June 26, 1962 O. J. McCULLOUGH 3,040,659

WELL PERFORATING DEVICE

Filed May 12, 1958 3 Sheets-Sheet 1

Fig. 1

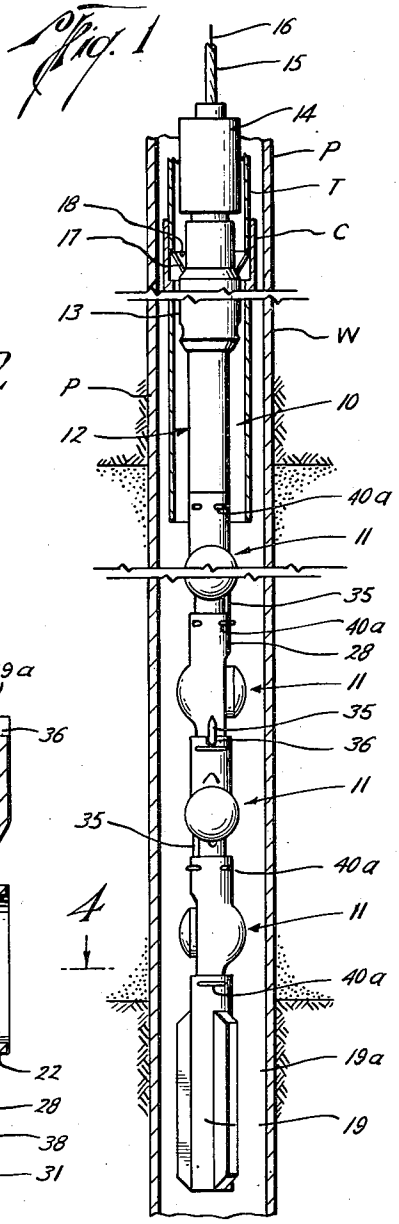


Fig. 2

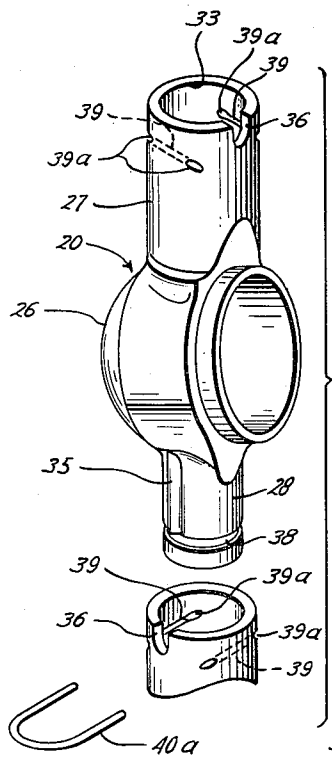


Fig. 3

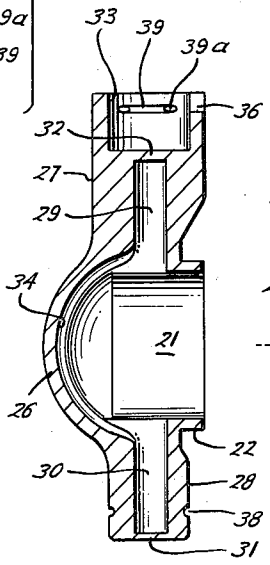
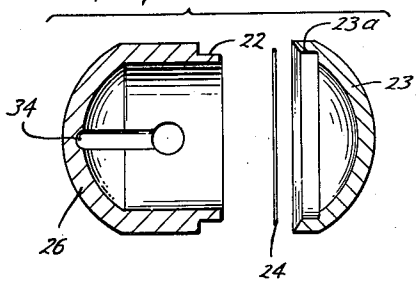


