Nov. 22, 1960 F. H. BELL 2,960,930

WELL PERFORATING APPARATUS

Filed April 3, 1957 2 Sheets-Sheet 1

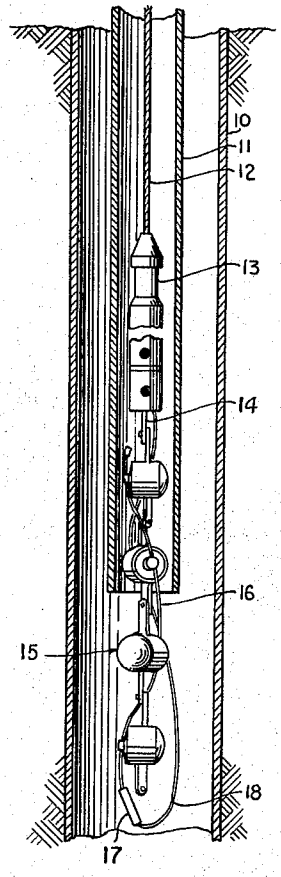


Fig. 1

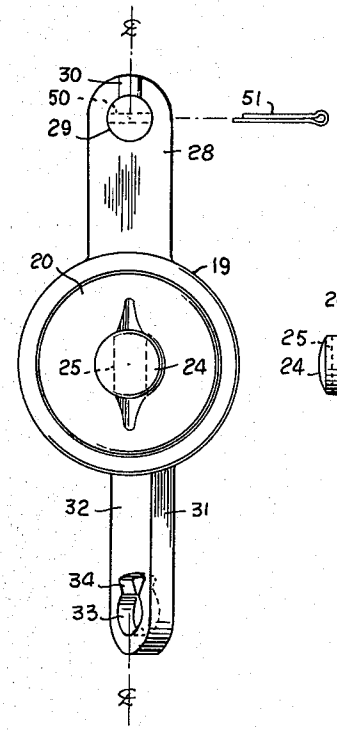


Fig. 2

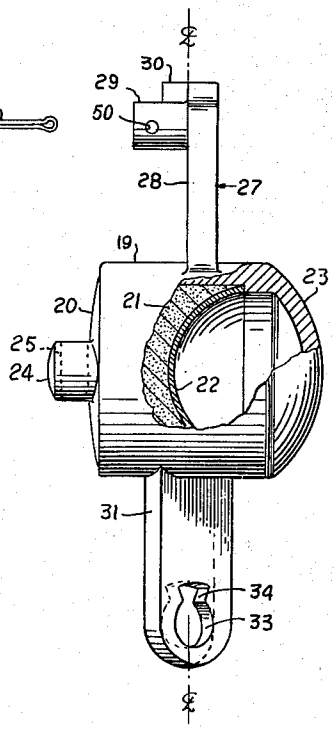


Fig. 3

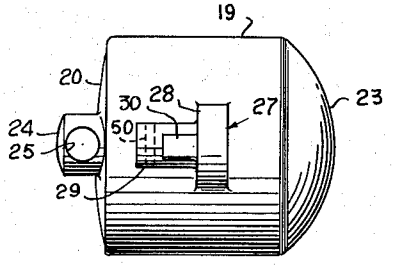


Fig. 4

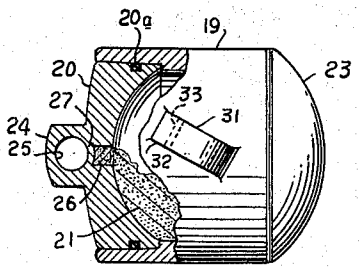


Fig. 5

INVENTOR
Frederick H. Bell

BY John O. Evans, Jr.
ATTORNEY

Nov. 22, 1960 F. H. BELL 2,960,930

WELL PERFORATING APPARATUS

Filed April 3, 1957 2 Sheets-Sheet 2

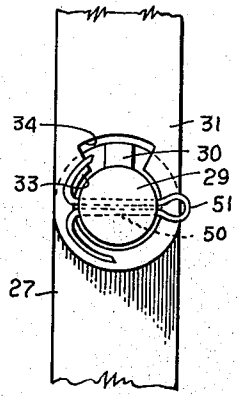


Fig. 6

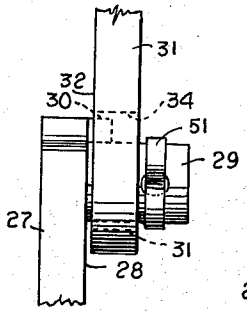


Fig. 7

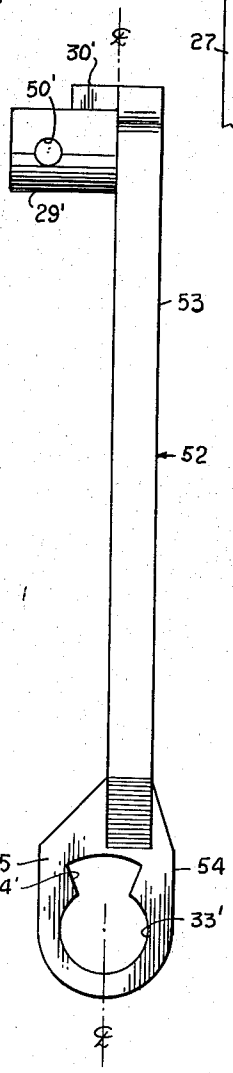


Fig. 8

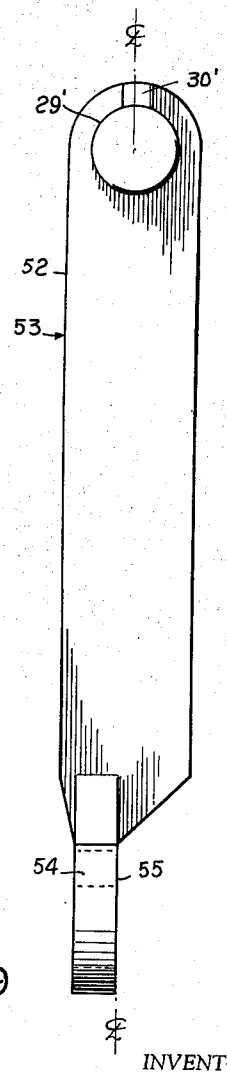


Fig. 9

INVENTOR

Frederick H. Bell

BY John O. Evans, Jr.

ATTORNEY

United States Patent Office 2,960,930
Patented Nov. 22, 1960

2,960,930

WELL PERFORATING APPARATUS

Frederick H. Bell, Arlington, Tex., assignor to Jet Research Center, Inc., Arlington, Tex., a corporation of Texas

Filed Apr. 3, 1957, Ser. No. 650,335

7 Claims. (Cl. 102—20)

This invention relates to well perforating apparatus and more particularly to such apparatus in which individual shaped explosive charge units are linked together to form a chain of units. The invention also relates to the individual shaped charge explosive units themselves.

In the perforation of oil wells, it is desirable to have perforating apparatus that may be quickly assembled in the field to provide a perforating gun of a length and having a number of perforating units suited to the job at hand. For the sake of simplicity and speed of operation, it is also desirable that a minimum number of tools be needed to assemble the perforating apparatus.

Frequently, oil wells are completed by so-called permanent type completion methods. In these methods, tubing is set in the casing and the top of the casing is capped with the usual well head equipment prior to performance of the perforating step. Perforating apparatus is then lowered by cable through the tubing and out of its lower end to the level at which the casing is to be perforated and the apparatus is fired. Any parts of the perforating apparatus that remain attached to the cable after firing are retrieved by withdrawal through the tubing. For these purposes, the perforating apparatus must be as efficient as possible. One requirement is that the apparatus must have a close sliding fit in the tubing in order to accommodate the largest possible quantity of explosive in each perforating unit which is designed to fire generally laterally of the well bore. At the same time, the apparatus must not bind in the tubing during descent.

The permanent type completion method is being adapted to directional wells wherein the well may be drilled vertically for a certain distance down from the earth's surface, and thereafter drilled at an angle to the vertical. Also, in some offshore installations the production tubing may rise vertically from the bottom of the well and thereafter be turned landward and run to the shore. In either case, the tubing is rather sharply bent at certain points which makes it very difficult to run perforating apparatus through the tubing.

