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(54) **DRILLING PROCESS MONITOR**

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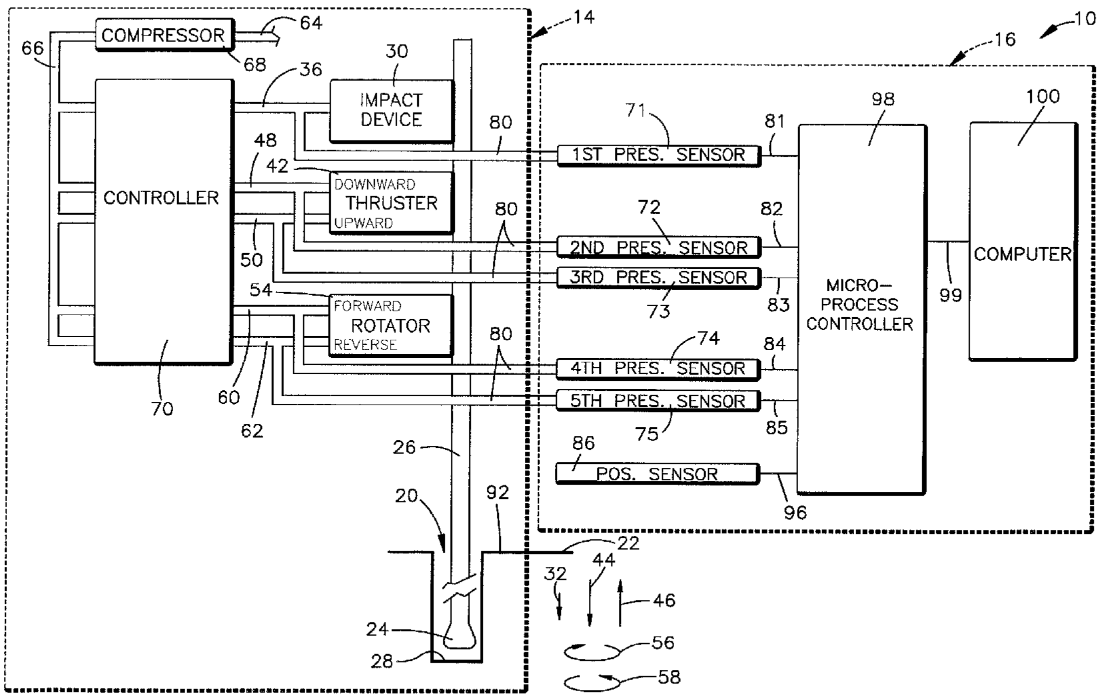
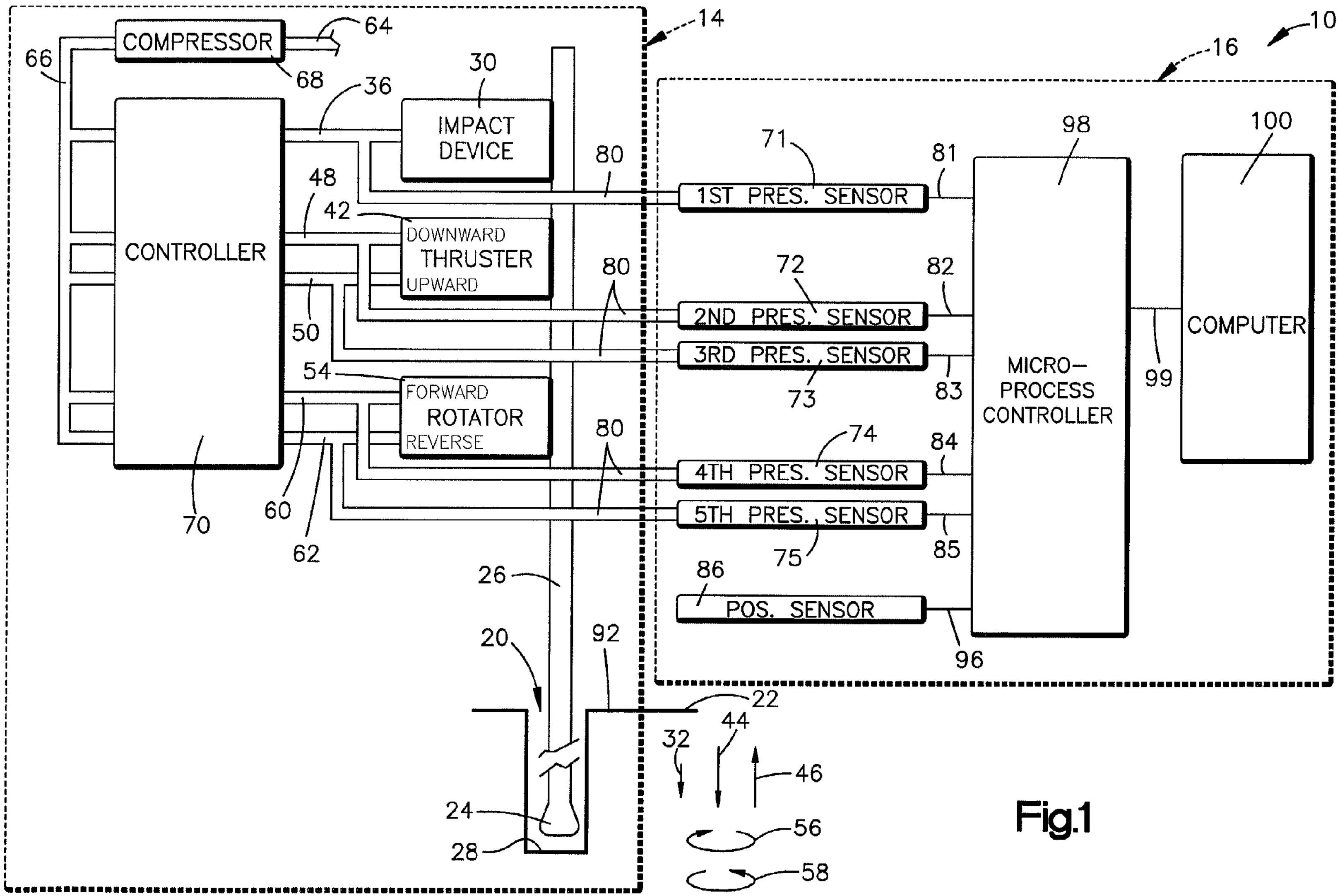
(52) **U.S. Cl.** **175/48**; 175/50