Fig. 4



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WELL PERFORATING DEVICE

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Fig. 5A

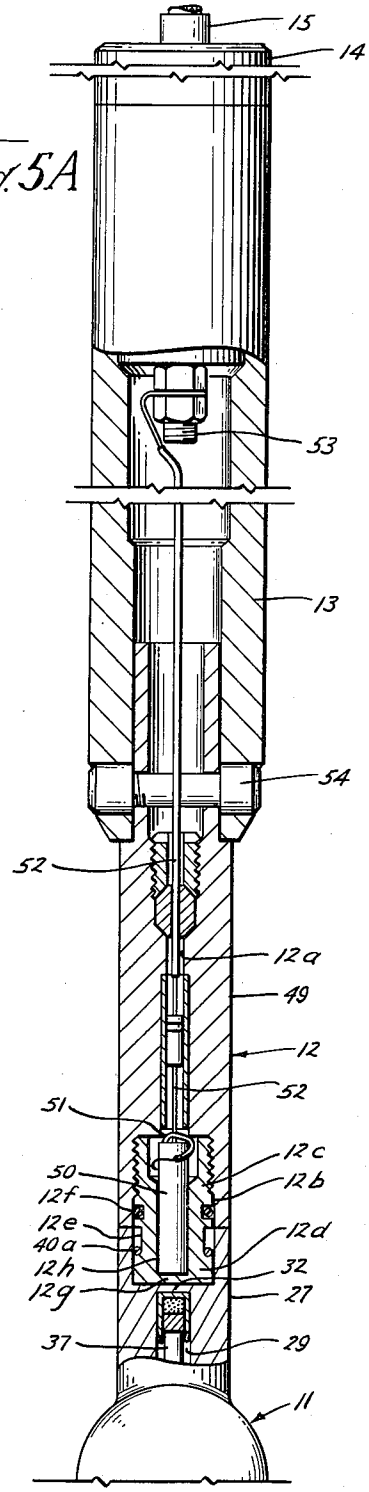

Fig. 5B

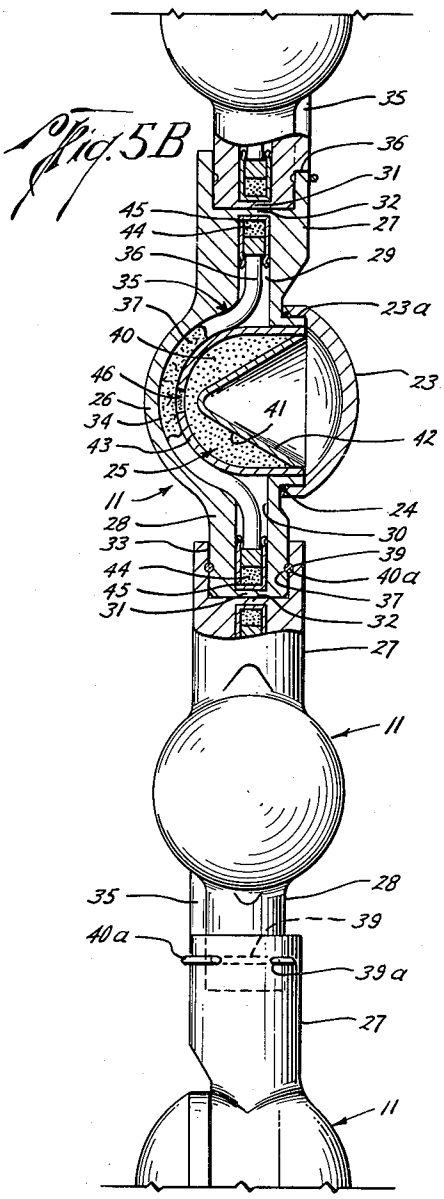

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Fig. 6

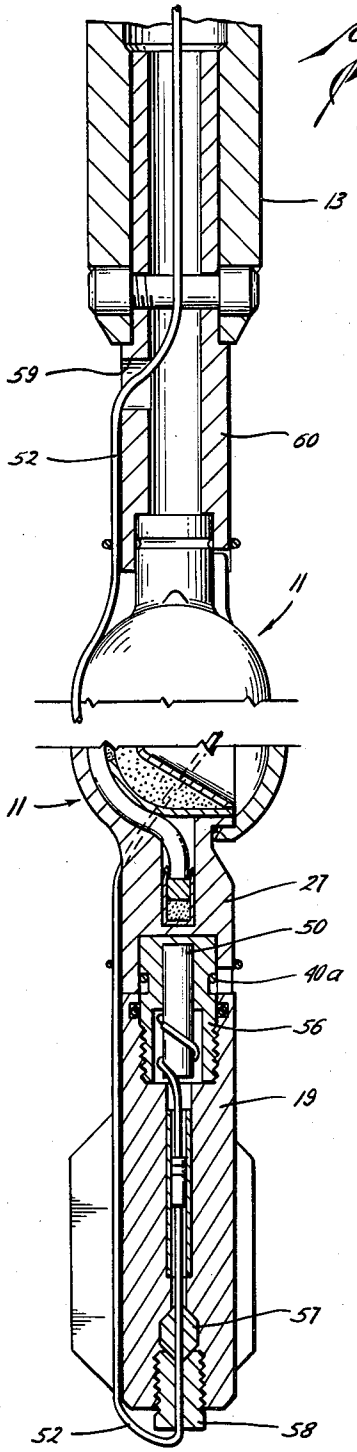
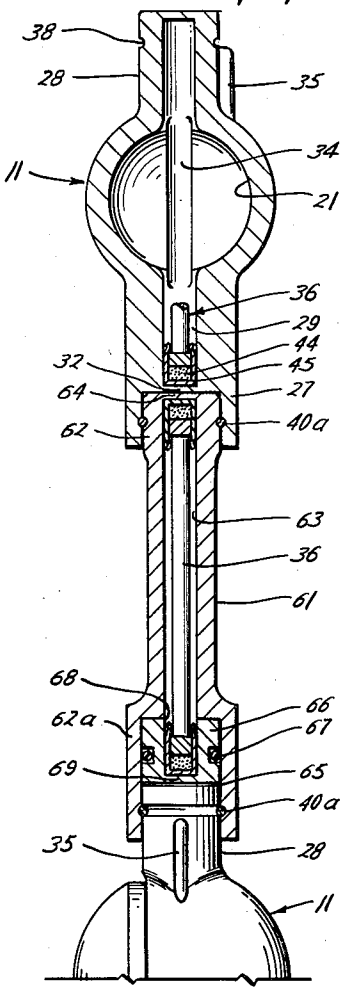


Fig. 7



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United States Patent Office 3,040,659 Patented June 26, 1962

3,040,659

WELL PERFORATING DEVICE

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Filed May 12, 1958, Ser. No. 734,521
4 Claims. (Cl. 102—20)

This invention relates to devices employed in perforating the wall of a well bore and relates particularly to improvements in perforating devices employing hollow or so-called "shaped" charges as the perforating elements.

In well perforating, the number of perforations which are required to be made vary very widely from well to well. In some cases only a few perforations are required and in others as many as several hundred perforations are necessary. The spacing on which the perforations are made will also vary. The number of perforations may be one, two or four perforations per foot of formation, or some other spacing arrangement. Also, it is often preferred to have the perforations extending in different directions through the wall of the well. As a result, it is of special advantage to provide perforating devices which are very flexible in their construction so as to permit adaptation of the device to meet the widely varying conditions encountered in different wells.

Among the more common arrangements heretofore employed in order to provide the desired flexibility in the perforating structures, there have been provided elongate, open type carriers supporting the requisite number of perforating charges at the desired spacing and orientation along the carrier. In carriers of this construction the detonating trains ordinariily comprise cord-type detonating elements which are strung along