Dec. 19, 1961

T. C. POULTER

MULTIPLE-JET SHAPED EXPLOSIVE CHARGE PERFORATING DEVICE

3,013,491

Filed Oct. 14, 1957

2 Sheets-Sheet 1

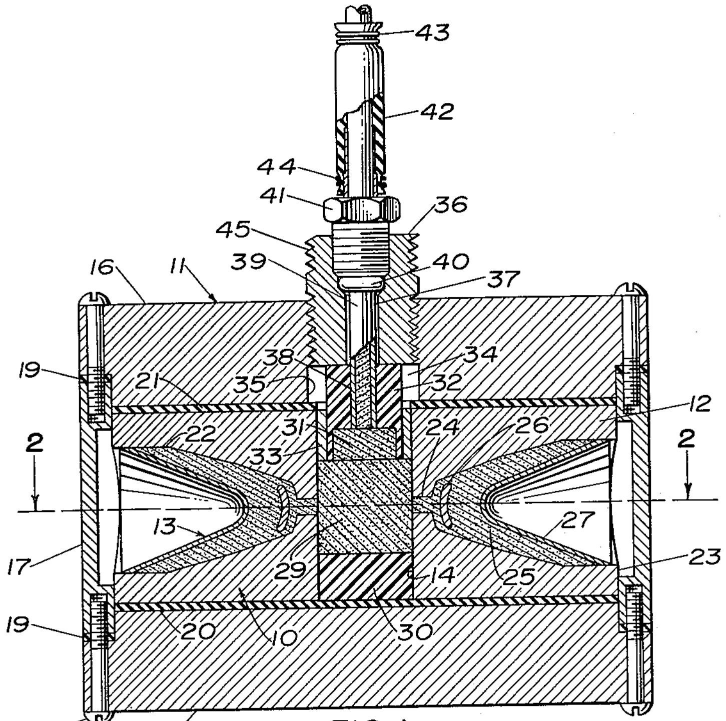

FIG. 1

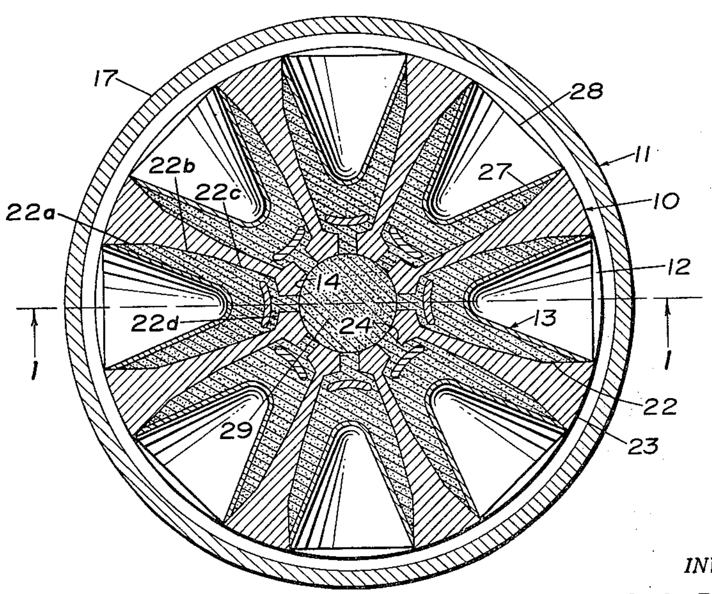

FIG. 2

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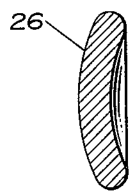

