

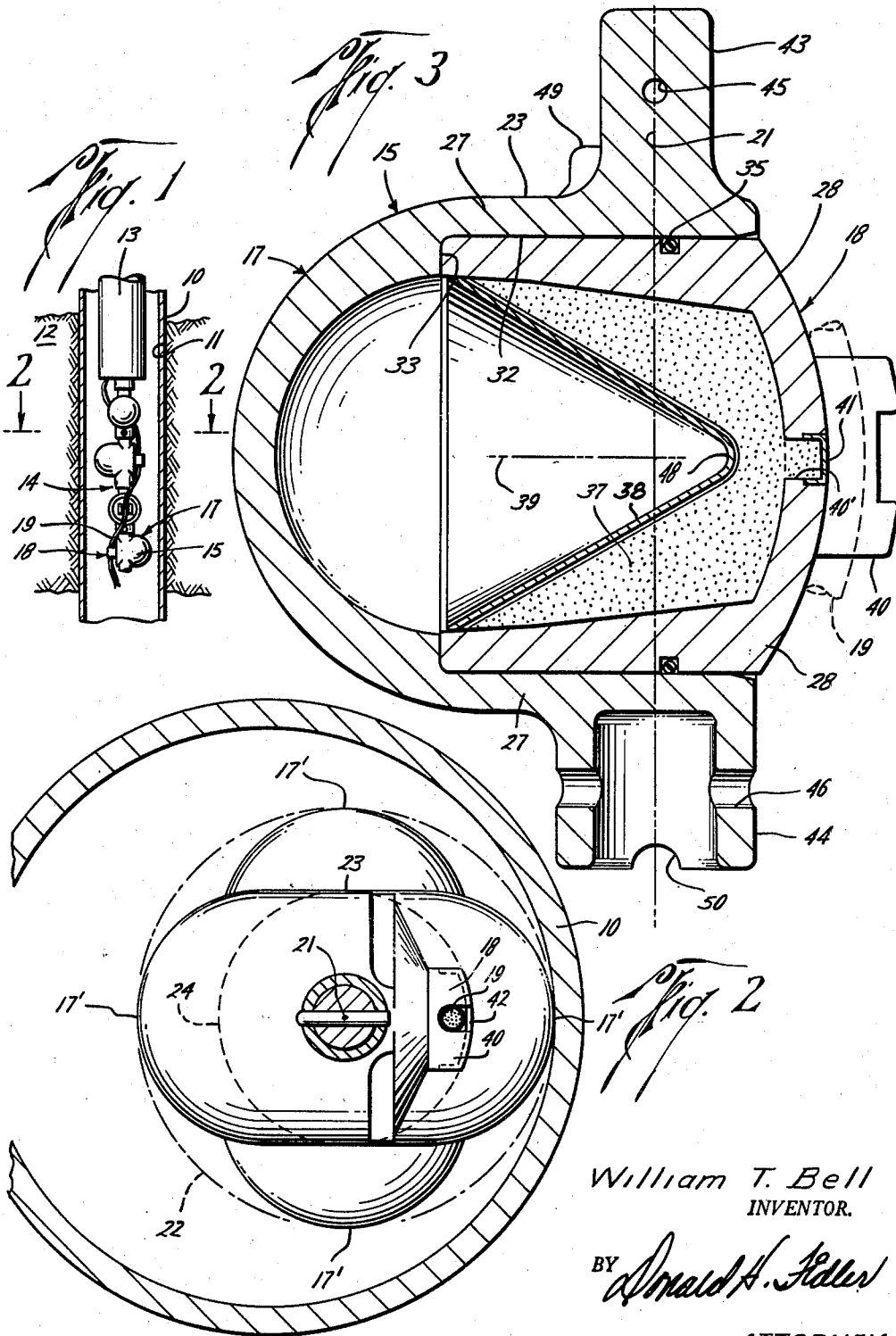
Aug. 4, 1964

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3,143,068

PERFORATING APPARATUS

Filed Feb. 17, 1960



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3,143,068

PERFORATING APPARATUS

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Filed Feb. 17, 1960, Ser. No. 9,324

5 Claims. (Cl. 102—20)

This invention relates to perforating apparatus for use in oil and gas wells and more particularly to so-called "capsule" type shaped charge apparatus for use in well bores.