(57) **ABSTRACT**

An apparatus is used with a drilling assembly for drilling a borehole. The drilling assembly has an impact device linked to a drill head. The impact device is powered by a first fluid under a first pressure to impart a percussive force to the drill head. The percussive force is a function of the first pressure. A thruster of the drilling assembly is also linked to the drill head. The thruster is powered by a second fluid under a second pressure to impart a thrust force to the drill head. The thrust force is a function of the second pressure. Additionally, a rotator of the drilling assembly is linked to the drill head. The rotator is powered by a third fluid under a third pressure to impart a torque to the drill head. The torque is a function of the third pressure. The apparatus includes a first pressure sensor communicating with the first fluid to output a first electrical signal that is a function of the first pressure. A second pressure sensor communicates with the second fluid to output a second electrical signal that is a function of the second pressure. A third pressure sensor communicates with the third fluid to output a third electrical signal that is a function of the third pressure. A position sensor outputs a fourth electrical signal that is a function of depth of the drill head relative to a reference location. A device monitors the first, second, third and fourth signals. The device produces respective graph traces of functions of the percussive force, the thrust force, the torque and the depth.




COMPRESSOR
IMPACT DEVICE
CONTROLLER
DOWNWARD
THRUSTER
UPWARD
FORWARD
ROTATOR
REVERSE
1ST PRES. SENSOR
2ND PRES. SENSOR
3RD PRES. SENSOR
4TH PRES. SENSOR
5TH PRES. SENSOR
POS. SENSOR
MICRO-PROCESS CONTROLLER
COMPUTER
10
14
16
20
22
24
26
28
30
32
36
42
44
46
48
50
54
56
58
60
62
64
66
68
70
71
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98
99
100

Fig.1

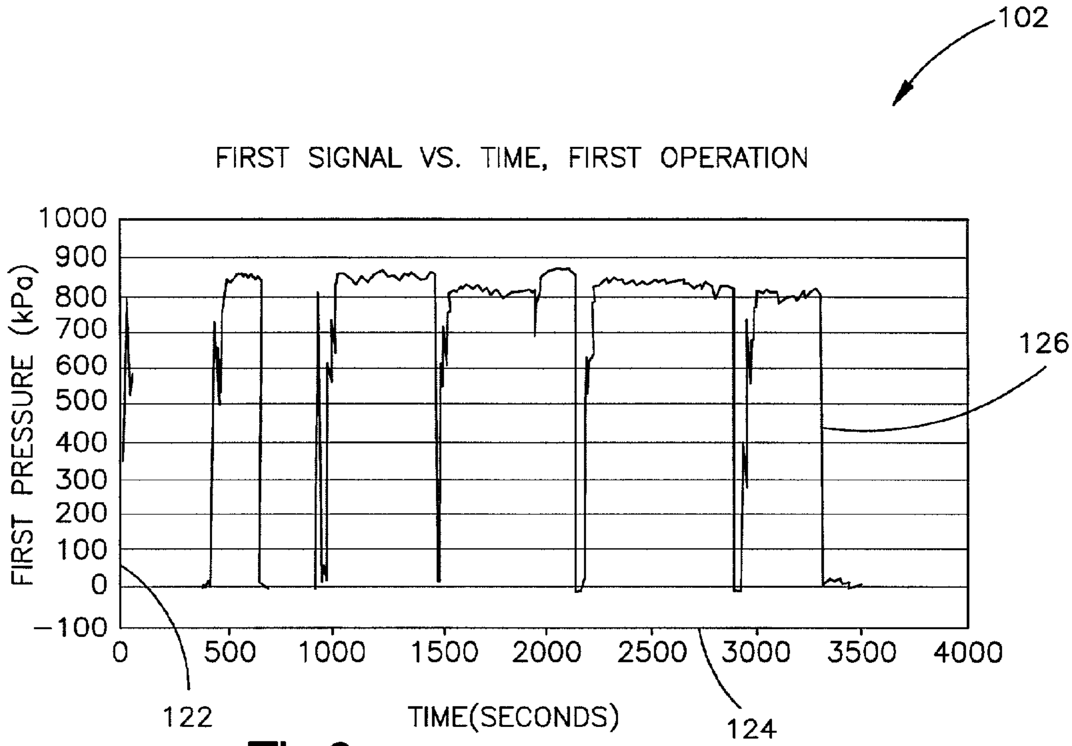
102
FIRST SIGNAL VS. TIME, FIRST OPERATION
FIRST PRESSURE (kPa)
1000
900
800
700
600
500
400
300
200
100
0
−100
0
500
1000
1500
2000
2500
3000
3500
4000
TIME(SECONDS)
122
124
126