the carrier in detonating contact with the several charges and adapted to be fired in the conventional manner by an electrically exploded cap positioned in detonating contact with one end of the detonating train. This type of carrier is subject to a number of difficulties in use, arising usually because the detonating train, being on the exterior of the carrier, will be exposed to the fluid in the well bore and to the pressure of such fluids which, at the great depths at which perforations are often made, may amount to several thousand pounds per square inch. Such pressures, acting on the exposed detonating system, will not only cause leakage of fluid into the system, which will be detrimental, but the pressure may also so crush or vary the normal density of the detonating explosive enclosed in the detonating elements as to make it more difficult to detonate these elements by the usual firing systems. Also, the exposed detonating train is subject to abrasion while the carrier is being run into the well, and is subject to attack by acid and other chemicals often present in the well bore fluids.

In other type structures designed to enclose the detonating train, there is ordinarily required a closed tube or cylinder in which the perforating units are mounted. Such structures are necessarily much more expensive and complicated in construction and lack the degree of adaptability desired for the many different conditions which must be met which may require adding or reducing the number of perforating charges, or changing their spacing or orientation to the degree which is necessary in order to make these perforating devices economical and effective.

The present invention has for its principal object the provision of a form of perforating device which is designed to overcome the disadvantages of existing perforating devices of the general character described above, and which will permit maximum flexibility and adaptability in meeting all perforating requirements, particularly with respect to the number of perforations, spacing, and orientation.

