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DRILLING RIG CONTROL

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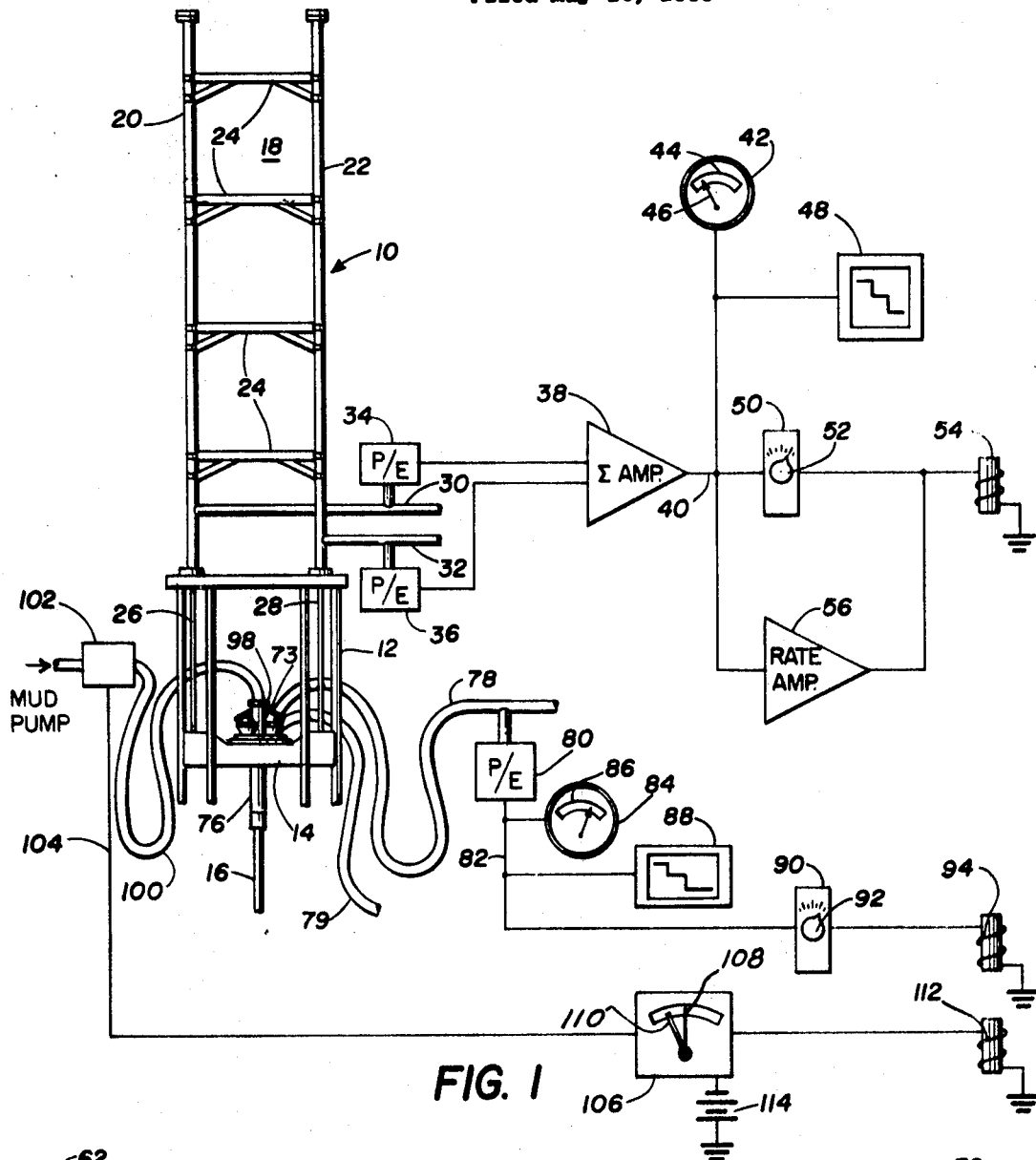


