Disclosed is a system for regulating and controlling well drilling operations where the control of the operations is interchangeable between a location at the rig for manual control and remote location away from the rig for remote control. The manual and remote control functions are continually compared and regulated to maintain a parity therebetween, thereby permitting "bumpless" transfer between the control at one location to the control at the other location.

24 Claims, 4 Drawing Figures
DRILLING CONTROL TRANSFER SYSTEMS

BACKGROUND OF THE INVENTION

This invention relates to control systems and more particularly, to control systems for selectively controlling operating parameters in a well drilling operation from either the drilling rig or a remote control station.

In a typical rotary drilling operation for an oil well, a tubular drilling string carries a drilling bit at its lower end and the string is rotated while weight is applied so that the bit will cut through formation strata. To remove the earth cuttings from the part of the bit and to cool the bit, a mud system is used. The mud system includes a surface located pump means coupled to a surface tank for delivering a drilling fluid to the drilling string. The mud is conveyed by the drilling string to the drilling bit and exits therefrom. The fluid returns to the surface by traveling upwardly in the annulus between the drill pipe and well bore and carries with it cuttings from the earth formations.

In the above operation there are several controlled drilling parameters such as:
1. bit weight — weight applied to the drilling bit which drills the hole;
2. rotary speed — the revolutions per minute (rpm) at which the string of pipe and attached drilling bit are rotated;
3. drilling fluid circulation rate — by control of the throttle and clutch of the mud pumps, the flow rate of drilling fluid is controllable;
4. standpipe pressure or casing pressure — by control of one or more variable chokes in the return fluid line to regulate the pressure of the drilling fluid;
5. standpipe pressure — by control of the throttles and clutch of the mud pumps, the standpipe pressure of the drilling fluid is controllable.

For control and information purposes, it is common to measure various other parameters such as hook load, rotary torque, block position, block speed, rate of penetration (ROP), standpipe mud flow rate - in and out, pump stroke rate and count, mud viscosity, and so forth. Functional relationships between the various parameters of the drilling operation are used to control the efficiency and safety of the operation and permit constant evaluation of the drilling operation.

Normally, the driller exercises a manual control of the drilling operation based upon the measured parameters. Assuming that you have a computer to apply to computer control to the oil well drilling operation, a unique problem is created in providing a capability to transfer control from the normal manual operation of the rig or machinery by the operator (or drilled) to the fully automatic control by a computer and vice-versa. The problem is that if the drilling parameters are not properly matched at the time of transfer, there can be a serious disruption in the continuity and operation of the process.

Concerning the present invention, it relates to a system which permits:
1. Manual control of a parameter at the rig by the driller, or
2. Remote control of the parameter at a remote location by either
   a. Manual remote control where an operator can control the parameter from a remote location,
   b. Semi-automatic control where an operator periodically adjusts a “set-point” control which, in turn, permits a controller to adjust the parameter to the set-point,
   c. Automatic control where a computer periodically adjusts a set-point control which, in turn, permits a controller to adjust the parameter to the set-point, or
   d. Automatic control where a computer adjusts the parameter directly.

Where the control function can be at either of two locations, it is desirable at such time as the control function is shifted between the locations that the control setting at each of the locations be similar so that the parameter is not suddenly affected by a significantly different control setting value. This is sometimes referred to in this Application as a “bumpless” transfer function.

SUMMARY OF THE PRESENT INVENTION

In the present system, parallel control means are provided for the parameter to be controlled at the drilling rig. One of the control means is in operational control as a prime control means and performs a relative control function of a parameter. The other control means also has a control function generated but is disengaged from operational control. The control function of each of the control means is compared and the comparison permits adjustment of the disengaged control means into parity or alignment with the prime control means so that if a transfer of control is effected between the control means, the control function for the parameter at each of the control means is similar. In the present system the process or apparatus serves to control the magnitude of an operating parameter. One of the two independent control systems is selected to control the magnitude of the operating parameter, and magnitude of a similar operating parameter at the other control system is used to provide a comparison value and produce a deviation signal when the magnitudes are dissimilar. A control loop is responsive to deviation signals from the comparison for adjusting the magnitude of the operating parameter of the parasitic or slave control system into parity with the directly controlled parameters so that if there is a transfer of control, the control can be smoothly transferred between systems without disrupting the drilling operation.

With respect to controlling the operations of a drilling rig, a local on-site rig control station and a remote control station are provided. The two independent stations are arranged so that either station, upon selection, exercises independent control of the throttle, for example, of a mud pump. For purposes of this discussion, control systems utilizing pneumatic pressure will be described. It will be readily appreciated that similar control action could be accomplished in systems using electrical, hydraulic, or other controlling means. At the local station where the pump is located, a manual control means adjusts the pneumatic pressure to the throttle of a pump. An electrically controlled fluid pressure generating means is coupled to one side of a pressure comparison cell, while the other side of the cell is coupled to the manual control pressure line. The difference in control pressures is sensed and transmitted as a signal indicating a balanced, higher or lower pressure at the rig. The signals are transmitted to a remote location. At the remote location, if the manual control is active, the signal representative of a higher or lower pressure will operate through a control loop to increase
or decrease the pressure of the electrically controlled generating means to balance the pressure to the comparison cell so that the pressure is constantly balanced to the pressure in the manual control pressure line. By a switching action, the control of the throttle can be switched at any time to the electrically controlled generating means which is controllable by the remote location, and the transfer is "bumpless" in that the pressure control of the throttle is the same for both manual and electrical pressure generating means. When setpoint controllers are employed, setpoint is also continually adjusted to match measurement (pump pressures, for instance) by comparison of setpoint feedback signal and measurement signal in the computer or analog counterpart. This results in coordination of setpoint and output of electrically controlled pressure generating means such that no deviation occurs between process and setpoint at time of transfer.