In accordance with this invention there is provided a perforating unit of a standardized form and dimensions containing a single shaped-explosive perforating charge, each unit being constructed and arranged for connection to like units in order to form a string of perforating charges of any desired length, in any relative orientation, and at any desired spacing.

Each of the perforating units contemplated by this invention is a self-contained structure of standardized form and dimensions, comprising a casing in which the perforating charge and an individual detonating element therefor are enclosed within the casing so that no portion of this explosive structure will be exposed to external fluids or pressures.

In accordance with a preferred embodiment of this invention, the perforating charge is seated in a chamber within the casing and positioned with its hollowed end facing outwardly of the casing. A pair of hollow, generally tubular connection members extend from opposite sides of the casing and have transverse walls closing their respective bores, the inner ends of which communicate with the interior of the chamber. The transverse walls constitute fluid-tight barriers in the bores and may be integrally formed with the connection members or may be removable sealed closures, as will be more fully described hereinafter. A detonating system, which is generally a flexible tube-type detonating element, is arranged in the interior of the casing to extend generally longitudinally thereof and having its opposite ends in abutting contact with the inner faces of the walls closing the bores of the respective connection members. An intermediate portion of the detonating element is arranged in detonating contact with the end of the perforating charge opposite the hollowed end.

With this arrangement of connection members, detonation from an initiating source is transmitted through the closure wall in the bore of one of the connection members to the abutting end of the detonating element. The latter transmits the detonating shock to the perforating unit and to the transverse wall in the other connection member through which the detonating shock will then be transmitted to an adjoined perforating unit.

The connection members on each perforating unit are constructed to define complementary male and female coupling elements which may be telescopically connected so that when two units are connected together the closure walls in the adjoined coupling members will be placed in abutting contact with each other so that detonating shock from one unit will be readily transmitted through the abutting walls to the adjoining unit.

Means are provided on the units for angularly orienting the perforating charges relative to each other about the longitudinal axis of the string of such units, and means are also provided for releasably securing the units to each other in any desired angular orientation.

By enclosing the perforating charge and its detonating system inside a completely enclosed leak-proof casing of standardized form and dimensions, it will be seen that any number of perforating units may be coupled together to form a string of any desired length. The units, themselves, being of standardized dimensions will space the perforating charges on uniform centers. The resulting spacing, however, may be varied, if desired, by employing a modification in accordance with another feature of this invention; namely, by interposing between pairs of the units, spacing elements which comprise tubular casings which enclose only a section of a detonating element which serves to transmit detonating shock between the perforating units separated from each other by the spacing element. These blanking or spacing elements may be of any desired length and will have end

connections complementing those on the perforating units.

Other and more specific objects and advantages of this invention will become apparent from the following detailed description when read in conjunction with the accompanying drawing which illustrates several useful embodiments in accordance with this invention.

In the drawing:

FIG. 1 is an elevational view of a perforating gun constructed from a plurality of perforating units in accordance with this invention and shown positioned in a well bore for perforating the wall thereof;

FIG. 2 is an exploded perspective view showing one of the units in elevation and a portion of the female coupling element of a sub-joining unit, together with the locking means employed to secure one unit to the next;

FIG. 3 is a longitudinal sectional view of the casing for one of the perforating units;

FIG. 4 is a cross-sectional exploded view taken along line 4—4 of FIG. 3 showing, in addition, the cap and seal elements employed to close the casing;

FIGS. 5A and 5B, together, comprise an enlarged elevational view, partly in section, of the perforating gun shown in FIG. 1, to better illustrate the several elements thereof, and also illustrating an arrangement for firing the string of perforating charges from the upper end of the gun;

FIG. 6 is a view generally similar to FIGS. 5A and 5B, but showing a modified arrangement of the initiating elements for firing the string from the lower end thereof; and

FIG. 7 is a longitudinal, partly sectional, view of a portion of the string showing one of the spacer elements for connecting two separated perforating units, this figure also illustrating a modified form of closure for one of the coupling elements.