FIG. 1

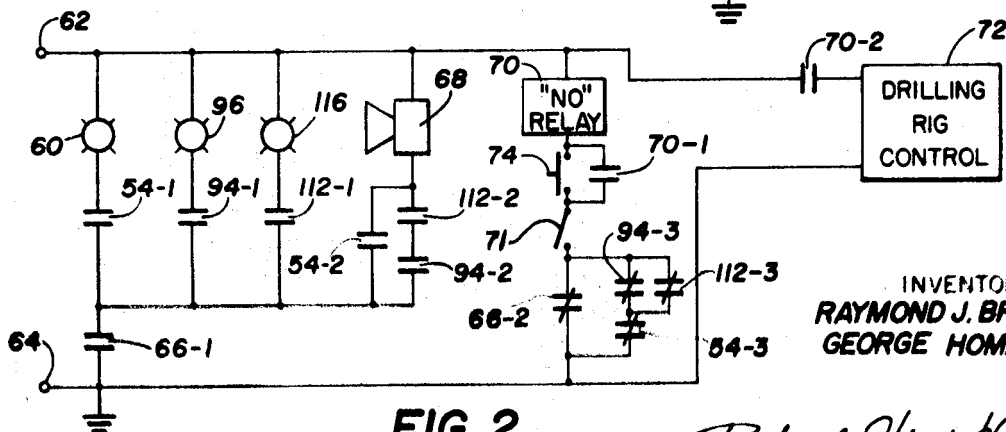


FIG. 2

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DRILLING RIG CONTROL

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10 Claims

ABSTRACT OF THE DISCLOSURE

The operation of a drilling rig is monitored and controlled to prevent damage or unnecessary delay due to the occurrence of off-normal operation. For example, drill string twistoff may be indicated by a sudden decrease in the total weight of the drill string, a sudden decrease in drilling torque, or a sudden decrease in mud pump pressure. Each of these three variables is monitored, and a departure of any one of the three from an established level may be used to sound an alarm. A sudden decrease in the drill string weight actuates a control relay which may shut down the drilling rig operation completely, or any part thereof. A sudden decrease in drilling torque and/or a sudden decrease in mud pump pressure similarly operates a control relay to shut down the drilling rig operation completely, or any part thereof.

BACKGROUND OF THE INVENTION

This invention relates to drilling rig control, and more particularly to a determination of off-normal operation upon the deviation of one of three variables from individually established levels.

This invention also relates to a determination of drill string twistoff and to the detection of "ledges" and "key-seats" in a hole, and the control of an automatic rig upon the detection of off-normal operation.

When drilling through a subsurface formation, many conditions can develop which will cause off-normal operation of a drilling rig. One of the most serious malfunctions is the separation of the drill string into sections; this is commonly known as "drill string twistoff." Once a drill string has twisted off, additional operation of the drilling rig may only compound the troubles and delay the time before drilling can be resumed. In addition to "drill string twistoff," other off-normal operations that have caused serious damage and unnecessary delay include a "sloughing shale" condition, a dull or blocked drill bit, and holes developing in the drill string. Each of these conditions, if not detected and corrected early, may result in damage to the drilling rig itself.

Although only careful drilling procedures will prevent or minimize the possibility of off-normal operation, a system in accordance with the present invention detects when a malfunction occurs such that immediate remedial action can be taken. Upon the occurrence of an off-normal condition, the system sounds an alarm and, if appropriate controls are provided, shuts down the drilling rig operation. The rig operators are immediately aware of off-normal operation and can stage steps to correct the malfunction and return to drilling with a minimum of down time.

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In accordance with the present invention, transducers convert the drill string weight into an electrical signal which is compared to a signal representing a calculated drill string weight. If the electrical signal output of the transducer drops below the established signal in a set point controller, a relay coil is energized to close a series of relay contacts, thereby sounding an alarm and shutting down the drilling rig operation. Another transducer converts the pressure of the hydraulic motors in the drill head into an electrical signal which is compared to either a signal representative of formal drilling torque plus a margin of safe over-torque, or a signal representative of normal drilling torque less a margin of safety. Any deviation of the output signal from the transducer above or below the established values will energize a relay coil. This relay coil operates contacts to sound an alarm and set up a condition to shut down the drilling rig operation upon the occurrence of an unexpected decrease in mud pump pressure. The mud pump pressure is converted into an electrical signal for comparison to an established value of mud pump pressure. When the mud pump pressure falls below or rises above the established value plus or minus a dead-band as a result of off-normal operation, a relay coil is energized to close contacts which sound an alarm and shut down the drilling rig operation, assuming a sudden decrease in drilling torque has also occurred.

