APPARATUS FOR WELL DRILLING OPERATIONS WITH EXPLOSIVES

FIG. 2.

FIG. 3.

FIG. 23.

DRILL PIPE

DRILLING FLUID

FIRING HEAD

DRILLING HEAD

CHARGE HOUSING

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This invention relates to explosive charge apparatus for use in boreholes, and more particularly to explosive charge apparatus for use in connection with well drilling operations.

Various techniques have been developed for the purpose of using the directional blasting characteristics of explosive-jet shaped charges to drill boreholes in the earth. A particular technique is that described in U.S. Patent No. 3,070,010. In this technique use is made of elongated shaped charges and elongated gouging charges adapted to be pumped down a well pipe. The jet charges and gouging charges are injected into a stream of drilling fluid pumped down a well pipe according to a predetermined path therefor by circulation of drilling fluid. The gouging charge, which may be a brisant or unbrisant explosive material, or a combination thereof, is detonated while tamped with drilling fluid. Drilling fluid is circulated after each detonation of an explosive charge so as to remove earth fragments and fragments of explosive charge housings from the borehole. Manifestly, it is desirable to blast as deeply into the earth as possible with each shaped charge so as to extend the borehole as far down as possible after each sequence of shaped charge and gouging charge or charges.

In connection with one aspect of the invention, there is provided an elongated housing terminating in an opening at one end thereof. Supported in the housing are a plurality of explosive-jet shaped charges, the charge supported in the end of the housing opposite the opening forming a conical opening facing toward the opening, with the axis of the conical opening being directed substantially at the point of the opening. The additional shaped charges are supported between the first shaped charge and the opening. Each of the additional charges has an opening therethrough at least a portion of which is frusto-conical in shape, the axes of the frusto-conical portion being substantially colinear with the axis of the conical opening of the first shaped charge. Connecting each adjacent pair of said shaped charges is a synergetic explosive charge having a burning time at least equal to the time required for substantially the entirety of the explosive-jet produced by the shaped charge farthest removed from the opening to pass into the opening through the other of said adjacent pair of shaped charges. The cone angle of the conical and frusto-conical openings of the shaped charges is substantially equal. Differential pressure responsive firing means are provided for igniting the first shaped charge responsive to hydro-static pressure of a given magnitude.

Objects and features of the invention not apparent from the above description will become evident upon consideration of the following detailed description of the invention taken in connection with the accompanying drawings, wherein:

FIGS. 1A and 1B, taken together, are a cross-sectional view of an embodiment of the invention.

FIG. 2 is a cross-sectional view of the apparatus of FIG. 1A taken along section 2-2.

FIG. 3 is a cross-sectional view of the apparatus of FIG. 1A taken along section 3-3.

FIGS. 4-22 are simplified views of a pair of the shaped explosive-jet charges shown in FIG. 1B, illustrating the manner in which the explosive-jet produced thereby is formed; and

FIG. 23 is a cross-sectional view of a portion of a borehole being drilled by the apparatus of the present invention.

With reference now to FIGS. 1A, 1B, 2, and 3, there is shown an elongated housing comprising housing sections 1, 3, and 5. The lower end of housing section 5 terminates in an ogive 51, which preferably is of relatively thin material. Supported within the housing are a plurality of shaped explosive-jet charges 37, 49a, 49b, and 49c. Shaped charge 37 has a conical opening facing toward ogive 51. The axis of the conical opening is directed substantially at the point of the ogive 51. Shaped charge 37 is provided with the usual liner 39, which may be formed of copper or aluminum. The explosive jets 49a, 49b, and 49c have openings therethrough, at least a portion of which is frusto-conical in shape. The axes of the frusto-conical openings of shaped charges 49a, 49b, and 49c are substantially colinear with the axis of the conical opening of shaped charge 37. Interconnecting shaped charges 37 and 49a is a synergetic or connecting charge 49a, which may be formed of an explosive material such as composition "B", which is a combination of RDX and TNT described in the text "The Science of High Explosives" by M. A. Cook (Reinhold Publishing Co., 1958). The synergetic charge 49a is held in position by a metal shield 45b comprising an upper frusto-conical section 43a, a lower frusto-conical section 47a (which also could form the liner for shaped charge 49a) with an annular connecting section. The synergetic charge 49a is generally annular in shape and has a burning time from the lower end of the upper shaped charge 37 to the upper end of lower shaped charge 49a such that the explosive-jet produced by the upper shaped charge will have passed into the opening of the lower shaped charge by the time that the lower shaped charge is ignited by the synergetic charge. This burning time may be determined by the conical angle of the metal shield section 43a and by the shortest distance from the lower end of line 39 to the upper end of shaped charge 49a measured along the synergetic charge. More particularly, this distance (D) may be determined from the formula