Referring to the drawing, FIG. 1 shows a well bore W lined with a casing P. Extending through the casing to a point above the lower end thereof is a tubing string T constructed of a plurality of joints of pipe connected by means of screw collars C in the usual manner. Extending through the lower end of tubing T into the bore of the casing is a perforating gun, designated by the numeral **10**, which comprises: a plurality of interconnected perforating units, designated generally by the numeral **11**, in accordance with the present invention; a firing head **12** connected to the uppermost one of the perforating units; firing head **12** being, in turn, connected to an adaptor **13** by which the gun structure is connected to a conventional rope socket **14**. The latter is suspended in the usual manner on a cable **15** by which the structure is adapted to be lowered into the well. It will be understood that cable **15** will include a conventional arrangement of electric conductors, as the conductor **16**, which lead to the surface and through which electric current may be transmitted to the initiating elements in the gun structure, as will be described more fully hereinafter.

Firing head **13** may be fitted with locating fingers **17** of a generally conventional type, adapted to engage abutments in the wall of the tubing, such as groove **18** formed between the ends of the pipe joints threaded into collar C. The locating fingers **17** are adapted to fix the location of the gun in the well in a manner well understood in this art. The lower end of gun **10** is provided with a head **19**, having radial ribs **19***a* adapted for guiding the gun through the tubing into the casing, and which also may be employed to add weight to the gun structure to assist its descent into the well.

Each of the perforating units **11** includes an elongate, generally tubular casing **20** (FIGS. 2 and 3) and a perforating charge, designated generally by the numeral **25**, of the hollowed or shaped-charge type, which is fully enclosed within casing **20** and hermetically sealed therein (FIG. 5B), together with a detonating element, designated generally by the numeral **35**, which may be in the form

of a flexible tube **36** constructed of fabric or plastic, or of a soft metal such as lead, and filled with a suitable detonating explosive **37** of any suitable or conventional type adapted to transmit high-order detonating shock to the shaped charges constituting the perforating elements.

Casing **20** is preferably constructed of a highly friable material which will shatter into very small particles when the charge is fired. Such materials may be metal, such as cast aluminum, or glass, plastic or ceramic material or combinations thereof. As best seen in FIGS. 2, 3 and 4, casing **20** is enlarged intermediate its ends to define a generally cylindrical chamber **21** extending generally at right angles to the longitudinal axis of the casing. One end of chamber **21** is open, the open end terminating in an annular flange **22** adapted to receive an enclosing cap **23** of outwardly curving concavo-convex shape, provided with an annular rim **23***a* formed to fit snugly about flange **22**. A seal ring, such as an O-ring **24**, may be interposed between flange **22** and rim **23***a* and sealing compound or adhesive may also be employed between these surfaces to assure a fluid-tight seal for the end of chamber **21**. The inner wall **26** opposite the open end of chamber **21** is of general spherical shape projecting outwardly of the casing. The portions of the casing extending on opposite sides of chamber **21** comprise generally tubular connection members **27** and **28**, having axial bores **29** and **30**, respectively, which communicate with the interior of chamber **21**. The outer end of connection member **28** is closed by a relatively thin transverse wall **31** and bore **29** is similarly closed by a relatively thin transverse wall **32**. The latter, however, is spaced inwardly from the outer end of connection member **29** which is counter-bored to provide an enlarged cylindrical socket **33** opening to the outer end of the connection member. Connection member **28** thus forms a male coupling element while the outer end of connection member **27**, as defined by socket **33**, forms a female coupling element whose internal dimensions are so related to the external dimensions of male member **28** as to form therewith complementary, telescopically engageable coupling elements for connecting one of the perforating units to another, and which when inter-enaged, will position wall **31** of one coupling element in abutting engagement with wall **32** of the related coupling element. A groove **34** of generally arcuate cross-section extends longitudinally across the inner face of rear wall **26** and merges at its opposite ends into bores **29** and **30**.

As best seen in FIG. 2, male coupling element **28** is provided on its exterior surface with a longitudinally extending spline **35**. Female coupling element **27** is provided with a longitudinally extending slot **36** opening to its outer end and adapted to receive the spline **35** of an adjoining male element **28** when the latter has been inserted into socket **33** to thereby lock adjoined against relative rotation and to fix the relative angular positions of adjoining units. Ordinarily, spline **35** on the male element will be angularly displaced 90° with respect to slot **36** on the female element of the same casing, so that adjoining perforating units will have their perforating charges spaced 90° apart about the longitudinal axis of the string of charges. It will be understood that other angular relations may be made by appropriately positioning the splines and the spline-receiving slots on the coupling elements.