In accordance with a specific usage of the present invention, on a hydraulic drilling rig, forces supporting the drill head are monitored as representing the drill string weight. Any appreciable decrease of the monitored force from an established level during the drilling operation is taken as an indication of drill string twistoff. The pressure at the hydraulic motors of the drill head is also monitored as representing drilling torque. Again, an appreciable decrease of the monitored pressure from an established value will be an indication of drill string twistoff. Mud pump pressure is also monitored as still another parameter that may be used as an indication of drill string twistoff. Should the mud pump pressure, during a drill cycle, suddenly decrease below an established value, there is a probability of drill string twistoff.

An object of the present invention is to provide automatic drilling rig operation. Another object of the present invention is to provide an indication of off-normal drilling operation as a result of a drill string weight change. A further object of this invention is to provide for automatically shutting down a drilling rig upon the detection of an apparent drill string weight change. Still another object of the present invention is to provide an indication of drill string twistoff upon a sudden decrease in drill string weight. Yet another object of this invention is to provide an indication of off-normal drilling rig operation upon the occurrence of a sudden increase or decrease in drilling torque. A still further object of this invention is to provide an indication of off-normal operation of a drilling rig upon the occurrence of a sudden increase or decrease in mud pump pressure. Another object is this invention is to provide an alarm system for detecting when a drill string encounters a "tight" hole condition when either going into or coming out of a hole shaft.

A more complete understanding of the invention and its advantages will be apparent from the following specification and claims and from the accompanying drawings illustrative of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of a drilling rig and three sub-systems for detecting off-normal drilling operation; and

FIG. 2 is an electrical schematic of a system for indicating to a rig operator an off-normal operation and for shutting down a drilling rig.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to FIG. 1, there is shown an application of the present invention to an automatic hydraulic drilling rig of the type described in U.S. Patent No. 3,158,213. The drilling rig 10 includes a mast 12 within which is slidably carried a vertically movable drill head assembly 14. Drill head assembly 14 supports a drill string 16, only a portion of which has been illustrated, that may be several thousand feet in length, by means of elevators (not shown) or threaded coupling. Movement of the drill head assembly 14 relative to the mast 12 is accomplished by a suitably braced tower 18 fixed to the top of the mast 12. The tower 18 includes cylinders 20 and 22, more than two may be used, which are braced by struts 24. Rods 26 and 28, which are mounted to pistons within the cylinders 20 and 22, respectively, effect vertical movement of the drill head upon introduction of hydraulic fluid into the cylinders through pipes 30 and 32.

Fluid flow rates within the pipes 30 and 32 may be controlled by a hydraulic system of the type described in the copending United States patent application of Raymond J. Bromell et al., Ser. No. 782,231, filed Dec. 9, 1968, and assigned to the assignee of the present invention. As described in this copending application, the yoke of a variable displacement pump is stroked to various positions to establish flow rates in the pipes 30 and 32 and thus vary the speed of raising and lowering the drill head assembly 14. The pressure maintained in the cylinders 20 and 22 by the variable displacement pump will be at a level established by the weight of the drill string 16.

Pressure transducers 34 and 36 are coupled to the pipes 30 and 32, respectively, and produce electrical signals proportional to the pipe pressure. Since there are two or more cylinders lifting the drill head assembly 14 and drill string 16, a pressure in the pipes 30 and 32 will be proportional to only a portion of the total weight of the drill head and drill string. Thus, the electrical signals from the transducers 34 and 36 are added in a summing amplifier 38 to produce a signal on a line 40 proportional to the weight of the drill string 16. The electrical signal on the line 40 is coupled to an indicating meter 42. This meter 42 has a scale 44 calibrated in drill string weight and a pointer 46 for indicating instantaneous drill string weight. In addition to the meter 42, the signal on line 40 connects to a recorder 48 which produces a permanent record of drill string weight for further analysis.