An object of the invention is to provide a well perforating apparatus which may be quickly assembled in the field principally from a plurality of identical, shaped explosive charge units. Due to the special construction of the charge units, such assembly may be accomplished without the use of tools.

Another object is to provide a perforating unit, a plurality of which may be linked together to form a perforating assembly of any desired length.

Another object of the invention is to provide a perforating assembly having articulated joints and being adapted to pass through relatively sharp bends in small diameter tubing. In addition to being adapted to pass through relatively sharp bends that are purposely made in tubing, it is a further object of the invention to provide a perforating assembly that can be run through closely fitting tubing that is inadvertently bent, twisted,

dented or otherwise damaged to a limited degree, as by being burred or somewhat corroded in the bore.

Still another object is to provide apparatus for perforating oil, gas and water wells that may be employed in permanent type completion methods.

Yet another object of the invention is to provide well perforating apparatus that is relatively simple and inexpensive to manufacture and that may be conveniently and rapidly assembled in the field.

Another object of the invention is to provide a well perforating apparatus including a plurality of capsulated shaped explosive charge perforating units linked together by a pivotal linkage construction having cooperating stops for limiting relative pivotal movement of adjacent units.

Another object of the invention is to provide blank interval members in a well perforating apparatus of the character disclosed which members carry no perforating charges but are linked in the assembly like the perforating units themselves.

These and other objects and advantages of the invention as may appear hereinafter are achieved in a well perforating apparatus that is adapted to be passed through small diameter tubing having relatively sharp bends which includes a plurality of longitudinally aligned well perforating units, articulated means linking adjacent units together to form a chain, and means limiting the angular movement of adjacent perforating units about the included linking means. The articulated joints lend flexibility to the chain of units permitting it to pass through sharply curved sections of narrow tubing. The articulated joints may include a pivot pin carried by one unit received in a complementary hole provided in an adjacent unit. Such joints may include a key or the like that retains the pivot pin in the hole and complementary stop means on adjacent units limiting their relative angular movement about the pivot point.

More particularly, the shaped explosive charge well perforating apparatus of the invention has a plurality of vertically aligned well perforating units, each unit including a pressure resistant, frangible container having a shaped explosive charge therein adapted upon detonation to project an explosive jet outwardly through a wall of the container and having a vertical axis intersecting the axis of the explosive jet at a substantial angle, the vertical axes of the unit being in alignment to define the vertical axis of the well perforating apparatus; the container of each unit having an upstanding and a depending arm; one of said arms having a terminal planar face containing the vertical axis of the unit; a cylindrical pin carried by said one arm, the pin extending from the terminal face and having its axis intersecting the vertical axis of the unit at right angles, the pin providing a transverse keyhole therethrough spaced from the terminal face, and a lug extending radially from the pin between the terminal face and the keyhole. The other of the arms has a terminal planar face containing the vertical axis of the unit, the other arm providing a cylindrical hole therethrough having its axis intersecting the vertical axis of the unit at right angles within the terminal planar face, the other arm having a lug-receiving recess communicating with the hole and extending radially outwards therefrom. The perforating units are linked together to form a chain wherein the pin on the one arm of one unit is received in the hole of the other arm of an adjacent unit, the terminal faces of the arms are in abutment and the lug is received in the recess, the sides of the lug being spaced from the sides of the recess to limit arcuate movement of the pin in the hole, and a key is disposed in the keyhole of the pin to retain the arm of the adjacent unit in the pin.

The present invention is an improvement in the in-

vention disclosed and generically claimed in the copending application of Blake M. Caldwell, Serial No. 650,334, filed April 3, 1957, for "Well Perforating Apparatus," which copending application is assigned to the same assignee as the present application.

The invention will be described with greater particularity with reference to the drawings in which:

Fig. 1 is a vertical sectional view through a portion of an oil well showing an exemplary embodiment of the well perforating apparatus of the invention suspended in the well;

Fig. 2 is an enlarged elevational view of one of the shaped charge perforating units used in the apparatus of Fig. 1;

Fig. 3 is a right hand side view of the shaped charge perforating unit of Fig. 2, parts of the shaped charge container being broken away;

Fig. 4 is a plan view thereof;

Fig. 5 is a bottom view thereof;

Fig. 6 is a still further enlarged fragmentary view showing one of the articulated joints of the well perforating apparatus;

Fig. 7 is a left hand view of the joint shown in Fig. 6;

Fig. 8 is an elevational view of a blank interval unit; and

Fig. 9 is a left hand view of the blank interval unit shown in Fig. 8.