Male coupling element **28** is provided with a circumferential locking groove **38** spaced slightly from the outer end of the coupling element. The interior wall of socket **33** is provided on diametrically opposite sides thereof, with transverse grooves **39** adapted to register with adjacent segments of locking groove **38** when a male coupling element **28** has been fully inserted in socket **33**. Each of the transverse grooves **39** opens at its opposite ends **39***a* through the wall of socket **33** and a U-shaped locking pin or staple **40***a* is employed to lock the coupling elements together, the legs of the locking pin being adapted to be pushed through wall openings **39***a* on opposite sides of

element 28 to extend through transverse grooves 39 and the adjacent segments of locking groove 38 which complement each other to form effective keepers for the legs of the locking pins. The free ends of the staple 40*a* which project from openings 39*a* may be crimped about the exterior of element 27, as best seen in FIG. 1, in order to prevent dislodgment of the locking pins.

As best seen in FIG. 5B, the perforating charge 25 is of the generally conventional shaped charge type, comprising a generally cylindrical body 40 of any high explosive commonly employed for well perforating, formed to provide a generally conical hollow 41 in one end thereof, the charge being seated in chamber 21 with hollow 41 facing the end covered by cap 23. A liner 42 of well known form and construction adapted to increase the penetrating effect of the explosive is seated in hollow 41. The body 40 may be encased in a capsule 43 which may be constructed of lead or plastic or any other suitable material; or, if desired, the body of explosive may be molded or pressed to the desired shape and size and employed without any encasing capsule.

Detonating element 36 is arranged interiorly of casing 20 to extend longitudinally thereof, the intermediate portion thereof being laid in groove 34 to be in detonating contact with the end of explosive body 40 opposite the hollowed end. The opposite end portions of detonating element 36 extend into bores 29 and 30 and into direct contact with the inner faces of walls 31 and 32. Each of the ends of detonating element 36 may be provided with a small body of booster explosive 44 which is secured to the end of the detonating element by an encasing clip or ferrule 45 (FIG. 5B). A small body 46 of a suitable booster explosive may also be positioned at the point of contact between the detonating element and inner end of explosive charge 40. These several booster charges serve to assure high order detonation throughout the explosive system of the perforating unit.

To form the gun structure illustrated in FIG. 1, a plurality of the perforating units 11 will be connected together to form a string of a length to include any number of units, the connections between the units being made by telescopically interconnecting the male and female members of adjoining units, in the manner previously described, and securing them together by means of the locking pins 40*a*. The centralizing head 19 will be secured to the lower end of the string, and the upper end of the string will be connected to the firing head 12, adaptor 13, and rope socket 14 for suspension of the cable 15.

As best seen in FIG. 5A, firing head 12 comprises a tubular body 49 having an axial bore 12*a*, which is counterbored from its lower end at 12*b* to receive a threaded tubular bushing 12*c* which projects out of the end of counterbore 12*b* to form a male coupling element 12*d*, corresponding generally in form and dimensions to one of the male coupling elements 28, to thereby be adapted to be inserted into the female coupling element 27 of the uppermost one of the units 11 in the string. The portion 12*d* of the bushing has a circular locking slot 12*e* which functions in the same manner as locking groove 38, for receiving one of the locking pins 40*a*, whereby the string of perforating units may be effectively secured to the firing head. Seal means, such as an O-ring 12*f*, is disposed about the bushing 12*c* to form a fluid-tight seal with the wall of counterbore 12*b*. Bushing 12*c* is axially bored at 12*h* from its inner end to a point just short of its outer end to provide an end wall 12*g* corresponding generally in form, dimensions and function to the transverse walls 31 and 32 of the perforating units. The axial bore 12*h* in the bushing is adapted to receive an electrically fired detonating cap 50, which may be of any conventional type, and is electrically connected in the conventional manner, as by means of leads 51 and 52, to the terminal of an electrode 53 which is electrically connected in the conventional manner (not shown) to conductor

16 in the lowering cable. The electrical firing elements are conventional and in and of themselves form no part of the present invention. The upper end of body 49 is secured to adaptor 13 in any suitable manner as by means of the interconnecting bolts 54.

When the gun structure is assembled, as described, and connected to the cable 15, it is lowered into the well to the desired depth and its position fixed by lodgment of locating fingers 17 in groove 18 of the nearest casing collar C. Cap 50 will then be fired in the usual manner, as by closing an electric switch (not shown) located at the surface, and the resulting detonation of cap 50 will be transmitted through end wall 12*g* of bushing 12*c*, thence through wall 32 of the female coupling element of the perforating unit connected thereto. From the latter the detonating shock will be transmitted to detonating elements 37 which is in contact with end wall 32, and thence will travel serially through all of the interconnected perforating units, setting off the perforating charges in each of the units as the detonating wave travels downwardly through the string.

