May 25, 1965 R. F. PARKHURST ETAL 3,185,089

FLEXIBLE LINEAR SHAPED CHARGE FOR UNDERWATER USE

Filed June 28, 1962 2 Sheets-Sheet 1

FIG. 1

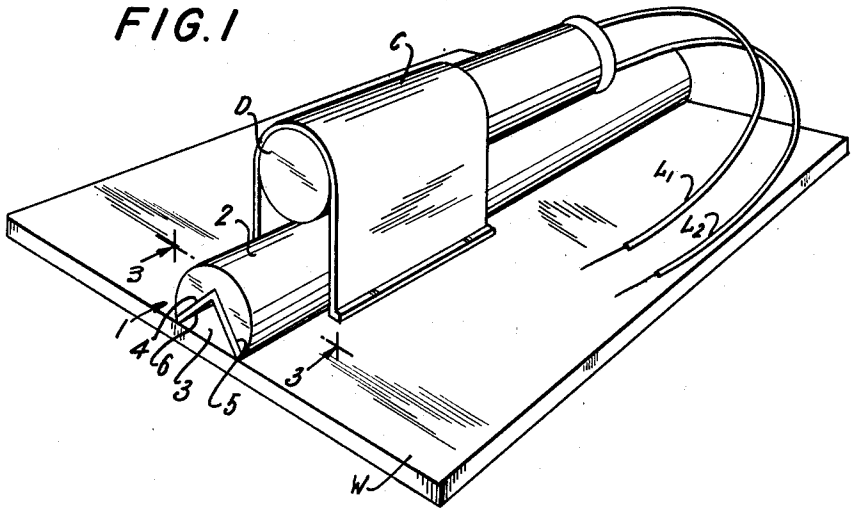


FIG. 2A

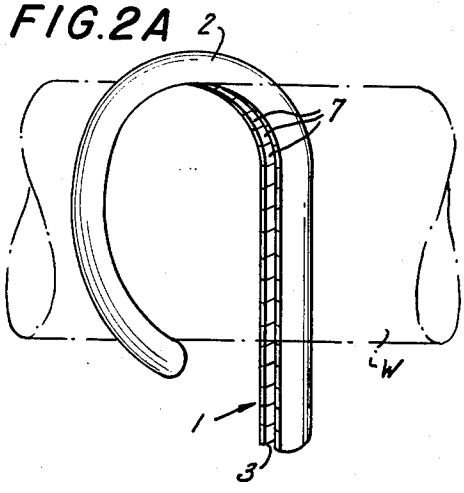
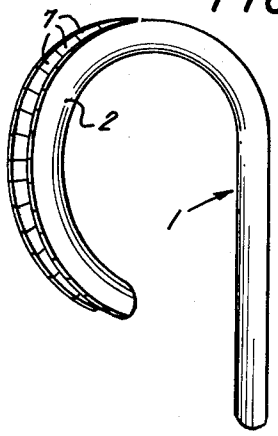


FIG. 2B



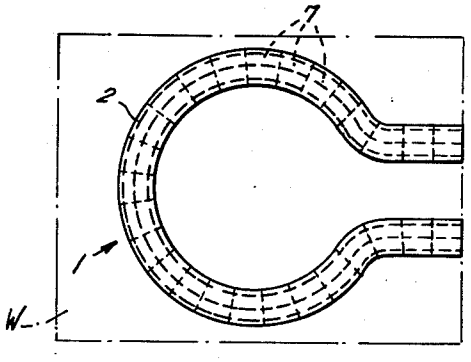


FIG. 2C

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FIG. 3

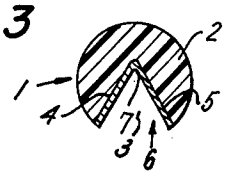


FIG. 4

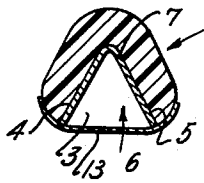


FIG. 5

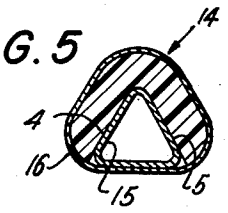
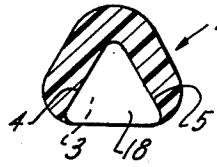