Referring to the drawing, particularly to Fig. 1, there is shown a section of an oil well having a casing **10** in which production tubing **11** is set. The perforating apparatus of the invention is shown as being suspended from the cable **12** which carries, as is conventional, a conductive wire through which current is passed for the purpose of firing the well perforating apparatus. The well perforating apparatus is lowered from the surface of the earth in well known manner.

The cable head **13** hangs from the lower end of the cable. From the bottom of the cable head an arm **14** depends, and this arm supports a plurality of interlinked, shaped explosive charge, well perforating units designated by the general reference numeral **15**. The perforating units are fired in a manner to be explained more fully hereinafter by a detonating fuse or Primacord **16** disposed adjacent the rear ends of the shaped charge units. Affixed to the lower end of the Primacord **16** in detonating relation thereto is a detonator or blasting cap **17**. A pair of wires **18**, through which igniting current is conducted to the blasting cap **17**, extend from the blasting cap and are wound in an upward direction about the chain of perforating units to enter the cable head **13** in which they are connected to the firing circuit.

The perforating apparatus is seen partially inside of the lower end of the tubing **11**. Before firing it is lowered below the bottom of the tubing to a point opposite the section of the casing to be perforated.

Referring to Figs. 2 through 5, the perforating unit of the invention has a charge case **19** closed at its rear end by a cap **20**. The cap fits tightly in the rear end of the case and the case may be sealed against ingress of bore fluids by means of an O-ring **20***a* or similar compressible seal interposed between the cap and the case. Disposed within the case near the rear end thereof is a charge of compressed high explosive **21** having a forwardly facing cavity therein lined with an inert liner **22**, preferably of copper or other metal. Stand-off space is provided between the front face of the liner **22** and the front wall **23** of the charge case to permit the perforating jet to form within the case upon detonation of the charge.

The cap **20** has a rearwardly projecting cylindrical boss **24** through which is bored a vertically extending fuse passage **25**. As shown in Fig. 5, the cap **20** has a booster cavity **26** separated from the fuse passage **25** by a thin wall **27'** through which detonating energy from the Primacord is transmitted to a booster charge in the cavity. The booster charge initiates the main explosive charge **21** to produce an explosive jet from the liner, the jet being projected forwardly along the cylindrical axis of the charge. This jet forms in the air space forwardly of the liner **22** and penetrates the front wall **23** of the charge case. Thereafter it penetrates the wall of the adjacent casing and perforates the surrounding earth formation. Upon detonation, some of the energy of the explosive charge serves to break or fracture the charge case and arms, forming small fragments and particles that fall harmlessly to the bottom of the well.

The charge case has an upstanding arm **27**, the face **28** of which contains the vertical center line CL of the unit. The face **28** is disposed at right angles to the charge axis. From the upper terminal end of the face **28** a cylindrical pivot pin **29** extends perpendicularly, the axis of the pin intersecting the center line. A lug **30** projects radially from the side of the pin **29** and extends in a direction upwardly along the center line CL. The lug also extends axially along the side of the pin **29** to a point near the hole or keyway **50** and between the hole **50** and the arm face **28**. A key **51** is inserted through the hole **50** in linking the charge units together, as will be explained more fully hereinafter. As shown, the upstanding arm **27** is of uniform thickness; however, the thickness does not have to be uniform as long as the terminal end of the planar face **28** adjacent the pin **29** is in a plane containing the center line.

The case of the unit also has a depending arm **31** which, in the embodiment shown, is of the same length as the upstanding arm **27**. The surface **32** of the depending arm contains the center line of the perforating unit. A cylindrical hole **33** is formed in the lower end of the depending arm. This hole is at right angles to the plane of the surface **32** and its axis intersects the center line. Extending upwardly from the hole **33** is an arcuate slot **34** that communicates with the hole and extends in a vertical direction along the center line CL of the perforating unit. The arcuate slot extends entirely through the arm **31**. It receives the lug **30** of a subjacent perforating unit when the apparatus is assembled and limits the pivotal movement of adjacent perforating units. In the particular form shown, the terminal end of the depending arm is of uniform thickness and the lower end of the face **32** contains the center line. However, the end of the arm near the case may be thicker or thinner than shown as desired. It will be noted that the depending arm makes an angle of 30° with the axis of the shaped explosive charge as best seen in Fig. 5.