\[
D = \frac{V_1 X}{V_2}
\]

where

\[
V_1 = \text{the detonation velocity of the synergetic charge, and}
\]

\[
V_2 = \text{the velocity of the jet, and}
\]

X is the perpendicular distance from the lower end of the shaped charge detonating the synergetic charge to the upper end of the next shaped charge. The distances D and X are shown in FIG. 1B.

The lower shaped charges 49b and 49c are positioned in the housing sections 3 in a manner similar to that of shaped charge 49a. The lengths of shaped charges 49b and 49c are determined in the same manner as described above for synergetic charge 49a. Shaped charges 49b and 49c are provided with metal shields 45b and 45c which are similar in design to metal shield 45a. The axes of the frusto-conical openings of charges 49b, 49c lie on the conical axis of the opening of explosive charge 37. It should be noted that the explosive charge 37 is held
in position by a substantially conical holding member 35, to which is connected a length of Primacord 33 for igniting the upper shaped charge 37. The Primacord is brought sufficiently close to shaped charge 49a to ignite the shaped charge at the upper end thereof. The Primacord 33 is fired by the apparatus illustrated in FIGS. 1A, 2, and 3. An igniter squib at the upper end of Primacord 33 is positioned in a fitting 29 supported within housing section 3. The upper housing section 1 supports a piston housing 7, within which is positioned a plunger or piston 11. The piston housing threads into an elongated spring housing 17. At the lower end of the spring housing is an annular section 28 projecting upwardly into the spring housing for supporting a shear pin 27 and a firing pin 23. The firing pin 23 is positioned immediately above the igniter squib 31. A compression spring 19 is held between a plate 15 connected to plunger 11 by connecting rod 13, and a plate 21 affixed to the upper end of firing pin 23. Responsive to pressure exerted upon the upper face of plunger 11, the plunger 11 moves downwardly as a result of the differential pressure between the upper end of housing section 1 and port 64. The pressure exerted on the firing pin 23 by spring 19 will increase until pin 27 bursts, releasing the firing pin 23 to detonate the igniter squib 31.

Holes 60 and 62 and port 64 are provided to place the underside of the piston at the pressure around housing section 5 at the level of port 64. Thus, the differential pressure against the piston will be the difference between the pressure at the upper end of the capsule and the pressure at port 64. The conical holding member 35 may be sealed fluid-tight at its edges to the housing section 5 so that liquid cannot penetrate member 35. As shown, the member 35 is formed as part of housing section 5.

When the lower housing section 5 is made heavy to withstand the hydrostatic pressure between the interior and exterior of the housing, then some provision should be made to assure it disintegrates when the charges are fired. This can be accomplished by making that section from a brittle material such as cast iron or a brittle alloy steel. Additional safety can be obtained by serrating the housing in the manner of a grenade. To couple the force of the explosion of the shaped charges to be more certain the housing is shattered, an acoustic coupling may be used within the housing, as by filling the spaces between the charge segments and the housing with a granular material as the charge is lowered into the housing. This can be done by filling the space with an inert powder or with a paste of a granular material as the charge sections are lowered into the housing. It is important that this acoustic coupling material does not make a physical bond with the housing, and accordingly, such materials as fine sand, clay, or barites should be used rather than a cementitious material which might hydrate and bond. An alternate material to fill this space could be a slow burning explosive material such as black powder or anastol (a mixture of TNT and ammonium nitrate). This explosive may be packed as a powder or molded in shape and inserted as the shaped charge is placed in the housing.

