June 23, 1964 R. F. HATFIELD 3,138,054

PROCESS OF MAKING LINEAR SHAPED CHARGE EXPLOSIVE DEVICES

Filed Nov. 7, 1960 3 Sheets-Sheet 1

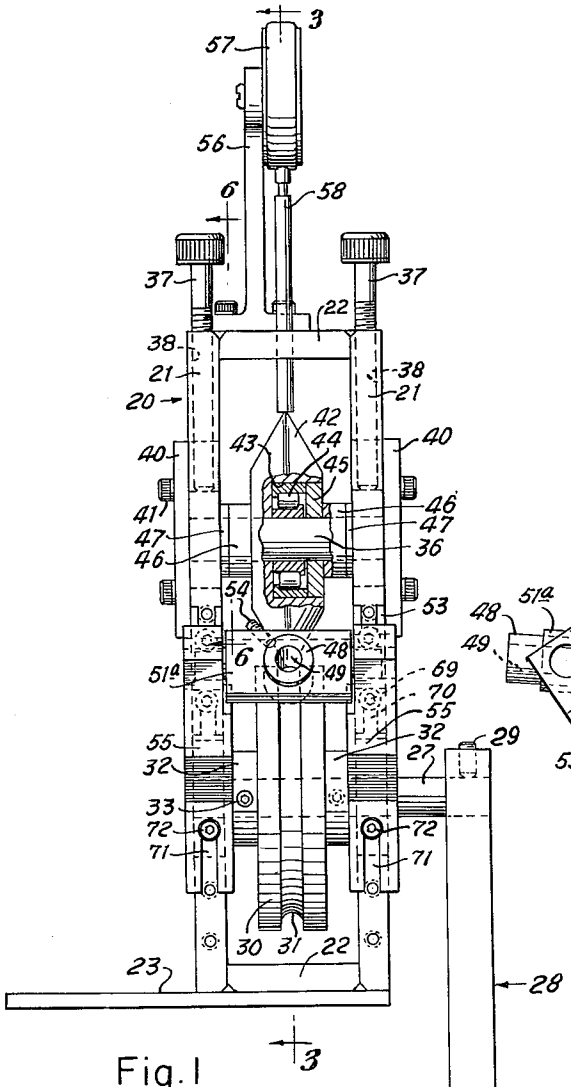


Fig. 1

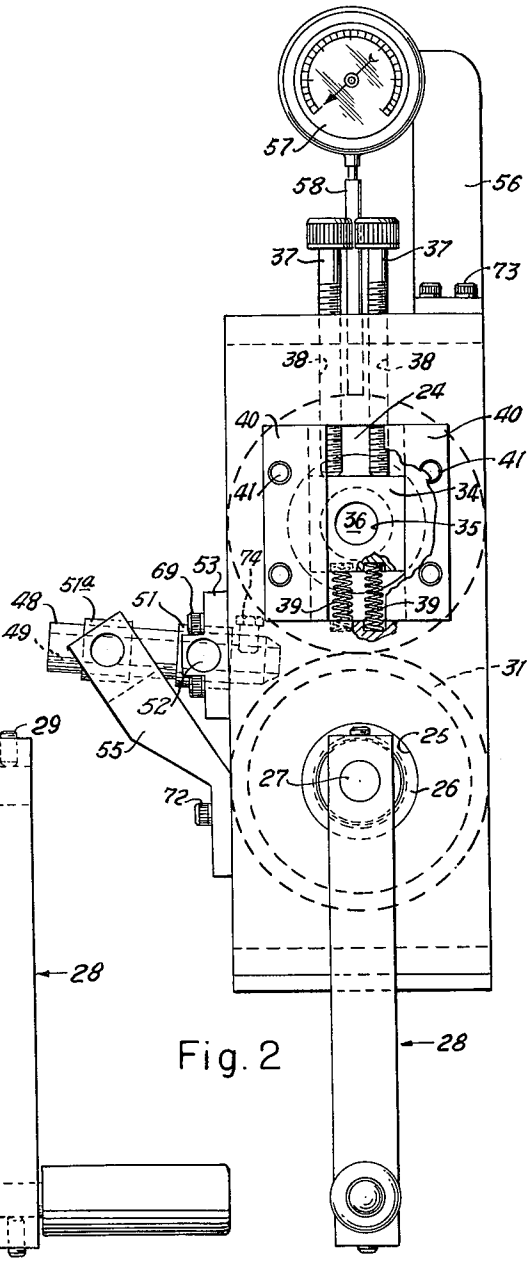


Fig. 2

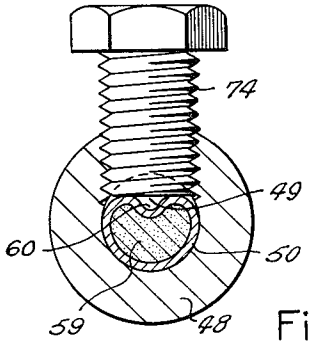


Fig. 11

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PROCESS OF MAKING LINEAR SHAPED CHARGE EXPLOSIVE DEVICES

