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[54] PROCESS FOR OPTIMIZING THE PENETRATION SPEED OF A DRILLING TOOL DRIVEN BY A MOTOR WHOSE TORQUE DECREASES WITH AN INCREASING RUNNING SPEED AND APPARATUS THEREFOR

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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **173/1,** 173/6, 175/26, 175/103

[51] **Int. Cl.** **E21b 3/12**

[58] **Field of Search** 173/1, 4, 6; 175/26, 103

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[57] **ABSTRACT**

A process for optimizing the penetration speed of a drilling tool driven by a motor whose torque decreases with an increasing running speed and vice-versa, comprising the steps of alternately increasing and decreasing the load on the tool about its optimum value by acting on the tensile stress exerted on the drill string, thereby defining periods of increase and periods of decrease of the ratio $-(\Delta Va/T)$ which is, with a changed sign the ratio between the variation of the penetration speed of the tool and the corresponding variation of the tensile stress exerted on the drill string, of controlling the passage from a tensile stress-increasing period, at the latest when the ratio $-(\Delta Va/T)$ attains, while decreasing, a lower limit value and of controlling the passage from a tensile stress-decreasing period to a tensile stress-increasing period at the latest when said ratio attains, while increasing, an upper limit-value, said lower and upper limit values being preselected and adjustable.

