

May 13, 1969

D. W. CROSS

3,443,518

MULTI-POINT IGNITION SYSTEM FOR SHAPED CHARGES

Filed Sept. 26, 1967

Sheet 1 of 2

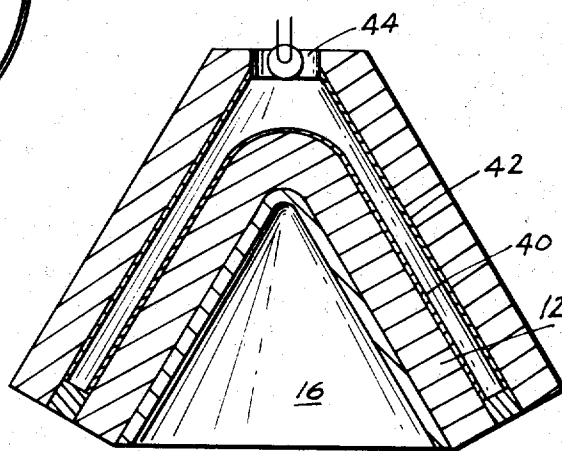
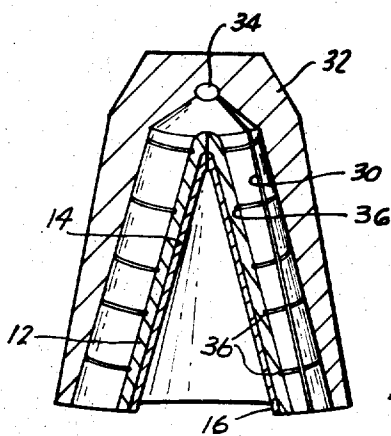
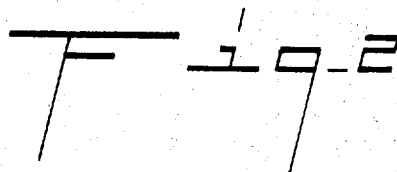
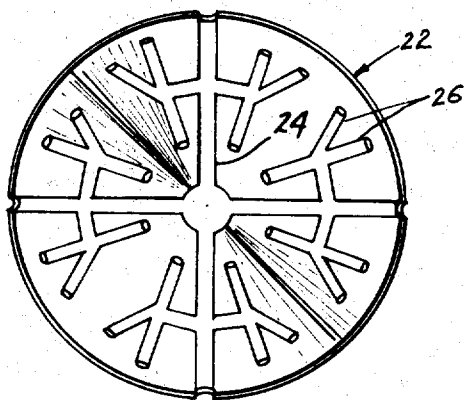
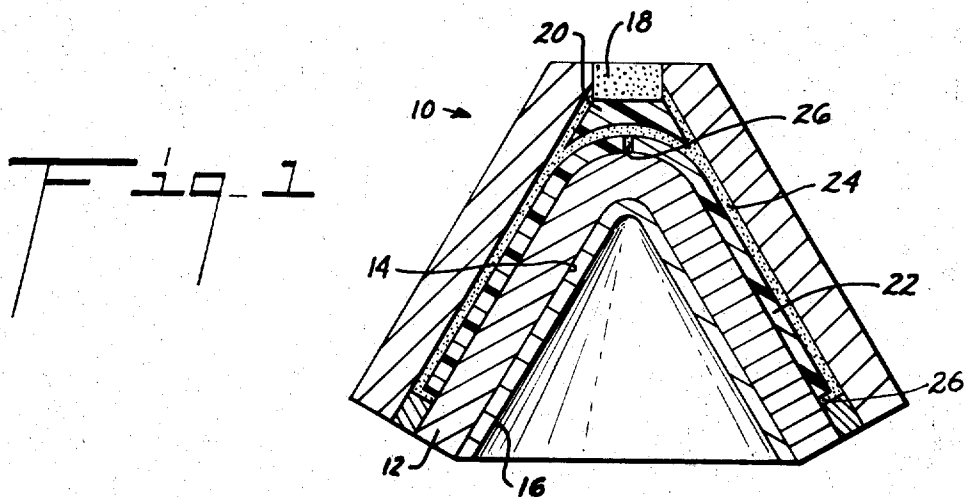


Fig. 12

INVENTOR.