Fig.2

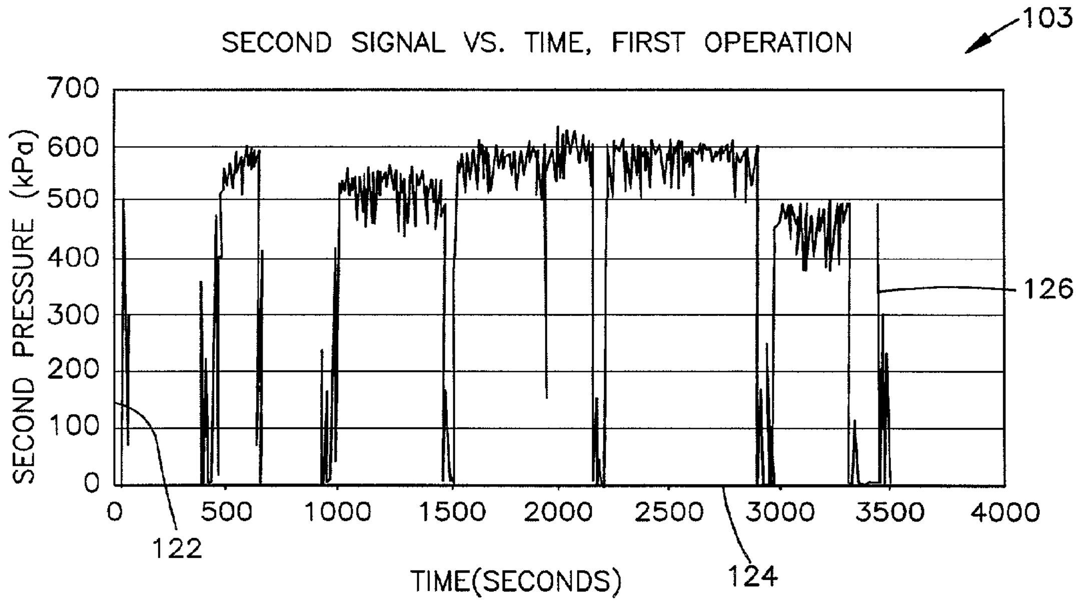
103
SECOND SIGNAL VS. TIME, FIRST OPERATION
SECOND PRESSURE (kPa)
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500
4000
TIME(SECONDS)
122
124
126

Fig.3

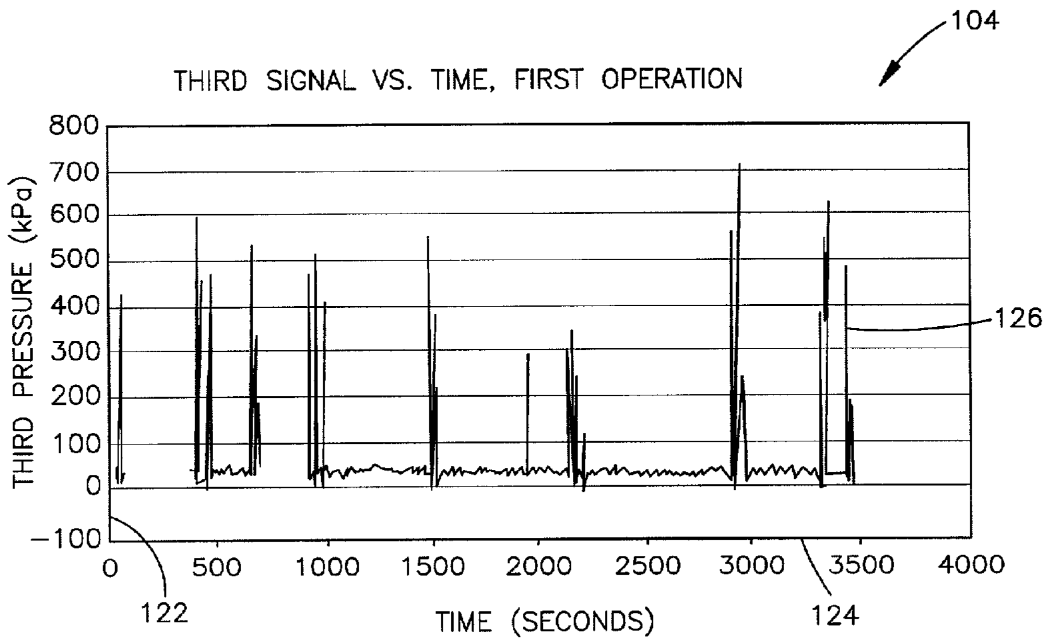
104
THIRD SIGNAL VS. TIME, FIRST OPERATION
THIRD PRESSURE (kPa)
800
700
600
500
400
300
200
100
0
−100
0
500
1000
1500
2000
2500
3000
3500
4000
126
122
124
TIME (SECONDS)