FIG. 6



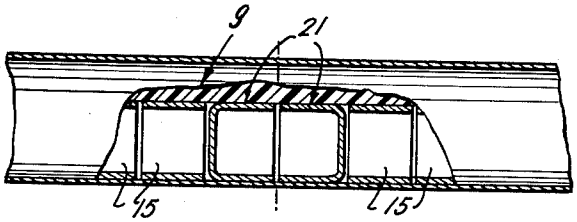


FIG. 7

FIG. 8

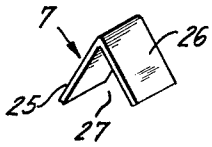


FIG. 9

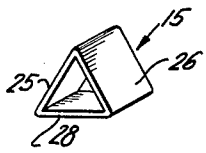


FIG. 10

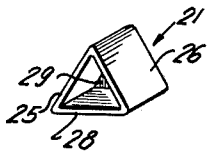


FIG. 11

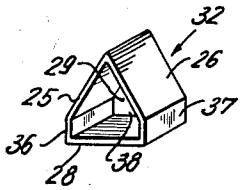


FIG. 12

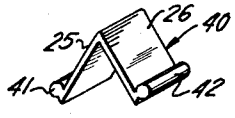


FIG. 13

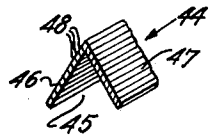


FIG. 14

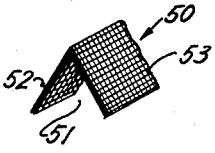
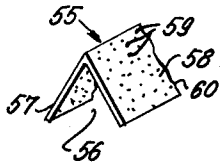


FIG. 15



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3,185,089

FLEXIBLE LINEAR SHAPED CHARGE FOR UNDERWATER USE

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8 Claims. (Cl. 102—24)

The present invention relates to explosive devices and more particularly to explosive devices in the form of a flexible "shaped charge" suitable for cutting solid materials of various geometrical forms when immersed in fluid media such as air, water, or other gases and liquids.

The term "shaped charge" refers to an explosive having a recess, preferably with a metallic liner, of a shape to concentrate the explosive force of the charge in a desired pattern as, for example, in a straight line when a "linear shaped charge" is used to cut a target. Explosive cutting of a solid material having various geometrical forms requires the use of a linear shaped charge device having a high degree of flexibility to adapt it to be applied to the material to be cut and one having unrestricted flexibility would be preferred in order to provide the best conformability to target configurations. Furthermore, it has been found that underwater cutting operations, such as demolition of explosive weapons, require that liquids be excluded from the liner cavity to prevent reduction of cutting efficiency.

Heretofore, devices have been produced wherein flexibility was imparted by a flexible tubular casing having a flexible partition extending longitudinally therethrough. These prior arrangements provide a lower or standoff portion and an upper or explosive portion. The partition comprised an elongated angular metal liner having lateral slots with continuous outer margins. Either particulate or putty-like explosives were employed. On occasions, a cordeau was incorporated to propagate the detonation wave. A thin membrane topping the liner was provided when required to prevent particulate explosives from falling through the liner slots. Other forms of flexible liners also have been proposed. However, all of these devices have a structural continuity along the liner. Thus, the flexibility of the device is limited in at least one plane because of the structural continuity of the liner. Moreover, the underwater cutting efficiency is generally impaired because liquids may enter the liner cavity.

One of the objects of the present invention is to provide a flexible linear shaped charge explosive device which may be flexed in all directions to adapt it to be applied to all shapes and forms of target to be cut.

Another object is to provide a linear shaped charge of the type indicated with a liner of disconnected metallic elements to adapt the charge to be flexed in all directions and produce a greater flexibility in any particular direction.

Another object is to provide a linear shaped charge of the type indicated which effectively excludes water from the liner to improve its cutting ability when used under water.

