APPARATUS AND METHOD FOR COMPUTING DRILLING COSTS

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References Cited

UNITED STATES PATENTS
3,364,494 1/1968 Dellinger et al. 73/151.5 X

[57] ABSTRACT

Apparatus and method for computing the cost per unit length of borehole drilled by a drilling apparatus, as for example, the cost per foot of borehole drilled. First signals representative of incremental lengths of an interval of borehole depth drilled and a second signal representative of the accumulated cost incurred in drilling the interval of depth are generated and used to generate a third signal representative of average cost of operating the drilling apparatus during the interval of depth. The third signal may be read out and may be graphically recorded as a function of the depth drilled during the interval.

14 Claims, 4 Drawing Figures
APPARATUS AND METHOD FOR COMPUTING DRILLING COSTS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to apparatus and method for determining the cost per unit length of borehole drilled by a drilling apparatus.

2. Description of the Prior Art

The cost of drilling a borehole into the earth with a drilling apparatus in a particular location is a function of the cost of the drill bit, the cost of operating the drilling apparatus per unit length of time, and the speed with which the drill bit penetrates the subterranean formations. Since the drill bit is a consumable apparatus which decreases in efficiency with age and must be replaced periodically, the total drilling time for producing a borehole includes actual bit penetrating time and the time required to remove the drill string from the borehole, replace the bit and resume drilling.

Therefore, a drilling operator was required to exercise his own subjective judgment based on his past experience in determining when a drill bit was consumed to the extent sufficient to justify the expense and productive cost of replacing the drill bit. If the drill string is tripped out of the borehole either too soon or too late, the over-all average cost per foot of drilling is increased. In order to minimize drilling costs, it is therefore important to be able to accurately determine the point at which drilling efficiency decreases with continued drilling. No prior art apparatus or method is available to accurately indicate instantaneous drilling efficiency or to determine the point of maximum drilling efficiency.

SUMMARY OF THE INVENTION

The apparatus of this invention for determining the cost of drilling a borehole per unit length of hole drilled, for example the cost in dollars per foot drilled, includes first means for generating a first signal representative of incremental lengths of an interval of borehole depth drilled and second means for generating a second signal representative of accumulated drilling costs incurred in drilling the interval of depth. Third means responsive to the first and second signals generates a third signal representative of the average drilling cost per incremental length of borehole drilled.

The second means preferably includes fourth means for generating a fourth signal representative of total drilling apparatus time and fifth means for generating a fifth signal representative of drilling cost during the apparatus use time. The fourth means preferably includes sixth means for generating a sixth signal representative of the rotating time of the drilling apparatus and seventh means for generating a seventh signal representative of trip time. Also included are eighth means for generating an eighth signal representative of the cost of the drill bit utilized in drilling the interval of borehole depth.

The apparatus of this invention also preferably includes means for reading out the average cost per incremental length of borehole drilled and means for graphically recording the average drilling cost per incremental length of the interval of borehole drilled as a function of the depth drilled during the interval.

The method of this invention includes generating the above-described first through eighth signals and graphically recording average drilling costs per incremental length of drilling interval as a function of the depth drilled during the interval.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings: FIG. 1 is a typical graph illustrating the change in drilling cost as a function of depth drilled during an interval of depth.

FIG. 2 is a block diagram illustrating the apparatus of the invention.

FIG. 3 is a block diagram showing in detail storage unit 4 of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, FIG. 1 illustrates a typical graph of average drilling cost as a function of depth drilled over an interval of drilling. This curve is based upon the relationship:

\[ D = C_t (t_r + t_i) + C_b \]

where:

- \( C_t \) = rig cost in dollars per hour
- \( C_b \) = bit cost in dollars
- \( t_r \) = rotating time in hours
- \( t_i \) = trip time in hours
- \( t_r + t_i \) = total drilling time in hours
- \( d \) = depth of drilling interval in feet

\[ D = \text{average drilling cost in dollars per foot} \]

Rotating time \( (t_r) \) is the actual drilling time on each bit. Trip time \( (t_i) \) is the time expended during the changing of a bit; i.e., the time required to remove all drill pipe in the borehole, replace the drill bit, and again run all drill pipe back into the borehole to place the new bit on bottomhole. The sum of rotating and trip time \( (t_r + t_i) \) is therefore the total rig time required for each drill bit.

Visual examination of the cost per foot curve of FIG. 1 illustrates the optimum or minimum drilling cost for a particular drill bit. During the interval between A and B, drilling costs are declining with accumulated depth. The cost at point B appears to reach an optimum value at which no further decrease in cost is apparent. The interval between point B and point C reflects a slight increase in cost, indicating a decreasing drilling efficiency. Point C can therefore represent the depth at which a new bit should be installed in order to operate at near optimum drilling efficiency.