FIG. 4

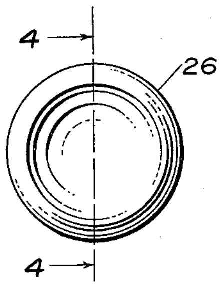

FIG. 3

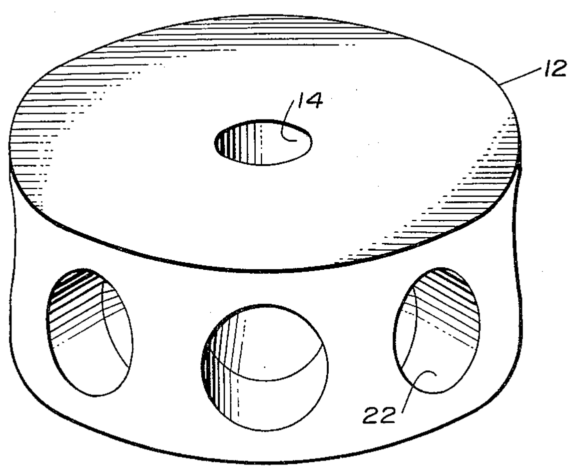

FIG. 5

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MULTIPLE-JET SHAPED EXPLOSIVE CHARGE PERFORATING DEVICE

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5 Claims. (Cl. 102—20)

This invention relates to a multiple-jet shaped explosive charge perforating device and subassemblies thereof.

In the completion of work-over of oil wells, gas wells, water wells and the like, where the well bore traverses a potentially productive zone which is relatively thin, and after well casing has been installed and it is desired to tap the thin productive formation, the well casing and surrounding productive formation are perforated to permit the valuable fluid burden of the formation to flow into the casing and to be withdrawn therefrom to the surface of the well. If the formation is very thin, having a thickness of from only a few inches to two or three feet, it is desirable to perforate the zone with as many holes as possible in the limited vertical distance available. Ideally, the perforations would radiate outwardly from the center of the well bore in a plane extending into the plane of the formation.

In oil field operations, after casing has been set in a well it is sometimes desirable or necessary to introduce a relatively short vertical annulus of cement between the outer periphery of the casing and the surrounding earth formation, as for example where it is desired to block the flow of water or other fluid in the annulus between the well casing and surrounding earth formation. Such a cementing operation is performed with the casing in place by first perforating the casing at a selected level and thereafter forcing or squeezing cement slurry from the bore of the casing outwardly through the perforations into the annulus. It is desirable, in perforating for a squeeze cementing operation, to provide the maximum number of holes in the casing in the shortest possible vertical distance. Here again, ideally, the perforations should radiate outwardly from the axis of the bore in a plane transverse the axis, and the angular spacing of the perforations should be as close as possible without destroying the strength of the casing.

In other oil field operations, hydraulic fracturing is employed for opening up the earth formation surrounding a well bore to increase productivity of the formation or to facilitate injection flooding of oil bearing strata. Hydraulic fracturing is accomplished by isolating the zone to be fractured and applying, through a fracturing liquid, high pressures to the formation to initiate and extend fractures in the formation. The over-burden is actually lifted by the hydraulic fluid under pressure in the fracturing operation. Prior to the application of hydraulic fracturing pressure, it is possible to locate the zone at which fracturing will take place by mechanically initiating the fracture in the earth formation. This may be done by firing a plurality of explosive jets radially outwardly from the well bore into the formation to be fractured, the penetrating jets preferably all lying in a plane along which the formation is desired to be fractured. Upon subsequent hydraulic fracturing, the formation will open up along the plane of the perforations produced by the penetrating jets.

It is, therefore, a principal object of the invention to provide a shaped explosive charge perforating device that simultaneously produces a plurality of jets of high penetrating power that radiate from a central point outwardly in a plane.

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Another object of the invention is to provide a multiple-jet shaped explosive charge perforating device capable of withstanding the high pressures encountered in the bores of deep wells and that may be lowered into such wells and fired to form perforations lying in a single plane in a thin productive formation, or to provide perforations preliminary to squeeze cementing, or, in fracture placement, to form perforations in preparation for hydraulic fracturing, or for other perforating purposes.

Another object of the invention is to provide a multiple-jet shaped explosive charge perforating device whereof the perforating jets have extremely high energy and are closely spaced circularly about a central axis.