The transmission of the detonating wave will occur through the abutting closure walls 31 and 32 between each pair of units, and the booster elements will aid in maintaining detonation of high order throughout the entire path of transmission of the shock wave.

The thickness of walls 31 and 32 will be made such as to afford ready transmission of the shock wave without decreasing it markedly. In general, the thickness of walls 31 and 32 will be in the range of from about 0.03125 to about 0.0925 inch, depending upon the type of material from which the walls are constructed. In the case of cast aluminum, the wall thickness will be 0.062 inch. While walls 31 and 32 preferably will be made to the same thickness, they may be of different thicknesses within the stated range.

In the arrangement shown in FIGS. 1, 5A, and 5B, it will be noted that firing of the charges takes place at the upper end of the string and is referred to as "top firing." FIG. 6 illustrates a modification in which the firing of the string of charges is initiated at the lowermost one of the perforating units and the shock wave caused to travel upwardly through the string. This arrangement, referred to as "bottom firing," is found to have advatnages in many instances. In the embodiment illustrated in FIG. 6, centralizing head 19 has mounted therein the initiating cap 50 which is seated in a connector bushing 56 which is substantially identical in form and arrangement to bushing 12*c*, whereby the firing head may be connected to the female coupling element 27 of the lowermost one of the perforating units 11. In this embodiment the electrical conductor 52 is led outside the lower end of head 19 through a seal 57 and closure bushing 58 and strung upwardly along the exterior of the string of perforating units, passing into the bore of the adaptor 13 through an opening 59 in the wall of a sleeve 60 which corresponds generally in form to body 49 of firing head 12, and serves similarly for connecting the uppermost perforating unit in the string to adaptor 13. With the arrangement illustrated in FIG. 6, when cap 50 is fired the shock wave will be transmitted upwardly through the detonating elements in the string of charges and will fire the charges successively upwardly from the lowermost one.

FIG. 7 illustrates one of the spacer sections, which may be inserted between a pair of the perforating units 11 in order to change the spacing between perforations. The spacing unit comprises a tubular sleeve 61 which has an enlarged portion at one end forming a pin or male coupling element 62 dimensioned to conform to the dimensions of male member 28 of the previously described perforating units. Sleeve 61 has an axial bore 63 which terminates just short of the end of pin 62 to form the closure wall 64, corresponding in dimensions and function to closure wall 31 of the casing 20 of the perforating units. At its opposite end, sleeve 61 has an enlarged por-

tion 62a which is counterbored to form the socket 65 which is adapted to form a female coupling element adapted to receive one of the male coupling elements 28. However, socket 65 is made somewhat deeper than sockets 33 of the female coupling element of casing 20 in order to receive a closure plug 66 which carries an external packing ring, such as the O-ring 67, to form a fluid-tight seal between the plug and the wall of socket 65. The inner end of plug 66 is provided with a counterbore 68, registering with axial bore 63 and of the same diameter, and terminating just short of the outer end of plug 66 to thereby define the closure wall 69 which corresponds in dimensions and function to closure walls 32 of the female coupling elements. A detonating element 36 is installed in bore 63, one end being placed in abutting engagement with the inner face of wall 64, and the other end being inserted into counterbore 68 of the closure plug and abutting closure wall 69. Thus, except for the absence of a perforating charge in the spacer element, the latter functions in exactly the same manner as one of the perforating units in transmitting detonating shock from one of the perforating units to another. As many of these spacing elements may be installed in a string of charges as may be desired to provide the necessary spacing arrangement.

From the foregoing, it will be evident that, in accordance with the present invention, there is provided a standardized perforating unit which is hermetically sealed, and which contains not only the perforating charge, but also the detonating system for setting off the charge and for transmitting detonating shock from one unit to another. The form and construction of the perforating unit is such as lends it admirably to the formation of strings of any desired length necessary to produce as many perforations as desired, in any desired longitudinal and angular spacing arrangement, and in each instance, initiation of the entire structure may be effected from a single point at one end of the structure.