DONALD W. CROSS

BY

Fig. 2A
Browning, Dennis, Hays & Schenck
ATTORNEYS

May 13, 1969

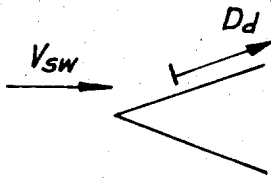
D. W. CROSS

3,443,518

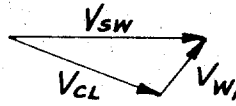
MULTI-POINT IGNITION SYSTEM FOR SHAPED CHARGES

Filed Sept. 26, 1967

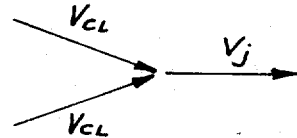
Sheet 2 of 2



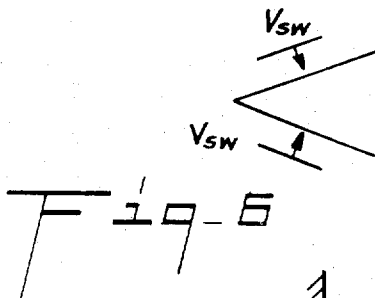
F19-3



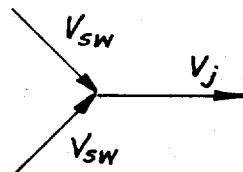
F19-4



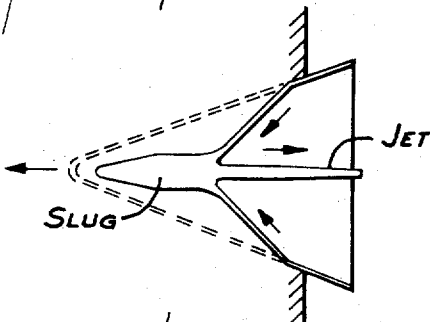
F19-5



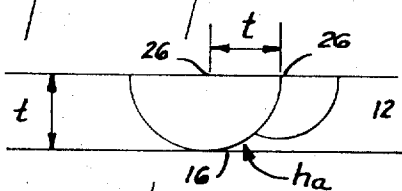
F19-6



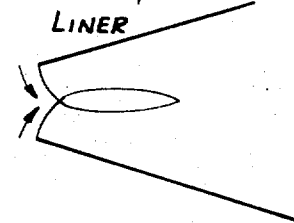
F19-7



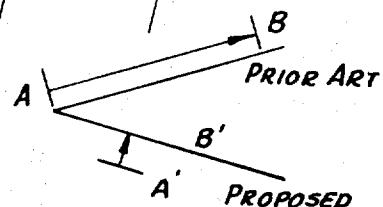
F19-8



F19-10



F19-9



F19-11

INVENTOR.

DONALD W. CROSS.

BY

Browning, Demme, Nyer & Eickenrodt

ATTORNEYS

1

2

3,443,518 MULTI-POINT IGNITION SYSTEM FOR SHAPED CHARGES

Donald W. Cross, P.O. Box 1642,
Houston, Tex. 77001

Filed Sept. 26, 1967. Ser. No. 670,743

Int. Cl. F42b 1/02, 3/00

U.S. Cl. 102—24

2 Claims

ABSTRACT OF THE DISCLOSURE

A shaped charge formed of a housing having a main block of explosive which is provided with a lined generally-conical cavity. A plurality of ignition points are positioned about the explosive to ignite the explosive in a predetermined manner to form a jet of optimum shape and velocity.

Background of the invention

This invention relates to shaped charges and, more particularly, to the means of igniting the main block of explosive therein.