Another object is to provide a linear shaped charge of a flexible explosive material and disconnected liner elements in a continuous cavity at one side keyed or otherwise attached thereto to provide a simple structure which may economically be manufactured.

Other objects will become apparent from the following description and drawing in which like reference characters denote like parts throughout the several views.

In the drawings:

FIGURE 1 is a perspective view showing a linear shaped charge incorporating the novel features applied to a plate to be cut;

FIGURES 2A, 2B and 2C are perspective views of the linear shaped charge to show how it can be flexed in any of three different positions;

FIGURE 3 is a transverse sectional view taken on line 3—3 of FIGURE 1 to show the angular recess and liner in the explosive material;

FIGURES 4, 5 and 6 are transverse sectional views of different modified constructions suitable for underwater use as well as for use in air or other gases;

FIGURE 7 is a side-view of a shaped charge device partly in section showing the liner composed of disconnected sections including end sections of closed construction to adapt the device for use underwater similar to FIGURE 5;

FIGURES 8 through 15 are perspective views of a number of liner elements of different shapes and constructions.

Referring now to FIGURE 1, a linear shaped charge device 1 incorporating the present invention is illustrated in position over solid target material W to be cut and assembled together with an initiating detonator D having a clip C for mounting it on the shaped charge device, the initiator being connected to a suitable power supply not shown. The device 1 comprises an elongated elastomeric explosive charge 2 having a longitudinally extending cavity 3 defined by a pair of converging walls 4 and 5 and a metallic liner 6 in the cavity. Liner 6 comprises a plurality of discontinuous and separate liner segments 7, shown in detail in FIGURE 8, placed in side by side relation and in intimate contact with liner cavity walls 4 and 5.

As shown in FIGURES 2A, 2B and 2C, the device 1 may be flexed in three different directions and combinations of these three directions to fit around a part to be cut of practically any shape; and flexed to practically any shape on the surface of a target, such as a plate or the like to cut a hole of the desired shape therein. The theory of operation of a shaped charge is based on the principle that the inclined sides of the recess 3 direct opposed explosive forces toward each other and then downwardly to produce a high speed jet of the metallic liner 6 which is impressed on the target material. The jet is produced by the collapse of the liner 6, due to a pressure wave traversing the explosive after detonation. The jet penetrates a first portion of the target material W and fractures the remaining portion. Less than one-third of the available energy of the explosive is used for jet formation.

The versatile flexibility of the present device 1 is attributed to simplicity of construction including an elastomeric explosive and a liner means comprised of a plurality of discontinuous metallic elements having angular sides and arranged side by side in a continuous row. In place of metal, other noninflammable, frangible materials may be used such as ceramics, glass and the like. The explosive charges may be composed of any suitable explosive materials, such as PETN, uniformly dispersed in a rubbery polymeric binder and later cast or extruded with a liner cavity of the desired shape. An explosive used in a number of experiments hereinafter described is identified as No. EL506D, manufactured by E. I. du Pont, and believed to comprise of from about 70 to 75% PETN, 10 to 15% butyl rubber polymeric binder, 10 to 15% petroleum oil plasticizer, and a red dye.

Since less than one-third of the energy available from the explosion is used for jet formation, proper distribution of explosives around the liner becomes an essential factor in obtaining the best penetration of target material W. The cylindrical cross-section of the explosive charge 2 shown in FIGURE 3 has been found to be most efficient for a PETN explosive charge weighing up to about 8 grams per linear inch at a density of 1.52 when used

with a soft aluminum liner having a 60° convergent angle. FIGURE 4 illustrates an optimum shape of an explosive charge composed of the same material and density, but at a weight in excess of 8 grams per linear inch, all other factors being substantially similar. The explosive cavity 3 must be contoured to the liner shape in order to provide the best explosive efficiency.