The apparatus and method of this invention allow automatic computation of average drilling cost per incremental length (e.g., per foot) of borehole drilled from the relationship:

\[ D = C_t (t_r + t_i) + C_b d \]

and provide an output which can be read out or indicated on a meter and can be applied to a strip chart recorder to produce a curve similar to that shown in FIG. 1 for each drill bit used. After a new bit has been installed, but before the drilling is resumed, rig cost \( (C_t) \), trip time \( (t_i) \) and bit cost \( (C_b) \) are entered into the apparatus as known quantities. Rotating time \( (t_r) \) is a real time variable, but is supplied by an internal source. Borehole depth \( (d) \), the second real time variable, must be supplied by an external source.

The cost per foot computer is therefore an electronic analog device requiring an input depth signal for each foot of borehole drilled and providing an output voltage proportional to the instantaneous value of the curve of FIG. 1. The preferred embodiment of the cost per foot computer apparatus of this invention is shown in block diagram in FIG. 2. Depth pulses 18 represent the only external variable input required.

Depth pulses 18 may be supplied by any convenient signal source compatible with this apparatus and with strip chart recorder 33. One suitable source for pulses 18 is manufactured by W. & L. E. Gurley Company of Troy, N.Y., and bears model No. 8602-1. Pulses 18 are stored in depth storage unit 19, as described below, and are supplied to strip chart recorder 33 which is used to record the output from the computer apparatus and to produce a curve similar to FIG. 1. Recorder 33 may be of any compatible type which is pulse driven in the horizontal plotting direction in order to provide horizontal chart movement proportional to borehole depth increases. One convenient type of recorder 33 is manufactured by Westronics, Inc. of Ft. Worth, Tex. and bears model No. YSD11-E.

Trip time \( (t_i) \) 6, bit cost \( (C_b) \) 14 and rig cost \( (C_t) \) 10 are entered into the computer apparatus as constants for any one computation. The internal variable, bit rotating time \( (t_r) \), is
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supplied by rotating time circuit 2. The output of circuit 2 is a series of pulses or clock signals representing a specific time interval. For example, one clock pulse might represent one-tenth of an hour. The clock signals are directed via conductor 3 to storage circuit 4 for accumulation and conversion to a proportionate analog DC voltage. A more detailed diagram of circuit 4 is shown in FIG. 3. Time pulses via conductor 3 are accumulated in digital register 27. The binary output of digital register 27 is applied through conductor 28 to digital-to-analog converter 29. The output of D-to-A converter 29 is applied via conductor 30 to buffer amplifier 31. Amplifier 31 supplies a DC voltage directly proportional to the number of time pulses accumulated by digital register 27. Rotating time voltage is then applied via conductor 5 to adder 8.

Trip time \( t_1 \) is set into the computer by a direct reading potentiometer control in circuit 6. A typical circuit of this type is shown in FIG. 4. The output of circuit 6 is an analog voltage which is directly proportional to trip time. Trip time voltage is applied via conductor 7 to a second input of adder 8. The output of adder 8 is equal to:

\[ T = t_1 + t_2 \]

where \( T \) = total of rotating time plus trip time. The total time \( T \) is directed via conductor 9 to multiplier 12. The second input to multiplier 12 is supplied on conductor 11 from rig cost circuit 10. This circuit was shown to be the same as trip time circuit 6 in FIG. 4, with an appropriate scale on potentiometer \( R_5 \) being provided to allow a direct setting of rig cost. The output of multiplier 12 is an analog DC voltage proportional to:

\[ C_5(t_1 + t_2) \]

This output of multiplier 12 is then applied via conductor 13 to adder 16. Bit cost \( C_5 \) is manually dialed into the computer by means of a direct reading potentiometer control in circuit 14. This circuit is the same as trip time circuit 6 with an appropriate scale for potentiometer control \( R_5 \) so that the analog DC output voltage is directly proportional to the desired bit cost in dollars. The output of circuit 14 is directed via conductor 15 to the second input of adder 16. Adder 16 combines the signals from multiplier 12 and bit cost circuit 14 to provide an output signal proportional to the total rig cost plus bit cost, or:

\[ C_0(t_1 + t_2) + C_6 \]

This voltage representing total cost is directed via conductor 17 to one input of analog divider 21.

Depth pulses 18 from the depth transmittion device (not shown) are directed to storage circuit 19 and to strip chart recorder 33. Storage circuit 19 may be identical to storage circuit 4 and is shown in more detail in FIG. 3. In storage circuit 19, depth pulses are accumulated in digital register 27. The binary output of register 27 is directed via conductor 28 to digital-to-analog converter 29. The output of D-to-A converter 29 via conductor 30 and buffer amplifier 31 represents an analog voltage whose absolute value is directly proportional to accumulated depth. The analog output of storage unit 19 is directed via conductor 20 to the second input of analog divider 21. The output of divider 21 represents the desired average cost per foot which is:

\[ D = C_0(t_1 + t_2) + C_6/d \]

The analog voltage representing cost per foot is directed via conductor 22 to scaling amplifier circuit 23. One output of circuit 23 is routed via conductor 25 to analog meter 26, providing an instantaneous readout or indication of average cost. The second output of circuit 23 is routed via conductor 24 to the vertical or Y-input of strip chart recorder 33. The horizontal or X-input of strip chart recorder 33 is pulse activated or driven by depth pulses 18 such that the chart is advanced for each pulse or unit of depth. Use of the described incremental advance strip chart recorder allows the curve to be automatically plotted. In addition, a wide range of resolution may be obtained by proper scaling of computer inputs and recorder functions.