One of the principal commercial uses of shaped charges in industry is the perforation of oil and gas wells. It has become accepted practice to mount one or more shaped charges either inside a suitable retrievable, fluid-tight, thick-wall cylindrical steel housing, or within individual expendable, fluid-tight containers. In either case, a plurality of shaped charges are usually employed, and they are positioned at suitable longitudinally spaced-apart intervals, with the axes of the shaped charges directed radially outward from the axis of the wellbore into which they are lowered. After the shaped charges are lowered to the desired depth in the well, they are detonated from the surface. The jet formed by the shaped charge penetrates the casing and the formation to form a flow path whereby fluid in the formation may flow into the wellbore. The effectiveness of the shaped charge depends upon the depth of penetration and a debris-free perforation.

Shaped charges for the above-described purposes are usually constructed of a housing containing a body of high-explosive material which is formed with an outwardly-facing concavity which may take various predetermined shapes for different purposes, but for the usual well perforating service is normally of conical form. The outwardly-facing surface of such concavity is provided with a relatively thin liner formed of suitable material. In order to detonate the shaped charge, a booster, customarily placed at the axial rearward end of the explosive charge, is ignited. The booster produces a shock wave which detonates the explosive charge as it travels through the explosive. As the wave of detonation of the main charge progresses from the point of initiation, it encounters the liner and the cavity. A progressive collapsing disintegration of the liner occurs with the wave front. This results in the material forming the liner converging at the longitudinal axis of the charge, resulting in the formation of a high-speed particle-laden jet. The tip of the jet has a velocity of about 30,000 ft./sec.; however, a portion of most common liners is not disintegrated and follows behind the faster jet stream as a relatively slow-moving slug which may only have a velocity of 8,000 ft./sec. The perforation is made by the resulting particle-laden stream of high velocity, high temperature and pressure, fluid jet. The slug is detrimental and many special types of liners have been developed in an effort to reduce or completely eliminate it.

It is the purpose of the present invention to develop a more effective means of detonating the explosive charge in order to form an optimum jet of maximum velocity.

Summary of the invention

The shaped charge of the present invention is generally similar in construction to the shaped charges now in use, that is, a main block of high-explosive is contained in a case and a lined concavity is located in the face of the explosive block. However, instead of having a single ignition point located at the rear apex of the block of explosive, there are a plurality of ignition points spaced in a predetermined manner about the block of explosive and an ignition path runs from a primary ignition area to the plurality of ignition points to detonate the block in a predetermined manner, thereby providing for the formation of pressure forces at the correct instant of time which will optimize the jet.

Brief description of the drawings

FIG. 1 is a cross-sectional view of a shaped charge constructed in accordance with the present invention,

FIG. 2 is a plan view showing the ignition paths,

FIG. 2a is a cross sectional isometric of a shaped charge illustrating an alternate form of the multi-ignition system,

FIG. 3 is a diagram showing the detonation paths of prior art charges,

FIG. 4 is a diagram showing the lost energy and detonation of prior art charges,

FIG. 5 is a diagram showing the formation of a jet of the prior art charges,

FIG. 6 is a diagram showing the detonation of the proposed charge,

FIG. 7 is a diagram showing the formation of a jet by the proposed charge,

FIG. 8 is a diagram showing the formation of the jet and slug in prior art charges,

FIG. 9 is a diagram showing the formation of a jet in the proposed charges,

FIG. 10 is a diagram showing the formation of hyper-pressure areas,

FIG. 11 is a diagram showing the time of detonation of a prior art charge and the proposed charge,

FIG. 12 is a cross sectional view of an alternative form of the multi-ignition system.

Description of the specific embodiment

Referring now to the drawings, it can be seen that the shaped charge of the present invention is formed of a cup-shaped housing 10 in which is located a block of explosive 12 having a cavity 14 in its front face. A liner 16 covers the face of the cavity. In the above respects, the shaped charge is similar to those in the prior art. However, instead of having a single ignition point located at the rear apex of the block of explosive 12, the shaped charge of the present invention is provided with a multi-point ignition system which ignites the main block of explosive in a predetermined manner.