At the remote location, the control for increasing or decreasing the electrical pressure generating means can be either manual or computer controlled.

**BRIEF DESCRIPTION OF THE DRAWINGS**

In the following detailed description of a specific embodiment of the present invention, the objects and advantages of the present invention will be more apparent when the following description is taken in connection with the accompanying drawings in which:

**FIG. 1** is a view of a general drilling system;

**FIG. 2** is a schematic illustration of a mud pumping system for an oil well drilling operation;

**FIG. 3** is a schematic illustration of a control system for a mud pumping system; and

**FIG. 4** is a schematic illustration of a remote/local control system which can achieve bumpless transfer of control between locations.

**DETAILED DESCRIPTION OF THE INVENTION**

Referring first to **FIG. 1**, a well drilling system embodying the invention is illustrated in relation to a conventional drilling rig and drilling well. In **FIG. 1**, the lower uncased portion of a borehole being drilled is identified by the number 10. The upper cased portion of the borehole contains the usual surface string or conductor string of casing 12 which has been set and cemented.

Within the borehole and at the surface above the borehole is shown a substantially conventional rotary drilling rig system including a drill string comprising a drill bit 13, tubular drill collars 14, and a drill stem composed of tubular drill pipe sections 15 which are connected at an upper end by a tubular Kelly joint 16 to a swivel 17. The swivel 17 is suspended from a traveling block hook 18 on a traveling block 19. Drilling lines 20 and a crown block 21 located in the top of a derrick 22 provide means for moving the traveling block 19 up and down. The Kelly joint 16 passes through conventional driving means in a rotary table 25 which is supported in a usual suitable manner upon the derrick floor or foundations. The rotary table 25 is adapted to be rotated by means of the usual rotary table drive which can be a bevel gear 26 and pinion 27.

The pinion 27 is driven by a conventional chain drive or through a suitable shaft drive from an independent prime mover (not shown), or as illustrated at 28, by the power unit of a drawworks 30. The drawworks 30 also spools or operates the drilling lines 20.

The drilling fluid circulation system includes a circulating pump 36 which has an input or suction pipe 38 which extends into a mud reservoir or sump 40 which contains a drilling fluid or liquid 39. The discharge connection 35 of the pump 36 is coupled by connecting pipes 32 and 33 to a flexible hose 31 which is attached to the swivel 17. The swivel 17, the Kelly joint 16, the pipe sections 15, and the drill collars 14 provide a fluid conduit to the drill bit 13. The pump 36 delivers fluid or liquid to the drill bit and the fluid or mud returns to the surface in the annulus between the borehole and drill string. At the upper end of the surface casing 12 is a lateral or side outlet pipe 42 which extends to the drilling fluid reservoir 40 for the discharge of returned drilling fluid to the reservoir 40. A surge chamber 45 or other suitable surge dampening means can be connected to the discharge 35 of the drilling fluid circulating pump 36 for the purpose of smoothing out or reducing the pump discharge pressure fluctuations.

Referring now to **FIG. 2**, an elemental mud circulation system is illustrated in simplified form for ease of understanding. In **FIG. 2**, the interior of a tubular casing or pipe string 15 in a well bore (shown in cross-section) is coupled to a well input line 31. A mud return annulus 44 is defined between the exterior of the drill string 15 and surface casing 12 for the well bore and is coupled to a mud return line 42. The mud return line 42 from the casing is coupled to shale shakers and other reconditioning devices (not shown) for reconditioning of the mud before it is returned to the mud tank. The various well-known elements of the reconditioning system are not shown since they form no part of this invention.

To supply the mud to the well bore the mud from the mud tank (not shown) is drawn into an input element 38 for the mud pumps illustrated as 46 and 47. The valves 43 and 45, respectively, in the inlets to the mud pumps can be manually operated to cut off the flow to a pump. The pump 46 outputs a liquid flow to the well input line 31 via a valve 48. The pump 47 outputs a liquid flow to the well input line 31 via a valve 50.

The mud pumps 46 and 47 (which are conventional) have important functions in the circulation system which include (1) the promotion of drilling by virtue of providing a liquid flow for a jetting action at the bit, (2) the circulation of a sufficient quantity of mud to keep the bit washed clean; and (3) the return of solid earth particles to the surface, thereby keeping the hole free of cavings, cuttings and weight material settings. The density, viscosity and gel strength of the mud used has a bearing on the operation of the pumps in that the pumps are required to maintain a necessary flow velocity to keep the hole clean.

The mud pumps usually are positive displacement reciprocating types and the horsepower of a pump is a function of the output volumetric flow rate and pressure. At its rated speed, a pump will reach its power rating at the maximum rated pressure for each liner size. To determine the horsepower needed for a given drilling operation, the volume of mud necessary to provide sufficient velocity to remove cuttings is determined. With the volume determined, pressure loss and pressure drops can be determined to find the pump pressure. The pressure-volume relationship can be used then to define the hydraulic horsepower required.