Penetration is affected by a number of factors such as quantity and type of explosive, convergence angle of the liner, and type and ductility of liner material. However, in view of the present type of construction, element spacing becomes another factor effecting depth of penetration. For example, other things being equal, a liner 6 having the smallest voids or spaces between liner segments 7 produces the best continuity penetration. The greater the discontinuity between segments 7, the more uneven the penetration. Uneven penetration also results from using segments having transverse end closure walls shown in the liner 9 in FIGURE 7. However, this result may be improved by using a frangible closure which requires less energy to collapse.

Another factor effecting penetration is the space relationship between the liner and explosive charge. The greater the intimacy between the two the better the cutting efficiency. In all constructions of the present invention, the liner 6 is placed intimately with the explosive charge 2 in the cavity 3. In some instances a thin film of adhesive is used to bond the liner 6 to the explosive charge 2 in cavity 3. Moreover, any of the liner segments may be embedded in the walls of cavity 3, adhered to the walls with an adhesive having characteristics of the explosive charge binder or keyed to the walls of the explosive material. In several embodiments of the invention, the best performance is obtained when liner segments abut each other, although spaces up to .050 inch is permissible in configurations utilizing up to about 12 grams per linear inch of PETN explosive charge, and using soft aluminum liners with walls converging at a 60° angle without producing significant differences in performance.

Other embodiments of explosive cutting devices, and especially those suitable for use in liquid media, are illustrated in FIGURES 4 through 7. In FIGURE 4 a shaped charge device 12 is illustrated comprising an elastomeric explosive charge of generally triangular shape with rounded corners having a liner cavity 3 defined by converging walls 4 and 5. A plurality of liner segments 7 are placed intimately within cavity 3 of the device illustrated in FIGURE 4 and bonded to its converging walls. A tape closure 13 extends longitudinally over the cavity 3 and is bonded to a part of the explosive to enclose the cavity and liner. In another embodiment shown in FIGURE 5, device 14 is a modification of device 12 and differs by the inclusion of liner of triangular segments 15 having walls closing all three sides as shown in FIGURE 9. In place of the tape closure 13, a spirally wrapped tape closure 16 is used having overlapped convolutions which also may be used in the form of construction illustrated in FIGURE 4. The construction illustrated in FIGURE 5 is suitable for use at greater depths under water than is FIGURE 4. This is because of the added strength afforded by liner segments 15, closed on all three sides, to oppose hydrostatic pressure and thereby reenforce the tape closure. FIGURE 6 illustrates an explosive device 17 which is comprised of an elastomeric explosive charge generally similar to that illustrated in FIGURES 4 and 5 having a longitudinally extending cavity 3 defined by a pair of converging walls 4 and 5, and a plurality of hollow fluid tight liner segments 18 having closure walls on all five sides in place of other forms of segments such as liners 7 and 15. In any of the foregoing constructions the device may be preassembled by coating liner cavity walls 4 and 5 with a suitable adhesive (not shown) and bonding the liner to the cavity.

FIGURE 7 shows a device having segments 21, illustrated in detail in FIGURE 10, for use in devices 12 or 14. It also illustrates a continuous device which may be cut between adjacent segments 21 into lengths at spaced intervals. End closure liner segments 21 are placed at a suitable location adjacent one another in liner means such as 15. Cutting efficiency of the aforementioned devices when submerged under water is in excess of about 70% of that achieved in air.

Liner elements of different shapes including elements 7, 15 and 18 as well as other modified forms are illustrated in FIGURES 8 through 15 to afford a selection suitable for most any combination of conditions. Liner segment 7 shown in FIGURE 8 is comprised essentially of a pair of metallic converging walls 25 and 26 having an angular cavity 27 conforming to the shape of the cavity 3 of the shaped charge 1 and provides a segment in its simplest form. FIGURE 9 shows liner segment 15 which differs from liner 7 by addition of wall 28 joining the extremities of walls 25 and 26. Wall 28 offers a supporting means for closures 13 or 16 in the underwater devices shown in FIGURES 4 and 5.