Referring now to FIG. 23, there is shown a drill pipe 55 having a drilling head 57 at the lower end thereof. The drilling head 57 is for the purpose of reaming out the event such is desirable. A shaped jet housing constructed in accordance with the invention is shown as having been landed in the borehole at the bottom end thereof. As the shaped charge housing passes through the drilling head 57, port 64 will be sufficiently covered so that a large differential pressure will momentarily exist across plunger 11 to shear the pin 27, thus detonating squib 31 to fire the shaped charges. The simplified schematic diagrams of a pair of shaped charges and an interconnecting or synergetic charge illustrated in FIGS. 4-22 illustrate the manner in which the resultant explosive jet is formed. The figures show the formation of the explosive jet at one microsecond intervals starting at zero time in FIG. 4. As illustrated, immediately after ignition of the shaped charge 37, the detonation front will progress downwardly. At 2 microseconds after ignition the explosive jet begins to form at the apex of the conical opening of shaped charge 37. The explosive jet increases in size and material content as the shaped charge burns, and gets progressively longer even after the shaped charge is completely destroyed. Between 7 microseconds and 12 microseconds after ignition of shaped charge 37, only the synergetic charge is burning so that no explosive material will be added to the explosive jet. At 12 microseconds, the upper end of shaped charge 49a is ignited and thereafter the explosive jet will continue to increase in material content as well as in length and volume. As illustrated in FIG. 22, at 18 microseconds after ignition of charge 49a, the combustion of shaped charge 49a is completed, and the explosive jet proceeds downwardly through the openings of subsequent shaped charges.

An advantage of the present invention is that the critical standoff distance for each of the shaped charges is well within the range of 1 to 12 inches required for most effective hole production from shaped charges. The reason for this is that the hole in the earth is sufficiently extended by the jets of previously ignited shaped charges to provide the optimum standoff distance for a given shaped charge in the apparatus. Using the apparatus of the present invention, it has been found that the standoff distance without increasing the cone angle of the shaped charges beyond the optimum. As noted, all of the cone angles of the shaped charges are substantially the same.

The above description and examples of the invention are for the purpose of illustration, and it is not intended that the invention be limited except by the scope of the appended claims.

What is claimed is:

1. An assembly for well drilling operations comprising:
   an elongated housing terminating in an ogive at one end thereof;
   a first shaped explosive charge supported in the other end of said housing, having a conical opening facing toward said ogive, the axis of said conical opening being directed substantially at the point of said ogive;
   at least one additional shaped explosive charge supported in said housing between said first shaped charge and said ogive, each said at least one additional shaped explosive charge having an opening therethrough, at an angle of which is frusto-conical, the axis of said frusto-conical portion being substantially co-linear with the axis of the conical opening of said one shaped charge;
   a synergetic explosive charge interconnecting each adjacent pair of said shaped charges, the burn time of said synergetic charge being at least equal to the time required for substantially the entirety of the explosive jet produced by one of said each adjacent pair of shaped charges to pass into the opening through the other of said each adjacent pair of shaped charges;

2. The purpose of the conical and frusto-conical openings of said shaped charges being substantially equal; and

3. Differential pressure responsive firing means for igniting said first shaped charge responsive to hydrostatic pressure magnitude, said differential pressure responsive firing means comprising a sealing housing section, an igniter charge connected to said first shaped charge, a firing pin supported in firing position relative to said igniter charge by means including a shear pin means, a cylindrical piston housing, a piston in said piston housing having one face exposed to fluid pressure, said shaped housing.
and an opposed face exposed to fluid pressure in said sealed housing, and compression spring means disposed between said piston and said firing pin.

2. The apparatus of claim 1 wherein the burning velocity of said syndetic charge is determined by the formula:

\[ V_1 = \frac{D V_2}{X} \]

where

\( V_1 \) is the detonation velocity of the syndetic charge,

\( V_2 \) is the velocity of the jet formed by the shaped charge,

\( X \) is the perpendicular distance from the lower end of the shaped charge detonating the syndetic charge to the upper end of the next lower shaped charge, and

\( D \) is the shortest distance from the lower end of the shaped charge detonating the syndetic charge to the upper end of the next lower shaped charge measured along the syndetic charge.

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