The pump 46 is operated by an engine 54 while the pump 47 is operated by an engine 55. The pump 46 and
engine 54 and the pump 47 and engine 55 are functionally combined units so that in the description to follow, the control or operation of a pump or an engine is synonymous with operation or control of its association unit. The engines 54 and 55 have a clutch (not shown) for controlling the application of power to the pump and a throttle for controlling the speed of the engine.

In FIG. 2, the present invention will be described in connection with a control for the throttles. Manually variable throttle control means 56 and are respectively illustrated for each of the engines for pumps 46 and 47. The control means 54 and 55 are operable to adjust the throttle of the engines by pneumatic pressure control systems. In one of the pneumatic pressure control systems is three-way valve 58 which can be independently operated between a position where the pressure control is exerted from the manual control means 56 to a valve position where the pressure control is from a remote control means 60. Similarly, a three-way valve 59 couples the manual throttle control means 57, the pump 55 and remote control means 60 to one another. The remote control means 60 provides an alternate control for each of the pumps and is responsive to electrical control signals from a remote location control means 61. When the remote location control means 61 is in command of the remote control means 60, the pumps are synchronized for operation in fixed relationship to one another in a manner which will be fully described in the discussion to follow.

Referring now to FIG. 3, the components of the remote control means 60 and an interrelated control means for the pumps are illustrated in more detail. For ease of understanding, various pneumatic control valves are illustrated by circles where the semi-circular portion which is shaded indicates a closed or blocked path in a valve and the unshaded semi-circular portion indicates a flow-through condition in a valve.

From the remote control location means 61 to be described later, an electrical control means (not shown) is coupled by an electrical path 63 to a current-to-pressure converter 64 in the remote control means 60. The current-to-pressure converter 64 is a commercially available device, for example, Model 69TA manufactured and sold by the Foxboro Co. The converter 64 is adapted to respond to an input electrical current and provide a proportionate output pneumatic pressure. The pressure output of the converter 64 is coupled to a pressure-to-pressure amplifier 65 which outputs an amplified pneumatic pressure proportional to the input pressure. The pressure output of the amplifier 65 is coupled by output conduits 66a, 67a and 65a, respectively, to a first selection valve 66, a second selection valve 67 and a pressure reducer amplifier 68. The valve 67 as shown, is in a position where the pressure in the conduit 67a is blocked off from the rest of the system. The pressure in the conduit 66a is coupled by the position of the valve 66 to couple the pressure into the conduits 69a and 69b. The conduit 69a couples to a valve 58 which, in the position shown, couples pressure to the throttle control for the engine 54 for control of the pump 46. Thus, it can be appreciated that operation of the control means 60, the remote location control means 61 produces an electrical control function which is converted to a pressure control at the drilling location for control of the engine 54 whenever the valves 66, 67 and 58 are in the positions shown in the drawings.

The pressure reducer amplifier 68 has output conduits 68a and 68b which respectively couple the reducer amplifier to the valves 66 and 67. In the position of the valves 66 and 67 shown in FIG. 3, the conduit 68a is blocked off by the position of the valve 66. The valve 67, in the position shown, couples the conduit 68b to the output conduits 71a and 71b of the valve 67. The conduit 71a couples to a valve 59, which, in the position shown, couples pressure to the throttle control for the engine 55. The pressure reducer amplifier 68 is a conventional Ratio Control Station and available from Moore Products. For purposes of explanation, reducer 68 is discussed in terms of reduction of pressure hereafter; however, the device 68 also can serve to amplify the pressure. Thus, device 68 broadly modifies the pressure. The reducer 68 can be selectively adjusted as schematically illustrated by the dial 72 to vary or modify the pressure on the output side relative to the input side by a fixed relationship. This relationship can be ratio or percentage. Thus, the pressure control to the engine 55 is a predetermined function of the pneumatic control to the engine 54 as determined by the setting of the reducer or amplifier device 68.

The valves 67 and 66 are selectively operable. The line and x designation to these valves schematically illustrate the switching means 121 (see FIG. 4) which are coupled to remotely located actuating means at the control means 61. When the actuating means for the valve 66 and 67 are operated, the position of both of the valves 66 and 67 is reversed. When the positions of the valves 66 and 67 are reversed, then the pressure from the amplifier 65 is supplied via the valve 67 and the valve 59 to the engine 55 and the reduced or lesser pressure from the reducer 68 is supplied via the valves 66 and 58 to the engine 54. Hence, either pump can be the master controlled pump relative to the other pump.

The manual control means 56 is coupled by a conduit 72a to another input of the valve 58 and, in the position shown, the conduit 72a is closed or blocked off by valve 58 while the conduit 69a is coupled by the valve 58 to the control for the pump 46. The manual control means 57 is coupled by a conduit 72a to a second input for the valve 59 and, in the position shown, the conduit 73a is closed or blocked off by valve 59 while the conduit 71a is coupled to the output conduit of the valve 59. The valve 58 is adapted for selective operation by a control means at the control center 61 which is connected to the control means for the valve as illustrated by the line with the designation "Y1". The valve 59 is adapted for selective operation by a switch means at the control means 61 which is connected to the actuating means for the valve by the line with the designation "Y2". Actuation of the valves 58 and 59 will reverse the pressure control from the remote control pressure lines 69a and 71a to the control of the manual control pressure lines 72a and 73a.

