ABSTRACT OF THE DISCLOSURE

This specification discloses a method and apparatus for utilizing shock waves in drilling a wellbore. The shock waves are created by arcing electrical energy between electrodes located in a drill bit. The electrical energy is generated downhole by converting mechanical energy into electrical energy with piezoelectric means.

BACKGROUND OF THE INVENTION

Field of the invention

The invention relates to methods and apparatus for drilling wellbores utilizing shock waves produced by arcing electrical energy between electrodes. The electrical energy is generated downhole by spark pumps comprised of piezoelectric means. The spark pumps convert mechanical energy into electrical energy which is thereafter arced or sparked between two or more electrodes to produce shock waves which fracture the formation.

Description of the prior art

Rotary drilling is the most commonly used method of drilling wellbores. In rotary drilling a drill bit is attached to one end of a drill string, the other end of which extends to the surface. The drill string has a passageway through which drilling fluids are passed. In carrying out rotary drilling operations, mechanical power in the form of rotational torque is applied at the surface to the drill string. This causes rotation of the drill string and of the drill bit at the bottom of the wellbore. Weight is applied on the drill bit by a specialized part of the drill string called drill collars which are of heavier weight than the other portion of the drill string called drill pipe. As the bit is rotated in contact with the wellbore bottom, the teeth of the bit break, fracture, and dig the formation. Drilling fluid is circulated from the surface of the earth to the bottom of the wellbore and back to the surface again. This circulating drilling fluid removes the formation debris from the wellbore and allows the bit to contact fresh formation. The drilling fluid may be, for example, drilling mud, gas or air. Pumps are used to circulate the drilling fluid between the surface and the wellbore bottom.

Though rotary drilling has proved to be in general the most practical method of drilling wellbores, it has many disadvantages. One of these disadvantages is the reduced power available at the drill bit compared to the power applied to the drill string. This power reduction results from such things as frictional losses in transferring mechanical energy in the form of rotational torque from the surface to the drill bit. Another disadvantage is that the drill pipe fails at times under this torsional stress causing expensive work in removing the parted section of the drill string remaining in the wellbore. Other methods of drilling have been tried in order to alleviate these problems. One such method is electric arc drilling. In electric arc drilling two or more electrodes are positioned at the bottom of a wellbore and are connected through conductor cables to electrical generating equipment at the surface. Electrical power is transmitted through the conductor cables and caused to continually arc between the electrodes to produce high temperatures which cause structural failure of the formation being drilled. Electric arc drilling has several principle problems. One of these involves the necessity of shielding the electrodes from liquid drilling fluid and surrounding them in a gas environment. This problem has been partially solved by providing a gas filled chamber surrounding the electrodes. A source of high pressure gas is used for pressurizing the electrode chamber. Another problem involves conducting electrical power downhole. This problem has not been successfully solved for deep wellbores. Still another problem which has not been successfully solved involves the replacement of consumed electrodes.

Shock wave drilling is another method of drilling wellbores. By this method a drill bit having multiple electrodes depending therefrom and a fluid passageway extending therethrough is attached to the lower end of a drill string. Liquid drilling fluid is circulated between the surface of the earth and the bottom of the wellbore by passing the drilling liquid through the drill string and drill bit to the wellbore bottom and returning it to the surface by way of the annulus between the drill string and wellbore walls. In this manner the electrodes are surrounded by liquid drilling fluid. The multiple electrodes are comprised of cathodes and anodes which are intermittently energized by electrical energy thereby producing a spark by arcing the electrical energy between adjacent cathodes and anodes. This spark or electrical arc initiates a shock wave in the drilling liquid which propagates through the liquid and fractures the earth formation. Drilling liquid is circulated between the surface and the wellbore bottom and cleans the wellbore of formation debris. This method of drilling shares with electric arc drilling the problem of conducting electrical energy downhole to the drill bit.