By enclosing the detonation elements together with the perforating charge in a fully sealed casing, the various difficulties encountered, as above described, with exposed detonators will be eliminated. Also, the units may be stored in large stocks for long periods of time without deterioration so that they will be readily available for assembly in any quantities and may be shipped and handled easily and safely.

The unitary perforating devices in accordance with this invention lend themselves particularly well to structures of small radial dimensions which will permit the ready passage of strings thereof through conventional 2 to 2½ inch well tubing into a surrounding casing or open well bore, while providing units having high penetrative characteristics sufficient to assure effective penetration of the casing or well bore wall even when spaced substantially from the charges.

Another advantage resulting from the devices constructed in accordance with the present invention is that, even though leakage of fluid may occur into one or more of the casings which might prevent high-order detonation of the perforating charges therein, the detonation wave will travel effectively through such units to succeeding units which will be set off at high order. Thus, unlike more conventional arrangements, failure of one or more perforating charges cannot render ineffective all charges beyond the defective one along the path of travel of the detonating wave.

It will be understood that other modifications and variations may be made in the details of the illustrative embodiments within the scope of the appended claims, but without departing from the spirit of this invention.

What I claim and desire to secure by Letters Patent is:

1. A well perforating device comprising: a casing having a chamber therein, only a single shaped explosive charge seated in said chamber, said charge having a hollow at one end facing outwardly along the charge axis, a pair of connection members for suspending the perforating device extending generally oppositely from spaced points on the casing and laterally with respect to said axis, said connection members having passages communicating with the interior of said chamber, imperforate transverse walls integrally formed with said connection members to close each of said passages to form a sealed space including said chamber, each of said walls being constructed and dimensioned to effectively transmit detonation shock therethrough from either face thereof to the other, and a detonating element comprising an elongate, continuous body of detonating explosive disposed entirely interiorly of said casing and said connection members, said detonating element having its opposite ends extending into said passages immediately adjacent said transverse walls to effectively transmit detonation shock from either of said transverse walls to the other and having its intermediate portion in detonation-transmitting contact with the end of said charge opposite said hollow.

2. A well perforating device as described in claim 1 wherein said detonating element includes booster charges encased with the ends thereof in said passages in detonation-transmitting relationship with said transverse walls.

3. A well perforating device comprising: a plurality of perforating units, each unit comprising a casing having a chamber therein, only a single shaped explosive charge seated in said chamber, said charge having a hollow at one end facing outwardly along the charge axis, a pair of connection members for suspending the unit extending generally oppositely from spaced points on the casing and laterally with respect to said axis, said connection members having passages communicating with the interior of said chamber, imperforate transverse walls integrally formed with said connection members to close each of said passages to form a sealed space including said chamber, each of said walls being constructed and dimensioned to effectively transmit detonating shock therethrough from either face thereof to the other, and a detonating element comprising an elongate, continuous body of detonating explosive disposed entirely interiorly of said casing and said connection members, said detonating element having its opposite ends extending into said passages immediately adjacent said transverse walls to effectively transmit detonation shock from either of said transverse walls to the other and having its intermediate portion in detonation-transmitting contact with the end of said charge opposite said hollow, said detonating element having booster charges encased with the ends thereof in said passages in detonation-transmitting relationship with said transverse walls; and means joining a connection member of one unit to a connection member of another unit to bring the transverse walls of said connection members into detonation-transmitting relationship.

4. A well perforating device as described in claim 3 wherein said means for joining a connection member of one unit to a connection member of another unit comprises means for bringing the transverse walls of said connection members into abutting relationship.

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UNITED STATES PATENT OFFICE

Certificate

Patent No. 3,040,659 Patented June 26, 1962

Otis J. McCullough

Application having been made jointly by Otis J. McCullough, the inventor named in the patent above identified; Ira J. McCullough, Los Angeles, California; and William G. Sweetman, Houston, Texas, for the issuance of a certificate under the provisions of Title 35, Section 256 of the United States Code, adding the names of the said Ira J. McCullough and William G. Sweetman to the patent as joint inventors, and a showing and proof of facts satisfying the requirements of the said section having been submitted, it is this 3rd day of September, 1963, certified that the names of the said Ira J. McCullough and William G. Sweetman are hereby added to the said patent as joint inventors with the said Otis J. McCullough.

[SEAL]

EDWIN L. REYNOLDS,
First Assistant Commissioner of Patents.