18 Claims, 8 Drawing Figures

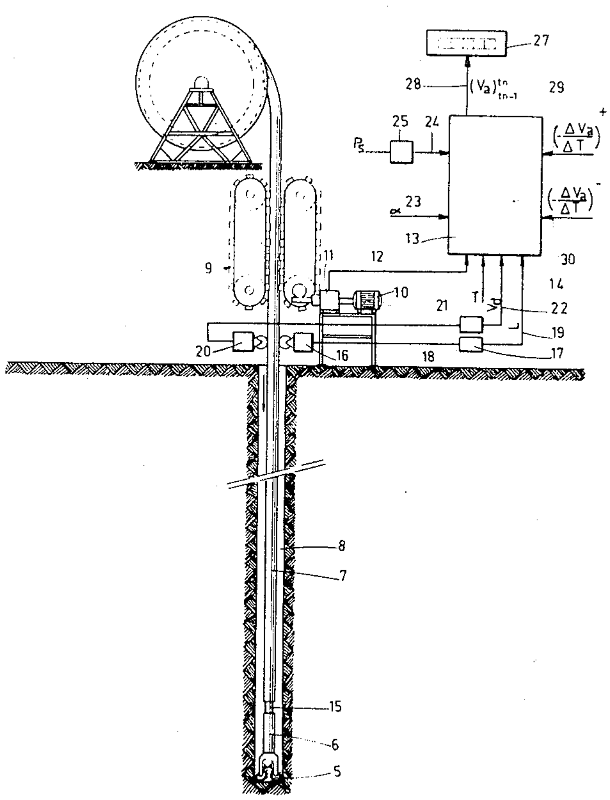

FIG. 1

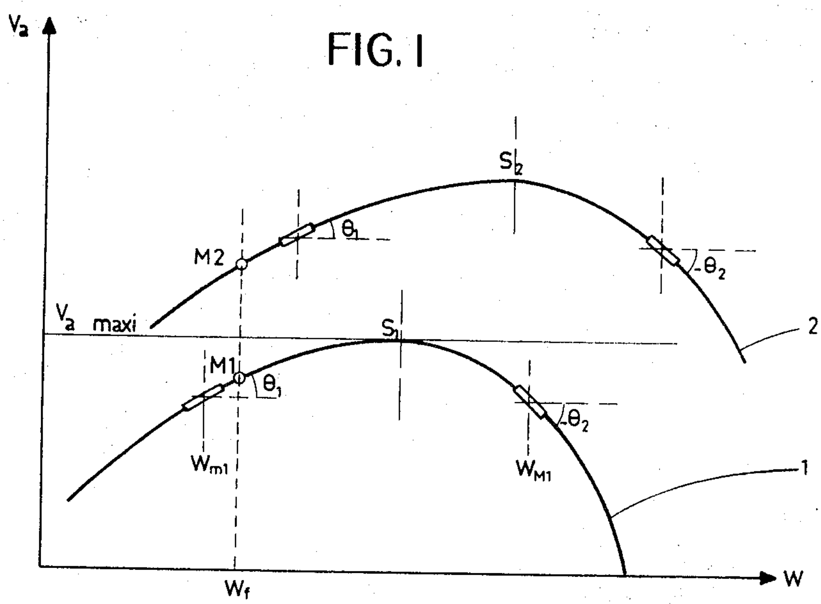

FIG. 3

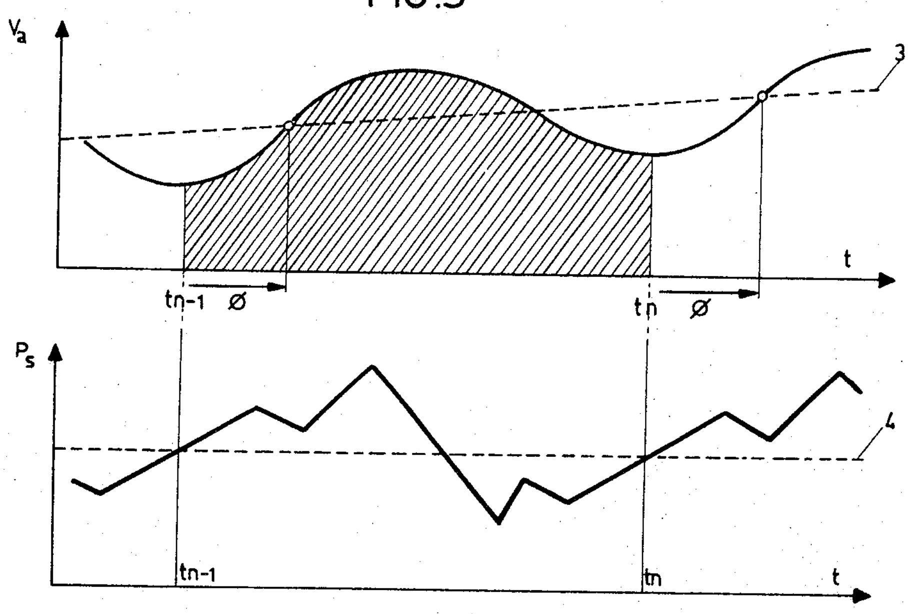

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FIG.2

