Oct. 12, 1965 I. J. McCULLOUGH ETAL 3,211,093

EXPENDIBLE GUN ASSEMBLY FOR PERFORATING WELLS

Filed Aug. 10, 1962 4 Sheets-Sheet 1

Fig. 1

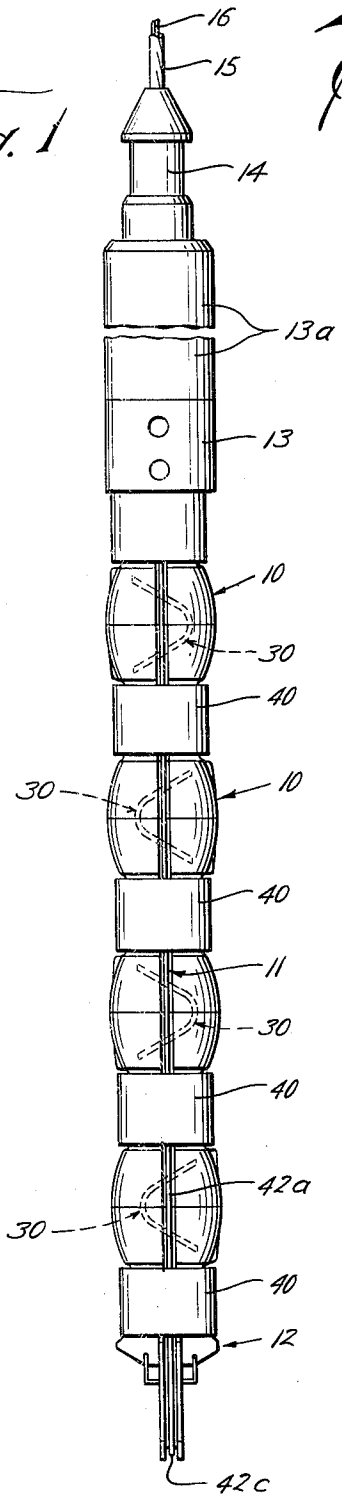
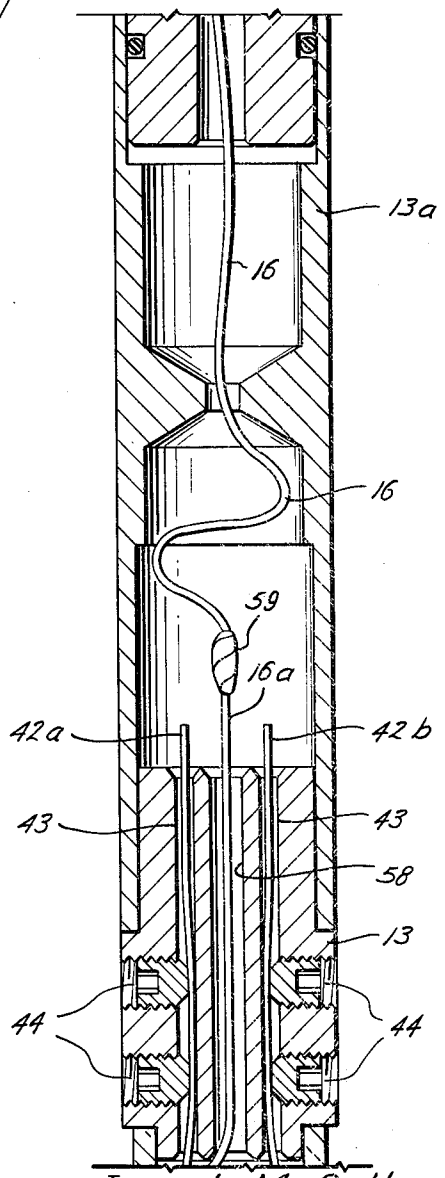