Fig.4

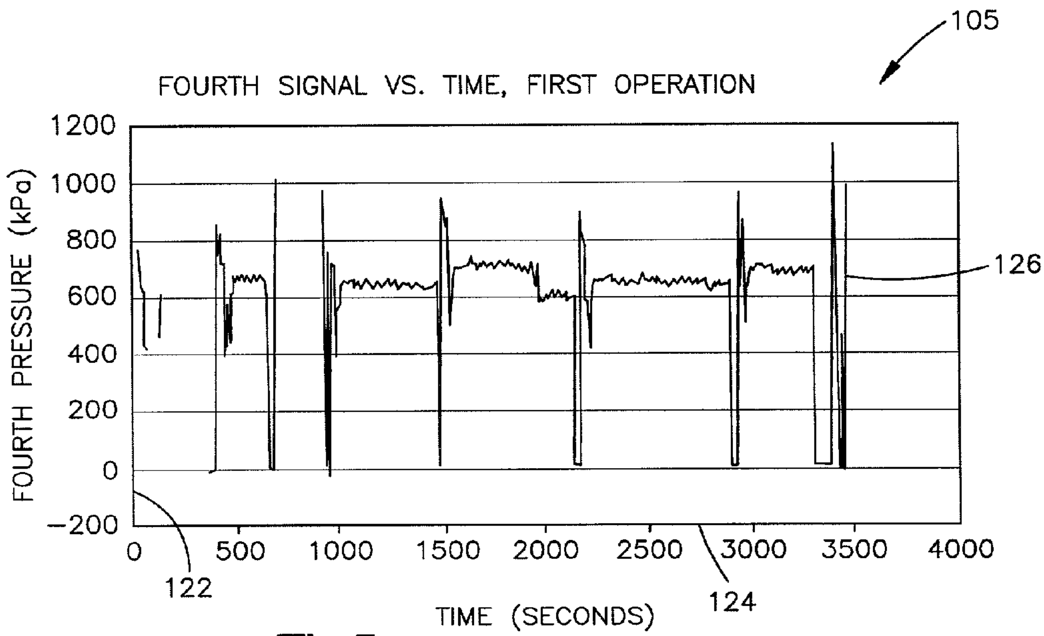
105
FOURTH SIGNAL VS. TIME, FIRST OPERATION
FOURTH PRESSURE (kPa)
1200
1000
800
600
400
200
0
−200
0
500
1000
1500
2000
2500
3000
3500
4000
126
122
124
TIME (SECONDS)

Fig.5

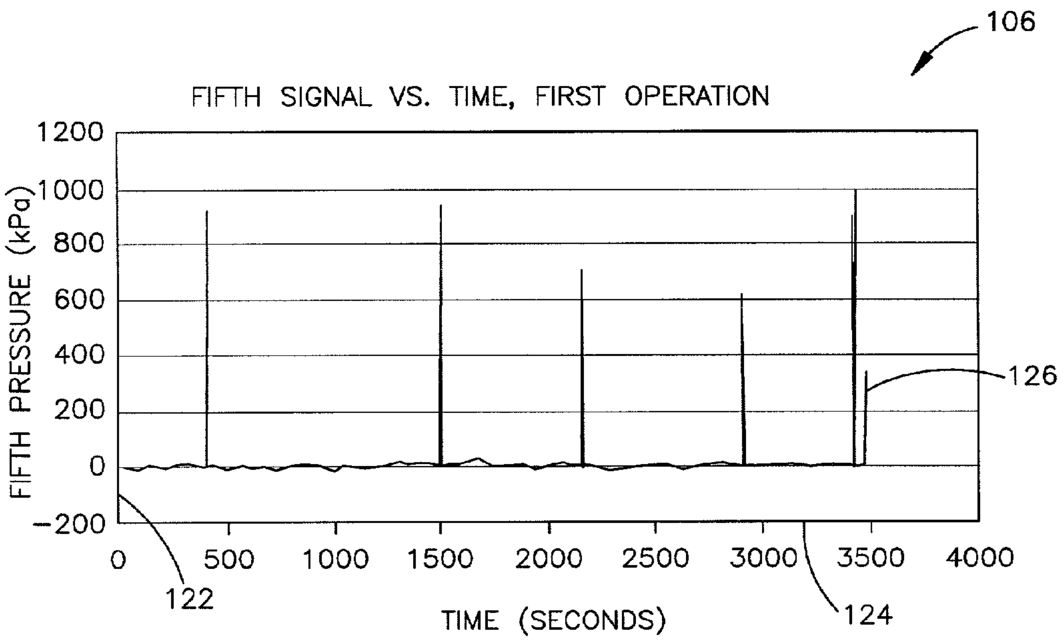
106
FIFTH SIGNAL VS. TIME, FIRST OPERATION
FIFTH PRESSURE (kPa)
1200
1000
800
600
400
200
0
-200
0
500
1000
1500
2000
2500
3000
3500
4000
TIME (SECONDS)
122
124
126