Accordingly, the case 10 is provided with a primary ignition area 18 which may be ignited by a Primacord or other well-known ignition means. Forward of primary ignition area 18 is an inner case 22 which is provided with a series of paths 24 extending from the primary ignition area 18. An explosive, having a known rate of detonation, may fill the paths 24. The inner case has a series of apertures 26 which are in contact with main block of explosive 12. The length of paths 24 is predetermined so that upon ignition of primary area 18, the explosive in paths 24 is ignited which results in the ignition of the explosive at apertures 26 which results in the ignition of the main block 12 in a predetermined manner. Any method for controlling the rate of detonation of the explosive block 12 may be utilized. For example, the length of the ignition paths 24, the thickness, density and

shape of the explosive in the paths or the main block may be varied.

The length of each ignition path 24 from the common primary ignition area 18 to the individual ignition points 26 on the main explosive charge is predetermined. By varying the lengths of paths 24 and knowing the rate of detonation of the main explosive charge and the explosive in ignition paths 24, a firing order can be developed which will form a jet of an optimum shape and of greater velocities than prior art charges. In order to accomplish this, the ignition of explosive charge 12 by the multiple ignition points preferably occurs before the detonation wave of the main explosive charge reaches such location. As a result, hyper-pressure areas are formed by the augmentation of the multiple shock waves which increase the velocity of the collapsing liner and the resulting jet.

FIG. 2 shows a typical ignition system which includes not only the primary paths shown in FIG. 1, but also various branches extending therefrom. As can be appreciated, with such a multi-point ignition system, there will be an overall superior form of ignition of the main block of explosive and, as a result, a more effective total detonation of the main block of explosive, and, as a consequence, an optimization of the jet. While the ignition system illustrated shows paths filled with high explosive, other types of ignition systems such as an electrical network or optical fibers with light-sensitive explosive may be used to provide the multi-point ignition. FIG 2A illustrates a shaped charge of the present invention having multi-ignition paths 30 in a main housing 32. As in the case of the shaped charge shown in FIGS 1 and 2, there is a main explosive charge 12 having a cavity 14 in its front face which is provided with a liner 16. The ignition paths 30 extend from a primary ignition area 34 to multi-ignition points 36 located on the rear surface of main explosive 12.

The ignition points 26 and 36 lie in rings and columns similar to the intersections of the longitudinal and latitudinal lines on a globe. The distance between neighboring points preferably approximate the thickness of the main explosive charge. The hyper-pressure area that is formed by three converging detonation waves, simultaneously initiated, is shaped in the form of a pyramid having concave sides with a base on the liner. With such a construction, the center of force will act on the liner at the centeroid of the pyramid.

In a shaped charge, the liner collapses due to high pressures from the detonation of the explosive charge and not the shock wave. However, the pressures formed and the shock wave are related since the shock wave is indicative of the pressure forces. If a pressure gradient is developed for detonation, it will indicate that the highest pressure is next to the shock wave and the pressure decreases further back from the shock wave. Therefore, the direction of the collapse of the liner due to pressure approximates the collapse as if it is caused by the shock wave. This phenomenon occurs because the pressure is not uniform over the surface of the collapsing liner because the detonation is not static but dynamic.

In the customary shaped charge, as previously mentioned, an ignition point or booster is located at the apex of the explosive charge. This booster is ignited and it, in turn, results in a detonation of the explosive charge. The direction of detonation is in the form of a spherical shock wave or a wave normal to the axis of the charge, see FIG. 3, where the vector V_{sw} indicates an assumed direction of the pressure force and D_d indicates the direction of detonation. Under static conditions, vector V_{sw} would be perpendicular to the liner. However, under dynamic conditions, it would have a tendency to move from the perpendicular direction towards the direction of detonation. Accordingly, there is a loss in velocity, see FIG. 4 where V_{sw} indicates the vector of the pressure force, vector V_{cl} indicates the liner collapse and the vector V_w indicates waste. The two vertical components

of the vector of liner collapse V_{cl} cancel each other out as the jet is formed and moves horizontally, see FIG. 5 where the two vectors V_{cl} represent the liner collapse and V_j represents the vector on the jet. One of the purposes of the present design is to eliminate this waste since, although the detonation is dynamic, the pressure is being applied in a direct line to the desired direction of travel of the liner, see FIG. 6 where the vector V_{sw} indicates the direction of detonation in the proposed charge. Accordingly, as can be seen in FIG. 7, the formation of the jet is caused by the converging of the two vectors V_{sw} . In this design the vertical components of vectors V_{sw} cancel each other and the jet will have greater velocity since there is only one waste of energy and not two.