Fig. 2A



Ira J. McCullough
Otis J. McCullough
William G. Sweetman
INVENTORS

BY

ATTORNEY

Oct. 12, 1965 I. J. McCULLOUGH ETAL 3,211,093

EXPENDIBLE GUN ASSEMBLY FOR PERFORATING WELLS

Filed Aug. 10, 1962 4 Sheets-Sheet 2

Fig. 2B

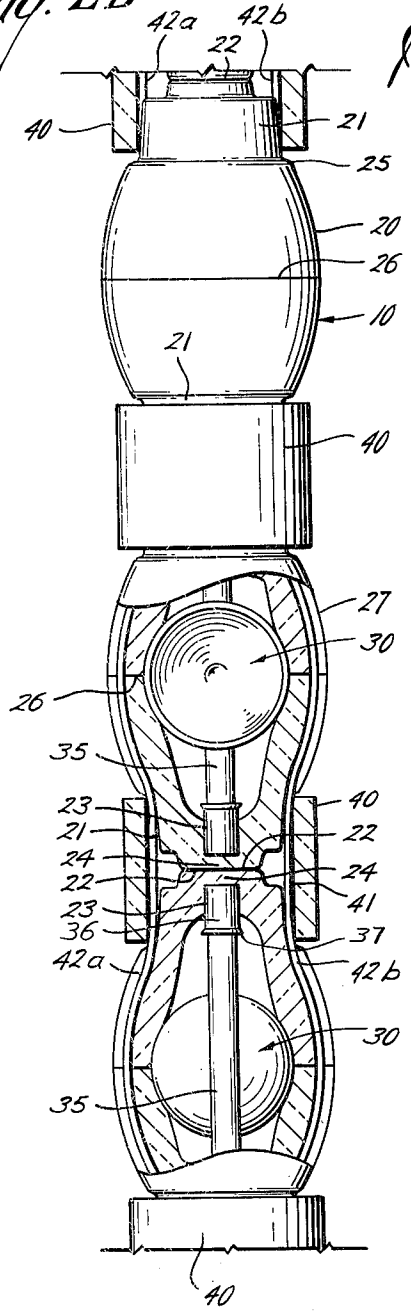


Fig. 2C

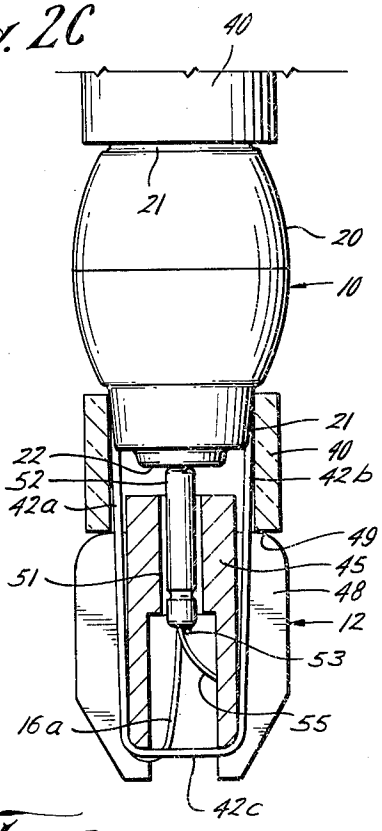
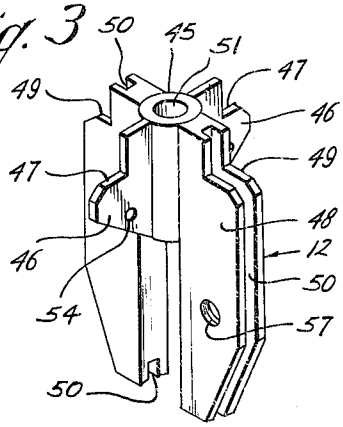