Fig.6

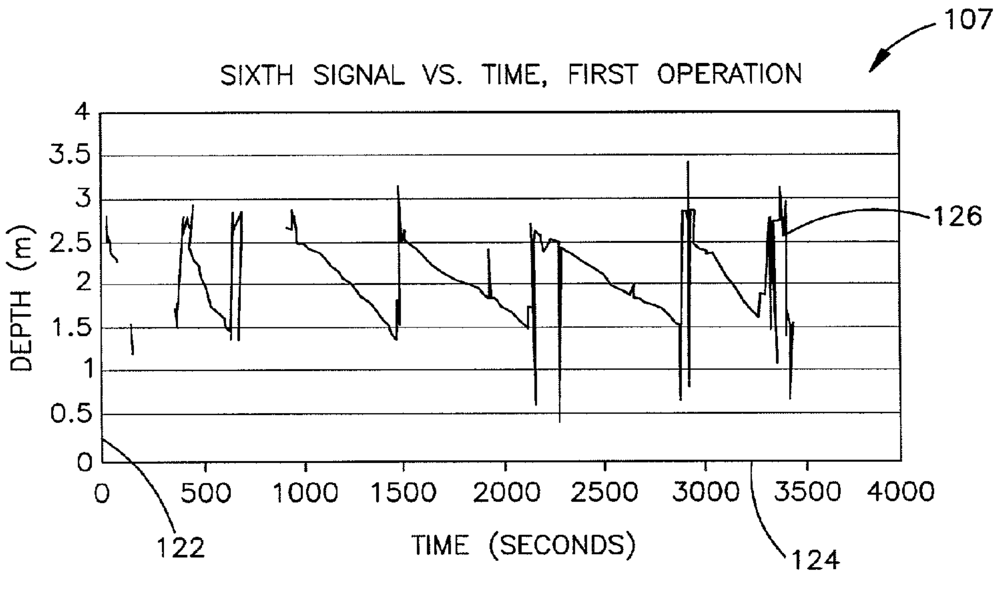
107
SIXTH SIGNAL VS. TIME, FIRST OPERATION
DEPTH (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
3500
4000
TIME (SECONDS)
122
124
126

Fig.7

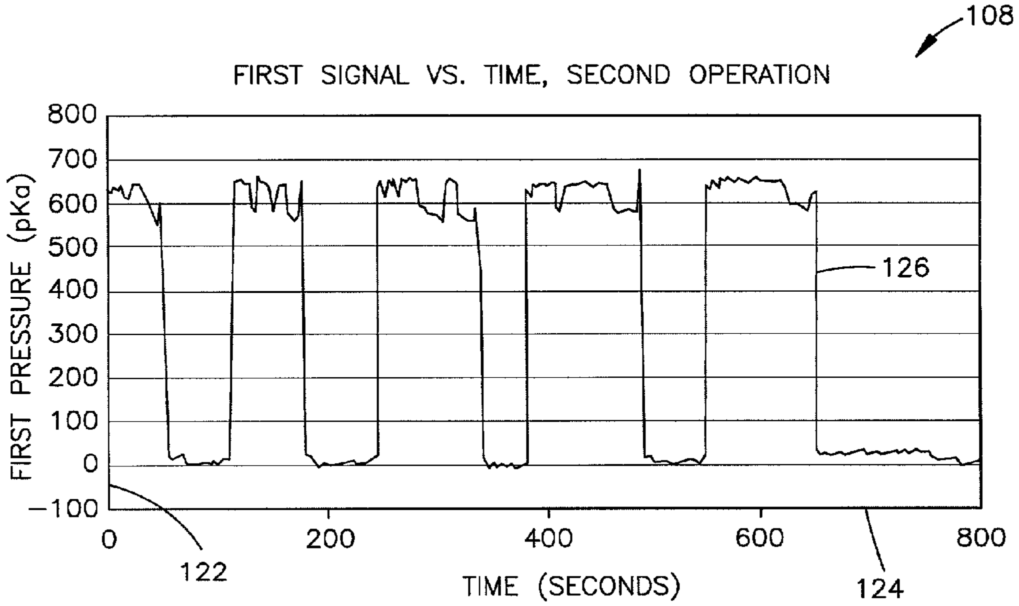
108
FIRST SIGNAL VS. TIME, SECOND OPERATION
800
700
600
500
400
300
200
100
0
−100
FIRST PRESSURE (pKa)
0
200
400
600
800
TIME (SECONDS)
122
124
126