Liner segment 21 shown in FIGURE 10 differs from segment 15 by the inclusion of an additional end wall 29, which configuration provides for an end closure in any of the underwater devices as shown in FIGURE 7. A hollow fluid tight liner segment 18 generally similar to segment 21 may be formed by adding a wall to close the open side and which is especially suitable in an underwater device because it obviates closure means. Liner segment 32 of FIGURE 11 shows an alternate method of constructing a hollow end closing liner segment and comprises a liner generally similar to liner segment 21 having side walls 25, 26, 28 and an end wall 29. End closure wall 29 is contemplated as being a frangible material, such as glass, bonded to metal liner 12. Standoff is obtainable by providing extensions 36, 37 and 38 from walls 25, 26 and 29 and joined by bottom wall 28. Wall 28 may be separated along the cutting axis to a width greater than the width of the jet whereby a slight improvement of penetration will occur. The foregoing types of liners may be pre-assembled in the explosive charge by the application of an adhesive to the liner cavity and bonding the liner thereto.

Liner elements for a snap-in-place type are shown in FIGURE 12. For example, liner segment 40 shown in FIGURE 12 is characterized by the keys 41 and 42 on the exterior of converging walls 25 and 26 and extending therefrom near their lower edges. In place of this construction the apex of the segment may be rounded to provide a key. Either of these forms may have a hollow bore and one or more keyways per segment. They offer the advantage of field assembly of a flexible spaced charge of any desired length and permit flexure without inducing undue localized stresses in the explosive charge. Longer segments produce better average penetration and less device flexibility, and vice versa.

While the aforementioned liner segments 7, 15, 18, 21, 32 and 40 provide a high degree of flexibility and cutting efficiency, other forms of liner elements may be substituted for the segments described above. Referring to FIGURE 13, a liner 44 having a cavity 45 defined by a pair of converging walls 46 and 47, with each of said walls being comprised of a plurality of parallel abutting polygonal shaped wires 48 extended longitudinally in the explosive charge cavity. An adhesive (not shown) is used to bond wires 48 to the walls of the explosive charge cavity. Round wires may be used in place of poylgonal shaped wires 48. Another form of flexible liner is wire cloth 50 as illustrated in FIGURE 14 having a cavity 51 defined by a pair of converging walls 52 and 53, each of said walls comprised of interwoven longitudinal and transverse wires. These other forms of liners are disposed longitudinally in the explosive charge liner cavity.

The greatest degree of flexibility is obtainable with the type of liner 55 shown in FIGURE 15, comprising

a plasticized powdered metal formed to provide a cavity 56 defined by a pair of converging walls 57 and 58. Each of said walls 57 and 58 contain a major portion of powdered metal 59 and a minor portion of flexible plasticizer 60. Powdered metals may be selected from aluminum, iron and copper and the like, of which aluminum appeared to provide the best penetration. Plasticizer may be selected from polymers of vinyl chloride, synthetic and natural rubbers and the like. The invention together with a number of different forms of liner segments having now been described in detail the mode of operation is explained below.

The flexible shaped charge 1 is applied to a target W to be cut in the manner illustrated in FIGURE 1. For example, clips C are used to connect the detonator D to the explosive shaped charge device 1 and the device need only be laid along the workpiece W to be cut. As will be noted from FIGURE 1, electrical connections L1 and L2 extend from the detonator for electric ignition. Where cylindrical forms such as pipes are to be cut, a strip of linear shaped charge device 1 is wrapped around the object, as illustrated in FIGURE 2A. When the shaped charge device 1 is bent, the disconnected segments 7, 15, 21, 32, 40, 44, 50 or 55 of the liner 6, depending upon the ones used, articulate with respect to each other, and the soft putty-like explosive 2 permits such flexure. The shaped charge 1 may be bent around the segments 7 as shown in FIGURE 2A, or the segments may be on the outside and bent around the explosive as illustrated in FIGURE 2B. In addition, the flexible strip may be bent to any desired form on the surface of a flat plate, or the like, with the segments contacting the plate as illustrated in FIGURE 2C to produce a correspondingly shaped cut in a workpiece W as, for example, a keyhole shaped slot. It will be observed from reference to FIGURES 2A, 2B and 2C that the flexible strip of shaped charge 1 may be bent or formed in three different directions or any combination of the three directions to produce any shape desired on the workpiece to be cut.

