, engineers at the operator's headquarters can supplement the rig data with inputs obtained from external databases and/or calculated using supplemental software programs.

[**0065**] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

**1**. A choke control system for the control of an oilfield hydraulic drilling choke comprising:

a choke axially reciprocable between a first position and a second position;

a choke actuator for applying reciprocatory motion to the choke;

a programmable controller in communication with the choke actuator, wherein the programmable controller provides operational control of the axial reciprocation of the choke;

a site radio transceiver in communication with the programmable controller;

a central processing unit; and

an offsite radio transceiver in communication with the site radio transceiver and the central processing unit, wherein the central processing unit communicates with the programmable controller to selectably determine the position of the choke between the first and the second position.

**2**. The choke control system of claim 1 having at least two axially reciprocable chokes.

**3**. The choke control system of claim 1, further comprising a choke manifold.

**4**. The choke control system of claim 3 having at least two axially reciprocable chokes attached to the choke manifold.

**5**. The choke control system of claim 4, wherein the programmable computer provides coordinated operational control of the axial reciprocation of the chokes attached to the choke manifold.

**6**. The choke control system of claim 1, further comprising a choke inlet control valve and a choke outlet control valve.

**7**. The choke control system of claim 6, wherein the programmable computer provides operational control of the choke inlet control valve and the choke outlet control valve.

**8**. The choke control system of claim 1, wherein the choke actuator is hydraulically operated.

**9**. The choke control system of claim 1, wherein the programmable controller is a computer.

**10**. The choke control system of claim 1, wherein the programmable controller is a programmable logic controller.

**11**. The choke control system of claim 1, further comprising a personal computer in communication with the programmable controller.

**12**. The choke control system of claim 1, further comprising a proportional-integral-differential control circuit interfacing between the programmable controller and the actuator.

**13**. The choke control system of claim 1, further comprising a drilling sensor in communication with the programmable controller.

**14**. The choke control system of claim 13, wherein the drilling sensor is a choke inlet pressure gauge, a well depth monitor, an annular mud density gauge, a choke position monitor, a pump stroke counter, or a combination of the same.

**15**. The choke control system of claim 1, wherein the offsite radio transceiver communicates with the central processing unit via the Internet.

**16**. The choke control system of claim 1, further comprising a satellite communication linkage between the site radio transceiver and the offsite radio transceiver.

**17**. The choke control system of claim 1, wherein the programmable controller transmits information to and receives information from the central processing unit.

**18**. The choke control system of claim 1, further comprising an onsite personal computer in communication with the programmable controller.

**19**. A choke control system for the control of an oilfield hydraulic drilling choke comprising:

a drilling choke manifold system having at least two drilling chokes attached to the choke manifold and a choke actuator in communication with each drilling choke;

a programmable controller having a memory, a power supply, and a plurality of data interfaces;

a proportional-integral-differential control circuit interfacing between said logic controller and the drilling choke manifold system;

a plurality of drilling sensors, wherein each sensor communicates with the programmable controller via one of the data interfaces;

a site radio transceiver in communication with the programmable controller;

an offsite central processing unit; and

an offsite radio transceiver in communication with the site radio transceiver through a satellite communication linkage.

**20**. The choke control system of claim 19, wherein the programmable computer provides coordinated operational control of the axial reciprocation of the chokes attached to the choke manifold.

**21**. The choke control system of claim 19, further comprising a choke inlet control valve and a choke outlet control valve.

**22**. The choke control system of claim 21, wherein the programmable computer provides operational control of the choke inlet control valve and the choke outlet control valve.

**23**. The choke control system of claim 21, wherein the programmable computer provides coordinated operational control of the choke inlet control valve, the choke outlet control valve, and the axial reciprocation of the chokes attached to the choke manifold.

**24**. The choke control system of claim 19, wherein the choke actuator is hydraulically operated.

**25**. The choke control system of claim 19, wherein the programmable controller is a computer.

**26**. The choke control system of claim 19, wherein the programmable controller is a programmable logic controller.

**27**. The choke control system of claim 19, further comprising a personal computer in communication with the programmable controller.

**28**. The choke control system of claim 19, wherein the drilling sensors include one or more of (a) a choke inlet pressure gauge, (b) a well depth monitor, (c) an annular mud density gauge, (d) a choke position monitor, and (e) a pump stroke counter.

**29**. The choke control system of claim 19, wherein the offsite radio transceiver communicates with a central processing unit via the Internet.

**30**. The choke control system of claim 29, wherein the programmable controller transmits information to and receives information from the central processing unit.

**31**. The choke control system of claim 19, further comprising an onsite personal computer in communication with the programmable controller.

**32**. A system for maintaining a fluid pressure within a well bore comprising:

a mud pump for pumping fluid into the well bore, wherein a flow rate of the pump is proportional to the fluid pressure within the well bore;

an axially reciprocable choke in fluid communication with an annulus of the well bore;

a choke inlet pressure gauge for measuring a choke inlet pressure;

a programmable controller providing operational control of the flow rate of the pump and the axial position of the choke; and

an offsite central processing unit in communication with the programmable controller via a communication satellite.

**33**. The system of claim 32 having at least two axially reciprocable chokes.

**34**. The system of claim 32, further comprising a choke manifold.

**35**. The system of claim 34 having at least two axially reciprocable chokes attached to the choke manifold.

**36**. The system of claim 35, wherein the programmable computer provides coordinated operational control of the axial reciprocation of the chokes attached to the choke manifold.

**37**. The system of claim 32, further comprising a choke inlet control valve and a choke outlet control valve.

**38**. The system of claim 37, wherein the programmable computer provides operational control of the choke inlet control valve and the choke outlet control valve.

**39**. The system of claim 37, wherein the programmable computer provides coordinated operational control of the choke inlet control valve, the choke outlet control valve, and the axial reciprocation of the choke.

**40**. The system of claim 32, further comprising a choke actuator

**41**. The system of claim 40, wherein the choke actuatoris hydraulically operated.

**42**. The system of claim 32, wherein the programmable controller is a computer.

**43**. The system of claim 32, wherein the programmable controller is a programmable logic controller.

**44**. The system of claim 32, further comprising a personal computer in communication with the programmable controller.

**45**. The system of claim 32, further comprising a proportional-integral-differential control circuit interfacing between the programmable controller and the actuator.

**46**. The system of claim 32, further comprising a drilling sensor in communication with the programmable controller.

**47**. The system of claim 46, wherein the drilling sensor is a choke inlet pressure gauge, a well depth monitor, an annular mud density gauge, a choke position monitor, a pump stroke counter, or a combination of the same.

**48**. The system of claim 32, further comprising a site radio transceiver, in communication with the programmable controller and the communication satellite, and an offsite radio transceiver, in communication with the communication satellite and the central processing unit.

**49**. The system of claim 48, wherein the offsite radio transceiver communicates with the central processing unit via the Internet.

**50**. A method of maintaining fluid pressure control of a well bore using the system of claim 32, the method comprising:

determining the flow rate of the pump;

determining the choke inlet pressure;

reporting the flow rate of the pump and the choke inlet pressure to the offsite central processing unit;

calculating the fluid pressure in the annulus of the well bore;

comparing the calculated fluid pressure with a desired annular fluid pressure;

calculating adjustments needed in the flow rate of the pump or the axial position of the choke to achieve the desired annular fluid pressure; and

transmitting the calculated adjustments to the programmable controller for implementation.

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