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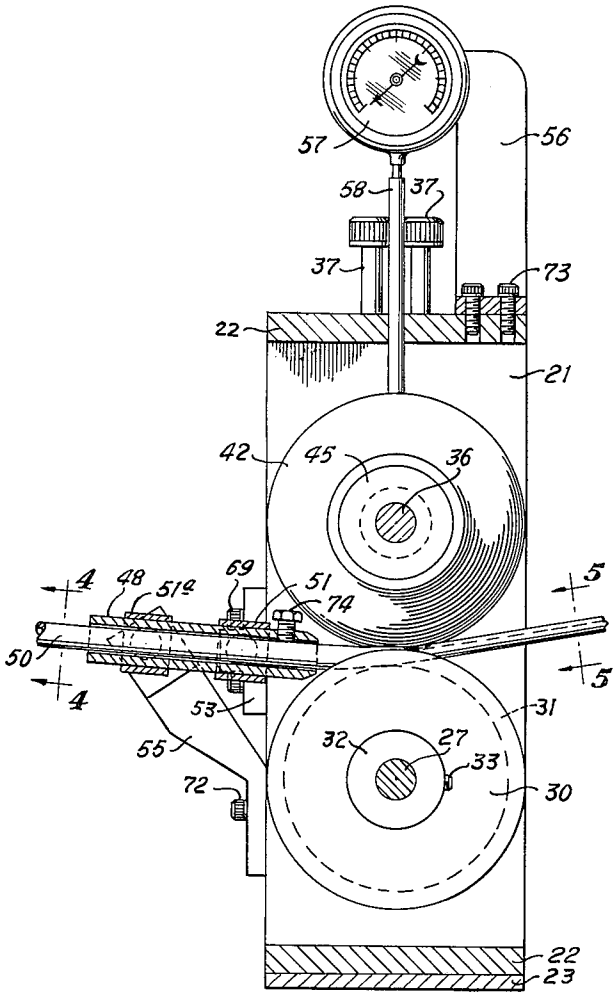


Fig. 3

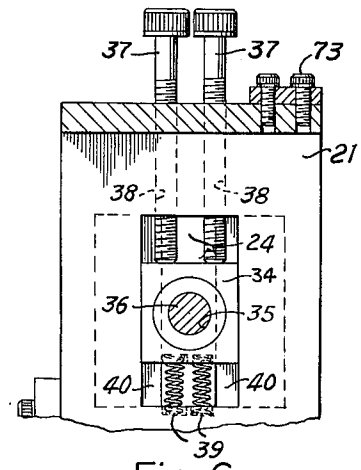


Fig. 6

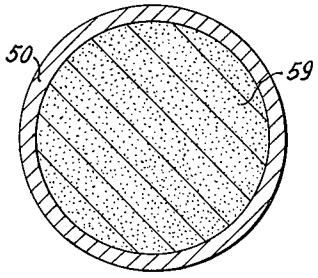


Fig. 4

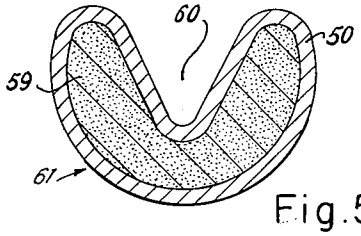


Fig. 5

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PROCESS OF MAKING LINEAR SHAPED CHARGE EXPLOSIVE DEVICES

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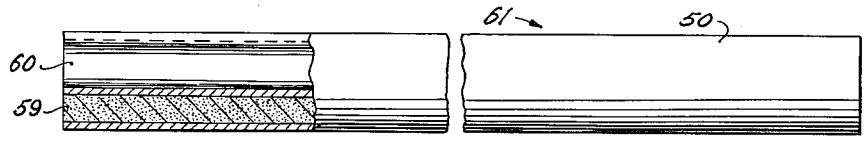