In addition to generating electrical signals representing drill string weight by converting pressure in the cylinders 20 and 22, other transducers may be employed. For example, strain gauges may be mounted on the rods 26 and 28 to produce electrical signals representing the drill string weight. Further, load cells may be mounted under the rig to produce electrical signals that vary with drill string weight.

Of particular significance to the operation of the present invention, the signal on line 40 is tied to an alarm controller 50. A typical controller 50 may include a potentiometer circuit coupled to a knob 52 for establishing a signal representing the calculated weight of the drill string 16. The alarm controller may also include an amplifier having a first output when the drill string weight is above a calculated value, a second output when the actual weight is at the calculated value, and a third output when the actual weight is below the calculated value. The first and third outputs of the amplifier energize a relay 54 to complete various alarm circuits and shut down the drilling rig operation, as will be described shortly. When the

first output energizes the relay 54, a "high" alarm condition exists such as would occur when a reduced hole, sloughing shale or "keyseat" is encountered when removing the drill string from a hole. Energizing the relay 54 from the third output indicates a "low" alarm condition such as would occur for a drill string twistoff or when encountering a ledge or bridge when lowering the drill string into a hole.

A signal on line 40 is also coupled to a rate amplifier 56 which energizes the relay 54 when the rate of change of the drill string weight exceeds an established level. Many rate amplifier circuits are available and additional description is not deemed necessary.

To indicate off-normal drilling rig operation with the weight alarm circuit described above, the knob 52 is set at a drill string weight calculated to be slightly less than then weight being supported. Pressure in the pipes 30 and 32 will be maintained at a level to support the drill string and will remain at some reasonably constant value for a given weight. Assume the drill string 16 is about two thousand feet long and a twistoff occurs at about the one thousand foot level, then the pressure in pipes 30 and 32 will be readjusted by means of automatic controls (not shown) to support the new weight and prevent the drill head assembly from running to the top of and damaging the tower. A lower pressure in the pipes 30 and 32 produces a signal of lower magnitude on the line 40 that will be less than a signal established by the knob 52. As a result, the alarm controller 50 energizes the relay 54, thereby closing a contact 54-1 in series with an indicating light 60 shown in FIG. 2. The light 60 will be connected to a source of voltage at the terminals 62 and 64 through a contact 66. The contact 66 has previously been closed in the normal sequence of operation. In addition to turning on the light 60 by closing the contact 54-1, energizing the relay 54 closes a contact 54-2 to energize a horn 68 to produce an audible alarm.

In addition to giving a visual and audible indication of a change in drill string weight, energizing the relay 54 also opens a contact 54-3 which de-energizes a relay 70, thereby shutting down the drilling rig. The relay 70 is energized at the start of the drilling operation by closing the switch 71 and pushing the reset button 74. This completes a circuit to the terminals 62 and 64 through a normally closed contact 66-2. Contact 66-2 is opened after the sequence of activating the drilling rig has been completed. The relay 70 will be energized through other normally closed contacts, to be described. Energizing the relay 70 closes contacts 70-1 and 70-2. Contact 70-1 completes a holding circuit for the relay 70 and the contact 70-2 connects drilling rig control circuitry 72 to the terminals 62 and 64.

For the alarm controller 50 to properly control the relay 54, the knob 52 must be adjusted for each additional length of drill pipe added to the drill string 16. This can be accomplished by hand or automatically by a computer. However, should adjustment of the knob 52 be overlooked, the weight alarm circuitry will give an indication of off-normal rig operation by means of the rate amplifier 56. The rate amplifier 56 energizes the relay 54 when the rate of change of drill string weight exceeds an established value. Under normal operating conditions for the drilling rig, that is, during the drilling operation or when lowering the drill string into a hole, the rate of change will be below the established level. When a drill string twistoff or other malfunction occurs, however, the rate of change of drill string weight will be high, thereby energizing the relay 54. Energizing the relay 54 closes contacts 54-1 and 54-2 to activate the light 60 and the horn 68, respectively. In addition, energizing the relay 54 opens a contact 54-3, thereby de-energizing the relay 70. This, as explained, shuts down the drilling rig operation.