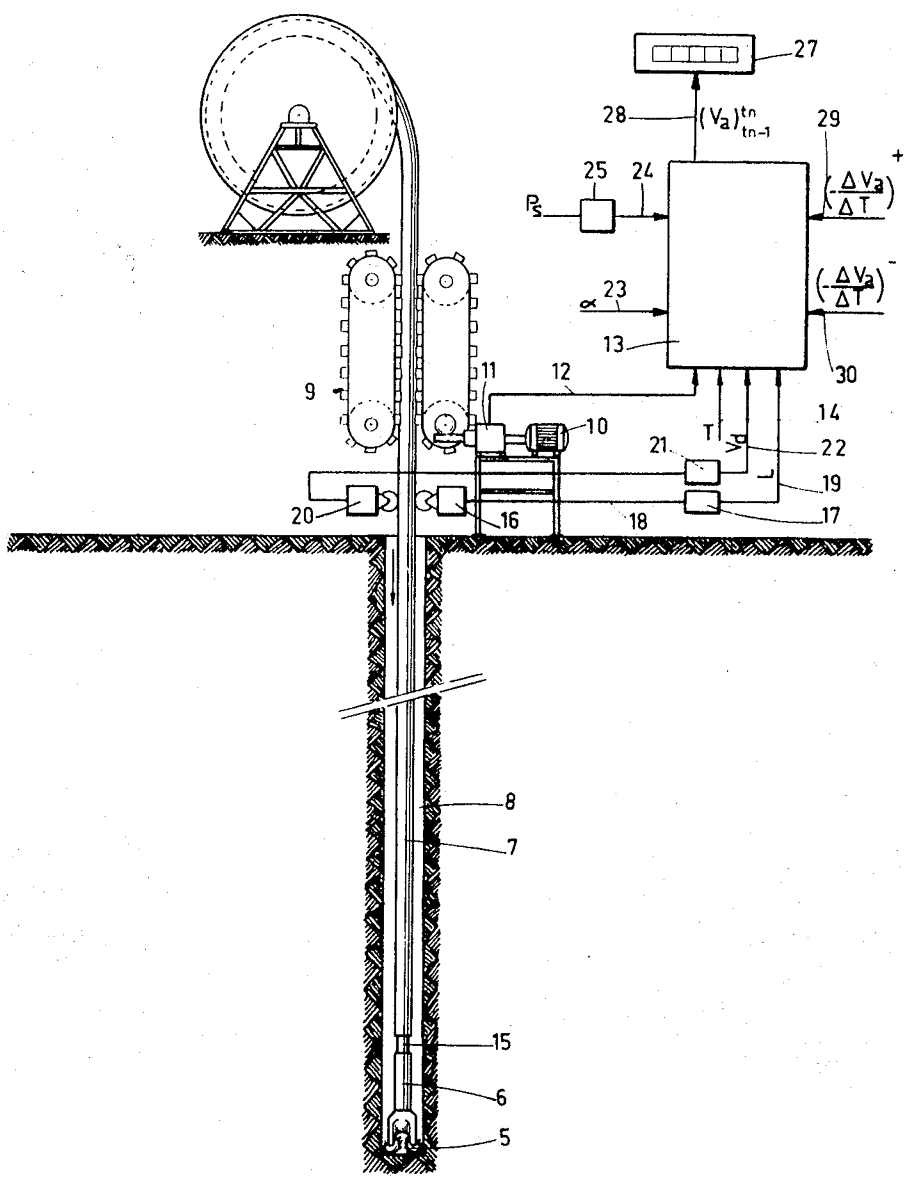

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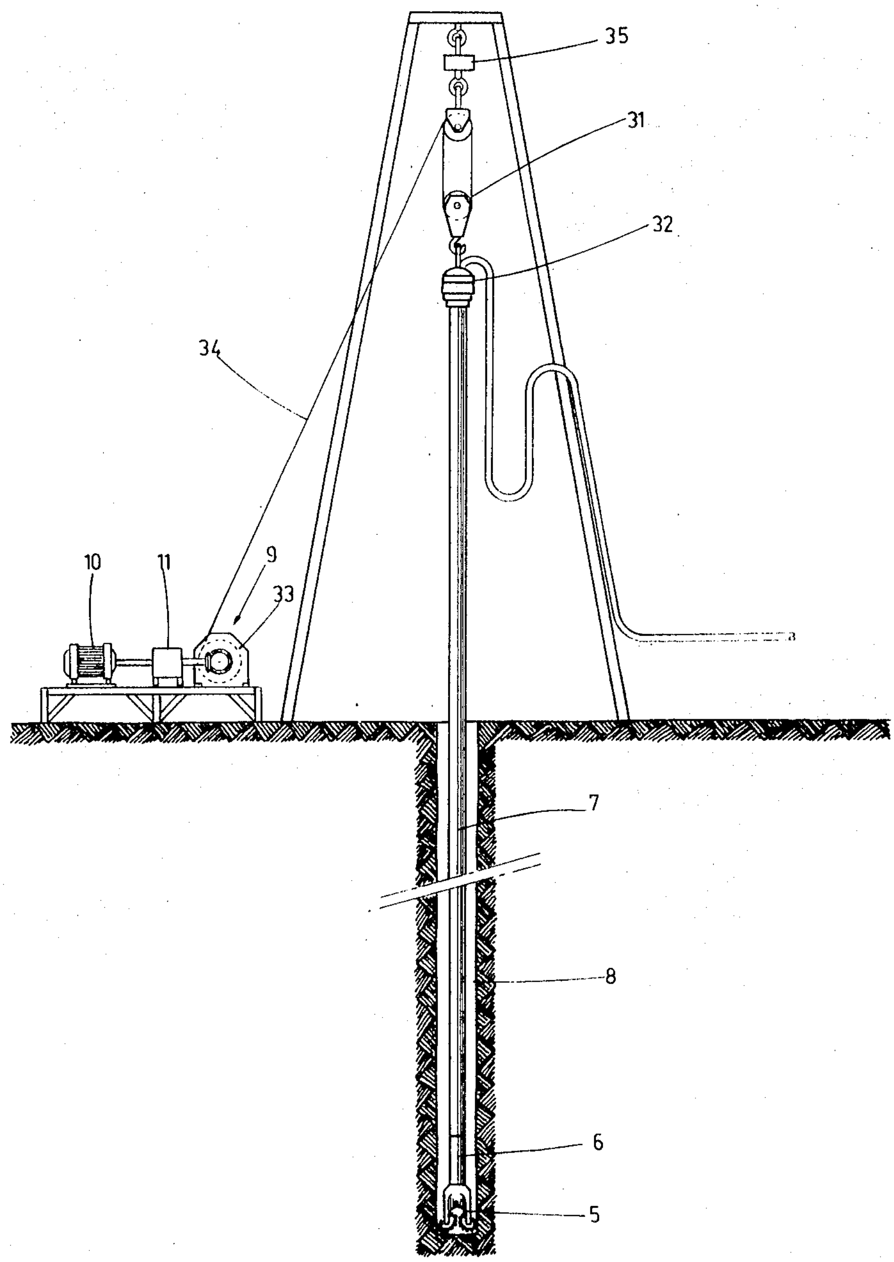
FIG. 2A



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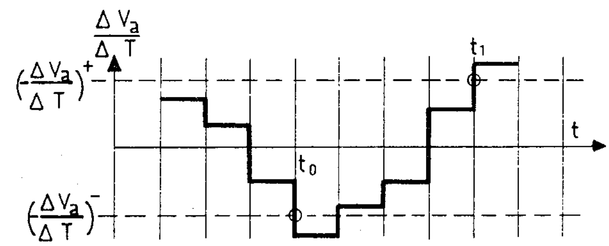