Another object of the invention is to provide in a device of this character means for confining to a high degree and in a practically symmetrical manner the explosive forces of a plurality of shaped explosive charges fired simultaneously in close proximity to one another.

Another object is to provide a perforating device of this type in which a number of shaped explosive charges positioned in close proximity to each other are fired simultaneously without interference.

Another object of the invention is to provide a multiple-jet shaped explosive charge perforating device that is simple in design, that may be readily fabricated, and that is easily adapted to use in conventional wire line oil field services operations.

The foregoing and other objects and advantages of the invention as may appear hereinafter are realized in a multiple-jet shaped explosive charge perforating device having a unitary, preferably a cylindrical block of metal, specifically a right cylindrical metal block. The metal block provides a charge case. It has an axial bore or other central opening and a plurality of radially disposed cup-shaped recesses opening outwardly through the cylindrical surface of the block, with the bottoms of the recesses terminating adjacent the axial bore. The axes of the recesses lie in a plane extending transversely of the cylindrical block. Lined shaped explosive charges are contained, one in each of the recesses. Detonating means is provided in the axial bore or central opening of the block in detonating relation with the shaped explosive charges. The charge case is symmetrical about a vertical axis.

A pressure-resistant water-tight housing means surrounds the charge case and the housing has means for suspending the device in a well. Preferably also the housing has top and bottom plates that reinforce the ends of the cylindrical charge case to provide balanced confinement for the shaped explosive charges.

In the drawings:

FIG. 1 is a vertical sectional view, taken along the line 1—1 of FIG. 2, of a multiple-jet shaped explosive charge perforating device embodying the principles of the invention;

FIG. 2 is a transverse sectional view taken along the line 2—2 of FIG. 1;

FIG. 3 is an enlarged view of one of the barrier members of the shaped charges of the assembly;

FIG. 4 is a sectional view taken along the line 4—4 of FIG. 3; and

FIG. 5 is an isometric view of the shaped charge case of the assembly.

Referring to the drawings, more particularly to FIGS. 1 and 2 thereof, the multiple-jet shaped explosive charge assembly shown has a shaped explosive charge unit designated by the general reference numeral 10 enclosed within a pressure-resistant, water-tight housing or container designated by the general reference numeral 11. The shaped charge unit 10 has a unitary cylindrical block of metal 12 forming a charge case containing a plurality of radially directed shaped explosive charges 13. An axial bore 14 is provided through the center of the block 12 to receive means for detonating the shaped explosive charges, which detonating means will be described in greater detail hereinafter.

The housing 11 includes a bottom plate 15 and a top plate 16 fastened to an intermediate ring member 17 by means of screws 18. Ring gaskets 19, of rubber, neoprene, or other suitable gasket material, seal the plates 15 and 16 to the ring member 17. Spacers 20 and 21, also of rubber or similar material, are interposed between the lower and upper plates and the charge case 12. The ring gaskets prevent ingress of bore fluids to the interior of the housing when the unit is lowered into the bore of an oil well or the like. As shown in FIG. 1, the relative thickness of the gaskets and spacers is exaggerated so that they will appear clearly. The spacers 20 and 21 may be omitted and the top and bottom plates of the housing may be in direct contact with the charge case 12.

The shaped explosive charges 13 are housed in radially extending cup-shaped recesses 22 bored in the block 12. The recesses open outwardly of the block through the outer cylindrical surface 23 thereof. The bottoms of the recesses terminate in the block 12 adjacent the axial bore 14. Radial passages 24, in line with the axes of the recesses, connect the bottoms of the recesses to the axial bore. In the illustrative embodiment shown, eight shaped charge recesses 22 are provided in the block. These recesses are arcuately spaced on axes disposed at 45° to one another. Fewer or more than eight cup-shaped recesses may be provided. It will be observed from FIG. 1 that the longitudinal axes of the recesses 22 lie in a horizontal plane through the line 2—2 of FIG. 1.