Fig. 7

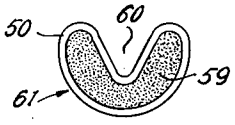


Fig. 8

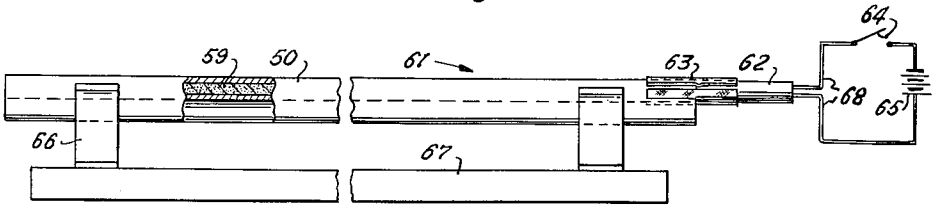


Fig. 9

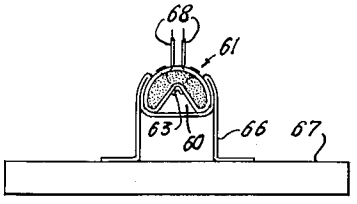


Fig. 10

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3,138,054

PROCESS OF MAKING LINEAR SHAPED CHARGE EXPLOSIVE DEVICES

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Filed Nov. 7, 1960, Ser. No. 67,317
3 Claims. (Cl. 86—1)

This invention relates to a process of making tubular, linear shaped charge explosive devices.

Some forms of tubular, linear shaped charge explosive devices utilizing preformed metal casings have been made heretofore by filling the casing with a molten explosive material and allowing the explosive to solidify in place. Even when using a flexible tubular casing, the extent to which such linear shaped charge devices can be bent to conform to the shape of an object to be cut is quite limited due to the brittle nature of most cast explosive compositions. Breaks produced in the rigid cast explosive material by bending the casings are likely to cause "cut-off" of the detonation wave as it proceeds down the length of explosive in the casing with the result that only a portion of the length of the charge device is detonated.

Thus, the use of particulate explosive materials in filling linear, tubular shaped charge devices is desirable to achieve a flexible shaped charge device that can be bent to cut irregular shaped objects and yet insure the continuity of a detonation wave throughout the length of the shaped charge device. In fact, some of the high explosive materials preferred for certain operations, such as Cyclonite and HMX, have such high melting points that they cannot be conveniently cast but are best used in the particulate form. It is well known in the art that increasing the apparent density of the explosive material in a shaped charge device will produce an increase in the penetrating ability of the device. Achieving the desired degree of compression of a particulate explosive material in situ in a preformed, elongated, tubular shaped charge device has heretofore been a difficult and time consuming operation. Small increments of explosive material are usually poured into a pregrooved tubular casing which is closed on one end and then compacted by a rod introduced through the open end of the tube. A uniform distribution of high density explosive material throughout the length of the casing is very difficult to obtain when using such packing methods.

Therefore, it is an object of this invention to provide a process for manufacturing tubular, linear shaped charge explosive devices which have a uniform distribution of highly compressed, particulate explosive material throughout the effective length of the shaped charge devices.

Another object of this invention is to provide a process for manufacturing tubular, linear shaped charge explosive devices wherein a longitudinal groove is formed in the wall of a permanently deformable, generally tubular casing and the explosive material in the casing is compacted to the desired density simultaneously with the grooving operation.

A further object of this invention is to provide a process for manufacturing tubular, linear shaped charge explosive devices which utilizes an economical, readily available component for forming a unitary shaped charge casing and liner.

A still further object of this invention is to provide a process for forming a longitudinal groove in a permanently deformable, generally tubular casing of a shaped charge explosive device and compacting the explosive material therein at the same time.

An additional object of this invention is to provide a process adapted for manufacturing tubular, linear shaped charge devices having various diameters.

A further object of this invention is to provide a process for manufacturing tubular, linear shaped charge explosive devices which contain a uniformly distributed, highly compressed, particulate explosive material throughout the effective length of the shaped charge device.