The proposed design presents a method of eliminating the slug in part or whole. Although in some prior art shape charges efforts have been made to eliminate the slug by other means, the source of the problem has not been eliminated. Therefore, in the prior art shape charges part of the mass of the liner is wasted as well as the energy that is used to eliminate its formation. If the tendency to form the slug is eliminated then this mass and energy could be put to useful work.

The source of the problem is that the shock wave is ahead of the collapse of the liner. If, on the other hand, the liner collapsed at a rate exceeding the rate of detonation of the explosive then the liner will collapse in a progressively forward direction, see FIG. 9. In such case, there is no shearing of the back part of the collapsed liner and no slug. Moreover, the jet and the collapsed liner are constantly pulling ahead of the detonation; therefore, there is no tendency for the collapsed liner to shear and form a slug; all of the liner is formed into a high velocity jet. The liner is sufficiently plastic that it will make the sharp bend at the instant of collapse.

A significant feature of multi-point detonation is the formation of hyper-pressure areas due to the concentration of pressure caused by several shock waves coming together. The formation of these high pressure areas is dependent upon the spacing of the ignition points and the thickness of the explosive charge.

Preferably, the distance between an ignition point and its neighboring point should be in a range approximating the thickness of the explosive charge. The correct distance is one that will create the maximum velocity of the jet by the most advantageous balance of all variables. If this distance is too great the shock wave will rupture the liner in an incorrect manner and the liner will not collapse properly. The closer the points of ignition are to a respective neighbor, the more intensified the hyper-pressure area will be. If the two points are detonated simultaneously or in rapid sequence the two shock waves are approximately converging on area *ha*, see FIG. 10. Since the detonation is a violent expansion of gas due to the rapid burning of the explosive and the two detonation waves are converging, tremendous pressures will be developed in the area between them which is designated as hyperpressure area *ha* in FIG. 10. These pressures will collapse the liner at a rate faster than the rate of detonation.

Another significant feature of the multi-point ignition system is that it detonates the shaped charge more quickly than the single point method, see FIG. 11 where the upper side illustrates the direction of detonation of the prior art, and the lower side illustrates the direction of detonation of the present invention. It can be seen that the detonation time is that required for the detonation to move from A to B, for prior art charges, and from A' to B' in the proposed charge. Therefore, the explosion will occur $AB/A'B'$ times faster. Assuming that the given amount of explosive in both systems possess the same amount of potential energy, the proposed design will release it $AB/A'B'$ times faster. Assuming the surface area of the liner is the same for both systems, a greater pressure during the time of detonation will be developed for the multi-

5

point system. This will likewise create a greater amount of work available for perforating the formation. Since the released kinetic energy is increased for an instant, the velocity of the collapse of the liner is greater, and this increase approaches

$$\sqrt{\frac{AB}{A'B'}}$$

in accordance with the following formula:

$$\begin{aligned} W &= Fd \\ &= (ma) \left(\frac{1}{2} at^2 \right) \\ &= \frac{1}{2} mv^2 \\ E &= \frac{1}{2} mv^2 \\ v^2 &= \frac{2E}{m} \end{aligned}$$

Therefore, all else being equal, the velocity of the jet should increase by approximately

$$\sqrt{\frac{AB}{A'B'}}$$

times due to this advantage. In this connection, rather than having the inner case with its plurality of apertures and ignition paths, the rear surface of the explosive charge or selected portions thereof may be provided with photosensitive explosive 40, see FIG. 12, and the charge spaced from the housing. The wall of the housing may be provided with a reflective surface 42 serving as the ignition from the primary ignition area to the multi-ignition points on the charge. The primary ignition area may be provided with a high-intensity light source 44. Therefore, ignition of the source 44 will cause ignition of the entire surface of the explosive charge in a predetermined manner. Such ignition will result in a more complete detonation of the charge and thereby optimize the formation of the jet.