Figs. 6 and 7 show in enlarged fragmentary detail the manner in which the upstanding arm **27** of one perforating unit is linked to the depending arm **31** of an immediately superjacent shaped charge unit. It will be seen that the pin **29** is received in the hole **33** with the lug **30** disposed in the arcuate slot **34**. A cotter key **51** is inserted in the keyway **50** of the pin **29** and the ends of the cotter key are bent over as shown to secure the depending arm **31** of the upper perforating unit to the pin **29**. As clearly shown in Fig. 6, the lug **29** is narrower than the arcuate slot **34** so that a limited pivoting of the arm **31** on the pin **29** is permitted before the sides of the lug engage the sides of the arcuate slot to stop the pivotal movement in either direction. In practice, it has been found that a pivotal movement of from a few degrees to as much as 30° to 45° is desirable and the lug and arcuate slot may be proportioned to permit any desired pivotal movement. The diameter of the hole **33** is somewhat greater than the diameter of the pin **29** providing a loose fit of the pin in the hole. It is also seen that the radius of the lug **30** is somewhat smaller than the radius of the arcuate slot **34** which also provides a loose fit. Referring to Fig. 7 it is seen that the distance from the terminal planar face **28** of the arm **27** to the cotter key **51** is somewhat greater than the thickness of the depending arm **31**, providing for a free fit of the arm **31** between the cotter key and

the arm 27. This free fit allows limited rocking movement in the plane of the drawing of Fig. 7 of the arm 31 in relation to the arm 27 and thus enhances the flexibility of the assembled perforating gun.

It will be apparent that the perforating units may be readily linked together and unlinked without the use of any tools, it being merely necessary to manually insert or remove the cotter key 51. As is seen from Fig. 7, the terminal planar face 32 of the arm 31 is opposed to the terminal planar face 28 of the arm 27 when the units are properly assembled. Thus, the center lines of adjacent charge units are substantially in alignment.

The charge units in assembled relationship as shown in Fig. 1 are adapted to be run through narrow tubing with close clearance. For this purpose, the charge containers are especially dimensioned to provide surfaces that will slide through narrow tubing without binding and will maintain alignment of the charge units. As seen in Figs. 3, 4 and 5, the front face 23 of the charge case is a segment of a sphere having its center on the center line of the charge unit at its intersection with the horizontal axis of the charge case 19. The boss 24 has a spherical rear face with its center at the same point and having the same radius as the front face 23. The circular rear edge of the charge case 19 lies in this sphere as does also the circular forward edge of the charge case where the spherical front face 23 intersects the cylindrical portion of the case 19. Thus it is seen that the charge case and cap provide a container in which all surfaces that can slide against the tubing are located on a spherical surface having its center on the center line of the perforating unit and preferably at a point midway between the axis of the pin 29 and the axis of the hole 33. Whereas, the arms 27 and 31 are shown as being of equal length, it will be understood that they may have different lengths, if desired, or they may be proportionately longer or shorter than shown in the drawings.

Owing to the hereinbefore described geometery of the charge unit, a linked assembly of such units will readily pass through a straight length of tubing having a bore with a diameter only slightly larger than the diameter of the spherical surface containing the faces and edges of the charge container that make sliding contact with the bore of the tubing. These faces and edges are termed the skating faces of the charge container, since they slide or skate along the bore of the tubing. Such an assembly of units is free to rotate on its vertical axis within the confines of closely fitting straight tubing without substantial lateral displacement of any of the units from alignment with the vertical axis of the assembly and without becoming lodged in the tubing as it is lowered therethrough. Moreover, the articulated joints linking adjacent units together and the angular phasing of such joints about the vertical axis of the assembly allow the assembly to pass readily through rather sharply curved lengths of closely fitting tubing.