Fig.8

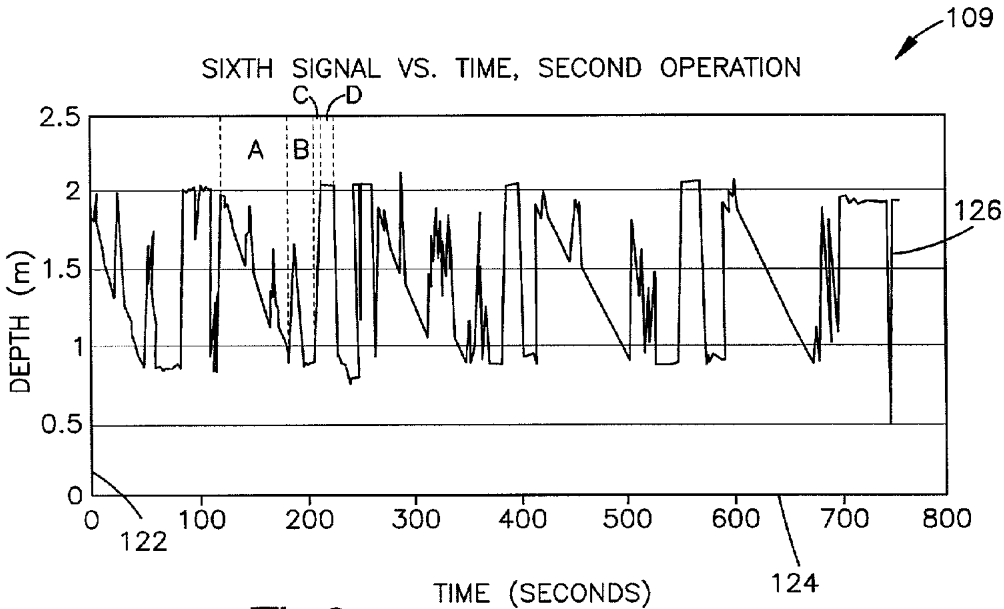
109
SIXTH SIGNAL VS. TIME, SECOND OPERATION
A
B
C
D
2.5
2
1.5
1
0.5
0
DEPTH (m)
0
100
200
300
400
500
600
700
800
TIME (SECONDS)
122
124
126

Fig.9

DRILLING PROCESS MONITOR

[0001] This application claims the benefit of U.S. Provisional Application No. 60/234,535, filed Sep. 22, 2000, and incorporates the Provisional Application by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to systems for drilling holes in the ground.

BACKGROUND

[0003] In a drilling operation, a drilling assembly is used to drill a hole in the earth. It is sometimes desirable to monitor the progress of the drilling operation.

SUMMARY OF THE INVENTION

[0004] An apparatus is used with a drilling assembly for drilling a borehole. The drilling assembly has a drill head. An impact device of the drilling assembly is linked to the drill head. The impact device is powered by a first fluid under a first pressure to impart a percussive force to the drill head. The percussive force is a function of the first pressure. A thruster of the drilling assembly is also linked to the drill head. The thruster is powered by a second fluid under a second pressure to impart a thrust force to the drill head. The thrust force is a function of the second pressure. Additionally, a rotator of the drilling assembly is linked to the drill head. The rotator is powered by a third fluid under a third pressure to impart a torque to the drill head. The torque is a function of the third pressure. The apparatus includes a first pressure sensor communicating with the first fluid to output a first electrical signal that is a function of the first pressure. A second pressure sensor communicates with the second fluid to output a second electrical signal that is a function of the second pressure. A third pressure sensor communicates with the third fluid to output a third electrical signal that is a function of the third pressure. A position sensor outputs a fourth electrical signal that is a function of depth of the drill head relative to a reference location. A device monitors the first, second, third and fourth signals. The device produces respective graph traces of functions of the percussive force, the thrust force, the torque and the depth.

[0005] In a preferred embodiment, the device produces the graph traces in real time during the drilling operation. The first, second and third electrical signals are analog signals. The fourth electrical signal is a digital signal. The graph traces are indicative of the occurrence of downward drilling, drilling stoppage, raising of the drill head, and addition of drilling rods.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] **FIG. 1** is a schematic view of a drilling system according to the present invention; and

[0007] FIGS. **2-9** are graphs produced by the drilling system of **FIG. 1**.

DESCRIPTION

[0008] An example of a preferred embodiment of the present invention is shown schematically in **FIG. 1**. The preferred embodiment is a drilling system **10** that includes a drilling assembly **14** and a monitoring system **16**. The drilling assembly **14** performs a drilling operation defined by drilling a borehole **20** in the earth **22**. The monitoring system **16** measures and displays dynamic parameters related to the drilling operation.

[0009] In this embodiment, the drilling assembly **14** is a pneumatic percussive rotary drilling machine. The drilling assembly **14** has a drill head **24** at the end of a drill string **26** defined by a series of drilling rods. During the drilling operation, the drill head **24** rotates and vibrates while being thrust into the bottom end **28** of the borehole **20**.

[0010] The drill head **24** is linked to an impact device **30** in a known manner. The impact device **30** applies a percussive force, indicated by arrow **32**, which is transmitted through the drill string **26** to the drill head **24** to fragment soil and drive the drill head **24** into the bottom end **28** of the borehole **20**. The impact device **30** is powered by a first fluid **36** under a first pressure. The percussive force at the drill head **24** is a function of the first pressure.

[0011] The drill head **24** is also linked to a thruster **42**. The thruster **42** can apply a downward force, indicated by arrow **44**, that is transmitted through the drill string **26** to the drill head **24** to thrust the drill head **24** into the earth **22**. The thruster **42** can also apply an upward force, indicated by arrow **46**, that is transmitted through the drill string **26** to the drill head **24** to raise the drill head **24**. The thruster **42** is powered by a second fluid **48** under a second pressure and a third fluid **50** under a third pressure. The downward force is a function of the second pressure. The upward force is a function of the third pressure.