Fig. 3



Ira J. McCullough
Otis J. McCullough
William G. Sweetman
INVENTORS

BY

ATTORNEY

EXPENDIBLE GUN ASSEMBLY FOR PERFORATING WELLS

Filed Aug. 10, 1962 4 Sheets-Sheet 3

Fig. 4A

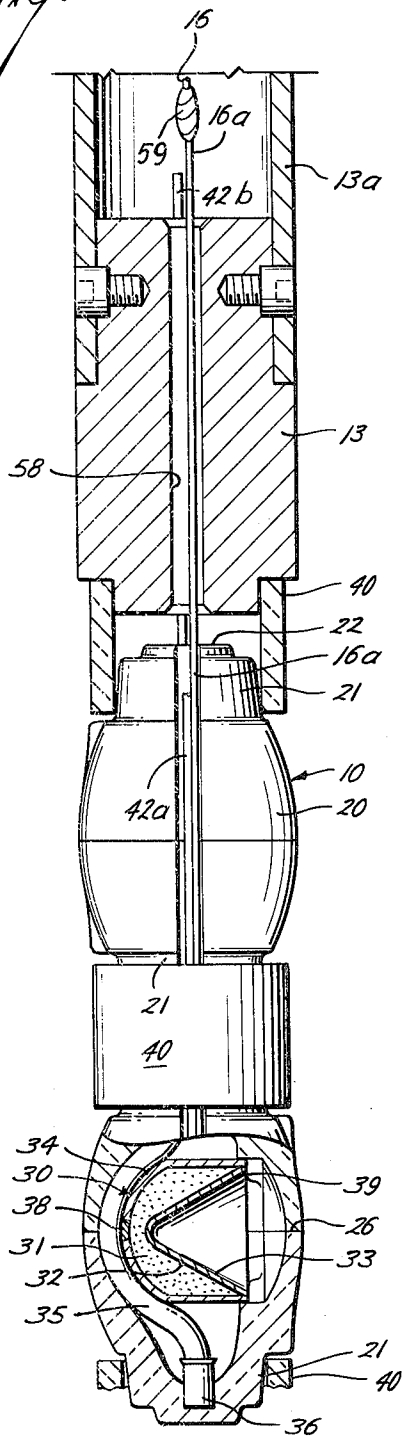
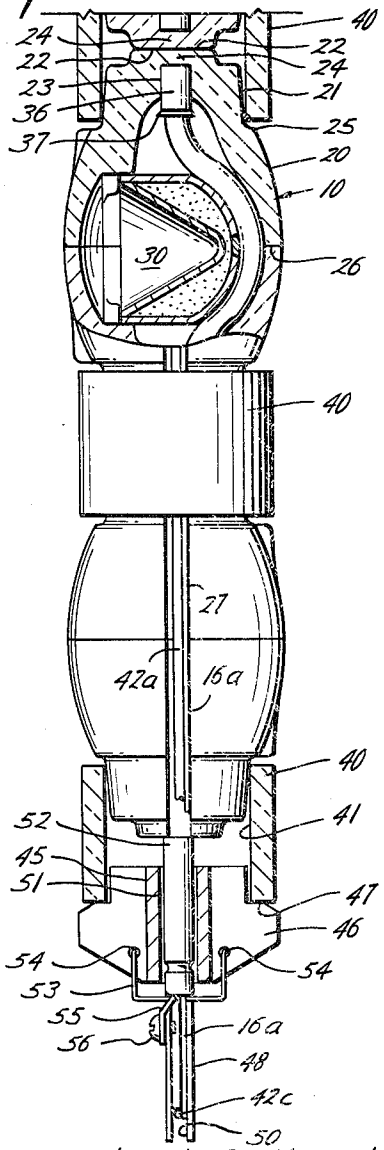