Still another object of this invention is to provide a process for making a semiflexible, tubular, linear shaped charge device having a unitary shaped charge casing and liner which contains a uniformly distributed, highly compressed, particulate explosive material throughout the effective length of the shaped charge device.

Briefly stated, the process of the invention includes providing a length of elongated, generally tubular casing having a longitudinally extending, deformable wall portion being capable of taking a permanent set; forcing inwardly the longitudinally extending deformable wall portion of the casing to produce a longitudinal groove in the casing thereby reducing the internal volume of the casing; thereafter filling the grooved casing with particulate high explosive material; and forcing inwardly the longitudinally extending deformable wall portion of the explosive filled casing along the longitudinal groove to produce a longitudinal groove of increased depth. Thus there is formed a re-entrant shaped charge cavity linear from the deformable portion of the casing. Moreover, the particulate high explosive material is compressed between the inner walls of the casing and is shaped to conform to the inner walls to produce a linear shaped charge having a lower explosive weight per unit length and a deeper longitudinal groove compared to a linear shaped charge produced as described in the foregoing steps with the exception that the casing is not pregrooved to reduce the internal volume thereof before being filled with particulate explosive material.

Further in accordance with the invention, the steps of grooving the casing or the steps of deepening the preformed groove may be carried out in a plurality of successive operations.

One form of apparatus for performing the process of the invention includes a supporting frame that supports a first shaft on which is mounted a backing wheel for rotation about its axis. The backing wheel provides an annular groove continuous about its periphery. A grooving wheel is supported by a second shaft on the frame for rotation about the axis of the grooving wheel. The rim of the grooving wheel is convex in axial cross-section. The axes of the wheels are disposed substantially parallel to each other, and the groove of the backing wheel and the rim of the grooving wheel are disposed substantially in a plane. Means for rotating at least one of the wheels is provided.

The product produced by the process of the invention includes a semi-flexible, tubular, linear shaped charge unit which has an elongated, generally tubular casing having a longitudinal, re-entrant portion in the wall thereof. A body of compressed, particulate high-explosive material is contained within the casing. The explosive material conforms in shape to the inner walls of the casing, having been compressed and conformed to the shape therein by inward deformation of that portion of the casing which provides the longitudinal re-entrant wall portion.

The process of the invention may be performed using various instrumentalities or even by hand, as will be explained more fully hereinafter. One such instrumentality, which itself forms a part of the present invention, is the machine shown in the accompanying drawings.

In the drawings:

FIG. 1 is an elevational view of a typical machine for forming, in accordance with the invention, linear shaped charge explosive devices;

FIG. 2 is a right side view of the machine of FIG. 1;

FIG. 3 is a sectional view taken along the line 3—3 of FIG. 1;

FIG. 4 is an enlarged cross-sectional view taken on line 4—4 of FIG. 3 of the casing before grooving and the explosive therein before compacting;

FIG. 5 is an enlarged cross-sectional view taken on the line 5—5 of FIG. 3, of the casing after grooving and the explosive therein after compacting;

FIG. 6 is a view in section taken along the line 6—6 of FIG. 1, showing in detail a means for adjusting the spacing between the grooving and backing wheels;

FIG. 7 is an elevational view, partially in vertical medial section, of a linear shaped charge exposive device made by the process of the present invention;

FIG. 8 is a side view of the linear shaped explosive charge device of FIG. 7;

FIG. 9 is an elevational view, partially in section, of a linear shaped charge exposive device mounted on an object to be severed, showing one system for detonating the charge;

FIG. 10 is a left side view of the organization of FIG. 9; and

FIG. 11 is a cross-sectional view of the centering tube and guide screw of a typical grooving machine.

Referring now primarily to FIGS. 1, 2 and 3 of the drawings wherein a typical embodiment of a machine for manufacturing generally tubular, linear shape explosive charge devices is shown, the rectangular shaped frame **20** has a pair of parallel, spaced apart side walls **21, 21** rigidly joined at their ends to a pair of spaced apart, parallel end walls **22, 22** by welding or other suitable means. A base plate **23** is rigidly attached, by welding or other means, to the outside of the lower end wall. The base plate extends a substantial distance to one side of the frame to provide a means for attaching the machine to a work table. The side walls provide a pair of generally rectangular, opposed openings **24** in the upper one-half of the walls. In the lower one-half of the side walls, a pair of generally cylindrical, opposed openings **25** are provided.