[0012] The drill head **24** is further linked to a rotator **54**. The rotator **54** can apply a forward torque, indicated by arrow **56**, that is transmitted through the drill string **26** to the drill head **24** to rotate the drill head **24** in a forward direction. Rotation of the drill head **24** in the forward direction causes the drill head **24** to abrade, and to be driven downward through, the bottom end **28** of the borehole **20**. The rotator **54** can also apply a reverse torque, indicated by arrow **58**, that is transmitted through the drill string **26** to the drill head **24**. Rotation of the drill head **24** in the reverse direction assists in removing the drill head **24** from the bottom end **28** of the borehole **20**. The rotator **54** is powered in the forward direction by a fourth fluid **60** under a fourth pressure. The rotator **54** is powered in the reverse direction by a fifth **62** fluid under a fifth pressure. The forward torque is a function of the fourth pressure. The reverse torque is a function of the fifth pressure.

[0013] In this embodiment, each of the first, second, third, fourth and fifth fluids **36**, **48**, **50**, **60** and **62** is a gas. However, for use with hydraulic drilling assemblies, these fluids would be liquids. These fluids **36**, **48**, **50**, **60** and **62** are compressed from a common fluid supply **64** into a manifold **66** by a compressor **68** and are delivered to the corresponding devices **30**, **42** and **54**. Delivery of each of these fluids **36**, **48**, **50**, **60** and **62** to the respective device **30**, **42** and **54** is controlled by a controller **70**.

[0014] The monitoring system **16** includes five individual pressure sensors **71**, **72**, **73**, **74** and **75** for measuring the pressure of the five fluids **36**, **48**, **50**, **60** and **62**, respectively. The pressure sensors **71**, **72**, **73**, **74** and **75** are in communication with the respective fluids **36**, **48**, **50**, **60** and **62** through fluid lines **80**. The pressure of each fluid **36**, **48**, **50**, **60** and **62** is conducted through the respective fluid line **80**

to the respective pressure sensor **71**, **72**, **73**, **74** and **75**. Each pressure sensor **71**, **72**, **73**, **74** and **75** produces an analog electrical signal that is a function of the pressure of the respective fluid **36**, **48**, **50**, **60** and **62**. The signals are output onto respective electrical lines **81**, **82**, **83**, **84** and **85**.

[**0015**] A position sensor **86** is operative to measure the depth of the drill head **24** relative to a reference location. The reference location is a fixed location **92** on the surface of the earth **22**. Alternatively, the reference location can be a fixed location (not shown) on the drilling assembly **14**. The depth measurement may be accomplished in any suitable manner known in the art. The position sensor **86** produces a digital signal representing a value that is a function of the depth of the drill head **24**. The digital signal is output on an electrical line **96**.

[**0016**] The five analog signals and the one digital signal are communicated over the lines **81**, **82**, **83**, **84**, **85** and **96** to a micro-processor controller **98**. The micro-process controller **98** converts the five analog signals and the one digital signal to six corresponding digital data typically in RS232 format. The micro-process controller **98** functions as a data buffer to manipulate the data and change data format. The micro-process controller **98** also controls the data collection of the six electrical signals in real time simultaneously via the six lines **81**, **82**, **83**, **84**, **85** and **96**. The micro-process controller **98** can continuously store the digital data on a disk drive (not shown) in real time.

[**0017**] In the present embodiment, the micro-process controller **98** outputs the digital data over an electrical line **99** to a computer **100**, which in the present embodiment is a personal computer. During the drilling operation, the computer **100** continuously stores the digital signals on a disk drive (not shown) in real time and can continuously produce graphs of the respective digital signals in real time. Each graph is displayed on a suitable medium, such as a sheet of paper.

[**0018**] FIGS. **2-7** show graphs **102**, **103**, **104**, **105**, **106** and **107** corresponding to the first, second, third, fourth, fifth and sixth digital signals, respectively, for a first typical drilling operation. **FIGS. 8 and 9** show graphs **108** and **109** corresponding to the first and sixth signals, respectively, for a second typical drilling operation.

[**0019**] The graphs **102**, **103**, **104**, **105**, **106**, **107**, **108** and **109** in FIGS. **2-9** have many features in common. These features can be explained with reference to the graph **102** of **FIG. 2**. Graph **102** includes a vertical axis **122** representing signal magnitude. The vertical axis **122** is graduated in terms of pressure in units of kPa. A horizontal axis **124** represents elapsed time relative to a start time designated as zero. The horizontal axis **124** is graduated in units of seconds. Graph **102** also includes a trace **126** based on the first digital signal corresponding to percussive force. The vertical position of each point along the trace **126** is a function of the first pressure at the time that point was measured.

[**0020**] In graph **103** of **FIG. 3**, the trace **126** is based on the second digital signal. The trace **126** is thus a function of the second pressure, corresponding to downward thrust. Similarly, the trace **126** of the graph **104** of **FIG. 4** is based on the third digital signal and is therefore a function of the third pressure, corresponding to upward thrust. Likewise, the trace **126** of the graph **105** of **FIG. 5** is based on the fourth digital signal. It is consequently a function of the fourth pressure, corresponding to forward torque. The trace **126** of the graph **106** of **FIG. 6** is based on the fifth digital signal. It is thus a function of the fifth pressure, corresponding to reverse torque.