The conduit 69b from the valve 66 is coupled to an input of a valve 74. The valve 74, in the position shown, couples the conduit 69b to one input of a pressure comparison means 75. The conduit 71b from the valve 67 is coupled to the other input of the valve 74 and is blocked off or closed by the position of the valve 74. A conduit 72b from the manual control means 56 is coupled to one input of a valve 76. The valve 76, in the position shown, couples the conduit 72b to the other input of the pressure comparison means 75. The conduit 73b from the manual control means 57 is coupled
to the other input of the valve 76. The valve 76, in the position shown, closes off the conduit 73b. The input pressures transmitted by valves 74 and 76 to the comparison means 75 are compared and an electrical output signal representative of any pressure difference is supplied via an electrical conduit 77 to the remote location control means 61. Since the comparator means 75 derives differences in pressure, in the described example, it can be determined how much difference in pressure exists between the output of the valve 76 and the pressure as determined by the control setting of the inactive manual control means 56. By the use of actuating means coupled by lines indentified with the character "z" to the switching control means of the valves 74 and 76, the valve positions can be reversed. Whenever the positions of the valves 74 and 76 are reversed the relationship of the pressure of the other manual control means 57 to the control pressure for the engine 55 can be determined.

Relative to the operation of the present system, for a well drilling operation, the mud properties, hole and pipe configuration, and pump characteristics are considered. Because two pumps have functionally related characteristics, their operation relative to one another to optimize their operation can be decided upon so that they can be operated in a fixed ratio relative to one another. This predetermined operational ratio is set by the operation of the selecting dial mechanism 72 of the converter 68.

Referring first primarily to FIG. 1, the drilling fluid, which is usually in the form of an aqueous or oil based drilling mud as commonly employed in the drilling industry, is continuously withdrawn from the reservoir or sump 40 through the suction pipe 38 of the drilling fluid circulating pump 36 and discharged under pressure from the pumps through pipes 33 and 32, through the flexible hose 31, and thence through the swivel 17 into the fluid passage in the Kelly Bar 16. The drilling fluid continues in its flow downward through the Kelly Bar 16, through the sections of the drill pipe 15 comprising the drill stem and through the passages in the drill collars, to the drill bit 13, from which it is discharged through the drill bit fluid outlet passages into the bottom of the borehole surrounding the drill bit. From the bottom of the borehole the drilling fluid, together with cuttings from the drill bit, flows upward through the annular space in the borehole 10 surrounding the drill string 15 and up through the surface string of casing 12, from which it is transferred through the lateral or side outlet pipe 42 and returns to the sump 40.

The surge chamber 45 acts partially to absorb and smooth out the drilling fluid flow pressure fluctuations from the pumps resulting in flow of the drilling fluid from the pumps to and through the drill stem having pressure pulsations and fluctuations which are of relatively low amplitude. Meanwhile, the rotation of the drill string and drill bit by means of the rotary table 25 may or may not be simultaneously maintained, as the occasion dictates.

To control the pumps relative to one another, the valves 66, 58, 67 and 59 are set in the position shown in FIG. 3 so that the remote location control means 61 can provide a current signal to the current-to-pressure converter 64. The converter 64 provides a pneumatic pressure proportionally related to the current input. The pressure amplifier 65 serves to provide an amplified pressure for the system. From the amplifier 65, the pressure output is supplied to the control for the engine 54 via the open valves 66 and 58. The pressure output of the amplifier 65 is reduced to a ratio value by the pressure reducer 68 and is supplied to the control for the engine 55 via the open valves 67 and 59. As the pressure from the reducer or pressure modifier 68 is increased or decreased in response to control signals then the pressure to the engine 54 proportionally increases or decreases the speed of the engine 55. Hence, in the above illustration, the pump 46 is the prime pump under control, and the pump 47 is the slave pump which is controlled in fixed relation to pump 46. If the remote control for the valves 66 and 67 is operated, these valves respectively change position so that the primary pressure control from the converter 64 is then supplied to the engine 55. The valves 66 and 67 thus serve as selection valves for selecting the prime pump and the follower pump to be controlled.

To convert the control operation from the remote location control means 61 to the manual control means 56 and 57, the control switch for the control valves 58 and 59 reverse the positions of the valves to couple the manual control means 56 and 57 to the engines 54 and 55, respectively. At this time, the driller can assume manual control for each of the pumps.

The manual control means 56 and 57 for each of the pumps are coupled to a comparison valve 76 while the remote control pressures for each of the engines is coupled to a comparison valve 74. With this arrangement and the valves 74 and 76 in the position shown in FIG. 3, the pressure in the manual control means 56 is compared to the pressure output from valve 66. In this regard the pressure comparison exists irrespective of the position of control valve 58 to the engine 54. The pressures supplied to the pressure comparison means 75 provide a signal output indicative of the pressure differential. Either the converter 64 or the manual control means 56 can be adjusted to equalize the pressures between the units. The merit of having equal pressures in the manual and remote control systems is that the control of the system can be shifted between these two modes as described above without changing the effect on the controlled engine. By operation of valves 74 and 76, the positions of the valves can be reversed so that both manual control means can be calibrated in terms of pressure with reference to the pressure control of the remote control.