Fig. 4B



Ira J. McCullough
Otis J. McCullough
William G. Sweetman
INVENTORS

BY

ATTORNEY

Oct. 12, 1965 I. J. McCULLOUGH ETAL 3,211,093

EXPENDIBLE GUN ASSEMBLY FOR PERFORATING WELLS

Filed Aug. 10, 1962 4 Sheets-Sheet 4

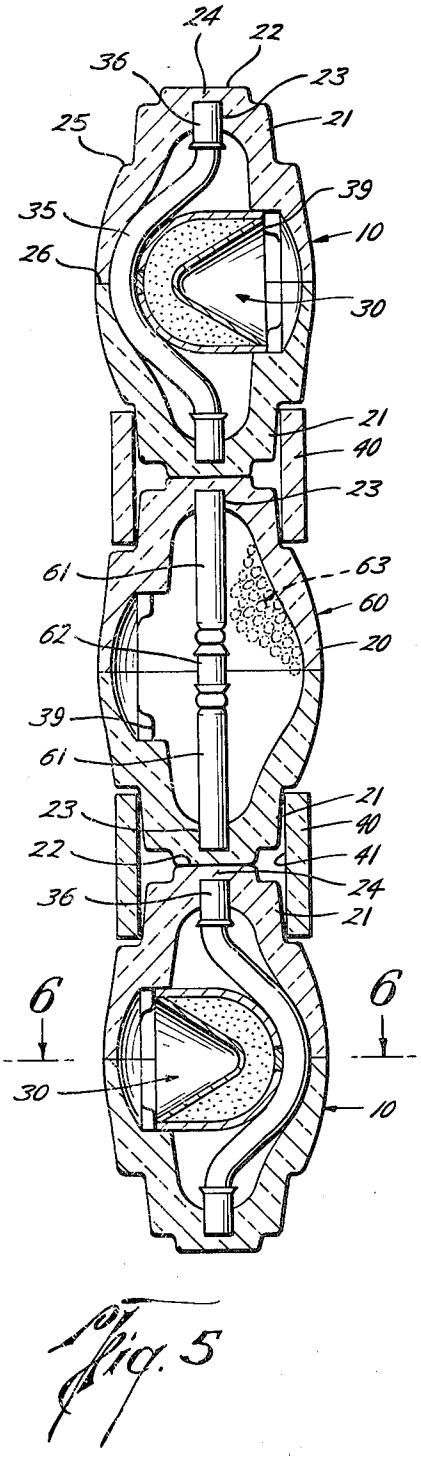


Fig. 5

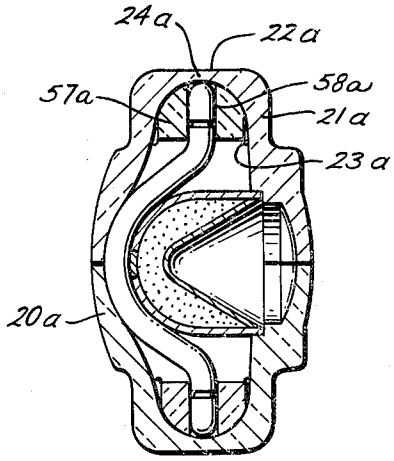


Fig. 7

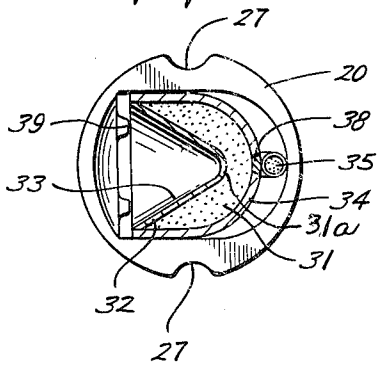


Fig. 6

Ira J. McCullough
Otis J. McCullough
William G. Sweetman
INVENTORS

BY

ATTORNEY

United States Patent Office 3,211,093
Patented Oct. 12, 1965

3,211,093

EXPENDIBLE GUN ASSEMBLY FOR PERFORATING WELLS

Ira J. McCullough, % McCullough Tool Company, 5820 S. Alameda St., Los Angeles 58, Calif., and Otis J. McCullough and William G. Sweetman, % McCullough Tool Company, P.O. Box 2575, Houston, Tex.

Filed Aug. 10, 1962, Ser. No. 216,112
5 Claims. (Cl. 102—20)

This invention relates to an expendible gun assembly for use in perforating in wells such as oil and gas wells, and more particularly to an improved expendible glass-encased explosive perforating unit, and a gun assembly comprising a number of such units connected by glass couplings and supported in a sling-type carrier.

The use of expendible well perforating devices employing shaped charges of explosives as the perforating elements have been widely adopted in the oil industry, however, the use of such perforators has been accompanied by the problem of the deposition of too much so-called "junk," that is, the metal debris resulting from the usual metal casings enclosing the perforating units and the various types of metal carriers conventionally employed for supporting and lowering the strings of perforating units into the well. Such debris frequently interferes with the production of oil and gas from the well by plugging flow valves, pumps, gas traps and wellheads. While producers suffer large expenses bailing and swabbing endeavoring to remove the debris after perforating. Very often it is impossible to run clean-out tools into a well after perforating due to high pressures which have been opened into the well through the perforations.

Many wells in accordance with current "slim-hole" completion and production practices employ quite small diameter pipe as casing and production strings, often only 2 inch or 2½ inch tubing, and even smaller sizes, which is cemented in place in the well bore. Since the casing bore in such a well is quite small, the employment of perforating devices which produce metallic "junk" or debris will fill up substantial amount of the casing or of the tubing, and seriously interfere with the production of oil and gas from the well, especially when, as is often the case, a perforating assembly or "gun" usually comprise a substantial number, and very often hundreds, of perforating units in one zone in a well.

In an effort to overcome these various disadvantages of more conventional perforators, some perforating units have been encased in glass, as disclosed in U.S. Patent No. 2,629,325 to W. G. Sweetman, and these have been mounted in recoverable carriers constructed of relatively thin strip metal, as disclosed in U.S. Patent No. 2,756,677 to I. J. McCullough. While this expedient has constituted a substantial improvement in this art, the removal of the carrier after use has presented some problems. U.S. Patent No. 3,040,659 to O. J. McCullough has provided a perforator comprising a series of self-contained perforating units which are also self-supporting in that they may be directly connected to one another by a coupling arrangement to form strings of any desired length. This construction has very successfully met the problem of space limitation in providing powerful perforating units dimensioned for use in small bore tubing, but the problem of excessive debris, while greatly reduced by the elimination of a separate carrier, has, nevertheless, continued to cause some difficulty in perforating operations.