When the flexible shaped charge 1 is to be used in the open, the form illustrated in FIGURE 3 with an open recess would be used. If the shaped charge 1 is to be used for cutting targets under water the forms of construction illustrated in FIGURES 4, 5, 6 and 7 would be used to exlude water from the recess 3. The form of construction illustrated in FIGURE 7 is particularly adapted for use with underwater targets to adapt sections of any desired length to be cut from a longer strip at any one of a number of separation lines. After the shaped charge 1 has been applied to the workpiece W to produce the cut desired, the detonator is electrically ignited to produce a concussion which, in turn, initiates detonation of the explosive charge 2. The explosive 2 when detonated is believed to break down the metal liner 6 into a mass of fluid particles which flow from the converging sides toward each other and then in a medial plane between the sides at a high velocity and penetrate the target material. Such penetration occurs up to some distance such as ⅔ the thickness of the plate or other target W being cut and the remainder of the plate is fractured along the line of penetration. Whatever the actual reason for the phenomenon the shaped charge 1 acts in the nature of a knife to cut through the target material and the depth of the cut is dependent upon the kind and amount of explosive used.

The following are examples of a particular application of the present invention. In one instance, a flexible linear shaped charge explosive device 1 like that illustrated in FIGURES 1 and 3 was constructed of a cylindrical elastomeric charge of Du Pont EL506D explosive of 0.86 inch diameter with a recess 3 having walls converging at a 60° angle and a base dimension of $^{11}/_{16}$ inch between the edges of the angular recess. The explosive charge of these dimensions has a weight of 7.75 grains per linear inch at a density of approximately 1.52 grams per cc. Segmented liners of 0.040 inch thick soft aluminum 0.50 inch long as illustrated in FIGURES 3 and 8 were bonded to the liner cavity 3 in an abutting relationship. The device was affixed to a mild steel plate ⅜ (0.375) inch supported in air at a zero standoff. The plate was completely cut after detonation of the linear charge which produced a penetration of 0.280 inch and the balance of the thickness of the plate was separated by fracture of the material along the line of the shaped charge. An identical linear shaped charge device 1 cut a ¼ (0.250) inch thick hard steel plate having an ultimate tensile strength of 200,000 pounds per square inch. Identical devices having a standoff of ⅛ inch, ¼ inch, and ⅜ inch produced a penetration in ⅜ inch mild steel plate of 0.375 inch, 0.275 inch and 0.230 inch, respectively.

In another application, a flexible linear shaped charge explosive device 1 constructed in accordance with FIGURE 7 and having a shape and covering as illustrated in FIGURE 5 with a 60° linear cavity and a liner wall thickness of 0.040 inch was applied to a mild steel plate suspended under water up to a depth of 50 feet. Liner segments 15 like those shown in FIGURE 9 were bonded to the cavity 3 in the explosive in end-to-end butting relationship, and end closing segments 21 like those illustrated in FIGURES 7 and 10 were provided at the ends of the device. The liner segments 15 and 21 were made of soft aluminum of 0.040 inch thickness. The device at zero standoff cut the plate. Generally, those devices having a V-shaped liner have a penetration 30% greater in air than under water and the V-shaped liner segments 7 have slightly greater penetration than those using triangular shaped segments 15.

In another application, a flexible liner 6 with an elastomeric explosive charge 2 was constructed of soft copper wires of 0.020 inch in diameter laid longitudinally in parallel abutting relationship in walls at 60° angles to each other and bonded to each other by a vinyl chloride composition as illustrated generally in FIGURE 13. The explosive weighed 277 grains per square foot at $^{3}/_{32}$ inch thickness and formed into a V-shaped having a 60° cavity and ½ inch base dimension. This arrangement produced a penetration of 0.018 inch in a ⅜ inch mild steel plate at zero standoff.