Referring to FIG. 2, it will be seen that the radially outermost section 22*a* of each recess 22 is cylindrical and extends inwardly from the case wall 23 for a distance slightly less than one-third the total depth of the recess. The cylindrical section joins an intermediate section 22*b* having the form of a truncated cone tapering inwardly. The intermediate section joins the rear section 22*c* which is another inwardly tapering truncated conical section having a projected apex angle slightly more obtuse than the projected apex angle of the intermediate section 22*b*. The bottom 22*d* of the recess is defined by a spherical surface symmetrical about the axis of the recess. Thus, in the zone of the medial transverse plane of the case, adjacent recesses 22 are separated by a thin web integral with the charge case, the web having a substantially rectilinear section between the rear portions 22*c* of the recesses, an outwardly diverging section between the intermediate portions 22*b* of the recesses, and a section diverging outwardly at a greater angle than the intermediate web section between the cylindrical portions 22*a* of the recesses.

The shaped explosive charge devices specifically shown by way of illustration are of the barrier type disclosed and claimed in my copending application Serial No. 439,564, filed June 28, 1954, now abandoned, for "Shaped Charge," now abandoned in favor of my continuation-in-part copending application Serial No. 786,888 filed January 14, 1959 for "Shaped Charge and Method of Firing the Same," to which reference is made for a full disclosure of the construction and operation of this type of shaped explosive charge.

For purposes of the present application, the barrier type shaped charge will be described briefly. It includes a charge of high explosive material 25, such as desensitized cyclonite or the like, seated in the recess 22. A portion of the explosive material extends from the base of the charge through the passageway 24 to the axial bore 14. A barrier member 26 is embedded in the explosive 25 between the base thereof and the inert cavity liner 27. The liner 27, which may be of copper or other suitable liner material, is generally conical and is positioned coaxially of the charge of explosive 25 and opens radially outwardly of the shaped explosive charge device. The base 28 of the liner has a diameter substantially equal to the diameter of the cylindrical section 22*a* of the recess 22 and is press-fitted into the mouth of the recess against the explosive material 25 to form the well-known shaped charge cavity in the explosive material. The space between the liner 27 and the inner wall of the housing ring 17 is filled with air to provide stand-off for jet formation.

As described in my aforesaid copending applications, the barrier 26 may be made of steel or the like and is of such thickness that a high-order detonation shock wave originating in the explosive behind the barrier is transmitted through the barrier with just sufficient intensity to initiate in the explosive at the forward side of the barrier a central low-order detonation. The high-order detonation front propagates radially outwardly in the explosive behind the barrier and travels around the rim of the barrier to produce an annular high-order detonation front in the explosive, which high-order detonation front surrounds the initially separate low-order central detonation front initiated in the charge by transmission of energy through the barrier. The annular high-order detonation front and the initially separate, central, low-order detonation front merge in the explosive between the barrier and the cavity liner to produce a composite front of unique characteristics and extremely high energy that attacks the cavity liner to provide a jet of superior penetrating power.

Within the axial bore 14 is a first booster pellet 29, of RDX with 5% graphite for example, that is in contact with the portion of the explosive charge 25 contained within the passage 24. In order not adversely to affect the symmetry of detonation, the first booster pellet 29 extends equal distances above and below the center plane of the unit. A cylindrical spacer 30 is inserted between the booster pellet 29 and the gasket 20 to support the bottom of the pellet in proper position.

In contact with the top of the first booster pellet 29 is a second booster pellet 31, typically of pure RDX, carried in the bore of a cylindrical plastic holder 32. The holder 32 is centered in the bore 14 by an annular spacer member 33. The upper part of the booster holder 32 is received in a chamber 34 in the upper housing plate 16, the chamber being closed by a plug 36 threaded into the top of the chamber. The booster holder 32 and the spacer 30 retain the first booster pellet 29 vertically centered in the bore 14.