Roller bearing assemblies **26** are press fitted into each of the openings **25** in the frame side walls. These bearing assemblies provide axial openings therethrough in which is received a cylindrical shaft **27**. The shaft is mounted flush with the exterior surface of the left side wall and projects a short distance out from the exterior surface of the right side wall. A crank **28** is rigidly attached to the projecting end of the shaft **27** by means of a set screw **29**. A backing or driving wheel **30** is axially mounted centrally on that portion of shaft **27** extending between the side walls **21**. The driving wheel provides an annular groove **31** continuous about the periphery and has integrally formed collars **32, 32** extending axially equidistantly from each side thereof. The driving wheel is attached to the shaft **27**, to rotate therewith, by set screws **33** received in threaded transverse openings in the collars **32**.

Referring now to FIGS. 2 and 6, the generally rectangular opening **24** provided in each of the upper one-half of the side walls **21** contains a rectangular support block **34**. The support blocks are constructed to provide a snug, slidable fit with the vertical walls of the openings **24** to permit vertical movement of the blocks within the openings **24**. Each of the support blocks provides a central opening **35** therethrough. A cylindrical shaft **36** extends between the side walls and the ends of the shaft are received in the openings **35** of the support blocks. The support blocks are vertically positioned within the openings **24** by adjusting screws **37, 37**. Two threaded vertical screw holes **38** are provided in each of the side walls to receive the adjusting screws **37**. A pair of springs **39** extend between the lower edge of the support blocks and the bottom wall of the openings **24** to urge the blocks into engagement with the adjusting screws **37**. The spring ends are seated in shallow opposed recesses in the edge of the support block and the bottom wall of opening **24** to retain the springs in position. A pair of retainer plates **40, 40** is attached to the outside of each of the side walls by means of screws **41**. These retainer plates are positioned adjacent to the openings **24** in the side walls and extend over the openings **24** a short distance on the vertical sides thereof. The overlap provided by the retainer plates prevents the supporting blocks **34** from working out of the openings **24**.

A grooving wheel **42** is axially mounted on shaft **36** centrally between the side walls **21** of the frame. An axial cylindrical opening is provided through the grooving wheel to receive shaft **36**. In one side of the grooving wheel an axial cylindrical counterbore **43** is provided to receive a roller bearing assembly **44**. A washer **45** on the shaft **36** fits into the counterbore to hold the bearing in place. Sleeves **46, 46** and adjacent spacer washers **47, 47** are received on the shaft **36** on each side of the grooving wheel. The axial dimensions of the sleeves and washers are such that the rim of the grooving wheel is positioned centrally over the groove **31** in the backing wheel **30**. The grooving wheel illustrated has a rim portion that is generally V-shaped in cross-section. The peripheral surface at the terminus of the V is rounded slightly to prevent cutting the shaped charge tubular casing when forming the shaped charge device. Other rim shapes may be utilized for the grooving wheel, such as parabolic or hemispherical, to provide the contour desired for the groove in the linear shaped charge device.

A tube straightener or centering device is mounted on one edge of the support frame as can best be seen in FIGS. 1, 2 and 3. The centering or straightener tube **48** is a thick walled, cylindrical section of metal providing a cylindrical opening **49** therethrough. It is adapted to snugly and slidably receive the tubing section or casing **50** for a tubular, linear shaped charge device and guide the casing into the groove **31** in the backing wheel adjacent to the edge of the grooving wheel. A guide screw **74** is threaded through the wall of the centering tube **48** adjacent the forward end. A forward tube holder block **51**, providing an opening therethrough, receives the tube straightener and positions it in line with the groove in the backing wheel. The block has trunnions **52** on each end received in openings provided in two bearing blocks **53**, each of which is attached by screws **69** to the side walls **21** of the frame. The bearing blocks have slots **70** in their bases to receive the mounting screws to permit vertical positioning of the forward end of the tube straightener. A set screw **54** in the forward holder block locks the tube straightener in the selected position. A rearward tube holder block **51***a*, like the forward tube holder block, supports the rearward end of the straightener tube **48**. A pair of brackets **55, 55** supports the rearward tube holder block. Slots **71, 71** are provided in the feet of the brackets for attachment to the edge of the side walls of the frame by screws **72, 72** to permit vertical positioning of the rearward end of the tube straightener. The edges of the frame side walls **21, 21** may be tapped at a number of places, as shown in FIG. 1, to provide a variety of positions for mounting the bearing blocks **53** and the brackets **55**.