In another application, the explosive device comprised a flexible liner construction 50 similar to the last described application except that the wire cloth as illustrated in FIGURE 14 was substituted for the flexible wires. A wire cloth of copper 0.015 inch thick having approximately 70% density and 30% voids penetrated 0.040 inch deep into a ⅜ inch mild steel plate at zero standoff.

Also flexible liners 55 were constructed of plasticized powdered metal as illustrated in FIGURE 15. As an example, a viscous solution comprising 80% by weight of finely divided aluminum and 20% by weight of a vinyl chloride adhesive binder was mixed and pressed into strips and allowed to solidify to a flexible plastic which was then bonded to the explosive charge. Strips 0.030 inch thick were then formed into a V-shape at a 45° convergent angle with ⅜ inch sides bonded to separate explosive charges ⅜ inch wide weighing 415 grains per square foot affixed to each leg of the liner. This construction produced a penetration 0.088 of an inch deep in a ⅜ inch mild steel plate. Powdered iron and powdered copper also were used in the same proportions as was aluminum and resulted in a penetration 0.087 and 0.073 inch deep, respectively. This form of construction is the most flexible, but did not produce a cutting action as good as that produced by solid aluminum segments.

In addition to cutting steel plates, the shaped charge devices described above are suitable for cutting wood, plastic and most any ductile material. These include railroad cars, rails, explosive weapons, generally without causing detonation, and standing trees. By combining any

of the several embodiments described herein, a flexible explosive shaped charge device may be produced which is adapted for use in most any fluid medium and will provide almost any degree of flexibility desired.

It will now be observed that the present invention provides a flexible linear shaped charge explosive device which may be flexed in all directions to adapt it to be applied to all shapes and forms of target to be cut. It will further be observed that the present invention provides a shaped charge of the type indicated with a liner of disconnected metallic segments to adapt the charge to be flexed in different directions. It will also be observed that the present invention provides a shaped charge of the type indicated which can be used to effectively exclude water from the liner to improve its cutting ability. It will still further be observed that the present invention provides an improved construction to adapt a linear shaped charge to be economically manufactured and one which is dependable in operation.

While a number of forms of construction are herein illustrated and described, it will be understood that further changes may be made in the construction and arrangement of elements without departing from the spirit or scope of the invention. Therefore, without limitation in this respect the invention is defined by the following claims.

We claim:

1. A linear shaped charge comprising a continuous and integral strip of elastomeric material formed with a continuous groove at one side having opposed inclined walls converging in the material, a liner for said continuous groove having side walls closely fitting the walls of said groove, and said liner being divided into short unconnected segments with each segment having a length longitudinally of the strip of elastomeric material less than its width and with the segments arranged in end to end relation for free movement relative to each other to permit the linear shaped charge to be flexed in any direction.

2. A flexible shaped charge in accordance with claim 1 in which a closure is provided for closing the open side of the linear cavity to exclude water when the shaped charge is used under water.

3. A flexible shaped charge in accordance with claim 2 in which the closure comprises a continuous adhesive web of an impervious material wound around the elongated elastomeric material and ends of the metal liner segments, and the edges of adjacent turns of the web overlapping each other.

4. A flexible shaped charge in accordance with claim 1 in which each liner segment has at least two sides arranged in angular relation to each other.

5. A flexible shaped charge in accordance with claim 4 in which each liner segment has at least three sides extending longitudinally of the shaped charge.

6. A flexible shaped charge in accordance with claim 1 in which each liner segment has at least two side walls extending longitudinally of the elongated elastomeric material containing an explosive and a transverse wall extending between the side walls.

7. A flexible shaped charge in accordance with claim 1 in which each liner segment has at least one key projecting therefrom, and said elongated elastomeric material containing an explosive having a recess of the same contour as the key and into which the latter projects to lock the liner segment therein.

8. A flexible shaped charge in accordance with claim 1 in which each liner segment comprises a flexible sheet having metallic portions spaced from each other.

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2,980,018	4/61	Turechek	102—20

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