The present invention, therefore, has for its principal object, the provision of an improved form of perforating device which eliminates or greatly obviates the aforementioned disadvantages of earlier devices, by providing a highly efficient perforating device particularly dimensioned for use in small bore tubing and producing a minimal amount of metallic debris.

In accordance with one embodiment of this invention, there is provided a perforating device comprising a series of self-contained shaped charge perforating units each enclosed in a casing completely constructed of glass and strung together in strings of any desired length by means of a unique connector arrangement comprising a wire sling extending lengthwise along opposite sides of the string of charges and passing through a series of constricting collars constructed of glass. One collar is disposed about the adjacent abutting end portions of each pair of perforating units and the wire sling is threaded through the collars and over the opposite sides of the perforating units. When the ends of the wire sling are drawn taut, the constrictive action of the collars serves to draw the perforating units together tightly in end-to-end relation to complete the gun assembly. The tight end-to-end engagement thus effected between the perforating units serves to establish effective successive transmission of detonating shock throughout the entire length of the string. Since the casings for the perforating units and the constricting collars are of glass, the only metallic debris resulting from setting off of the perforating device will be that formed from the relatively thin wire sling, it will be evident that the present device will practically eliminate the plugging problem encountered with more conventional devices.

Another object of this invention is the provision of a glass-encased shaped-charge perforating unit embodying several novel features of construction providing a highly efficient self-contained perforator for use in multiple unit strings particularly adapted for running in small diameter well tubing.

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

In the drawing:

FIG. 1 is an elevational view of a perforating device embodying this invention;

FIGS. 2A, 2B, and 2C, together, comprise an elevational view, generally similar to FIG. 1 but in larger scale, having portions thereof broken away to illustrate the details of the device;

FIG. 3 is a perspective view of one of the elements of the device;

FIGS. 4A and 4B, together, comprise a view generally similar to FIGS. 2A, 2B and 2C, but viewed in a position turned 90° from that of the latter figs.;

FIG. 5 is a fragmentary view of a portion of a string of perforating units showing an arrangement for varying the spacing between the units;

FIG. 6 is a cross-sectional view taken along line **6—6** of FIG. 5; and

FIG. 7 is a longitudinal cross-sectional view of a modified form of a perforating unit.

As seen in FIG. 1, the gun assembly comprises a plurality of perforating units, each designated generally by the numeral **10**, strung together in end-to-end relation in a sling-type carrier, designated generally by the numeral **11**, which also supports a bottom firing head, designated generally by the numeral **12**, in detonating relation to the lower end of the string of charges. The upper end of carrier **11** is secured by means of a hanger sub **13** to weight bars or other generally conventional rope socket **14**, by which the perforating device is lowered into a well on a wire rope or cable **15**, the latter carrying the conduc-

tor **16** through which firing current may be transmitted from the surface to the firing head.

Each of the perforating units **10** comprises a hollow casing **20** having a generally ovoid or oblate spheroidal shape and having integral end portions **21**, the exteriors of which are of generally cylindrical shape and substantially smaller in diameter than the main body of the casing. End portions **21** terminate in end walls **22** closing the ends of the casing. End walls **22** are substantially flat on their outer faces while their inner faces are provided with axial sockets or recesses **23**, the outer ends of which are closed by relatively thin sections **24** of the end walls. The thickness of end sections **24** is dimensioned to effectively transmit detonating shock from either face thereof to the other. The change in shape of end portions **21** and their reduction in diameter with respect to the main body of the casing defines the external annular shoulder **25** at the base of each end portion. Casing **20** is split transversely at its mid-point to form two symmetrical half-sections which are secured together at **26** by means of any suitable industrial adhesive when the unit is assembled. Casing **20** is provided on opposite sides thereof with longitudinally extending grooves **27** of a depth to accommodate the carrier sling and an electrical conductor wire, as will be subsequently described.

An explosive perforating charge, designated generally by the numeral **30**, is encased by casing **20** and is of any generally conventional shaped or hollow charge type, comprising, a generally cylindrical body **31** of any high explosive material commonly employed for well perforating, formed to provide a generally conical hollow **32** in one end thereof, and the opposite end **31***a* being rounded, as shown (FIG. 6). The charge is seated in the interior of casing **20** at the mid-portion thereof with hollow **32** facing to the side of the casing at an angle of 90° with respect to the grooves **27**, the hollowed end being seated against an internal shoulder **39** provided in the interior of casing **20**. A liner **33**, of well-known form and construction adapted to increase the penetrating effect of the explosive, is seated in hollow **32**. Explosive **31** may be encased in a like-shaped capsule **34**, 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 the encasing capsule.