A gage support bracket **56** is attached by screws **73** to the top end wall **22** of the frame. A dial-reading micrometer gage **57** is attached to the support bracket. The gage is actuated by the upper end of an extension rod **58**, which is slidably mounted in a vertical opening in the top end wall member **22**. The lower end of the extension rod rests on the rim of the grooving wheel **42**. The gage and extension rod provide a means for determining the amount of change in vertical spacing between the grooving wheel and the backing wheel, as will be more fully explained hereinafter.

A particularly advantageous feature of the foregoing apparatus is adaptability of the apparatus to the manufacture of linear shaped charge units having different diam-

eters. A number of backing wheels 30 may be provided, each having a peripheral groove 31 of a different radius corresponding to the radii of commonly available sizes of tubing. Separate backing wheels each having a peripheral groove radius to accommodate tubing in the sizes ¼ in., ⅜ in., ½ in., and ¾ in. O.D. are normally used. Referring to FIG. 1, it can be seen that the backing wheel 30 can be readily changed by loosening set screws 33, sliding the shaft 27 out of the bearing assemblies 26, removing the grooving wheel and replacing it with one of a different groove radius. The same grooving wheel 42 is used for manufacturing linear shaped charge units of the several diameters.

The process for manufacturing linear shaped explosive charge units or devices utilizing the foregoing apparatus is as follows:

A section of tubing of suitable length is cut from a roll of tubing of the selected diameter and straightened to provide the casing 50 for the linear shaped charge unit. Refrigeration grade, soft-drawn copper tubing is preferred for the casing, but other tubing capable of taking a permanent set, such as aluminum or lead, may be used. One open end of the section of tubing is closed by a strip of tape, or by inserting therein a cork or rubber stopper (not shown). The tubing section is then supported in the vertical position with its open end uppermost. A particulate detonating explosive material 59 (as shown in FIG. 4) is then poured into the open end of the tubing section to substantially fill the section. It is advantageous, particularly when filling smaller diameter tubing sections, to add the explosive slowly accompanied by gentle tapping on the tubing wall to prevent bridging of the explosive and consequent formation of voids or spaces. The upper end of the tubing section is then sealed in the same manner as the lower end. Referring now to FIGS. 3, 4 and 5, a backing wheel 30, providing the proper sized peripheral groove to accommodate the size of tubing used for the casing 50, is mounted in the grooving assembly as hereinbefore described. The screws 37 are screwed out to permit the grooving wheel 42 to be raised by springs 39 a sufficient distance to allow the casing 50 to pass freely underneath the grooving wheel edge. One end of the explosive filled tubing section 50 is then inserted through the opening 49 in the centering tube 48 to extend into the groove 31 opposite the rim of the grooving wheel 42. The screws 37 are then screwed in until the edge of the grooving wheel 42 contacts the wall of the casing 50. The micrometer gage 57 scale is then rotated to set 0 opposite the pointer. The casing 50 is then pulled back out of contact with the grooving wheel 42 and the backing wheel 30.

The most satisfactory method of forming the groove 60 in the shaped charge unit casing is to pass the casing through the grooving machine a number of times, increasing the groove depth on each pass. Forming the groove to its total depth in one pass through the grooving machine may cause the casing 50 to split longitudinally at the apex of the groove. The screws 37 are screwed in until the micrometer indicates that the grooving wheel 42 has moved toward the backing wheel 30 a fractional part of the distance desired for the total depth of the groove 60 in the casing 50, for example, one-fourth the distance desired for the total depth. The explosive filled casing is then pushed into the groove 31 of the backing wheel and the crank 28 is rotated to draw the casing between the wheels where the edge of the grooving wheel 42 forms a longitudinal groove in the casing. When the casing has passed through the machine, the screws 37 are screwed in again until the micrometer indicates that the grooving wheel is lowered another incremental distance. The casing 50 is inserted in the centering tube 48 and the guide screw 74 is screwed in until it projects into cylindrical opening 49 to lightly contact the edges of the grooved casing 50, as may be seen in FIG. 11. The guide screw 74 prevents the casing from twisting or turning as it passes through the machine. If the casing is allowed to twist or turn, it will cause the groove 60 to have a twisted path around the casing. The casing 50 is then run through the grooving machine again to increase the depth of the groove 60. This process is repeated until the final depth desired for the groove 60 is achieved.