In addition to indicating drill string twistoff, the weight alarm circuitry will indicate a "ledge" condition before any damage amount of weight has been applied to a

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drill bit when lowering a string into a previously formed hole. The knob 52 is set, by hand or automatically, at a drill string weight slightly lower than the pickup weight, that is, the hanging weight of the string. If the drilling bit comes in contact with a "ledge," the pressure in the pipes 30 and 32 will suddenly decrease, thereby setting up the same conditions that were described previously with regard to a twistoff. The light 60 and the horn 68 will be activated and the relay 70 de-energized to shut down the drilling rig, thus preventing bending of the drill string and damage to the drill bit. This additional feature of the weight control circuitry shuts down the rig before an excessive amount of weight damages the drill string or the drill bit.

Still another feature of the weight alarm circuitry, the drilling rig will be shut down before the drill bit binds in a "tight" hole or "keyseat" when removing the drill string from a hole. For this feature, the knob 52 is set at a drill string weight slightly higher than the pickup weight of the string. The setting of the knob 52 should not, however, be at a level such that they relay 54 will be energized. A "tight" hole or "keyseat" condition will be detected when removing the drill string by the "thigh" alarm (the third output) signal from the controller 50 which energizes the relay 54. As the drill bit encounters a "keyseat" or "tight" hole, the pressure in the pipes 30 and 32 will rapidly increase, thereby generating the high alarm signal from the controller 50. Energizing the relay 54 will activate the light 60 and the horn 68 by closing contacts 54-1 and 54-2, respectively. The relay 70 will be de-energized by opening the contact 54-3 to shut down the rig, thus minimizing the possibility of pulling the drill string in two or collapsing the mast.

Another variable that provides an indication of off-normal drilling rig operation is the torque required to rotate the drill string. The drill head assembly 14 includes one or more fluid motors 73 coupled through pinion and gear mechanisms to a pipe gripper section 76. A complete description of the drill head assembly 14 will be found in the U.S. Pat. No. 3,158,213. Hydraulic fluid for operating the motors 73 will be provided through flexible hoses, such as the input hose 78 and the return hose 79. The torque alarm circuit includes a transducer 80 for converting the pressure in the hose 78 to an electrical signal on a line 82. The signal on line 82 therefore represents the pressure in the hose 78 and in turn the torque produced by the hydraulic motor 73. The signal on line 82 is coupled to an indicating meter 84 having a scale 86 calibrated in units of torque. A recorder 88 also connects to the line 82 and produces a permanent record of the torque required for rotating the drill string 16.

To indicate an off-normal operation, e.g., a probability of drill string twistoff, the signal on line 82 connects to an alarm controller 90 which may include an amplifier having a first output when the signal on line 82 is above a minimum setting and a second output when this signal drops below the setting. The alarm controller 90 includes a knob 92, which may be set by a computer, for setting a minimum and maximum value of torque to be developed by the hydraulic motor 73. Any change in torque produced by the motors 73 above or below the setting on controller 90 will energize a relay 94.

Energizing the relay 94 closes a contact 94-1 to connect a light 95 to the terminals 62 and 64. Energizing the relay 94 also closes a contact 94-2 and opens a contact 94-3 in the circuit for the horn 68 and relay 70, respectively. Note, closing the contact 94-2 does not activate the horn 68 and opening the contact 94-3 does not de-energize the relay 70. Since a decrease in torque is not a positive indication of a drill string twistoff with the system illustrated, only the light 96 is turned on to indicate to the operator a probable twistoff or that some other malfunction has occurred.

In addition to indicating a drill string twistoff, a change in torque may also indicate a dull drill bit. As the drill

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bit wears with usage, additional torque will be required to penetrate the subsurface layers. When this increase in torque exceeds the value set by the knob 92, the relay 94 will be energized, thereby indicating an off-normal operation.

For a sudden decrease in torque to activate the horn 68 and de-energize the relay 70, there must be an accompanying non-programmed decrease in mud pump pressure. Drilling mud may be pumped into the drill string 16 via a mud tube 98 and a hollow portion of the section 76. A hose 100 connects to the mud tube 98 and a mud pump (not shown). The mud pump pressure alarm circuit includes a transducer 102 connected in the hose 100 to convert the mud pump pressure to an electrical signal on line 104. Usually, the transducer 102 will be installed in an oil chamber which is separated from the drilling mud by a flexible diaphragm. Such transducers are readily available and additional description is not deemed necessary.