Normally, in a typical oil well completion process, after a casing has been cemented in the borehole, a carrier type perforating apparatus is lowered to a level from which production is expected and the apparatus is operated thereby to develop perforations in the casing and the formations. A carrier type apparatus, of course, involves a thick walled housing suitably provided with ports through which perforating jets emanate to accomplish the perforation of casing and cement, the housing being re-usable several times. As contrasted to a capsule type shaped charge perforator, in which a number of encapsulated shaped charges are linked to one another, the carrier type apparatus is more expensive and has smaller explosive loads. Heretofore, capsule type perforators in open-hole usage have been successful in increasing productivity of wells containing tight or low permeability formations because they can contain an exceedingly large explosive load which can develop a deep penetration in the formations as well as a large diameter of the penetration opening. However, when the capsule type perforator is used in cased holes, it has been found to cause casing damage, that is, the casing is often split and otherwise distorted which adversely affects the subsequent use of packers or the like in the casing. Because of the desirable operational and performance characteristics of this type of perforator due to the large explosive load capabilities and excellent penetration depth and hole size, it is extremely desirable to use a capsule-type perforator in a cased well bore.

In the realization of the present invention, it has been established that the explosive forces of a shaped charge cause a very minimum of damage to a casing in the general direction of the perforation jet, that is, in or the region about the perforation because here the forces are concentrated into a stream of high-energy, pressure-generating, metallic particles which perform the penetrating action. Further, it has been established that the shock wave from an exploding shaped charge primarily causes the damage to the casing and the maximum damage to a casing has been found to be due to this development of high-energy shock waves primarily about the rear and sides of the shaped charge. Also, besides the relative distribution of shock wave forces, the intensity of shock wave is a principal factor in considering casing damage. Laboratory investigations during the development of the present invention have established that the forces produced by the shock wave are a function of the amount of explosive in the charge and the proximity of the explosive charge to the casing wall. Also, it has been found that the peak pressure exerted by the shock waves varies directly as the cube root of the explosive weight and inversely as the distance of the charge to the wall of the casing.

By means of the present invention, casing damage is controlled by spacing the shape charge explosive in the capsules from the wall of the casing through a suitable configuration of the charge container. This is accomplished by preventing the rear and sides of the containers enclosing the shaped charge explosives from coming into contact with the casing. At the same time, the configura-

tion of the containers and explosive therein is arranged so that the breakup of the containers is enhanced to produce relatively smaller pieces of debris. Also, by bringing the rearward end of a container closer to the central axis of the perforator assembly, the length of Primacord between adjacent containers may be shortened so that the time interval between detonation of the successively located capsules is reduced, minimizing adverse shock wave interference effects between charges and thereby improving the performance of the perforator.

Accordingly, it is an object of the present invention to provide new and improved capsule type perforating apparatus for use in cased well bores.

It is a further object of the present invention to provide new and improved capsule type perforating apparatus in which the "breakup" of the capsule container is greater than heretofore.

A still further object of the present invention is to provide new and improved capsule type of perforating apparatus having an arrangement affording a short time interval between detonation of successively located capsules.

Apparatus in accordance with the present invention includes a plurality of elongated, hollow containers interconnected with one another to form a longitudinally-extending shaped charge assembly, each container enclosing a shaped explosive charge adapted to produce a perforating jet along a perforating axis transverse to the central axis of the assembly. Each container is elongated in a direction transverse to the length of the assembly with a forward projecting end located on and about the perforation axis along which the perforating jet travels, the projecting end extending outwardly from the central axis of the assembly for a given distance. The rearward portion of each container which receives the Primacord initiator extends outwardly from the central axis of the assembly a lesser distance than the aforesaid given distance. Adjacent containers (and thus the perforating axes) are angularly oriented with respect to one another so that by virtue of the angular relation of the containers, the forward projecting ends of certain containers which may contact the wall of the casing serve to space the rearward and side portions of other containers from the wall and thereby provide a stand-off spacing for all of the containers.

Hence, by virtue of the stand-off spacing, explosive pressure areas developed at the sides or circumferences and rearward portions of the containers are displaced from the wall of the casing thereby minimizing the effect of explosive shock waves on the casing. By positioning of the shaped charge explosive, the greatest explosive pressure area produced by the explosive load is aligned with the central axis of the assembly so that interconnecting links of the containers aligned with the central axis will be subjected to the maximum explosive shock thereby facilitating breakup of the container and links. The Primacord initiator is shortened by the proximate location of the rearward portions of the containers to the central longitudinal axis of the assembly so that only a short length of Primacord is necessary to interconnect the containers.