SUMMARY OF THE INVENTION

This invention concerns a method and apparatus for shock wave drilling. By this invention electrical energy is generated downhole by a spark pump comprised of piezoelectric means. The spark pump converts mechanical or compressive energy into electrical energy which is arced or sparked between electrodes to produce shock waves in drilling liquid surrounding the electrodes. These shock waves propagate through the drilling liquid and break or crush the formation. Drilling liquid is circulated in the usual manner to remove formation debris from the wellbore.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a cross-sectional view of one embodiment of a downhole drill tool showing a lifting sub, spark pump sub, and drill bit.

FIGURE 2 is a perspective view of a portion of FIGURE 1 showing an apparatus for transferring mechanical energy from the drill string to the spark pump.

FIGURE 3 is a cross-sectional view of another embodiment showing a jet edge generator in combination with a spark pump sub.

FIGURE 4 is a diagrammatic view of yet another embodiment showing a cable drill tool employing a spark pump.

DESCRIPTION OF THE PREFERRED EMBODIMENT

This invention is comprised of a method and apparatus for drilling a wellbore utilizing acoustical shock wave energy. Mechanical and hydraulic energy is converted downhole into electrical energy by a spark pump which is comprised of a plurality of piezoelectric means electrically connected one with the other. This electrical energy is arced or sparked between electrodes immersed in a drilling liquid and associated with a drill bit. This arc pro-
duces shock waves in the drilling liquid which propagate to the formation being drilled and effect fracturing and failure of the formation.

In one embodiment of this invention, a drill tool comprising means for generating electrical energy and a drill bit having cutting edges and electrodes is positioned in a wellbore such that the means for generating electrical energy is spaced from but closely adjacent the wellbore bottom. The drill bit is rotated and the cutting edges from an annular cut in the earth formation. The means for generating electrical energy which may be, for example, a spark pump is actuated to produce said electrical energy which is arced between the electrodes to generate shock waves in the drilling liquid which break the earth formation which otherwise would be encompassed by the annular cut. The means for generating electrical energy is moved at a rate commensurate with the drilling of the wellbore to maintain it at a substantially uniform distance from the wellbore end being drilled.

In another embodiment of this invention, a drill tool comprising a spark pump and a drill bit having cutting edges and electrodes is alternately raised from and dropped to the wellbore bottom thereby actuating the spark pump and producing electrical energy which is arced between the electrodes to generate shock waves which effect failure of the formation. Simultaneously the earth is fractured by contact of the cutting edges of the drill bit with the wellbore bottom. The cutting edges may be, for example, blades as are used in conventional cable, drag or rotary bits.

This invention is described in more detail by reference to the drawings. Referring specifically to FIGURE 1 there is seen a drilling tool 10 in a borehole 12. This drilling tool 10 is comprised of a lift sub 14, spark pump sub 16, and drill bit 18. Drill bit 18 is attached to spark pump sub 16. Spark pump sub 16 is attached to lift sub 14 by connecting means 17 which permit vertical motion and differential rotation between lift sub 14 and spark pump sub 16. Spark pump sub 16 is comprised partly of a case 19 having a chamber therein. The interior surfaces of the chamber are coated with an insulating material, e.g., ceramic. Piezoelectric means 22 are stacked in this chamber. Appropriate piezoelectric means for use in this embodiment may typically be discs, cylinders, or rings made of lead zirconate-lead titanate ceramic. These piezoelectric means have the interior portion removed to form approximately a cylindrical passage which has the central axis of the passageway coinciding with the central axis of the piezoelectric means. The faces of the piezoelectric means 22 are silvered.