The grooving machine is readily adjusted to produce shaped charge units in a straight or curved form. Curved shaped charge units may be made with the groove 60 facing toward or away from the center of curvature. A curved shaped charge unit having the groove 60 facing toward the center of curvature is produced by positioning the brackets 53 and 55 so that the axis of the centering tube 48 intercepts the groove 31 in the backing wheel 30 from above the horizontal. A curved shaped charge unit having the groove 60 facing away from the center of curvature is produced by positioning the brackets 53 and 55 so that the axis of the centering tube 48 intercepts the groove 31 in the backing wheel 30 from below the horizontal. Increasing the angle between the axis of the centering tube 48 and a horizontal line between the grooving and backing wheels will shorten the radius of curvature of the shaped charge unit and vice versa.

A modification of the hereinbefore described process for manufacturing linear shaped charge devices has been developed which permits varying the weight of explosive material contained in a unit length of tubing of given diameter. Thus, the cutting power of linear shaped charge units made from the same diameter tubing may be widely varied to fit the specific job at hand. The variation in explosive weight per unit length of casing is controlled primarily by pregrooving the empty tubing section before it is filled with explosive material. A secondary control of the explosive density may be effected by tamping the explosive into the pregrooved tubing section with a tamping rod. The following table gives some specific data concerning the explosive loadings per unit length when using the process utilizing pregrooving of the empty tubing section and tamping the explosive.

TABLE

Explosive Load (Gm.) Per Unit Length (Foot) When Using 0.500" O.D. Soft Copper Tubing

Pregroove Depth in Tubing (in.)	Weight of Explosive Without Tamping (gm./ft.)	Weight of Explosive With Tamping (gm./ft.)
0.050	26.38	29.21
0.100	25.20	28.65
0.150	22.40	26.05
0.200	20.00	23.42
0.250	17.26	20.31

The pregrooving of the empty tubing sections is handled in the same manner as the grooving of a tubing section containing explosive. The total pregroove depth is achieved by making successive passes of the tubing section through the grooving machine. Between each pass of the tubing through the machine, the grooving wheel is lowered slightly to increase the depth of the groove in the casing. The successive passes are repeated until the desired pregroove depth in the tubing section is reached. When making linear charges using 0.500 in. O.D. copper tubing, it has been found that an increase in groove depth of 0.050 in. in the tubing section per pass is satisfactory. The grooving increment is decreased when using smaller diameter tubing for the casing, and increased when using larger diameter tubing. After pregrooving, the tubing section is filled with particulate explosive material. The explosive may be tamped as the tubing section is filled to increase the weight of explosive if desired. The explosive filled tubing section is then passed through the grooving machine the additional number of times required to achieve the final depth desired for the groove and, also, to further compact the explosive within the tubing section.

The groove 60 in the casing 50 of the linear shaped charge unit should not be made so deep that substantially all the explosive material 59 is forced from between the apex of the grooved portion of the sidewall of the casing and the opposite side wall. Charges grooved too deeply do not form a properly shaped jet and, consequently, have very low penetrating energy.

As stated hereinbefore, the process of the present invention for manufacturing linear shaped charge devices may be carried out utilizing a number of different instrumentalities. For example, a machine press may be used which has a bed fixedly supporting the explosive filled, tubular casing and a powered V-shaped die extending the length of the casing adapted to be moved into engagement with the supported casing to press a re-entrant cavity in the casing. Another suitable machine is one wherein the explosive filled, tubular casing is held fixed to a rigid support structure and a lateral force is applied to the casing by a grooving tool which is moved the length of the casing to form the re-entrant cavity in the casing. The process is also capable of being carried out by hand using simple hand tools, such as a hammer and a properly shaped punch, to produce the re-entrant cavity in the casing and to compress the explosive therein simultaneously.

For the purposes used herein, "tubular casing" is defined as including not only circular tubular casing, but those of semi-circular, oval, elliptical, polygonal and other similar shapes. Also, the term includes tubular casing of the shapes enumerated having a longitudinal groove formed in a wall portion thereof prior to filling the casing with explosive material and further deepening the groove to compact the explosive material.