A detonating explosive fuze **35** of elongate, flexible form, is arranged interiorly of casing **20** to extend generally longitudinally thereof, the intermediate portion of the fuze element being disposed in detonating contact with the end **31***a* of the explosive body **31**. The opposite end portions of fuze element **35** extend into recesses **23** at the opposite ends of the casing and into direct contact with the inner faces of sections **24** of walls **22**. Each of the ends of fuze element **35** may be provided with a small body of booster explosive **36** which is secured to the end of the fuze element by an encasing clip or ferrule **37**. A small body **38** of a booster explosive may be positioned at the point of contact between fuze element **35** and end **31***a* of explosive charge **31**. These several booster charges serve to assure high-order detonation throughout the explosive system of the perforating unit. Fuze element **35** may be conventional Primacord or a similar flexible detonating fuze.

To form the gun structure illustrated in FIG. 1, a plurality of the perforating units **10** will be connected together to form a string of a length to include any desired number of units. The units are connected together by inserting the end portions **21** of adjacent units into the opposite ends of a collar **40** having a bore **41** which fits with a small degree of looseness about the end portions, the length of the collar being slightly less than the overall length of the two abutting end portions **21**. Sling **11**, which is preferably formed from a single length of flexible wire, is employed to secure the several perforating units together in a unified string. In its final form sling **11** constitutes a generally U-shaped structure comprising the arm portions **42***a* and **42***b* connected by the bottom portion **42***c* and is applied by threading the opposite arm portions **42***a* and **42***b* upwardly through the grooves **27** along opposite sides of the string of units, the wire passing through the bores of the successive collars **40** and being drawn upwardly by any suitable means until bottom portion **42***c* engages beneath and around firing head **12**, which will be described in greater detail hereinafter. When the sling is in place about the string of charges, arm portions **42***a* and **42***b* will be drawn taut in the upward direction. As the diameter of bores **41** of collars **40** are made substantially less than the external diameter of casings **20**, the collars will serve to constrict both arms of the sling wire so that as the upper ends are pulled tight, collars **40** will serve as fulcrums causing the perforating units to be drawn tightly together in abutting end-to-end relation. In drawing the arm portions of the sling tight, the ends thereof will be led through longitudinally extending holes **43—43** provided in hanger sub **13** (FIG. 2A) and set screws **44** are screwed through the wall of the hanger sub to clamp the ends of the wire tightly against the walls of holes **43**, thereby effectively securing the sling to the hanger sub. In mounting the perforating devices in the sling, firing head **12** will be inserted into the lowermost collar **40**, which is positioned about lower end portion **21** of the lowermost ones of the perforating units **10**. The firing head, which is preferably made of light, thin metal, such as aluminum, has a central core **45** from which a pair of ribs **46** extend outwardly in opposite directions, defining shoulders **47** which are adapted to abut against the lower end of the lowermost collar **40** when core **45** of the head is inserted into the bore of the collar, as best seen in FIG. 4B. A second pair of ribs **48** extend oppositely from core **45** intermediate the ribs **46** and are of greater length than ribs **46**. Ribs **48** likewise have shoulders **49** adapted to abut the lower end of the lowermost collar **40**. Ribs **48** are split longitudinally to form the channels **50** through which the sling is threaded in passing it around the lower end of the string of charges. Thus, when the ends of the sling are drawn taut, head **12** will be pulled tightly up against the lower end of the lowermost collar **40**. Core **45** has an axial bore **51** adapted to receive an electrically fired detonating cap **52** (FIGS. 2C and 4B) which is secured in a manner to project from bore **51** into abutting engagement with end wall **22** of the lowermost perforating unit, being held in engagement by means of a wire clip **53** which extends transversely across the lower end of cap **52** and is secured on opposite sides thereof in openings **54—54** provided in ribs **46**, as best seen in FIG. 4B. An electrical conductor **16***a* is laid in groove **27** but extends only along one side of the string of perforating units, being threaded through the bores of the several collars **40**. This conductor is connected to cap **52** and a ground wire **55** is secured by means of a screw **56**, which is threaded into an opening **57** in one of the ribs **48** of the firing head to complete the electrical circuit to cap **52** (FIGS. 2C and 3). The upper end of conductor **16***a* is threaded through a bore **58** in hanger sub **13** and is connected at **59** to the main conductor lead **16**, which leads to the surface through cable **15**, and the other portions of the device above connector sub **13**.