The foregoing is exemplified in an actual embodiment of the invention constructed in accordance with the accompanying drawing in which the distance between centers of the pin 29 and the hole 33 was 3", the diameter of the spherical surface containing the aforementioned faces and edges of the charge container was $1\frac{11}{16}$", and the center of the spherical surface was located on the center line of the charge unit midway between the pin 29 and the hole 33. Ten charge units so constructed and dimensioned when linked together to form a chain, as shown in Fig. 1, were found to run freely in straight lengths of tubing having a bore measuring 2" in inside diameter and to negotiate bends in such tubing having a radius of 5' without binding or becoming lodged therein.

In preparing or assembling a perforating gun in the field, a charge 15 is linked to the arm 14 of the cable head 13. The arm 14 has a hole and arcuate slot therethrough, similar to the hole and arcuate slot of the charge unit hereinbefore described, in which the linking pin of

the topmost charge unit is inserted. As many additional perforating units as desired are added to form a chain of units. It will be seen that adjacent charge units are disposed at an angle of 120° to each other about the vertical axis of the assembly. Detonating fuse 16 is threaded through the passageways 25 of the perforating units and wound about the assembly in helical disposition as shown. The lower end of the fuse 16 is equipped with a detonator 17, the wires 18 of which are led upwardly to the cable head in which they are connected to the firing circuit whereby the detonator may be initiated from the surface of the earth. The assembly is lowered into the well as shown in Fig. 1 to the desired level. The firing circuit is energized. The blasting cap 17 detonates the Primacord 16 which practically simultaneously detonates the individual perforating units 15 to perforate the casing and surrounding earth formation. The charge units 15 are frangible and are broken into small fragments which fall to the bottom of the well as innocuous debris. The cable head 13 is of massive construction and is not destroyed by the explosion. It is withdrawn after firing for re-use.

While the well perforating unit shown in the drawings has but a single hole 33 in the depending arm 31, it is contemplated that an additional hole or holes of the same kind may be formed in the arm 31, thus giving a selection of holes in any one of which the pin of an adjacent unit may be inserted, whereby the spacing of the charges may be varied in assembling the units. The plurality of holes are spaced along the center line of the charge unit. Score marks may be made between adjacent holes along which that portion of the arm 31 below the hole that is selected for use may be broken off and discarded.

A blank interval member or unit 52 is shown in Figs. 8 and 9. This unit has an elongated flat body 53 having a pin 29' at the upper end provided with a keyway 50' and a lug 30' similar to the pin and lug construction of the perforating unit shown in Figs. 2 through 5. The axis of the pin 29' intersects the center line at right angles as best seen in Fig. 9. At the lower end of the blank interval unit is provided a flange 54 that lies in a plane at right angles to the plane of the body 53. The surface 55 of the flange includes the center line CL. A cylindrical hole 33' is formed through the flange 54 and a connected arcuate lug receiving slot 34' is also provided for purposes similar to the hole 33 and arcuate slot 34 in the depending arm 31 of the shaped charge unit shown in Figs. 2 through 5. Although the flange 54 of the illustrative blank interval unit is shown as being at right angles to the plane of the body 53 and parallel to the axis of pin 29', it will be understood that this angle may be varied as desired.

It will be apparent that one or any number of the blank interval members may be inserted in or substituted for the shaped charge explosive units 15 in the assembly shown in Fig. 1 where it is desired to space the active charge units 15 at desired vertical intervals.

From the foregoing description of a typical embodiment of the invention, persons skilled in the art will readily perceive a wide variety of variations and modifications coming within the spirit of the invention and the scope of the claims. For example, it is contemplated that the detonating fuse 16 may be fired from the top instead of from the bottom by merely changing the position of the blasting cap 17. It is also contemplated that the lower end of the assembly may be provided with a suitable bull plug if desired. It is also contemplated that the perforating units need not embody shaped explosive charge devices; instead, they may include bullet perforating devices. Although, in the illustrative chain of units herein disclosed, adjacent charges are phased at angles of 120° to each other, any other convenient phase angle may be employed; for example angles of 60°, 90° or 180° may be found convenient, or all charges may face in the same direction.