When piezoelectric means 22 are compressed, an electrical potential develops between opposite silvered faces that is proportional to the applied pressure. This potential appears essentially instantaneous. Thus, a condition is developed where one silvered face of piezoelectric means 22 has a positive potential as compared to its opposite face. Piezoelectric means 22 are stacked in the chamber of spark pump sub 16 by a method of alternately inverting each during stacking so that positive faces contact one another and negative faces contact one another. The lower end of the column of piezoelectric means 22 is supported partially by a shoulder 25 of case 9 and partially by a support structure 27. Support structure 27 is comprised of concentric electrically conducting cylinders 24 and 26 potted in an insulating material 28, e.g., plastic having structural strength. Channels 34 and 36 are recessed in case 9 and open into the chamber therein. Channels 34 and 36 house electrical conductors 30 and 32 which are used to connect in parallel piezoelectric means 22. Conductors 30 and 32 are electrically insulated from case 9. This insulation may be provided about conductors 30 and 32 themselves or may be provided by coating the surfaces of channels 34 and 36 with an insulating material, e.g., ceramic.
distance from the shoulders to the bottom of the vertical faces of cam follower 14 and cam 16. The frequency of the vibrations is related to both the differential rotation rate between the cam follower and cam and the number of shoulders and troughs employed. For example, if there are 10 shoulders and 10 troughs in the cam surfaces of both the cam follower and cam and the differential rotation rate is 60 revolutions per minute or 1 revolution per second, the cam follower will be vibrated 10 times per second and thus the vibration frequency is 10 cycles per second.

Lifting sub 14 is provided with center extension 72 of approximately the same size and shape as plate 74 of spark pump sub 16. Center extension 72 extends to a position intermediate trough 66 and shoulder 68. Metal plate 74 extends to a position intermediate trough 62 and shoulder 58. On each downward vibration of lifting sub 14, center extension 72 contacts metal plate 74 thereby transferring the weight of drill string 15 from case 9 to center extension 72, through plate 74, bearing 76, and metal plate 78 to the column of piezoelectric means 22. In this manner piezoelectric means 22 are compressed and produce electrical energy which is arced between electrodes 42 and 46 to produce shock waves.

Another embodiment of this invention is illustrated by FIGURE 3. In this embodiment a jet-edge generator of the type, for example, as described in U.S. 3,315,755 to Warren B. Brooks is used instead of the cam previously described to compress piezoelectric means 22. Jet-edge generator 80 is attached by threads 82 to drill string 15 and by threads 89 to spark pump sub 16. Drilling liquid 52 is forced through jet-edge generator 80 which converts the hydraulic energy of the moving drilling liquid 52 into mechanical energy of vibrating piston 84. Piston 84 contacts or very nearly contacts metal plate 86 which is electrically insulated from the column of piezoelectric means 22 by, for example, an insulation washer 83. The vibrating piston 84 intermittently transfers mechanical energy to the column of piezoelectric means 22 and thereby intermittently compresses the piezoelectric means to generate electrical energy. The vibrational frequency produced by the jet-edge generator is dependent upon the velocity of the drilling liquid. A frequency of 100 cycles per second is both obtainable and operational. However, this frequency is by no means critical.

Still another embodiment of this invention is illustrated by FIGURE 4. This embodiment uses the spark pump sub in cable tool operations. The drill tool is intermittently raised and dropped to the bottom of the wellbore. The energy of the impact of the drilling tool with the wellbore bottom is used to compress the piezoelectric means and thereby produce electrical energy which is arced between the electrodes to produce shock waves. In carrying out this operation, jet-edge generator 80 of FIGURE 3 is removed and its stead a collar 19 is attached to spark pump sub 16. The upper end of collar 19 connects to flexible drilling conduit 94 which extends to the surface. Collar 19 fits firmly down upon metal plate 86 thus firmly fixing the upper end of the column of piezoelectric means 22. The flexible conduit may be, for example, reinforced cable and is used both for the purpose of supporting the drill tool and for passing drilling liquid therethrough to the bottom of the wellbore.

A spark pump sub of approximately 10 feet in length develops sufficient electrical energy for drilling a wellbore by all embodiments of this invention. The piezoelectric means employed are approximately four inch ceramic rings one inch high and having a one inch diameter central hole therethrough for passage of circulating drilling liquids. One hundred such ceramic rings are used in a typical 10 foot sub. A suitable ceramic for making these rings is lead zincate-titanate.