The plug 36 has an axial bore 37 aligned with a bore 38 in the booster holder 32. A length of pressure-resistant, water-proof covered detonating cord 39, such as Primacord, extends through the bores 37 and 38 into detonating contact with the second booster pellet 31. The detonating cord 39 is surrounded by a gland 41 threaded into the bore 37, and the gland is sealed to the bore by a ferrule 40 pressed between the bottom of the gland and a shoulder in the bore 37. The fuse is sealed to the ferrule by a neoprene sleeve 42 surrounding the fuse and the upper portion of the ferrule, the sleeve being contracted over the fuse by a wrapping of wire 43 and being secured to the upper portion of the ferrule by another wrapping of wire 44.

The plug 36 is threaded exteriorly at 45 for attachment of the assembly, by means of an extension (not shown) to a firing head (not shown), the firing head being supported from the usual cable (not shown) by which the device is lowered in an oil well. The detonating cord 39 is led upwardly to the firing head which contains a well-known arrangement, including an electrical blasting cap, for detonating the fuse.

Detailed views of the barrier member 26 are shown in FIGS. 3 and 4. The barrier has a disc shape and is of substantially uniform thickness. It is concave on the front face and convex on the rear face. The rim of the barrier is rounded.

FIG. 5 shows the charge case 12 in isometric view. The case may be machined from a solid block of zinc-base, die-casting alloy known as "Zamak." However, any suitable metal, such as brass or steel, may be used for the charge case. Other appropriate methods of forming the case may be employed and other solid explosive charge confining material, such as glass or hard synthetic resinous material, such as Bakelite, may form the charge case.

In operation, the multiple-jet perforating device is attached to a firing head which in turn is suspended from a cable by which the unit is lowered into an oil well to be perforated. When the unit reaches the point at which perforations are desired, the detonating fuse 39 is initiated in the firing head. A detonation wave travels down the fuse and fires the second booster pellet 31. Energy from the second booster pellet detonates the first booster pellet 29. The portions of the explosive within the passages 24 are detonated simultaneously by the first booster pellet, and the main charges 25 are fired in unison to provide, as described hereinbefore, a plurality of radial jets that penetrate the housing ring 17, the fluids within the well bore, the well casing and cement, and the surrounding earth formation. The perforations thus produced lie in a common plane and extend radially outwardly from a common point on the axis of the device.

Owing to its unique construction, the multiple-jet unit of this invention produces uniform perforating jets of great penetrating power. In accomplishing this desirable result, the shaped explosive charges are fired simultaneously. The detonation wave fronts of all the charges advance outwardly at the same rate without creating interference between the charges. Since the metal of the charge case transmits shock waves at a velocity only about two-thirds the velocity of the detonation wave in the explosive, and since the detonation waves of the separate charges advance radially outwardly of the case in unison, it is seen that the shock waves in the charge case lag behind the detonation waves advancing in the explosive charges and, hence, the detonations in adjacent charges cannot interfere with each other.

Moreover, the construction of the device of the invention assures practically uniform and a high degree of confinement of each shaped charge unit. Referring to FIG. 1, the first booster pellet 29 is cylindrical and is positioned with its transverse medial plane coinciding with the medial plane of the charge case. When the pellet is detonated along its axis, the detonation wave front produced radiates substantially symmetrically outwardly. The wave front generates an advancing shock wave in the metal of the charge case 12 rearwardly of each of the shaped explosive charges, which shock wave lags the detonation wave front advancing through the shaped explosive charges and symmetrically opposes the inward reaction forces of the detonating shaped explosive charges to confine the latter from the rear.

Considering FIG. 2 with regard to lateral horizontal confinement of the shaped explosive charges, the detonation wave fronts, advancing outwardly in each of the shaped explosive charges, set up opposed shock waves in the webs of the case that separate adjacent shaped explosive charges. The opposed shock waves interact in the webs to effect high and symmetrical lateral confinement of the charges in the horizontal plane.

Referring once again to FIG. 1, lateral confinement of the shaped explosive charges in the vertical direction is provided substantially entirely by the masses of metal in the charge case and in the top and bottom plates of the housing that lie above and below the shaped explosive charges. The mass of metal either above or below each shaped charge is approximately equivalent in its ability to confine the charge in the vertical direction as is the combination of the metal web backed up by an adjacent exploding charge in its ability to confine the charge laterally in the horizontal direction.