FIG. 4

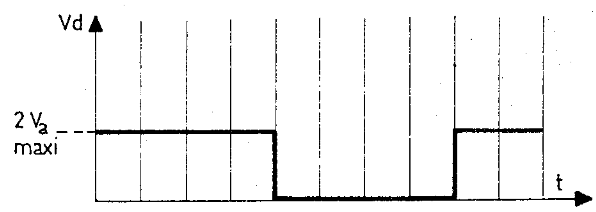

FIG. 5

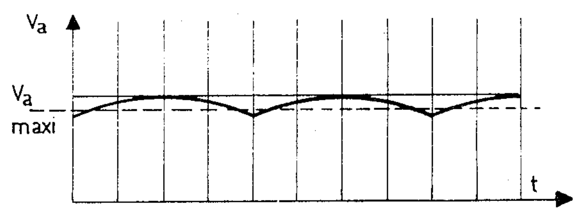

FIG. 6

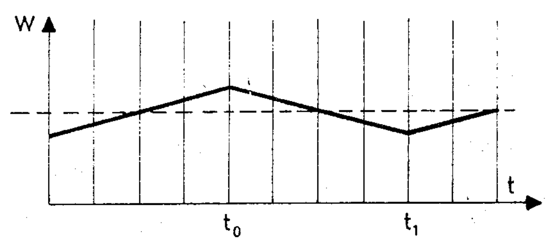

FIG. 7

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PROCESS FOR OPTIMIZING THE PENETRATION SPEED OF A DRILLING TOOL DRIVEN BY A MOTOR WHOSE TORQUE DECREASES WITH AN INCREASING RUNNING SPEED AND APPARATUS THEREFOR

This invention relates to a process and an apparatus for optimizing the penetration speed of a drilling tool driven by a motor giving a torque which decreases with an increasing running speed and vice-versa, so that the speed of penetration of said tool in the ground will be as high as possible, for any power supply, irrespective of the type of bit used and the traversed formations.

The bottom motors such as turbines used in the turbodrilling process and the series wound or compound electric motors used in the so-called electrodrilling process have this characteristic relationship between torque and motor running speed.

It must be understood however that the scope of the invention is not limited to the case where the driving motor of the tool is directly coupled therewith at the lower end of the drill string, but also includes the case where the tool is driven by rotation of the drill string through a surface motor provided that it communicates to the tool a torque which is a decreasing function of the rotation speed thereof.

With such a torque-speed relationship, it is observed that, when starting from a low value of the thrust load or weight on the drilling tool and progressively increasing said weight, the penetration rate begins to increase up to a maximum value and then decreases with still increasing weight on the tool, until stalling of the tool occurs.

The optimum value of the weight on the tool, to which corresponds the maximum penetration speed, varies according to the nature of the formations traversed by the bore hole.

The essential object of the present invention is to provide a process and an apparatus for a regulation, optionally completely automatic, of the weight on the drilling tool, so as to keep the penetration speed of the tool as close as possible to its maximum value for each of the geological strata traversed by the bore hole.

The process of the invention, whereby this object is achieved, is characterized in that the value of the load on the tool is alternatively decreased and increased about its optimum value, by correspondingly increasing and decreasing the tensile stress exerted on the drill string and accordingly the ratio $-(dVa/dT)$ which is the ratio with a changed sign, of the variation of the penetration speed of the tool to the corresponding variation of the tensile stress at a given point of the drill string, in that the passage from a tensile stress increasing phase to a tensile stress decreasing phase is initiated at the latest when the value of said ratio $-(dVa/dT)$ during its decreasing phase has reached a lower limit-value and the passage from a decreasing to an increasing phase for said tensile stress is initiated at the latest when the value of said ratio has reached an upper limit-value, said two limit-values being preselected and adjustable.

The reversing of the direction of variation of the tensile stress exerted on the drill string may be effected before the ratio $-(dVa/dT)$ reaches any one of said limit-values, in the case where at least another operating parameter of the drilling apparatus, such as the tensile stress T exerted on the drill string or the rotation speed of the tool, will reach a predetermined safety limit.

An automatic apparatus for carrying out the process of the invention is characterized by the combination of means for gradually varying the weight on the tool, means for reversing the direction of variation of said weight, means for measuring the algebraic value of $-(dVa/dT)$ which is the ratio with a changed sign of the variation of the penetration speed of the tool to the corresponding variation of the tensile stress exerted on the drill string at a point thereof, means for setting an upper limit-value and a lower limit-value of said ratio, means for comparing the value of said ratio with said limit-values, said means for comparing being connected to said means for measuring said ratio and to said means for reversing the direction of variation of the weight on the tool and being adapted to initiate a decrease in this weight at the latest when the value of said ratio reaches said lower limit-value and an increase in this weight when the value of said ratio reaches said upper limit value.

The apparatus may be provided with means for comparing at least one other drilling parameter, such as the tensile stress of the drill string and the rotation speed of the tool, with a preset safety limit, said means being also connected to said means for reversing the direction of the variation of the weight on the tool, so as to actuate this means when the value of said parameter reaches said safety limit.

One particular embodiment of the invention, given by way of illustrative example, is hereafter described more in detail with reference to the accompanying drawing wherein :

FIG. 1 illustrates, in the case of drilling with use of a bottom motor, the law of variation of the bit speed of penetration in terms of the weight applied thereto,

FIGS. 2 and 2A diagrammatically show two examples of apparatus according to the invention,

FIG. 3 shows, facing each other, a curve of variation of the penetration speed of the bit versus time and the corresponding variation of pressure of the drilling fluid as measured at the surface,

FIG. 4 shows the law of variation of the ratio $(\Delta Va/\Delta T)$ versus time, when using the process of the invention,

FIG. 5 shows the corresponding law of variation of the feeding rate of the drill string at the surface, and

FIGS. 6 and 7 respectively show the corresponding variations of the speed of penetration of the drilling tool and of the weight exerted thereon.