The electrical signal representing mud pump pressure on the line 104 connects to an indicator/alarm meter 106 or to a controller, such as controller 90. An indicator/alarm meter suitable for the system shown includes an indicating needle 108 and a set point needle 110. When these two needles coincide, they operate electrical contacts to energize a relay 112 from an electrical power source 114. Energizing the relay 112 closes a contact 112-1, as shown in FIG. 2, to connect a light 116 to the terminals 62 and 64. Energizing the relay 112 also closes a contact 112-2 and opens a contact 112-3 for the horn 68 and the relay 70, respectively. Closing the contact 112-2 will not actuate the horn 68 and opening the contact 112-3 will not de-energize the relay 70 unless the relays 94 and 112 are energized at the same time. If the relays 94 and 112 are energized together, then the contacts 94-2 and 112-2 will be closed and the horn 68 will be energized to give an audible signal to an operator that a drill string twistoff has occurred. Opening the contacts 94-3 and 112-3 at the same time will disconnect the relay 70 from the terminals 62 and 64, thereby shutting down the drilling rig by opening the contact 70-2.

By monitoring mud pump pressure, off-normal operations other than a drill string twistoff may be detected. For example, if the drill strings develop holes, the drilling mud will be lost through these holes and the mud pump pressure will drop. By substituting the controller 90 for the meter 106, a high mud pump pressure will cause an energization of the relay 112. High mud pump pressure will result when the drill bit becomes plugged or when a sloughing shale condition develops. When a drill bit becomes plugged, it is important that the drilling be stopped to avoid damaging the bit. Not all deviations of mud pump pressure from a normal setting, however, require a complete shutdown of the rig operation. In fact, it may be desirable to continue the flow of drilling mud at some nominal value. In a sloughing shale condition, the mud pump pressure will be reduced to avoid damage to the hole through fracturing by excessive pressure, but some drilling mud flow is desirable to prevent the shale from packing around the drill string.

Although the circuit of FIG. 2 illustrates that a drill string weight change is an indication of a drill string twistoff independent of the other variables, it should be understood that by modifying the contact arrangement, a twistoff indication may not be given unless there was a change in drill string weight accompanied by deviation of one of the other variables from their established levels. By various contact arrangements, an indication of drill string twistoff can be made to be dependent upon a deviation from established levels of any combination of two of the three variables described. Thus, it should be understood that the contact arrangement described illustrates only one embodiment and is not intended as a limitation to the system shown.

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In conventional drilling rigs, fluid pressures may not be available to convert to electrical signals for representing the desired variables. For example, in a conventional rotary drilling rig, an electrical signal representing drill string weight may be produced by a wire-line anchor converting pull on the "dead line" to hydraulic pressure which may then be converted by the transducer 34. Mechanical devices are also available for detecting changes in tension in the rotary drive chain of a conventional rig. These mechanical devices include transducers for converting rotary drive chain tension into electrical signals representing drilling torque. On electrically driven conventional rigs, the torque pickup may be a device for generating an electrical signal proportional to the electric current supplied to the rotary table drive motors.

While only one embodiment of the invention, together with modifications thereof, has been described in detail herein and shown in the accompanying drawings, it will be evident that various further modifications are possible without departing from the scope of the invention.

What is claimed is:

1. In a drilling rig having means for raising and lowering a drill string, means for rotating the drill string and circuitry for controlling the operations of the means for raising, lowering and rotating the drill string, a system for detecting off-normal operation, comprising:

means for generating a signal proportional to the drill string weight both during tripping of the drill string in and out of a borehole and during the period the drill string is being rotated;

means coupled to said generating means for producing a weight alarm signal when the drill string weight deviates from an established value during tripping; and

means responsive to the weight alarm signal for actuating the circuitry controlling the drill string raising and lowering means.

2. The apparatus of claim 1, wherein the means coupled to said generating means also produces a weight alarm signal when the drill string weight deviates from an established value during rotation of the drill string.