Regarding lateral confinement of the shaped explosive charges in directions intermediate the vertical and horizontal, it is seen from the drawings, particularly FIG. 5 thereof, that the webs separating adjacent shaped explosive charge recesses become thicker, and the spacing of explosive material in adjacent charges becomes greater, as the distance above or below the horizontal mid-plane of the charge unit increases. Thus, in proceeding from the mid-plane either upwardly or downwardly, confinement is dependent more upon increasing mass of metal and less upon interaction of opposed shock waves in the metal itself, the two confining effects substantially complementing one another around each shaped explosive charge to accomplish substantially uniform confinement of the charges laterally in all directions. In this connection, the housing 11 has the relatively massive bottom and top plates 15 and 16 top faces. Lateral charge confinement in the vertical direction is thus effected by a combination of the metal of the charge case as reinforced by the top and bottom plates. Therefore, if the top and bottom plates are made thinner, the over-all thickness of the charge case is correspondingly increased to provide equivalent charge confinement, and vice versa. In accordance with this principle, the relative thicknesses of the charge case and of the top and bottom plates of the housing can be varied as dictated by design requirements to obtain optimum penetration performance.

In one multiple-jet shaped explosive charge unit, in accordance with the drawings, suitable for perforating wells having 5" casing or larger, the outside diameter of the housing is 4.5" and the height of the housing from the top surface of plate 16 to the bottom surface of plate 15 is 3.25". The top and bottom housing plates, the intermediate ring member, and the top plug are made of Duralumin with the top and bottom plates each being 0.875" in thickness. The charge case 12 has an outside diameter of 4" and a thickness of 1.5" and is made of Zamak. The axial bore in the charge case is 0.75" in diameter. The cylindrical section *22a* of each charge recess has a diameter of 1.063" and the length of the passages 24 is 0.156". The barrier is of steel 0.344" in diameter and 0.062" thick with the radius of the concave depression being 0.313". The cavity liners are of copper 0.030" thick and have a projected apex angle of 45° with the inner radius of the tip of the liner being 0.125". The first booster pellet is made of waxed RDX with 5% powdered graphite. Each shaped explosive charge consists of 9.5 grams of RDX. The second booster pellet consists of Cyclonite. The assembly is initiated by a length of 70-grain RDX Primacord.

Although the device of the invention as illustrated and described herein employs barrier type shaped explosive charges, it will be understood that conventional shaped charges without barriers may be used without unduly decreasing performance. Moreover, whereas the illustrative charge case is a right cylindrical block, the case may have a polygonal cross-section; therefore, the term cylindrical as used herein to characterize the charge case is to be construed broadly to include not only a true cylinder but also those solid shapes not truly cylindrical but approaching the cylindrical which serve to hold the explosive charges with a high degree of confinement and symmetry.

From the foregoing description it will be seen that the invention provides a greatly improved multiple-jet shaped explosive charge perforating unit. In the light of the description, various changes will occur to those skilled in the art without departing from the invention.

I claim:

1. A multiple-jet shaped explosive charge perforating unit comprising: a unitary cylindrical solid block of metal providing an axial bore, a plurality of radially disposed cup-shaped recesses opening outwardly through the cylindrical surface of said block with the bottoms of the recesses terminating adjacent said axial bore, and a plurality of radical passages, one connecting the bottom of each

recess with said bore, all of said recesses and said radial passages having their axes lying in a single transverse plane and spaced at equal angles to one another, said block providing continuous webs between the sides of adjacent recesses; a plurality of charges of explosive material, one seated in each of said recesses and extending through the associated passageway to said bore, each said charge having a cavity coaxial with said recess and opening outwardly thereof; inert liner means lining the walls of each cavity; a booster charge in said axial bore in detonating relation to the portions of said charges of explosive in said passageways; and a detonator charge in said bore in detonating relation to said booster charge.