In operation, the time required to trip the drill string out of the borehole, replace the drill bit and return the bit to the 75 borehole bottom is measured and entered by the drilling operator in circuit 6. At the same time, the cost of the new bit is entered into circuit 14 and the hourly drilling apparatus cost is entered into circuit 10. As drilling begins, rotating time circuit 2 is activated to produce clock pulses which are stored in circuit 4 and a depth recorder (not shown) produces depth pulses 18 which are stored in circuit 19. As described above, the computer apparatus therefore continuously calculates average drilling cost in dollars per foot, which figure is applicable to the interval drilled with the new drill bit.

The method of this invention may be practiced using the apparatus described above. A depth recorder (not shown) senses incremental increases in depth during the interval of drilling with each bit and produces signals 18 representative thereof. Circuits 2 through 10 may be the same as trip time circuit 17 which is representative of the total operating cost during the time necessary to drill the interval of depth. The signal on conductor 17 is then divided by the depth signal 18 that has been stored in circuit 19 to produce an output signal on conductor 22 representative of the average cost of operating the drilling apparatus for each incremental depth of borehole drilled during the drilling interval. This output signal may be monitored with meter 26 and may be recorded on strip chart recorder 33.

The foregoing is to be construed as illustrative only and further modifications and alternate equivalent embodiments will be obvious to those skilled in the art in view of this description.

What is claimed is:

1. Apparatus for determining drilling cost while drilling a borehole, comprising:

   - first means for sensing successive incremental lengths of an interval of borehole depth drilled and generating first electrical signals representative thereof;

   - second electrical means for generating a second signal representative of accumulated drilling cost incurred as said interval of depth is drilled;

   - third means responsive to said first and second signals for generating a third electrical signal representative of average operating cost per incremental length of borehole drilled over said interval of depth.

2. The invention as claimed in claim 1 including:

   - means responsive to said third signal for reading out the average cost per incremental length of borehole drilled.

3. The invention as claimed in claim 1 wherein said second means includes:

   - fourth electrical means for generating a fourth signal representative of the length of time said drilling apparatus is utilized in boring said interval of depth;

   - and, fifth means for generating a fifth electrical signal representative of the cost of operating said drilling apparatus during said length of time.

4. The invention as claimed in claim 3 wherein said fourth means includes:

   - sixth electrical means for generating a sixth signal representative of the rotating time of said drilling apparatus;

   - and, seventh electrical means for generating a seventh signal representative of the amount of time in excess of rotating time that said drilling apparatus is utilized in boring said interval of depth.

5. The invention as claimed in claim 4 including:

   - eighth electrical means for generating an eighth signal representative of the cost of the drill bit utilized in drilling said interval of depth.
6. The invention as claimed in claim 5 including: means responsive to said third signal for reading out the average cost per incremental length of borehole drilled.

7. The invention as claimed in claim 5 including: means for graphically recording said average drilling cost per incremental length of said interval of depth as a function of the depth drilled during said interval.

8. The method of determining drilling costs including the steps of: sensing successive incremental lengths of an interval of borehole depth drilled and generating a first electrical signal representative thereof;
generating a second electrical signal representative of accumulated drilling cost incurred as said interval of depth is drilled;
and, generating a third electrical signal responsive to said first and second signal representative of average operating cost per incremental length of borehole drilled over said interval of depth.

9. The invention as claimed in claim 8 including: reading out said third signal as an indication of the average cost per incremental length of borehole drilled.

10. The invention as claimed in claim 8 wherein said step of generating said second signal includes: generating a fourth electrical signal representative of the length of time said drilling apparatus is utilized in boring said interval of depth;

11. The invention as claimed in claim 10 wherein said step of generating said fourth signal includes: generating a fifth electrical signal representative of the cost of operating said drilling apparatus during said length of time.

12. The invention as claimed in claim 11 including: generating a sixth electrical signal representative of the length of time said drilling apparatus is rotating a drill bit in said borehole;
and, generating a seventh electrical signal representative of the length of time in excess of said rotating time that said drilling apparatus is utilized in boring said interval of depth.

13. The invention as claimed in claim 12 including: indicating in response to said third signal the average cost per incremental length of borehole drilled.

14. The invention as claimed in claim 12 including: graphically recording said average drilling cost per incremental length of said interval of depth as a function of the depth drilled during said interval.
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CERTIFICATE OF CORRECTION

Patent No. 3,660,649

Dated May 2, 1972

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 10;
Column 2, line 40;
Column 3, line 60;

\[ D = C_r(t_r + t_t) + C_b/d \]

should be

\[ D = C_r \frac{(t_r + t_t)}{d} + C_b \]

Signed and sealed this 29th day of August 1972.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCALK
Commissioner of Patents