[**0021**] In graph **107** of **FIG. 7**, the vertical axis **122** is graduated in terms of depth in units of meters. This is in contrast to the graphs **102**, **103**, **104**, **105** and **106** (FIGS. **2-6**, respectively) in which the vertical axes **122** are graduated in terms of pressure. In graph **107** of **FIG. 7**, the trace **126** is based on the sixth digital signal. The vertical position of each point along the trace **126** is consequently a function of depth of the drill head **24** (**FIG. 1**) at the time that point was measured.

[**0022**] The graph **108** of **FIG. 8** is similar to the graph **102** of **FIG. 2**, but is for the second drilling operation. Likewise, the graph **109** of **FIG. 9** is similar to the graph **107** of **FIG. 7**, but is for the second drilling operation.

[**0023**] In this embodiment, the traces **126** are plotted on separate graphs **102**, **103**, **104**, **105**, **106**, **107**, **108** and **109** (FIGS. **2-9**), each having a separate horizontal axis **124**. However, the horizontal axes **124** of graphs relating to the same operation are the same in size and in time scale. For example, the horizontal axes **124** of the graphs in FIGS. **2-7** all have the same time scale, 0-4000 seconds.

[**0024**] During and after the drilling operation, an operator can interpret the graphs shown in FIGS. **2-9** to assess the progress of the drilling operation, to note any irregularity in the operation, and to discern the subsurface profile and properties. The operator can also interpret these graphs to determine when different operations have been performed. For example, referring to graph **109** in **FIG. 9**, section A corresponds to downward drilling, section B corresponds to drilling stoppage, section C corresponds to raising of the drill head **124**, and section D corresponds to addition of drilling rods.

[**0025**] The invention has been described with reference to preferred embodiments. Those skilled in the art will perceive improvements, changes and modifications. Such improvements, changes and modifications are intended to be within the scope of the claims.

1. Any in-situ devices or instruments to automatically and continuously measure and record the drilling process while drilling holes in ground using pneumatic percussive rotary drilling machines, comprising:

a distance sensor device to measure the downward, upward or stoppage movement of the drill chuck or head in vertical, horizontal or inclined directions with respect to fixed points on the ground or the drilling machines;

air pressure transducers to measure the compressed air pressures from the drilling machine controller applied to the drilling rig; and

a micro-process controller and a personal computer to convert, transfer and store the distance and pressure measurements in digital format.

2. Any in-situ devices or instruments to automatically and continuously measure and record the drilling process while drilling holes in ground using hydraulic percussive rotary drilling machines, comprising:

a distance sensor device to measure the downward, upward or stoppage movement of the drill chuck or head in vertical, horizontal or inclined directions with respect to fixed points on the ground or the drilling machines;

fluid pressure transducers to measure the compressed fluid pressures from the drilling machine controller applied to the drilling rig; and

a micro-process controller and a personal computer to convert, transfer and store the distance and pressure measurements in digital format.

3. Any in-situ devices or instruments to automatically and continuously measure and record the drilling or boring process while drilling holes in ground using hydraulic rotary drilling machines, comprising:

a distance sensor device to measure the downward, upward or stoppage movement of the drill chuck (or head) in vertical, horizontal or inclined directions with respect to fixed points on the ground or the drilling machines;

fluid pressure transducers to measure the compressed fluid pressures from the drilling machine controller applied to the drilling rig; and

a micro-process controller and a personal computer to convert, transfer and store the distance and pressure measurements in digital format.

4. An apparatus for use with a drilling assembly for drilling a borehole, the drilling assembly having:

a drill head;

an impact device linked to the drill head, the impact device being powered by a first fluid under a first pressure to impart a percussive force to the drill head, the percussive force being a function of the first pressure;

a thruster linked to the drill head, the thruster being powered by a second fluid under a second pressure to impart a thrust force to the drill head, the thrust force being a function of the second pressure; and

a rotator linked to the drill head, the rotator being powered by a third fluid under a third pressure to impart a torque to the drill head, the torque being a function of the third pressure;

said apparatus comprising:

a first pressure sensor communicating with the first fluid to output a first electrical signal that is a function of the first pressure;

a second pressure sensor communicating with the second fluid to output a second electrical signal that is a function of the second pressure;

a third pressure sensor communicating with the third fluid to output a third electrical signal that is a function of the third pressure;

a position sensor that outputs a fourth electrical signal that is a function of depth of the drill head relative to a reference location; and

a device that monitors said first, second, third and fourth signals, and that produces respective graph traces of functions of the percussive force, the thrust force, the torque and the depth.

5. The apparatus of claim 4 wherein said device produces said graph traces in real time during the drilling operation.

6. The apparatus of claim 4 wherein said first, second and third electrical signals are analog signals.

7. The apparatus of claim 4 wherein said fourth electrical signal is a digital signal.

8. The apparatus of claim 4 wherein said graph traces are indicative of the occurrences of downward drilling, drilling stoppage, raising of the drill head, and addition of drilling rods.

* * * * *