3. The drilling rig of claim 1, including:

means associated with the means for rotating the drill string for generating a torque signal proportional to the torque being applied to said drill string; and means coupled to the torque signal generating means for producing a torque alarm signal when the drilling torque deviates from an established value.

4. A system in the operation of a drilling rig as set forth in claim 1, which rig additionally includes a mud pump and circuitry for controlling the operation of the mud pump, and which system also includes:

means operably associated with the mud pump for generating a mud pump signal proportional to mud pump pressure; and

means coupled to the mud pump signal generating means for producing a pump alarm signal when the mud pump pressure signal deviates from an established level.

5. In a drilling rig having means for raising and lowering a drill string, means for rotating the drill string, a mud pump and circuitry for controlling the operations of the drill string raising, lowering and rotating means and the mud pump, a system for detecting off-normal operations, including:

means operably associated with the drill string rotating means for generating a signal proportional to the torque being applied to the drill string;

means coupled to said generating means for producing a torque alarm signal when the drilling torque deviates from an established value;

means operably associated with the mud pump for generating a pump signal proportional to mud pump pressure;

means coupled to the pump signal generating means for

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producing a pump alarm signal when the pump signal deviates from an established level; and means responsive to the torque alarm signal and the mud alarm signal for actuating the circuitry controlling the drill string raising, lowering and rotating means and the mud pump.

6. The system of claim 5, including:

means for generating a signal proportional to the drill string weight;

means coupled to said generating means for producing a weight alarm signal when the drill string weight deviates from an established value; and

means responsive to the weight alarm signal for actuating the circuitry controlling the drill string raising, lowering and rotating means and the mud pump.

7. In a drilling rig having means for raising and lowering a drill string comprising cylinders and means for supplying a hydraulic fluid to said cylinders for raising and lowering said drill string, means for rotating said drill string comprising a drill head and means for circulating a hydraulic fluid through said drill head for rotation of the drill string, means for circulating fluid through the drill string and circuit means for controlling the operation of the means for supplying hydraulic fluid to said cylinders, the means for circulating a hydraulic fluid through said drill head and the means for circulating fluid through the drill string, the improvement which comprises:

a first transducer for converting the hydraulic pressure in the drill string raising and lowering cylinders into an electrical signal proportional to drill string weight while said drill string is rapidly moving, as during insertion and removal of the drill string from a borehole and while said drill string is moving relatively slowly, as during the period when the borehole is being drilled;

a controller coupled to the first transducer and responsive to the drill string weight signal for producing a weight alarm signal when the drill string weight signal deviates from an established value; and

control means responsive to the alarm signal for actuating the circuit means.

8. In a drilling rig having means for raising and lowering a drill string comprising cylinders and means for supplying a hydraulic fluid to said cylinders for raising and lowering said drill string, means for rotating said drill string comprising a drill head and means for circulating a hydraulic fluid through said drill head for rotation of the drill string, means for circulating fluid through the drill string and circuit means for controlling the operation of the means for supplying hydraulic fluid to said cylinders, the means for circulating a hydraulic fluid through said drill head and the means for circulating fluid through the drill string, the improvement which comprises:

first transducer means for converting the hydraulic pressure at the drill head into an electrical signal which is proportional to drilling torque;

a first controller coupled to the first transducer means for producing a signal when the drilling torque signal deviates from established values;

second transducer means for converting the pressure of the fluid being circulated through the drill string into an electrical signal which is proportional to the fluid pressure;

a second controller coupled to the second transducer means for producing a signal when the fluid pressure signal deviates from established values; and

control means responsive to the signals from the first and second controllers for actuating the circuit means when both signals are present.

9. The system of claim 8, including:

third transducer means for converting the hydraulic pressure in the drill string raising and lowering cylinders into an electrical signal proportional to the drill string weight;

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a third controller coupled to the third transducer means
for producing a signal when the drill string weight
deviates from an established value; and
control means responsive to the signal from the third
controller for actuating the circuit means.

10. A system in the operation of a hydraulic drilling
rig for detecting off-normal operation as set forth in claim
9, including:

means responsive to the rate of change of drill string
weight for producing a weight alarm signal when the
rate of change of the drill string weight deviates from
a preset value.

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