2. A multiple-jet shaped explosive charge perforating unit comprising: a unitary right cylidrical solid block of metal providing a plurality of radially disposed identical charge-receiving recesses opening outwardly through the cylindrical surface of said block, said recesses being defined by surfaces of revolution, all of said recesses having their axes radially disposed in the medial transverse plane of said block and being spaced at equal angles around the axis of said cylindrical block, said recesses tapering radially inwardly of said block, the bottoms of said recesses terminating in said block at points spaced from the axis of said block, said block providing continuous webs between the sides of adjacent recesses; a plurality of charges of explosive material, one seated in each of said recesses, each said charge having a substantially conical cavity coaxial with said recess and opening outwardly thereof; inert liner means lining the walls of each conical cavity; and means disposed within said block symmetrical about the axis thereof for initiating said charges simultaneously at the radially inward ends thereof.

3. A multiple-jet shaped explosive charge perforating unit comprising: a unitary right cylindrical solid block of metal providing a plurality of radially disposed identical charge-receiving recesses opening outwardly through the cylindrical surface of said block, said recesses being defined by surfaces of revolution, all of said recesses having their axes radially disposed in the medial transverse plane of said block and being spaced at equal angles around the axis of said cylindrical block, said recesses tapering radially inwardly of said block, the bottoms of said recesses terminating in said block at points spaced a substantial distance from the axis of said block, said block providing continuous webs between the sides of adjacent recesses; a plurality of charges of explosive material, one seated in each of said recesses, each said charge having a substantially conical cavity coaxial with said recess and opening outwardly thereof; inert liner means lining the walls of each conical cavity; said block further having an axial opening therein and providing restricted passages communicating said opening with each of said recesses axially of said recesses; a booster charge in said axial opening in detonating relation to said charges of explosive material through said passages; and means for initiating said booster charge.

4. A multiple-jet shaped explosive charge perforating unit as defined in claim 3 including pressure-resistant, water-tight housing means surrounding said block, said housing means having massive top and bottom plates engaging the ends of said block over substantially the entire areas of the ends.

5. A multiple-jet shaped explosive charge perforating unit comprising: a unitary solid block of metal having a vertical, cylindrical, outer face and horizontal top and bottom faces, said block providing a plurality of radially disposed, cup-shaped recesses opening outwardly through the cylindrical face of said block, said recesses having their axes lying in a single horizontal plane substantially midway between said top and bottom faces, said recesses being disposed at equal angles circumferentially about said block, the bottoms of said recesses lying in a circle having its center in the vertical axis of the block, said block providing continuous webs between the sides of adjacent recesses, said block providing an axial cylindrical opening extending from one of said horizontal faces into said block beyond said single horizontal plane, said block providing a plurality of radial passages, one connecting the bottom of each said recess with said axial opening; a pressure-resistant, sealed housing closely surrounding said block, said housing having massive top and bottom plates engaging the top and bottom faces of said block over substantially the entire areas of said faces and a cylindrical side wall member having a thin annular section intersected by said single horizontal plane; a plurality of main charges of explosive material, one seated in each said recess and having an inner portion extending through the radial passage at the bottom of said recess, each said charge having a substantially conical cavity coaxial with said recess and opening outwardly thereof; inert liners, one seated in the cavity of each said charge; a cylindrical charge of booster explosive seated in said axial opening adjacent the inner ends of said radial passages and adapted to detonate the main explosive charges; a length of detonating fuse extending axially through one of said housing plates into detonating relation with said booster explosive, said fuse being sealed in said one plate; the diameter of said axial opening being substantially greater than the diameter of said fuse; and means on said housing for suspending the same in a well.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,013,491 December 19, 1961

Thomas C. Poulter

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 14, for "of", first occurrence, read -- or --; column 6, line 16, before "top" insert -- which reinforce the charge case 12 on its bottom and --.

Signed and sealed this 1st day of May 1962.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents

UNITED STATES PATENT OFFICE
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