Particulate explosive materials most suitable for use in preparing the linear shaped charge devices are desensitized Cyclonite or RDX (cyclotrimethylenetrinitramine) and desensitized HMX (cyclotetramethylenetrinitramine). The term "particulate explosive material" includes explosive material in a crystalline, granular or other discrete small particulate state as distinguished from fused or cast explosive materials.

A description of an exemplary setup for cutting an object explosively using a tubular, linear shaped charge device made according to the present invention follows.

A finished linear shaped charge unit 61, from which the sealed ends have been removed, is shown in FIGS. 7 and 8. The corks or other sealing means (not shown) used to seal the open ends of the casing 50 are normally left in place until the linear shaped charge is ready for use. If cork or rubber stoppers are used to seal the casing ends, they are tightly held by the groove 60 and cannot be easily removed. To prepare a linear shaped charge for detonation, the casing 50 is notched, using a file or other means, immediately to the rear of the cork and the end of the charge is broken off. The severed end of the charge provides a fresh area of explosive material 59 flush with the edge of the casing 50, which is desirable for good contact with the detonating means.

Referring now to FIGS. 9 and 10, an electric blasting cap 62 is held endwise in direct contact with the explosive material on one end of the linear shaped charge by means of strips of adhesive tape 63. Other means may be used to attach the blasting cap to the end of the shaped charge, such as a metal clip, adhesives or cements. The linear shaped charges can be adapted for under water use by sealing each end and attaching a detonator with any suitable waterproof adhesive. A pair of electric lead wires 68 are attached to the blasting cap and extend to a safe, remote location where one leg wire is connected through switch 64 to one side of a battery 65 and the other leg wire is directly connected to the battery. The linear shaped charge is supported by brackets 66 to provide the proper standoff distance from the target 67. These brackets are conveniently made of strips of metal, such as brass or aluminum and are adapted to clip over the charge casing 50 to retain the charge 61 in position with the groove 60 facing the target 67.

While the linear shaped charge devices shown are longitudinally straight, it is to be understood that curvilinear forms of the charge devices are anticipated. As hereinbefore stated, one of the principal features of the linear shaped charge devices produced by the process of the present invention is their adaptability to cut curved or irregular shaped objects. When a soft tubing is used for the charge casing, the shaped charge unit can easily be bent by hand or by using an ordinary tubing bender to the shape of most irregular shaped objects that it is desired to cut.

It is to be understood that the apparatus, the process and the tubular, linear shaped charge explosive devices described herein are subject to wide modification without departing from the scope and spirit of this invention. Accordingly, the specific embodiments herein described and depicted are to be considered as merely illustrative and not as restricting the scope of the following claims.

I claim:

1. A process for producing a linear shaped explosive charge unit which comprises: providing a length of elongated, generally tubular casing having a longitudinally extending, deformable wall portion being capable of taking a permanent set; forcing inwardly said longitudinally extending deformable wall portion of said casing to produce a longitudinal groove in said casing thereby reducing the internal volume of said casing; thereafter filling said grooved casing with particulate high explosive material; and forcing inwardly the longitudinally extending, deformable wall portion of said explosive filled casing along said longitudinal groove to produce a longitudinal groove of increased depth, thereby forming a re-entrant shaped charge cavity liner from said deformable portion of said casing, compressing said particulate high explosive material between the inner walls of said casing and shaping said high explosive material to conform to said inner walls, to produce a linear shaped charge having a lower explosive weight per unit length and a deeper longitudinal groove compared to a linear shaped charge produced as described in the foregoing steps with the exception that the casing is not pregrooved to reduce the internal volume thereof before being filled with particulate explosive material.

2. A process for producing a linear shaped explosive charge unit as set forth in claim 1 wherein the step of forcing inwardly the longitudinally extending, deformable wall portion of said explosive filled casing along said longitudinal groove to produce a longitudinal groove of increased depth is carried out in a plurality of successive operations whereby the depth of the groove is increased by each said successive operation.

3. A process for producing a linear shaped explosive charge unit as set forth in claim 1 wherein the step of forcing inwardly said longitudinally extending, deformable wall portion of said casing to produce a longitudinal groove in said casing, and the step of forcing inwardly the longitudinally extending, deformable wall portion of said explosive filled casing along said longitudinal groove to produce a longitudinal groove of increased depth, are both carried out in a plurality of successive operations whereby the depth of the groove is increased by each said successive operation.

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