In FIG. 1, wherein curve 1 and curve 2 represent, for two ground layers, respectively, the variation of the penetration speed of the tool versus the thrust load W or weight exerted thereon, points M_1 and M_2 represent the respective operating points for these two ground layers whose abscissae correspond to the weight Wf applied on the tool and the ordinates to the corresponding penetration speed through the considered ground layer. It can be seen that, when increasing the weight Wf from the operating point M_1 or M_2, this operating point moving to the right of the figure on any of the two curves, the speed of penetration Va of the tool increases and attains a maximum at point S_1 (or S_2), the curve portion described by the operating point corresponding to stable operating conditions. Beyond the vertex of the operation curve the operating conditions are unstable and the penetration speed decreases with an increasing weight on the tool until stalling of the bottom motor.

As shown in FIG. 3, the penetration speed of the tool undergoes fluctuations of time variation about an average curve 3. These fluctuations are of a frequency associated with the pulsing rate of the drilling mud circulation pump and cannot be filtered without introducing a time constant which is incompatible with the response time required for an automatic device for optimizing the penetration speed of the drill bit, which device must prevent any possibility of stalling of the bit.

This inconvenience can be avoided by taking in consideration the average penetration speed of the tool over a time interval equal to the pulsing period of the mud pumps or to a multiple thereof.

The instants t_{n-1} and t_n, which are the limits of such period intervals (FIG. 3) may be selected as being the instants at which the alternating component of the pressure P_s of the drilling fluid, as measured at the surface, passes through the value zero, such pressure value oscillating about an average value corresponding to the straight line 4, at the same frequency as the penetration speed, but with a time lag ϕ corresponding to the lag between the respective pressures of the drilling fluid at the surface and on the hole bottom.

The average penetration speed on the hole bottom between instants t_{n-1} and t_n is given by the formula :

(1)
$$(\overline{V}_a)_{t_{n-1}}^{t_n} = (V_d)_{t_{n-1}}^{t_n} + \frac{\alpha L}{t_n - t_{n-1}}[T_n - T_{n-1}]$$

wherein $(Vd)_{t_{n-1}}^{t_n}$ is the average value of the linear speed of the drill string as measured at the surface between the two instants under consideration, α the lengthening coefficient of the drill string under the effect of a tensile stress, and T_{n-1} and T_n are the respective tensile stresses to which the drill string is subjected at instant t_{n-1} and instant t_n.

FIGS. 2 and 2 A diagrammatically illustrate two optional embodiments of apparatus for carrying out the invention; FIG. 2 illustrates the case of a flexible drill string unwound from a storing reel and FIG. 2 A the case of a drill string formed of rigid elements.

On these figures reference **5** indicates the drilling tool suspended from the drill string **7** and driven by the bottom motor **6** consisting, for example, of a drilling turbine fed with hydraulic energy from the surface, reference **8** indicating the bore hole.

The drill string is lowered in the bore hole through a handling device which may consist of one or more caterpillar chains carrying jaws or clamping shoes in the case of FIG. 2 and of a winch **33** with a cable **34** wound thereon and supporting a pulley block **32** in the case of use of rigid drill pipes forming the drill string **7** (FIG. 2 A). This handling device is driven by a motor **10**, through an irreversible coupling device **11**, which can be engaged or disengaged at will by means of electric signals transmitted through control cable **12**.

A digital computer in actual time **13**, receives the measuring value of the tensile stress T applied to the drill string, which measuring value can be supplied, in the case of the embodiment of FIG. 2, through electric conductors **14**, by a device **15** comprising at least one strain gage placed at the lower end of the drill string **7** or at **35**, on the dead end of the pulley block **31**, at the surface, in the case of embodiment of FIG. 2 A.

A device **16** is used for measuring the length L of the drill string suspended from the surface through device **9**.

This device may consist, for example, of a roller in contact with the drill string **7** and driven in rotation by the linear displacement thereof, said roller driving in turn in rotation the emitter of a synchromechanism well known in the art as "-Selsyn" and whose receiver, to which it is electrically connected through cable **18**, actuates a revolution counter device providing, in the form of a series of electric pulses, a digital measuring value of length L, supplied to computer **13** through cable **19**.

The feed rate Vd of the drill string, at the surface, can be measured by devices **20** and **21**, respectively similar to devices **16** and **17**, the digital value of said speed being supplied to the digital computer **13** through cable **22**.

For this measurement of Vd it is preferred to use devices separate from those used for measuring L, so as to determine with a sufficient accuracy the linear speed of the drill string.

The value of the elasticity coefficient of the drill string **7** is set up at **23** in the computer and there is also supplied to said computer, through conductor **24**, a signal representing the digital value of the alternating component of the pressure Ps of the drilling mud at the surface, this pressure being measured by any suitable pressure sensor not shown in the figure, placed in the mud circuit and supplying a measuring signal filtered through device **25**, which keeps only the alternating component of this signal supplied to the computer.