While dual pumps are used, only one pump is primarily regulated. Thus, referring now to FIG. 4, the interrelationship of the remote location control means 61 relative to one pump means only is illustrated for convenience and ease of explanation. This eliminates the need for illustration of valves 66, 67, 74 and 76, the pressure modifier 68 and associated piping. Similar numbers used in FIG. 4 relate to similar components as described with respect to FIG. 3.

As illustrated in FIG. 4, an electrical current path 63 couples to the current-to-pressure converter 64 which produces a pneumatic pressure output proportional to an electrical current input. The converter 64, in turn, has its pressure output coupled to a pressure-to-pressure amplifier 65. The output conduit 69a from the
amplifier 65 is coupled to the valve 58. From FIG. 3, it will be recalled that there are two inputs 69a and 72a to the valve 58 and one output to the throttle control of engine 54. To simplify the illustration, the valve 58 is shown as two sections 58a and 58b in FIG. 4, where the valve section 58a couples the conduit 69a via a common output conduit 78 to a pneumatic control cylinder 79 connected to the throttle for the engine 54. The other output conduit 69b of the converter 65 is coupled to one input of the pressure comparator 75 while the conduit 72a from the throttle control means 56 is blocked or closed by the valve section 58b. The pressure comparator 75 functions to compare the two input pressures and produces an electrical output representative of the difference between the two input pressures. An electrical resistance 81 in the output electrical path 77 of the comparator 75 is coupled across an electrical meter 82 which provides an indication relative to a null position whether the pressure is balanced or unbalanced, how much of an imbalance in terms of magnitude and direction exists relative to the static control.

At the remote location control station or means 61, there is another null meter 83 which is coupled in the electrical path 77 to provide an indication of the balance or imbalance of the pressures at the remote control location means 61. Also located at the station 61 is a direct control means 84, a setpoint control means 85 and a computer control means 86. The direct control means 84 is connected to a switch means 87a. The switch means 87a connects one of three switch contacts “D”, “M” or “A” to the direct control means 84. Switch contacts D, M and A respectively stand for Digital, Manual and Analog control. The digital and manual contacts D and M are electrically connected to one another. The contact D connects is operated by the computer 86. The switch 118 has a “set-point” contact and a “Direct” contact. In the position of the switch illustrated, the set-point control means 85 is connected by the digital and analog contacts of the switch 87a to the direct controller 84. The direct controller couples to the current-to-pressure converter 64 via the electrical conduit 63. When the relay coil 118a is actuated by a signal from the computer 86 and the switch 87a is moved to the digital D contact, the switch 118 is coupled via an output conductor 117 to the computer 86. Thus, control signals from the computer 86 are conveyed via the switch 118 and the switch 87a to the direct controller 63. The switch means 87a therefor selectively couples one of the remote location control means 85 or 86 to the direct current controller 63, which in turn connects to the I/P converter 64 which is located at the rig site. At the rig site a selector switch 88 which the driller can use to actuate the computer 86 via an electrical path 89. The computer 86 assures regulation of the control means 85 and 86 when the drilling control is transferred from the rig site to the remote location station 61.

At the rig site is clutch control means 92 for an engine. The clutch control means 92 provides a manual control for the clutch of the engine via a pneumatic control 95 which includes a piston and cylinder or pneumatic clutch which is responsive to pneumatic pressure in lines 96 and 97. In line 97 is a pressure-responsive switch 98 which indicates whether pneumatic pressure is sufficient to engage the clutch. The clutch (not shown) which engages and disengages the driving shaft of the engine is controlled by the pneumatically operated piston and cylinder or pneumatic clutch control element 95. The input conduit 97 to the control element 95 can be coupled by a selectively operable valve 102 either to the manual control means 92 or to a rig located pressure source (not shown) coupled to an input conduit 101. In the input conduit 101 is a selectively operable valve which includes a valve element 100a and a valve element 100b. The valve element 100a couples pressure directly to the valve 102 via a conduit 100c in the valve position shown while a valve element 100b closes off a vent passage. The valve elements 100a and 100b are controllable by an actuating means (not shown) which is activated by an electrical signal applied to the control input at D. The valve element 100b is movable between a position coupling the pressure source to the valve 102 and a position disconnecting the pressure source from the conduit 100c. Thus, an electrical power source 120 at the remote location can be connected through a switching means 121 to operate the valve elements 100a to 100b and valve 102. To relieve the pressure in conduit 100c and disengage the clutch, the valve element 100b can coupled the valve 102 to the atmosphere.

The valve 102 in the position shown, couples the input conduit 101 to the control element 95 so that the remote station has control of the clutch. An actuating means for the valve is selectively and independently actuable via an electrical input at C to move the element from the position shown to a position coupling the conduit 97 to a conduit 96 of the manual control means 92. When the manual control means 92 is coupled to the control element 95, the driller can engage and disengage the clutch by manual operation of the control means 92. In the conduit 97 is a pressure responsive device 98 which responds to pressure within the conduit 97 to activate an electrical switch 104 in the device 98 so that an electrical indication can be transmitted to the remote location via the electrical lead 106. Thus, determination of whether clutch is engaged or not is indicated by the presence or absence of an electrical indication on the electrical conductor 106. Also at the rig site is a shaft rotation sensing means 93 for sensing the speed of pump. This can be accomplished by a toothed gear element 93a which magnetically produces an electrical response in the sensing element 93 proportional to the speed of the element 93a. This signal can be output via an electrical conductor 109 to an indicator (not shown) at the remote location and indicated at the rig location by an indicator 110. The speed signal output may also be selectively coupled by means of a switch 122 to an output conductor 114 for application of a control function at the remote location when pump speed is the desired control criterion.