The novel features of the present invention are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by way of illustration and example of certain embodiments when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a view in partial cross section of a portion a cased borehole in which a perforating apparatus embodying the present invention is disposed;

FIG. 2 is a horizontal cross section in an enlarged scale taken along line 2—2 of FIG. 1; and

FIG. 3 is a cross-sectional view of a capsule configuration as embodied by the present invention.

Referring now to FIG. 1, a portion of a casing 10 is disposed in a borehole 11 which, as illustrated, traverses earth formations 12. A capsule-type perforator or capsule assembly 14 in which the present invention is embodied is coupled to a conventional cable connector head 13, the assembly and head being sized so as to pass through the casing 10 to a level to be perforated. A conventional cable and winch arrangement (not shown) may be employed to transport the arrangement through the casing.

As shown in FIGS. 1 and 2, the capsule assembly 14 includes a plurality of elongated capsule containers 15 suitably interconnected to one another and each container is angularly oriented with respect to adjacent containers about a central axis of the assembly. Preferably, the angular orientation of the capsule container is 90°, that is, a forward end portion of one container is displaced angularly by 90° from the forward end portion of an adjacent container. Hence, perforating jets produced by the conventional explosive loads in the capsule containers which emanate through the forward end portions will be phased at 90° about the central axis of the assembly.

As shown in FIGS. 1-3, a forward projecting portion or end 17 of each capsule container extends a considerable distance outwardly of a central axis 21 of the capsule assembly while a rearward portion or end 18 of each capsule container terminates proximate to the aforesaid central axis. In a preferred embodiment, for example, the forward end extends outwardly a distance greater than twice the distance that rearward end extends outwardly from the central axis 21. In a practical embodiment, a 3½ overall diameter perforator, a suitable ratio of distances has been found to be 2 to 1. The forward projecting ends 17 of certain capsule containers therefore serve to space the rearward portions of the certain containers as well as other (i.e., oppositely directed) containers from the wall of the casing. The rearward portions 18 of the capsule containers receive the initiating Primacord 19 and since the rearward portions terminate near the central axis of the assembly, the length of Primacord between capsule containers is shortened. Thus, a shock wave from a detonated shaped charge is less likely to reach an adjacent capsule container prior to the normal development of the jet of the adjacent capsule shaped charge so that interference with adjacent jets by the shock wave is minimized.

Referring now to FIG. 2, it can be seen that when the perforator assembly is disposed in the casing 10, the extremities 17' of the forward projecting portions 17 of the containers extend a given distance from the longitudinal or central axis 21 of the assembly to define a radius for an imaginary cylinder enclosed within the dashed line 22. At least two extremities 17' of containers disposed angularly at 90° from one another will contact the wall of the bore to provide a minimum standoff distance for the charges in the assembly. More particularly, it is the longitudinal axis 21 of the assembly which is spaced from the casing by the minimum standoff distance. This standoff distance is slightly less than the radius of cylinder 22.

The rearward portion 18 and cylindrical portion 23 of a container in which the entire charge 37 is disposed in each of the containers are generally enclosed within an imaginary cylinder defined by the dashed line 24 which has a radius roughly equal to the distance from the central longitudinal axis 21 to the extremity of rearward portion 18. The aforesaid cylinder 24 represents generally the cross-sectional area in which the peak explosive pressures emanate and this area is spaced from the sidewall of the casing 10 by the standoff distance provided by the forward ends of the containers. Hence, the pressure or shock waves are permitted to attenuate while traveling over the

standoff distance and thus their effect on the casing is minimized.

Referring now to FIG. 3, a capsule shaped charge device is more specifically illustrated. The container 15 generally includes a hollow case 27 and a hollow closure member 28. The case 27 is an integral, cup-like member which includes the cylindrical portion 23 and an adjoining forward projecting end portion 17 which is hemispherical. The cylindrical portion 23 of the case has a cylindrical bore 32 extending from its open end to an internal, rearwardly directed annular shoulder 33 formed in the forward portion 17. The closure member 28 is cup-like with an externally cylindrical surface sized to be received snugly by the cylindrical bore 32 and only its curved rearward portion 18 extends slightly beyond the open end of the case 27. The wall thickness of the closure member increases from its open end to about double the thickness of the front end and of the rearward portion 18. A conventional O ring 35 between the closure member 28 and case 27 provides a suitable fluid-tight seal for the interior of the container.