The numerical value of α will be preferably measured periodically in the hereunder stated manner, after stopping the drilling operation, the average value of the coefficient α corresponding to the depth reached.

This measurement can be effected by raising the drill bit over a few meters and then lowering it again so as to rest it on the well bottom without drilling.

By observing during this lowering of the drill bit the variations in the tensile stress T on the drill string, of the linear speed Vd of the drill string at the surface and in the penetration speed Va, it will be seen that the tensile stress T progressively decreases from instant t_A until the bit reaches the bottom of the bore hole, in proportion to the elastic shortening of the drill string.

This shortening is terminated at instant t_B when the feed rate at the surface becomes zero.

The relationship:

$$(\overline{V}_a)_{t_{n-1}}^{t_n} = (\overline{V}_d)_{t_{n-1}}^{t_n} + \frac{\alpha L}{t_n - t_{n-1}} T_n - T_{n-1} \qquad (1)$$

shows that, between instants $t = t_A$ and $t = t_B$ the value of V_a given by the computer **13** will be different from zero if the value of α which is used is not the proper one.

More precisely the value of V_a will be kept positive between instant t_A and instant t_B, when the value of α which is used by the computer **13** is too low since, in such case, the absolute value of the negative term

$$\alpha L \frac{T_n - T_{n-1}}{t_n - t_{n-1}}$$

will be too low for having the right-hand side of equation 1 equal to zero, the value of $(Vd)_{t_{n-1}}^{t_n}$ thus being the greater in said right-hand side and resulting in a positive value of $(V_a)_{t_{n-1}}^{t_n}$

On the contrary, if the value of α is too high, the absolute value of the negative term will be greater than that of $(Vd)_{t_{n-1}}^{t_n}$ and will accordingly result in a negative value of $(V_a)_{t_{n-1}}^{t_n}$ determined by the computer **13**.

The exact value of α, measured in situ for the drilled depth, may be calculated by computer **13**, using the fact that if t_k and t_{k-1} indicate two instants within the time interval between t_A and t_B, the following relationship is applicable:

$$(Vd)_{t_{k-1}}^{t_k} (t_k - t_{k-1}) = -\alpha L (T_k - T_{k-1}) \qquad (2)$$

wherein L is the drill string length supported from the surface, T_{k-1} and T_k are the respective tensile stresses applied to said drill string at instants t_{k-1} and t_k.

The digital computer **13** is adapted to determine the value of the ratio

$$-\frac{\Delta Va}{\Delta T} = -\frac{(\overline{V}a)_{t_{n-1}}^{t_n} - (\overline{V}a)_{t_{n-2}}^{t_{n-1}}}{(\overline{T})_{t_{n-1}}^{t_n} - (\overline{T})_{t_{n-2}}^{t_{n-1}}} \qquad (3)$$

wherein:

$$(\overline{V}a)_{t_{n-2}}^{t_{n-1}}, (\overline{T})_{t_{n-2}}^{t_{n-1}}, (\overline{V}a)_{t_{n-1}}^{t_n} \text{ and } (\overline{T})_{t_{n-1}}^{t_n}$$

respectively represent the average values of the penetration speed of the tool and of the tensile stress on the drill string, as determined by the computer **13** between instants t_{n-2} and t_{n-1} and between instants t_{n-1} and t_n as hereabove defined and indicated at **24** on the computer as explained above.

The computer **13** determines the values of $(Va)_{t_{n-2}}^{t_{n-1}}$ and $(Va)_{t_{n-1}}^{t_n}$ by using the above formula (1).

In this embodiment such values are successively displayed by the computer on device **27** to which it is connected through cable **28**.

The ratio $-(\Delta V_a/\Delta T)$ is equal to the ratio $(\Delta Va/\Delta W)$ when the mud flow rate Q is constant and accordingly corresponds substantially, on the operating curve **1** or **2** of FIG. 1, to the slope of the tangent at the operating point M_1 or M_2, this slope being equal to zero when the penetration speed attains its maximum value for the considered ground layer.

The computer **13** is supplied, by setting up at **29** and **30** respectively, a negative limit-value $(-\Delta Va)^-/\Delta T$ and a positive limit-value $(-\Delta Va)^+/\Delta T$ of the calculated ratio $-(\Delta Va/\Delta T)$, these two values corresponding respectively to a positive limit-value θ_1 and a negative limit-value θ_2 (FIG. 1) of the angle of inclination, with respect to the abscissae axis, of the tangent to the operating curve (**1** or **2**) at the operating point.

The apparatus works as follows: the device **9** drives the drill string **7** downwardly with a feed rate higher than the maximum penetration speed (Va max) of the drilling tool **5** (FIG. 5); e.g twice such a speed, which results in an increase of the weight

W on the tool and makes the operating point M_1 (or M_2) describe the operating curve 1 (or 2) towards the right side of the FIG. 1. The penetration speed Va first increases with the weight W on the tool (FIGS. 6 and 7), reaches a maximum and then decreases, while $-(\Delta Va/\Delta T)$ decreases.