Another control device at the rig site includes a pressure sensing device 120 coupled to the well pipe 120a for sensing the stand pipe pressure and producing a proportionate electrical signal on an electrical lead 121a. The electrical lead 121a is connected to the switch 122 and can be selectively coupled to the electrical lead 114 for providing a control function to the remote control location when pressure is the desired control criterion. A pressure indicator 121 can provide a visual indication of the pressure.
Turning now to the remote location control means 61, the imbalance electrical signal from the pressure comparator 75 is supplied via the conductor 77 to a current sensing relay 125. The current sensing relay 125, which is conventional, detects deviation of the input signal relative to upper and lower selected values and produces output signals whenever one of the selected values is transgressed. An output signal from the relay means 125 is passed via the switch 127 (operated by the solenoid coil means 127a) and a conductor 128 to the D input of switch means 118. The controller means 85a includes the switch 87a which is selectively operable to provide one of three connections, i.e., a connection to the manual switch 115, a connection to the common switch control element of switch 118, or a connection to the analog control element of the switch which is connected to the common switch element of switch 118. When switch 87a is actuated to its "analog" or "digital" switch 118 is in a "direct" position and switch 127 is in a "track" or "T" position, the signal from the current relay 125 is input via the conductor 128 to the direct control means 84.

It will be appreciated that if the direct controller 84 at the remote location is in command and if switch 87a is in the manual position M, that the manual switch 115 can be used by the operator to increase or decrease the speed of the engine by increasing or decreasing the pneumatic pressure to the throttle control. The manual switch 115 includes a spring biased contact switch in a neutral position which can be moved to stationary contacts to provide either "up" or "down" signals dependent upon the location of the switch. The pneumatic pressure developed by the current-to-pressure converter 64 and pressure amplifier 65 in response to an electrical signal is applied via the valve element 58a to the throttle controller 78. At the rig site the pressure differential between that pressure applied to the throttle control and that pressure present in the manual control means 56 is monitored by the pressure comparator 75 and reflected at the visual indicators 82 and 83. The driller at the rig site can alter the pressure at the manual control means 56 to match the pressure of the remote control means so that if the driller operates the switch 88 and takes control, the engine speed will be constant at the time the interchange of control is made. If the driller is in control by means of the throttle means 56, then the pressure comparator 75 provides a signal to the current relay 125 which can keep the direct control 84 aligned with the control of the driller.

A setpoint device 85 is included in the controller 85a, which, for example, can be a model 62HDM available from the Foxboro Company. The setpoint device 85 is adapted to provide a control of the pump based upon the setpoint value in the device 85. The setpoint can be adjusted continuously by manual operation or by inputs from the computer, provided that the switch 87b is in the Digital position. The switch 87 and 87a are mechanically gauged to one another. In the D position of switch 87, a stepping motor 87c is operated in response to the computer via a conductor 106. The stepping motor 87c operates a potentiometer 87d. The potentiometer 87d can also be controlled by a manual adjustment 87b. The potentiometer 87d and an input from conductor 114 supply a setpoint signal and a measured value signal to a comparator 87e. The comparator 87e supplies a signal to an adjustment signal circuit 87f which couples to the setpoint contact of the switch 118.

The adjustment circuit 87 can be set to desired range of operation. The output of the setpoint device 85 may be connected via switch means 118 (operated by solenoid coil means 118a) and switch 87a to the direct control means 84. The adjustment control 85b is provided for manual adjustment of the setpoint value.

The computer means 86 receives all of the various inputs from measured or derived parameters of the well drilling operation. The computer means 86 is programmed and provides control outputs as selected. Any of the well known drilling equations can be programmed into the computer to provide a selected output control parameter in response to the input parameters. One of the outputs 117 of the computer is an electrical signal representative of the computation for the speed or pressure at which the pump means should be driven based upon the input parameters. This signal is transmitted via the switches 118 and 87a to the direct control means 84. In another form of control, a switch 87b can be employed to couple a computer output to the adjustment circuit 87f for setpoint control means 85. In this manner, the setpoint can be continuously adjusted by the computer and the setpoint means 85 will provide the input to the direct control means 84.

In the operation of the foregoing system, various parameters can be input into the computer 86 to provide output control signals. For an understanding of what computer operations can be performed reference can be made to various published articles on the subject. The output control signals of the computer 86 are the values controlling the pump operation for the foregoing described system although other parameters are equally subject to the type of control embodied in the present invention.

In applying the computer 86 to control the operation of the pumps using the standard automatic setpoint controller 85a, when the operation or a particular loop is on computer control, the computer 86 transmits the desired setpoint for the parameter to the controller 85a. The controller 85a receives as an input variable the parameter under control and compares it to the setpoint signal. If an error exists, the setpoint controller 85 adjusts its output according to its type of control action desired, i.e., proportional, proportional plus reset, or proportional plus reset plus derivatives, to adjust the measured variable to the setpoint. The adjustment circuit 87f can provide the foregoing described type of control action. The converter 64 which receives the output of the controller 85a provides pressure which ultimately physically moves the throttle control element for the engine.