Received within the hollow closure member 28 is a conventional explosive load 37 having a forward hollowed-out portion suitably fitted with a liner 38 in a conventional manner. The explosive load 37, when detonated, is thereby adapted to develop a perforating jet along a perforating axis 39. The major axis of the container is disposed generally coincident with axis 39 and perpendicular to the central axis 21 of the assembly. At the closed rearward portion 18 of the closure member, a central opening 40' is filled with conventional primer explosive and sealed with a cap member 41 which is arranged to be in proximate contact with the primacord 19 (shown in dotted lines). Integral with the rearward portion 18 of the closure member are outwardly extending ears 40 (see FIG. 2) spaced on either side of opening 40' to receive the Primacord 19. Securing means such as a thin metal clip band 42 (FIG. 2) suitably secured to the closure member 28 may be provided to insure the placement, retaining and intimate contact of the Primacord 19 between the ears 40.

Integral with the cylindrical portion 23 of the case 27 are pin and socket connecting portions 43 and 44 which are provided with suitable transverse pin openings 45, 46 to receive a pin (not shown) for linking adjacent connecting portions to one another. The connecting portions 43, 44 are aligned with and disposed centrally on the central axis 21.

From the foregoing description, it will be noted that the central axis 21 intersects the perforating axis 39 shortly in front of the apex 48 of the liner 38 and extends generally through the center of mass of the explosive load 37. Thus, the connecting portions 43, 44 are in a location where the greatest explosive pressures are developed thereby enhancing the break-up of the connecting portions. It should also be noted that the radius defined between the point of intersection of the axes 21 and 39 and the outer extremities of the ears 40 is substantially the same as the radius of the imaginary cylinder 23.

The perforator device is assembled by interconnecting the connecting portions 43 and 44 of adjacent containers to one another with pins, the forward portions 17 of container being continuously angularly oriented with respect to one another at 90° from one another. To facilitate the angular orientation, the pins 43 are provided with a key portion 49 near their base which cooperate with slots 50 in the open end of the sockets 44. The Primacord 19 is then attached to the closure members 28.

In operation, assembly of capsules is transported through the casing 10 to a level to be perforated where the conventional detonator (not shown) for the system is fired to initiate the Primacord 19, the detonator being in the usual lowermost position on the assembly. When

the Primacord initiates the shaped charges, the shaped charge explosives will form perforating jets in a well-known manner. Since large explosive forces are generated in the cylindrical portion 23 of the case 27 along the central axis 21, the break-up of the coupling members is enhanced. Also, the proximity of the Primacord 19 to the central axis 21 minimizes the length of Primacord between capsules so that initiation or detonation of one shaped charge permits the formation of the jet of an adjacent charge prior to the arrival of the shock wave from the first mentioned shaped charge. The standoff spacing of the cylindrical portion 23 and rearward portion 18 of the containers from the casing wall provides for attenuation of the explosive pressures thereby minimizing the effects of the explosive forces on the casing.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects, and therefore the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. Well perforating apparatus for use in a cased well bore comprising an assembly of shaped charge containers, each having interconnections extending along a central axis of said assembly, each of said containers enclosing therein a shaped explosive charge having a hollowed forward end and adapted to develop a perforating jet along a perforating axis, said containers and charges being arranged so that said perforating axis is disposed transversely of said central axis, said containers further having forward and rearward ends, said forward ends extending outwardly from said central axis for a substantially greater distance than said rearward ends and said rearward ends receiving the main portion of said explosive charge, said containers being angularly oriented with respect to one another about said central axis so that at least two of the outwardly extending forward ends may contact the wall of the casing and space all of the said rearward ends containing said explosive charges a substantial distance from the wall of the casing sufficient to minimize shock waves to the casing from the detonation of said explosive charges, and blasting cord means extending along the length of said assembly and attached to said rearward ends of said containers for detonating said explosive charges.