One of the important features of the present invention is that casings **20** and collars **40** are all constructed of glass. The glass is desirably high strength boro-silicate glass, such as that made by Corning Glass Works, Corning, N.Y., which, while having great compressive strength sufficient to withstand high hydrostatic pressures, will, upon being shattered, break down into extremely fine powder-like particles. Other types of glass may, of course, be employed, since, in general, any glass material will, on being shattered, break down into quite small particles which will cause no difficulties in well pipes such

as is occasioned by detritus produced by metallic structures commonly used in perforating operations.

The thickness of wall sections **24** will be made such as to afford ready transmission of the shock wave from one of the units to the next. In general, the thickness of wall sections **24** will be in the range of from about 0.05 to 0.10 inch, depending upon the type of glass and the pressure conditions to which the casings are to be subjected. In the case of the particular glass mentioned above, this wall thickness will be about 0.09 inch.

FIG. 7 illustrates a somewhat modified form of the perforating unit. It includes a casing **20***a* which is identical in external configuration with casing **20** but differs therefrom primarily in the internal form of the end portions. In the modification of FIG. 7, the bores of end portions **21***a* are shaped to provide generally hemispheric recesses **23***a*. The apex portion of recess **23***a* defines a thin end wall section **24***a* which, except for its hemispheric interior shape, corresponds generally in thickness at the center to end wall section **24** of the previously described embodiment, particularly in having the substantially flat external end face **22***a*, as previously described.

A centralizer or spacer element **57***a* having a hemispheric shape complementary to that of recess **23***a* is seated in the latter and secured to the walls thereof by a suitable industrial adhesive. Centralizer element **57***a* has an axial bore **58***a* extending therethrough to receive the end of fuze element **35** which, as in the previously described embodiment may be encased with a booster explosive pellet **36** by means of the ferrule **37**. Centralizer element **57***a* is preferably constructed of glass, ceramic or other non-metallic readily frangible material which will shatter to a palpable powder upon explosion of explosive-shaped charge **30**. The latter and fuze element **35** are identical in form and arrangement to the previously described embodiment.

In operation, the string of units secured together in the manner described, will be lowered into a well to a point at which perforation is to be effected. Electrical current will then be sent through conductors **16** and **16***a* to fire cap **52**. The resulting detonation will be transmitted through the end wall sections **24** and thence through the several detonating fuzes **35**, setting off the several explosive charges in succession in upwardly ascending order. The detonation of the several perforating charges will, of course, shatter the casings **20** and collars **40**, as well as the wire comprising sling **11**. The wire, which is a relatively thin, high strength wire, represents only a small amount of metal, and as a result, very little detritus or so-called metallic "junk" can accumulate in the well, even though quite a number of the perforating units may be employed in the string. The type of detritus so formed is easily washed from the well by the flow of well fluids during the initial stages of production of the well.

In order to vary the spacing between the perforating units, where different spacing than that produced by directly abutting the units is desired, spacer units may be employed, these being illustrated in FIG. 5, wherein a spacer unit, designated generally by the numeral **60**, is shown interposed between a pair of the units **10**. Spacer unit **60** may be identical in construction to units **10**, except that the perforating charge **30** is replaced by a pair of coaxially aligned explosive caps **61** which extend longitudinally through the interior of the casing, having their opposite ends seated in the respective recesses **23**, the two caps being joined together by a short piece of Primacord **62**. As a result, when a detonating wave is transmitted through one of the perforating units **10** abutting a spacer unit, this detonating wave will travel through the abutting wall sections **24** into the adjacent end of one of the caps **61** and thence through the fuze section **62** and the other cap **61** to the next adjacent unit **10**. Any number of the spacing units **60** may be installed between perforating units to vary the spacing of the perforations, as may be desired by the operator.

Spacing units **60** may, if desired, be filled with lead shot **63** (FIG. 5) in order to increase the weight of the string, so that it may be more readily lowered through the fluids normally present in a pipe string or well bore into which it is run.

Ordinarily the over-all length of each of the units **10** will be about 3 inches so that if a series of units are assembled in a string without spacing units **60**, perforations will be made in 3 inch centers or four to the foot. The spacing units being substantially identical in size to the perforating units, by interspersing one spacing unit between each pair of perforating units, perforations on 6 inch centers will result. Also, if only one perforation per foot is desired, three spacing units will be interposed between each pair of perforating units. It will be understood that spacing units **60** need not be identical in size or form with the perforating units but may be of any suitable dimensions, provided they are capable of effectively transmitting the detonating shock wave from one perforating unit to the next.