In applying an automated computer control system to a drilling rig, it is highly desirable to leave the rig controls intact and instantly operable so the driller can assume normal control at any time. It is also desirable that control can be transferred to the computer and vice-versa "on-the-fly", without shut down of the operation or upset of smooth operation. Because of space and environmental considerations, it is not practical to place the sophisticated controllers at the driller's console and allow him to make local manual adjustments with the controller's manual mode "knob" as would be the case in a plant type operation. The controller and computer are housed in a unit off the rig floor, therefore, any mode of control from them has been referred to as "remote".

The various remote control modes are as follows:
1. Computer Automatic Remote Control — with the switches 87 and 87a in the digital D position, the computer 86 establishes the set point for the controller 85a and the controller 85a automatically adjusts its output to the final control element.

2. Automatic Remote Control — with the switches 87 and 87a in the analog A position, the operator establishes the set point by knob 87b for automatic control by the controller 85a.

3. Manual Remote Control — with the switches 87 and 87a in the manual M position, the operation manually adjusts the switch 115 to adjust the output of the direct control 84 to the final control element.

4. Computer Control — with the switches 87 and 87a in the digital D position, the switch 118 is actuated and the computer 86 provides a direct control output signal via conductor 117 to direct control 84.

When the driller desires to transfer from computer automatic remote mode to local manual, he has two methods at his option as provided by the system of this application:

1. Automatic Bumpless Transfer — In this method, the driller closes a switch 88 which operates the remote control means 61 and thus the operating parameters of the process loop come under control of the remote location means 61.

2. Manual Bumpless Transfer — In this method, the driller observes a tracking meter 82 on his control panel which reads the output of the pressure comparator 75. If the tracking meter 82 reads low, he increases his throttle output by manual adjustment until the meter nulls, or if it reads high, he reduces his throttle output similarly. In increasing or decreasing his inactive throttle output to match the then active controller output, he is pre-balancing signals, so that when he positions the driller's request switch 88 to local manual, the computer returns control of the operation to the driller, but the control is transferred at the operating parameters which were dictated by the computer immediately prior to the transfer request.

The pump engine throttle control of a drilling rig was used as a typical example of the system of this disclosure, but it is not intended to be limited to this application. The intent is that it apply to the computer or remote control of any type machinery or process which requires local manual controls at the process and automatic controls in a remote control station. It is likewise not limited to computer control of these remote controls, as the tracking and signal balancing system is applicable to any remote analog control, incorporating either electronic controllers as described herein, or pneumatic controllers when properly instrumented. This disclosure is likewise not intended to be limited to the exact component devices described herein, since these control schemes could be accomplished either entirely with electric devices for sensing and articulating or with pneumatic devices entirely.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and therefore, the aim in this appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A system for controlling drilling operations interchangeably between a remote control location and a manual control location on a drilling rig comprising:

a. means on a drilling rig responsive to a control input means for developing a drilling operation parameter;

b. first manual control input means on a drilling rig for producing a first control function for controlling the operation of said developing means;

c. first translation means for coupling said first manual control input means to said developing means and for producing a control input for said developing means in response to said first control function;

d. second control input means at a location remote to a drilling rig for producing a second control function for controlling the operation of said developing means;

e. second translation means for coupling said second remote control input means to said developing means and for providing a control input for said developing means in response to said second control function;

f. means for selectively coupling one of said translation means to said developing means;

2. The apparatus as defined in claim 1 and further, wherein said first translating means includes first means for developing fluid pressure for providing a first control input pressure function and wherein said second translation means includes second means for developing fluid pressure in response to electrical signals for providing a second control input pressure function.

3. The apparatus as defined in claim 2 and further including means for deriving electrical signals in response to another drilling operation parameter, and means responsive to said derived signals for providing said electrical signals to said second translation means.

4. The apparatus as defined in claim 1 and further, wherein said comparing means receives each of said control inputs for producing electrical output signals representative of the difference in said control inputs.

5. The apparatus as defined in claim 4 and further including means responsive to said electrical output signals for continuously adjusting one of said control input means and maintaining said control inputs in a predetermined relationship relative to one another.

6. A system for controlling drilling operations interchangeably between an electrical control at a remote location and a manually operated fluid control on a drilling rig comprising:

a. means responsive to a control input for developing a drilling operation parameter;

b. first control means on a drilling rig including a manually manipulatable control device for producing first control input fluid pressures for controlling the operation of said developing means;

c. second control means at a remote location including electrical control means for producing input electrical control signals;
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15 pressure generating means for generating second control input fluid pressures proportional to said input electrical control signals;
means for sensing control input fluid pressures existing in said manually manipulable control device and in said pressure generating means and for providing electrical output signals as a function of any pressure differential therebetween; and
means for selectively coupling one of said manually manipulable control device or said pressure generating means to said developing means.

7. The system as defined in claim 6 and wherein said second control means for producing electrical control signals includes at said remote location, detector means for receiving said electrical output signals.

8. The apparatus as defined in claim 7 and further, wherein said developing means includes a mud pump and said first control means is a throttle control for said engine, and
means at said remote location responsive to said electrical output signals for controlling said remotely located second control means.

9. The apparatus as defined in claim 7 and further including means for deriving measurements of another parameter, and means at said remote location responsive to said derived measurements for controlling said remotely located control means.