The computer 13 compares the calculated value of the ratio $-(\Delta Va/\Delta I)$ with each of the aforesaid limit-values: when this value becomes at instant t_o (FIG. 4) lower than the negative limit-value $(-\Delta Va)^-/\Delta T$ the computer 13 delivers a pulse controlling the disengaging of device 11 and, the device 9 being no longer driven, the displacement of the drill string is stopped (FIG. 5), thereby releasing the load exerted on the tool (FIG. 7) which disengages itself.

The operating point M_1 (or M_2) now describes leftwards the operating curve (FIG. 1) and the penetration speed again begins to increase up to a maximum value and then decreases again while $-(\Delta Va/\Delta T)$ increases (FIG. 4).

When at the instant t_1 the calculated value of ratio $-(\Delta Va/\Delta T)$ becomes greater than the positive limit-value $(-\Delta Va)^+/\Delta T$, the computer 13 actuates through conductor 12 the clutch of device 11, thereby starting again the displacement of the drill string (FIG. 5), which results in an increase of the weight on the tool. A new cycle, identical to the preceding one, can then start again and so on indefinitely.

It is apparent that this results in a continuous oscillation about its optimum value, of the weight on the tool, said oscillation resulting in the maintenance of the average penetration speed at a value very close to the maximum value, the difference being dependent on values $(-\Delta Va)^+/\Delta T$ and $(-\Delta Va)^-/T$ which can be selected at will and as close to each other as permitted by the drilling procedure and the control apparatus.

The rapid control of the weight on the tool obtained through actuation of an engaging or a disengaging system, avoids any possible stalling, when, beyond the maximum of the operating curve (FIG. 1) the operating point enters the zone of unstable operating conditions.

The above-mentioned selection method of instants t_{n-1}, t_n, t_{n+1}, etc . . . delimiting the time intervals in which is determined the average penetration speed of the drill bit, gives the penetration speed with the required accuracy for a proper operation of the apparatus without incurring the risk of improper actuations of the engaging or disengaging system of device 10 which might result in alternative changes of the penetration speed Va at constant weight on the tool (FIG. 3) if the instantaneous value of said speed were supplied to the computer 13.

In order that the time intervals during which the device 10 is disengaged be substantially equal to those during which it is engaged (so that the computer may have the maximum efficiency in case of change of ground layer), it is advantageous to have a linear speed Vd at the surface equal to about twice the penetration speed Va of the bottom tool. This can be obtained by controlling the driving speed of device 9 by means of the maximum value read at 27 (FIG. 2). This control, which can be effected by the computer 13, does not need a high accuracy and allows a relatively long time constant, due to inertia of motor 10 (FIG. 2).

The apparatus according to the invention automatically adjusts itself to changes in the nature of the drilled formations. Such changes result in fact in a mere change of operating curve (FIG. 1), point M_1 being shifted to M_2.

The negative threshold $(-\Delta Va)^+/\Delta T$ being reached later than if the operating point had been kept on curve 1, it results that the weight on the tool increases more, the penetration speed Va attains a greater value and consequently the feed rate Vd, which is controlled by the value 2 Va_{max}, will increase accordingly, thereby achieving the adaptation to the new ground layer traversed by the drill bit.

The adjustment of the feed rate Vd of the drill string might also be achieved by hand, in accordance with the indications read at 27 (FIG. 2).

It is of course also possible, without departing from the scope of the invention, to assign to the apparatus through the computer, more complex orders for controlling the engaging and disengaging systems, so as to obtain a very safe operation.

For example, the actuation of the disengaging system, the triggering of which was supposed to take place only when the actual operating value of the ratio $-(\Delta Va/\Delta T)$ runs past the negative threshold of the calculated value $-(\Delta Va/\Delta T)$, will be also triggered, by means of any logical system such as electric circuits of the "OR gate" type, not only when $-(\Delta Va/\Delta T)$ runs past the preselected negative threshold, but also when the weight W on the tool attains a preset maximum value, or if the speed of the turbine falls below a predetermined threshold etc . . .

Similarly the actuation of the engaging system, so as to increase the weight on the tool, may be triggered not only when $-(\Delta Va/\Delta T)$ runs past the preselected positive threshold, but also when the weight W on the tool is reduced in a predetermined proportion, or when the running speed of the turbine exceeds a predetermined limit-value and so on.

In these conditions the triggering of the engaging or the disengaging system is initiated at the latest when $-(\Delta Va/\Delta T)$ attains one or the other of said negative or positive threshold (or limit-values) which have been selected for it, said triggering being optionally initiated sooner when at least one of the other drilling parameters such as the weight on the tool or the running speed of the turbine exceeds a predetermined safety limit.

What I claim is:

1. A process for optimizing the penetration speed of a drilling tool driven by a motor whose torque decreases with an increasing running speed and vice-versa, comprising the steps of alternately increasing and decreasing the load on the tool about its optimum value by acting on the tensile stress exerted on the drill string, thereby defining periods of increase and periods of decrease of the ratio $-(\Delta Va/\Delta T)$ which is, with a changed sign the ratio between the variation of the tensile stress exerted on the drill string, of controlling the passage from a tensile stress-increasing period, at the latest when the ratio $-(\Delta Va/\Delta T)$ attains, while decreasing, a lower limit-value and of controlling the passage from a tensile stress-decreasing period to a tensile stress-increasing period at the latest when said ratio attains, while increasing, an upper limit-value, said lower and upper limit values being preselected and adjustable.