Instead of the bottom-firing arrangement illustrated herein, the string may be fired by placing the initiator cap in detonating contact with the topmost perforting unit. Both firing arrangements are commonly employed in well perforating devices using multiple shots.

The sealed self-contained perforating units, such as herein described, provide, in addition to the numerous other advantages previously noted, an important function depending upon the relation of the volume of air or free space in the casings to the amount of explosive in the charges **31**. In the usual well perforating operation, the well pipe in which the perforator is run and which is to be perforated is generally filled with heavy mud or other liquid. Also, the well pipe to be perforated will most often be tubing having an internal diameter of two inches or less. In such narrow confines and being submerged in liquid, the perforating units will, when fired, generate heavy shocks which, by reason of the incompressibility of the submerging liquid, will be transmitted to the pipe walls and to the cement sheath normally surrounding the pipe. As a result, in addition to the perforations effected by the shaped charges, the pipe may be ruptured and the cement sheath shattered or cracked over substantial length, permitting leakage of formation fluids through the thus broken cement, a condition which can be highly destructive to the well.

With perforating units constructed according to this invention, the free space inside each casing **20** being filled with air, provides a compression chamber and a compressible medium which will absorb most of the undesirable shock produced by the detonation of the perforating charges and thereby obviate the undesirable results mentioned above.

To provide this shock-absorbing characteristic, the size of casings **20** may be selected so to provide a predetermined volume of free air space in relation to the mass of the explosive charge. In general, it is found that from about 5 cc. to about 10 cc. of free air space per gram of explosive will effectively reduce the collateral shock of the explosion to magnitudes which will not seriously damage the pipe or the surrounding cement sheath.

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

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

1. An expendible perforating gun assembly for use in wells, comprising, a plurality of self-contained perforating units, each unit including a hollow casing adapted for carrying a shaped explosive charge and having closed opposite end portions, and carrier means for supporting said units in an elongate string with said end portions

in abutting end-to-end relation, said carrier means including collar members separate from and surrounding each pair of abutting end portions, a generally U-shaped flexible wire sling having its bottom portion disposed in supporting relation beneath the lowermost one of said units and its arm portions threaded through the bores of said collar members and extending upwardly along opposite sides of said units, and means securing the upper ends of said arm portions in tension about said units, said casings and said collar members being constructed of glass.

2. A perforating gun assembly according to claim 1, including means mounted on said carrier for firing said charges from one end of said string.

3. An expendible perforating gun assembly for use in wells, comprising, a plurality of self-contained perforating units, each unit including a hollow casing adapted for carrying a shaped explosive charge, each of said units having closed opposite end portions of reduced diameter with respect to the intervening portion of the casing, and carrier means for supporting said units in an elongate string with said end portions in abutting end-to-end relation, said carrier means including a hanger member disposed above the uppermost one of said units, a generally U-shaped flexible wire sling depending from said hanger member, said sling having its bottom portion disposed in supporting relation between the lowermost one of said units and its arm portions extending upwardly along opposite sides of said units, means securing the upper ends of said arm portions to said hanger member in tension about the string of units, collar means separate from and slidably surrounding each pair of abutting end portions and the adjacent portions of said sling to secure said units to the sling, the internal diameter of said collar means being less than the external diameter of said intervening casing portions whereby to radially constrict said adjacent portions of said sling to increase the tensional force exerted by said sling to urge the abutting end portions of said units into tight engagement, said casings and said collar means being constructed of glass.

4. A perforating gun assembly according to claim 3, including means mounted on said carrier for firing said charges from one end of said string.

5. An expendible perforating gun assembly for use in wells, comprising, a plurality of self-contained perforating units, each unit including a hollow casing adapted for carrying a shaped explosive charge and having closed opposite end portions, and carrier means for supporting said units in an elongate string with said end portions in abutting end-to-end relation, said carrier means including collar members separate from and surrounding each pair of abutting end portions, a generally U-shaped flexible wire sling having its bottom portion disposed in supporting relation beneath the lowermost one of said units and its arm portions threaded through the bores of said collar members and extending upwardly along opposite sides of said units, and means securing the upper ends of said arm portions in tension about said units.

References Cited by the Examiner

UNITED STATES PATENTS

2,708,408	5/55	Sweetman	102—20
2,761,383	9/56	Sweetman	102—20
2,819,673	1/58	Cecil et al.	102—20
2,927,534	3/60	Le Bus	102—20
2,990,773	7/61	Toelke	102—20
2,990,774	7/61	Toelke	102—20
3,040,659	6/62	McCullough	102—20

SAMUEL FEINBERG, *Primary Examiner.*