10. A system for controlling drilling operations interchangeably between a manual control system at a rig site and an electrical control system at a remotely located site comprising:
means at a rig site for developing a drilling function;
a manually manipulable fluid pressure control device adapted for coupling to said drilling function means at said rig site and for controlling said drilling function;
a remote fluid pressure control device for generating input electrical control signals;
fluid pressure generating means at said rig site for generating fluid pressures proportional to said input electrical control signals, said fluid pressure means being adapted for coupling to said drilling function means;
means for sensing pressures existing in said manually manipulable control device and in said pressure generating means and for providing electrical output signals as a function of said existing pressures;
means for selectively coupling one of said manually manipulable control device or said pressure generating means to said control means; and
means at a remotely located site for establishing a predetermined operational set point for said pressure generating means and for controlling said remote fluid pressure control device and said input electrical control signals as a function of said electrical output signals.

11. The apparatus as defined in claim 10 and wherein said set point means are also manually adjustable to different values.

12. The apparatus as defined in claim 10 and further including means for receiving drilling parameter data signals from the rig site and for computing an operational set point values, said receiving means being coupled to said set point means for adjusting said set point means to such computed set point values.

13. The apparatus as defined in claim 10 and further including at said remotely located site, manually operated means for selectively supplying said input electrical control signals as a manual function.

14. The apparatus as defined in claim 10 and further including means for measuring a drilling operation parameter and providing electrical control signals, means for coupling said measuring means to said set point means and responsive to said electrical control signals whereby said set point means can maintain a control for said pressure generating means as determined by said determining means.

15. The apparatus as defined in claim 14 and wherein said drilling function means are pump means and said measuring means includes means for providing said electrical control signals as a function of speed of the pump.

16. The apparatus as defined in claim 14 and wherein said drilling function means are pump means and said measuring means includes means for providing said electrical control signals as a function of the mud pressure at a location in the mud circulation system for controlling mud pressure at said location.

17. A system for controlling drilling operations interchangeably between a manual control system at a rig site and an electrical control system at a remote control site comprising:
means for supplying a drilling fluid for the drilling operation and having a pneumatically actuated throttle control;
valve means coupled to said pneumatically actuated throttle control, said valve means having at least two inputs and being selectively operative for coupling of one of said two inputs to said pneumatically actuated throttle control;
first manually operable means for variably operating said throttle control and including first pneumatic pressure means coupled to one of said inputs of said valve means;
second electrically controllable means for variably operating said throttle control and including second pneumatic pressure means coupled to the other of said inputs to said valve, said second pressure means being responsive to electrical input signals for generating corresponding pneumatic pressures;
pressure comparator means coupled to each of said variable operating means for determining the pressure differential therebetween, and for providing electrical signals representative of the pressures to said comparator means;
remote control means including means for generating electrical input signals and means for operating said valve means.

18. The apparatus of claim 17 and further including clutch control means for said drilling fluid supplying means for engaging and disengaging said drilling fluid supplying means for operation, means at said rig site for operating said clutch control means, remote control means for operating said clutch control means, and means for selective coupling one of said clutch operating means to said clutch control means.

19. The system of claim 17 wherein said electrical signal generating means in said remote control means provides said electrical signals within a selected range of operation.

20. The system of claim 19 and further including means at the rig site for measuring a drilling operation parameter and for providing electrical measurement
signals to said electrical signal generating means, said electrical signal generating means being responsive to said measurement signals for controlling said second electrically controllable means.

21. The system of claim 20 wherein said measuring means is responsive to driving means for measuring the speed of the drilling fluid supply means.

22. The system of claim 20 wherein said measuring means is responsive to pressure in a mud system for measuring mud pressure.

23. A system for controlling a drilling parameter in a drilling operation and for interchanging such control between a rig location and a remote location comprising:

- means for developing a drilling rig parameter;
- fluid pressure responsive means for controlling said developing means;
- parallel control means for producing a control function in terms of a fluid pressure for operational control of said fluid pressure responsive means;
- means for selectively disengaging one of said control means from operational control of said fluid pressure responsive means;
- means for comparing said control functions for obtaining a comparison for adjustment purposes;
- one of said control means including a current-to-pressure converter means for receiving an input electrical signal and providing an output fluid pressure; and
- electrical control means coupled to said one of said control means.

24. A system for controlling drilling operations interchangeably between a manual control system at a rig site for a well drilling operation and an electrical control system at a remotely located site comprising:
- a first means at a rig site for developing a drilling function;
- means at said rig site for developing signals as a function of the parameters of the drilling operation;
- a manually manipulatable fluid pressure control device adapted for coupling to said first drilling function means at said rig site and for controlling said drilling function;
- a remote fluid pressure control device for generating input electrical control signals;
- fluid pressure generating means at said rig site for generating fluid pressures proportional to said input electrical control signals, said fluid pressure means being adapted for coupling to said drilling function means;
- means for sensing pressures existent in said manually manipulatable control device and in said pressure generating means and for providing electrical output signals as a function of said existent pressures; and
- means for selectively coupling one of said manual manipulatable control device or said pressure generating means to said control means; and
- means at a remotely located site responsive to said parameters of the drilling operation for establishing a predetermined operating point for said pressure generating means and for controlling said remote fluid pressure control device and said input electrical control signals as a function of said parameters of the drilling operation.