The determination of the total electrical energy which is developed by a typical 10 foot spark pump sub is calculated as follows:

\[ C_0 = \frac{\varepsilon_0 K A}{L} \text{ farads} = 0.0035 \text{ microfarad} \]

where

- \( C_0 \) = capacitance of each ceramic element;
- \( \varepsilon_0 = 8.85 \times 10^{-12} \text{ farads/meter} \);
- \( K = 1300 \) (for PZT-4 ceramic spark pump as manufactured by Clevite);

\[ A = \frac{\pi}{4} (4^2 - 1) \times 0.45 \times 10^{-4} \text{ m}^2 \]

\[ L = 1 \times 2.54 \times 10^{-2} m \]

The total capacitance of 100 elements wired in parallel is:

\[ C = 100 \times \frac{1}{100} C_0 = 0.35 \text{ microfarad} \]

The electro-mechanical constant \( \varepsilon_{33} \) for PZT-4 ceramics is 4.2 volts/inch/p.s.i. By loading a column of ceramics with a drill string weighing approximately 85,000 pounds the applied stress will be of the order of 7200 p.s.i. and the electrical field generated by the stress will be

\[ E_r = \frac{85,000}{\text{Area}} \times 4.2 = 30,000 \text{ volts/inch} \]

What is claimed is:

1. In a method of drilling a wellbore in an earth formation, the steps which comprise:
   positioning means for generating electrical energy spaced from but closely adjacent to the wellbore end being drilled.
   circulating a drilling liquid in said borehole, periodically actuating said electrical generating means to periodically generate electrical energy, periodically discharging said energy in said drilling liquid to generate shock waves such that drilling is obtained.
   moving said means for generating electrical energy at a rate commensurate with the rate of drilling of said wellbore to maintain said means for generating electrical energy at a substantially uniform distance from said wellbore end being drilled.
2. A method of drilling a wellbore into subsurface formations employing a drill string having a liquid passageway therethrough and a drill bit having electrodes for arcing electrical energy therewithwhere the method which comprises:
   periodically generating electrical energy downhole, circulating drilling liquid between the surface of the earth and the bottom of the wellbore, discharging said electrical energy in said liquid between said electrodes to produce shock waves for fracturing said formation in advance of said electrodes, and removing the formation debris to the surface of the earth by said circulating drilling liquid.
3. The method of claim 2 wherein the electrical energy is periodically downhole by positioning a spark pump adjacent the wellbore bottom and periodically applying mechanical energy to the spark pump.
4. The method of claim 3 wherein the mechanical energy applied to the spark pump is generated by alternately raising and lowering the lower end of the drill.
string with respect to the spark pump to alternately apply to and remove from the spark pump a compressive force.

5. The method of claim 3 wherein the mechanical energy applied to the spark pump is generated by converting hydraulic energy of circulating drilling liquid into mechanical energy of a vibrating mass and applying said mechanical energy to said spark pump.

6. The method of claim 3 wherein the mechanical energy applied to the spark pump is generated by alternately raising and dropping a drill bit to the wellbore bottom.

7. In a combination rotary and shock wave method for drilling a liquid-filled wellbore employing a drill bit the steps which comprise:

rotating a drill bit to cut an annular ring through an earth formation,

generating shock waves in said liquid at a position spaced above but in the vicinity of the bottom of said wellbore, said shock waves being transmitted through said liquid to fracture an earth core encompassed by said annular ring, and

removing the earth fractures from the wellbore by circulating drilling liquid.

8. A combination rotary and shock wave drill bit for forming a wellbore in earth formations comprising:

a bit body having a longitudinal axis, cutting edges on said bit body spaced laterally from said longitudinal axis of said body and terminating in a lower extension below said body, and

electrodes on said bit body spaced laterally between said cutting edges and said longitudinal axis, said electrodes extending below said bit body to a position intermediate said bit body and said lower extension of said cutting edges.

9. A combination rotary and shock wave drill bit for forming a wellbore in earth formations comprising:

a body having a longitudinal axis and a liquid passageway therethrough, cutting edges on said body spaced laterally from said longitudinal axis, said cutting edges terminating in a lower extension whereby an annular cut is made in said earth formation upon rotation of said bit in contact with said earth formation, and

electrodes on said bit body spaced laterally intermediate said cutting edges and said longitudinal axis, said electrodes extending below said bit body and said lower extension of said cutting edges.