2. A process according to claim 1 wherein said ratio $-(\Delta Va/\Delta T)$ is determined from average values of the penetration speed Va and tensile stress T over time intervals equal to the pulsing period of the drilling fluid circulation pumps.

3. Automatic apparatus for optimizing the penetration rate of a drilling tool driven by a motor whose torque decreases with an increasing running speed and vice-versa, comprising in combination means for progressively varying the weight on the tool, means for reversing the direction of said weight variation, means for measuring the algebraic value of the ratio $-(\Delta Va/\Delta T)$ which is, with a changed sign, the ratio between the variation of the penetration speed of the tool and the corresponding variation of the tensile stress exerted on the drill string, means for setting up an upper limit-value and a lower limit-value of said ratio, and means for comparing the value of said ratio with said limit-values, said means for comparing being connected to said means for measuring said ratio and to said means for reversing the direction of variation of the weight on the tool and being adapted to initiate a decrease in this weight at the latest when the value of said ratio attains said lower limit-value and an increase of this weight when said ratio attains said upper limit-value.

4. Apparatus according to claim 3 further comprising means for comparing the value of at least one other drilling parameter with a preset safety limit, said means being also connected to said means for reversing the direction of variation of the weight on the tool, so as to actuate the latter when the value of said parameter attains said limit.

5. A process for controlling the penetration speed of a drilling tool driven by a motor, the torque of which varies in inverse proportion to the running speed, comprising the steps of:

measuring the penetration speed of the drilling tool;
detecting a change in said penetration speed;
measuring the tensile stress exerted on the drilling tool;
detecting the change in said tensile stress;
determining the ratio of a change in said penetrating speed for a change in said tensile stress negative with respect thereto; and
maintaining said ratio within prescribed maximum and minimum limits by controlling the load on the drilling tool in response to said ratio.

7. A method according to claim **5**, wherein said step of controlling the load on the drill tool comprises the steps of alternately increasing the load on the tool until said ratio reaches said prescribed minimum limit and then decreasing the load exerted on the tool until said ratio reaches said prescribed maximum limit.

6. A method according to claim **5**, wherein said ratio is determined from the average values of the penetrating speed and tensile stress over time intervals equal to the pulsing period of the fluid circulation pumps for the drilling fluid.

8. A method according to claim **7**, wherein said step of increasing the load on the tool includes the step of driving the drill string downwardly with a feed break greater than the maximum penetrating speed of the drilling tool.

9. A method according to claim **7**, wherein said step of decreasing the load exerted on the tool comprises the step of terminating the displacement of the drill string to thereby release the load on the drill tool.

10. A method according to claim **7**, wherein said step of controlling the load on said drill tool further includes comparing said ratio with each of said prescribed maximum and minimum limits.

11. A method according to claim **10**, wherein said step of driving said drill string comprises the step of driving said drill string at a linear speed substantially equal to about twice the penetration speed of the drill tool.

12. An apparatus for controlling the penetration rate of a drilling tool by a motor, the torque of which varies inversely with respect to the running speed, comprising:

first means for controlling the penetration speed of the drill tool;
second means, responsive to said first means, for detecting a change in said penetrating speed;
third means for measuring the tensile stress exerted on the drill string;
fourth means, responsive to said third means for detecting a change in said tensile stress;
fifth means, responsive to said second and fourth means, for determining the rate of a change in said penetrating speed for a change in said tensile stress negative with respect thereto; and
sixth means, responsive to said fifth means, for maintaining said ratio within prescribed maximum and minimum limits by controlling the load on the drill tool in response to said ratio.

13. An apparatus according to claim **12**, wherein said sixth means comprises means for alternately increasing the load on the drill tool until said ratio reaches said predetermined minimum limit and means for decreasing the load exerted on the tool until said ratio reaches said predetermined maximum limit.

14. An apparatus according to claim **13**, wherein said means for increasing the load exerted on the drill tool comprises means for driving the drill string downwardly with a feed rate greater than the maximum penetration speed of the drilling tool.

15. An apparatus according to claim **14**, wherein said means for decreasing the load exerted on the drill tool comprises means for terminating the displacement of the drill string to thereby release the load on the drill tool.

16. An apparatus according to claim **12**, wherein said sixth means includes means for comparing said ratio with each of said prescribed maximum and minimum limits.

17. An apparatus according to claim **16**, wherein said driving means comprises means for driving said drill string at a linear speed substantially equal to about twice the penetration speed of said drill tool.

18. An apparatus according to claim **16**, wherein said comparing means includes means for comparing the value of at least one other drilling parameter with a preset safety limit, being connected to said displacement terminating means, so as to actuate said terminating means when the value of said parameter attains said limit.

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