2. Well perforating apparatus of the capsule type comprising: a shaped charge container arranged for interconnection with like containers in a longitudinally-extending assembly; said container including an integral cup-like case having a hemispherical forward portion and a cylindrical rear portion disposed about a first axis, said case further having pin and socket connecting portions extending oppositely from said cylindrical rear portion along a second axis transverse to said first axis of said case; said forward portion having an internal rearwardly directed annular shoulder adjacent the bore of said cylindrical portion; said container further including a cup-like closure member having a cylindrical portion, a rear end portion closing its cylindrical portion, and Primacord guiding portions extending rearwardly from said rearward portion for a distance with respect to said central axis substantially less than the distance of said forward case portion from said central axis, said closure member being slidably received in the bore of said cylindrical case portion to abut against said shoulder; sealing means disposed between said closure member and said cylindrical case portion; and a shaped explosive charge received by said closure member with a hollowed forward end intersected by said second axis and facing toward said forward portion of said case.

3. Perforating apparatus for use in a cased well bore comprising: a plurality of elongated, hollow containers respectively having extensions interconnected to one an-

other to form a longitudinally-extending assembly with a longitudinal central axis through said extensions, each of said containers having extremities along a major axis disposed transverse to the central axis of said assembly, means for interconnecting said extensions whereby one extremity of a container is disposed one side of said central axis and is spaced a substantially longer distance from said central axis than the other extremity of the container disposed on the opposite side of said central axis, each of said interconnected containers being arranged in angularly oriented positions about said central axis so that at least two of the first extremities spaced farthest from said central axis may tangentially contact the wall of the casing bore to provide a substantial stand-off distance for the second extremities spaced nearest to said central axis from the wall of the casing adequate to minimize explosive shock effect to the casing, shaped explosive charges in said containers having hollowed-out forward portions respectively facing towards said first extremities and having rearward portions disposed within said second extremities of said containers, said explosives being disposed in said containers so as to be intersected by said central axis and so that the apex of the hollowed-out forward portions is disposed on the opposite side of said central axis from said one extremity of said container to facilitate breakup of said containers and said interconnecting means, and detonating means attached to the other extremities of said containers proximate to said explosives for detonating said shaped charge explosives.

4. Well perforating apparatus for use in a cased well bore comprising: an assembly of shaped charge containers, each of said containers including a cup-like case having a hemispherical forward portion and a cylindrical rear portion disposed about a first axis, said forward portion having an internal, rearwardly directed annular shoulder adjacent the bore of said cylindrical portion; said container further including a cup-like closure member having a cylindrical portion; a rear end portion closing its cylindrical portion, and Primacord receiving portions extending rearwardly from said cylindrical portion, said cylindrical closure portion being slidably received in the bore of said cylindrical case portion to abut against said shoulder; said case further having pin and socket connecting portions extending oppositely from said case cylindrical portion along a second axis intersecting and perpendicular to said first axis of said case, said connecting portions being disposed near the open end of said case so that said forward portion of said case is substantially eccentrically disposed relative to said Primacord receiving portions about said second axis of said connecting portions; a shaped explosive charge received by said closure member with its hollowed portion facing towards said forward portion of said case; means for securing adjacent connecting portions to one another; said containers being angularly oriented with respect to one another so that at least two of the eccentric forward portions may contact a wall of the casing to space the rear end portions of the containers from the wall of the casing a distance great enough to minimize explosive shock effects to the casing.

5. Well perforating apparatus for use in a cased well bore comprising an assembly of shaped charge containers, each of said containers including a cup-like case having a hemispherical forward portion and a cylindrical rear portion disposed about a first axis, said forward portion having an internal rearwardly directed annular shoulder adjacent the bore of said cylindrical portion, said container further including a cup-like closure member having a cylindrical portion, a rear end portion closing its cylindrical portion, and Primacord receiving portions extending rearwardly from said cylindrical portion, said cylindrical closure portion being slidably received in the bore of said cylindrical case portion to abut against said shoulder, said case further having pin and socket con-

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necting portions extending oppositely from said cylindrical case portions along a second axis intersecting and perpendicular to said first axis of said case, said connecting portions being disposed near the open end of said case so that said forward portion of said case is substantially eccentrically disposed relative to said Primacord receiving portions about said axis of said connecting portions, a shaped explosive charge received by said closure member with its hollowed portion facing towards said forward portion of said case, means for securing adjacent connecting portions to one another, means on said connecting portions for orienting said containers at 90° with respect to one another so that at least two eccentric forward

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portions may contact a wall of the casing to space the remaining portions of the containers from the wall of the casing a distance great enough to minimize explosive shock effects to the casing.

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