10. The drill bit of claim 9 wherein the electrodes are comprised of concentrically electrically conductive cylinders.

11. A shock wave drill tool for drilling a wellbore into subsurface formations comprising in combination:

a jet-edge generator including a moveable piston for converting hydraulic energy of flowing drilling liquid into mechanical energy,
a spark pump sub comprising a column of piezoelectric means which when compressed converts mechanical energy into electrical energy, means for connecting said piston to said piezoelectric means to alternately compress said means, a drill bit having cutting edges and at least two electrodes in close proximity to the bit face, said electrodes being spaced so that arcing of electrical energy takes place therewithin upon said electrical energy attaining a predetermined potential, and means for electrically connecting said piezoelectric means to said electrodes.

12. In a combination rotary and shock wave method for drilling a wellbore into an earth formation employing a drill bit the steps which comprise:
circulating drilling liquid between the surface of the earth and the wellbore bottom, rotating said drill bit in contact with said earth for

mation to fracture the perimeter of said wellbore bottom, periodically generating electrical energy downhole adjacent said drill bit, intermittently discharging said energy within said periphery to generate shock waves in said liquid, said shock waves being transmitted through said liquid to fracture the wellbore bottom inside the periphery, and

removing the fractured formation to the surface by the circulating drilling liquid.

13. A combination rotary and shock wave drilling system which comprises:

means for circulating drilling liquid between the surface of the earth and the wellbore bottom, bit means supported at the lower end portion of said means for circulating drilling liquid, said bit means comprised of a bit body having a longitudinal axis, cutting edges on said bit body spaced laterally from said longitudinal axis of said body and terminating in a lower extension below said body, and electrodes on said bit body spaced laterally between said cutting edges and said longitudinal axis, said electrodes extending below said bit body to a position intermediate said bit body and said lower extension of said cutting edges, means positioned near said bit means for generating electrical energy downhole, spaced electrodes mounted on said bit means having portions exposed to said drilling liquid, means interconnecting said generating means and said electrodes to conduct the electrical energy to said electrodes for discharge therebetween to create shock waves which propagate through said drilling liquid to the formation and fracture it, and means for rotating said drill bit in contact with the formation to fracture it, said fractured formation being removed to the surface by the circulating drilling liquid.

14. A combination rotary and shock wave drilling system which comprises:

means for circulating drilling liquid between the surface of the earth and the wellbore bottom, bit means supported at the lower end portion of said means for circulating drilling liquid, spark pump means positioned near said bit means for generating electrical energy downhole, said spark pump means being comprised of a column of piezoelectric means utilized for converting mechanical energy into electrical energy, spaced electrodes mounted on said bit means having portions exposed to said drilling liquid, means interconnecting said generating means and said electrodes to conduct the electrical energy to said electrodes for discharge therebetween to create shock waves which propagate through said drilling liquid to the formation and fracture it, and means for rotating said drill bit in contact with the formation to fracture it, said fractured formation being removed to the surface by the circulating drilling liquid.

15. A combination rotary and shock wave drilling system which comprises:

means for circulating drilling liquid between the surface of the earth and the wellbore bottom, bit means supported at the lower end portion of said means for circulating drilling liquid, means positioned near said bit means for generating electrical energy downhole, spaced electrodes comprised of concentrically electrically conductive cylinders mounted on said bit means and having portions exposed to said drilling liquid, means interconnecting said generating means and said electrodes to conduct the electrical energy to said electrodes for discharge therebetween to create shock
waves which propagate through said drilling liquid to the formation and fracture it, and means for rotating said drill bit in contact with the formation to fracture it, said fractured formation being removed to the surface by the circulating drilling liquid.

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U.S. Cl. X.R. 175—93, 104
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,506,076 Dated April 14, 1970
Inventor(s) Frank A. Angona

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

Column 1, line 12, "utilizing" should read --utilizing--.
Column 2, line 9, "successfully" should read --successfully--.
Column 3, line 9, "from" should read --form--.
Column 6, line 61, after "downhole," start a new paragraph with --circulating....--; Column 6, line 70, "periodically downhole" should read --periodically generated downhole--.

SIGNED AND SEALED
AUG 25 1970

(SEAL)
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