I claim:

1. Shaped explosive charge well perforating apparatus adapted to be passed through small diameter tubing having relatively sharp bends comprising: a plurality of vertically aligned well perforating units, each unit including a pressure resistant, frangible container having a shaped explosive charge therein adapted upon detonation to project an explosive jet outwardly through a wall of the container and having a vertical axis intersecting the axis of the explosive jet at a substantial angle, the vertical axes of said units being in alignment to define the vertical axis of the well perforating apparatus; the container of each unit having a single upstanding and a single depending arm; one of said arms having a terminal planar face containing the vertical axis of said unit; a cylindrical pin carried by said one arm, said pin extending perpendicularly from said terminal face and having its axis intersecting the vertical axis of said unit, said pin providing a transverse keyhole therethrough spaced from said terminal face, and a lug extending radially from said pin between said terminal face and said keyhole; the other of said arms having a terminal planar face containing the vertical axis of said units, said other arm providing a cylindrical hole therethrough extending perpendicularly to the terminal planar face and having its axis intersecting the vertical axis of said unit, said other arm having a lug-receiving recess communicating with said hole and extending radially outwards therefrom; said perforating units being linked together to form a chain wherein the pin on the one arm of one of said units is received in the hole of the other arm of an adjacent unit, the terminal faces of said arms are in abutment, and said lug is received in said recess, the sides of said lug being spaced from the sides of said recess to limit arcuate movement of said pin in said hole; and a key disposed in the keyhole of the pin of said one arm retaining the arm of the adjacent unit on the pin.

2. Well perforating apparatus adapted to be passed through small diameter tubing having relatively sharp bends comprising: a plurality of vertically aligned well perforating units; each unit having a single upstanding and a single depending arm; each of said arms having a terminal planar face, said terminal planar faces containing at least one common straight line; said units being assembled with the terminal planar face of the depending arm of each unit abutting the terminal planar face of the upstanding arm of the immediately subjacent unit; pivot means interconnecting adjacent units for relative pivotal movement of said adjacent units about an axis extending perpendicularly from said abutting planar faces and intersecting said common straight line; complementary pivot interlocking means carried by said arms; and complementary stop means carried by said arms limiting relative pivotal movement of the units about the axis of said pivot means.

3. Well perforating apparatus as defined in claim 2 wherein said pivot means includes a pin extending from one of said abutting planar faces received in a complementary hole extending from the other of said abutting planar faces.

4. Well perforating apparatus as defined in claim 2 wherein said pivot means includes a pin extending from one of said abutting planar faces received in a hole extending from the other of said abutting planar faces and said complementary stop means includes a lug extending radially from said pin received in an arcuate slot extending radially from said hole.

5. Well perforating apparatus as defined in claim 2 wherein said pivot means includes a pin extending from one of said abutting planar faces received in a hole extending from the other of said abutting planar faces, said complementary stop means includes a lug extending radially from said pin received in an arcuate slot extending radially from said hole, and means preventing withdrawal of said pin from said hole.

6. A well perforating unit comprising: a container having an explosive charge therein adapted to project a perforating means outwardly therefrom; a single upstanding unit-interconnecting arm on said container; a single downwardly extending unit-interconnecting arm on said container; each of said arms having a terminal planar face; said terminal planar faces containing at least one common straight line; complementary pivot means carried by said arms and extending perpendicularly one from each of said terminal faces with the pivot axes of said pivot means intersecting said common straight line; complementary pivot interlocking means carried by said arms; and complementary pivotal-movement-limiting stop means carried by said arms.

7. A well perforating unit as defined in claim 6 wherein said complementary pivot means includes a pin extending from one of said terminal faces and a hole extending from the other of said terminal faces; and wherein said complementary pivotal-movement-limiting stop means includes a lug extending radially from said pin and an arcuate slot extending radially from said hole, said slot having a greater radius and a greater arcuate length than said lug, said lug and said slot each being spaced the same distance from the terminal planar face of its respective arm.

References Cited in the file of this patent

UNITED STATES PATENTS

548,899	Wade	Oct. 29, 1895
1,598,293	Luck	Aug. 31, 1926
2,026,061	Prikel	Dec. 31, 1935
2,616,370	Foster	Nov. 4, 1952
2,633,329	LeBus	Mar. 31, 1953
2,799,224	Long	July 16, 1957
2,853,944	Robertson	Sept. 30, 1958

FOREIGN PATENTS

701,074	Great Britain	Dec. 16, 1953