The proposed design tends to focus the shock wave which may be useful in rupturing the perforated hole. Since the present design presents a scheme for gaining a more effective use of the available energy, equal penetration of a formation could be obtained by using a smaller charge. This would mean less casing and gun damage for a hole of the same penetration.

A sequenced detonation has one additional value. It allows for the elongation of the jet. If all points are detonated simultaneously, the liner is blasted into a mass the length of which cannot exceed the length of the liner. However, in the sequenced detonation the jet is allowed to elongate some just as it does in the prior art charges. This gives greater penetration of the formation and less damage to the plug of the gun and the casing. For example, if the jet is moving at a velocity three times the rate of detonation, the apex will move three times the distance l in the time to detonate the distance l .

$t=0$, collapse of apex of liner, velocity 3 times that of liner

$t=1$, detonation complete, apex (tip of jet) moved 3 times the length of the detonation (as abbreviated due to the firing order) plus the distance from each point on the liner to the longitudinal axis.

For a liner $1\frac{1}{2}$ " long with 6 rings of ignition points equally spaced the jet would be approximately $2\frac{3}{4}$ " in length. The entire jet is moving at the same velocity. In the prior art shaped charges the back part of the jet is moving at a velocity of about $\frac{1}{4}$ of that of the tip. For this reason, the present charges have more elongated jets,

6

but the back part is not effective since it is moving at a relatively slow velocity.

As can be seen from the foregoing, the shaped charge of the present invention is provided with multi-point ignition which initiates the detonation of the main explosive charge in a predetermined manner. As a result, the detonation of the explosive block is improved and there is an optimizing of the jet. Moreover, if the ignition is in a predetermined sequence, there is developed hyper-pressure areas which will collapse the liner at a rate faster than the rate of detonation and form a jet of optimum shape and velocity.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the apparatus.

I claim:

1. A shaped charge comprising a cup-shaped housing, a cup-shaped main charge of explosive in said housing, a cavity in the face of said explosive charge, a cup-shaped liner covering said cavity, a primary ignition area at the rear of said housing, a plurality of longitudinally spaced rings of ignition points on the rear surface of the explosive charge, the ignition points of each ring being equally spaced and means for igniting each ring of ignition points in sequence with the ring adjacent the primary ignition area being ignited first and then the next closest, and the next until all rings have been ignited and the ring farthest from the primary ignition area being the last to ignite with the time interval between the ignition of each ring being such that the ring of ignition points adjacent the primary ignition area is ignited before the shock wave from the portion of the main charge ignited by the primary ignition area reaches the first ring and each subsequent ring being ignited after the ring adjacent to it but before the shock wave from the adjacent ring reaches it to cause the shock waves traveling from each ignition area to converge and produce areas between them of hyperpressure that will force the liner to collapse ahead of the shock wave from each successive ignition point and move forward with the forward moving jet formed by the progressive firing of the ignition points, said shaped charge being further characterized by having each ring of ignition points spaced to create hyperpressure areas that are so spaced that the liner will be collapsed inwardly without shearing the liner.

2. The shaped charge specified in claim 1 wherein each ring of ignition points and the ignition points of each ring are spaced from each other at a distance approximating the thickness of the main explosive charge.

References Cited

UNITED STATES PATENTS

2,763,210	9/1956	Church et al. -----	102-24
2,856,850	10/1958	Church et al. -----	102-24
3,170,402	2/1965	Morton et al.	
3,311,055	3/1967	Stresau, Jr. et al.	
3,325,317	6/1967	Voigt.	

FOREIGN PATENTS

1,051,708	2/1959	Germany.
1,172,591	6/1964	Germany.

VERLIN R. PENDERGRASS, *Primary Examiner*.