This invention relates to perforating apparatus and, more particularly, to shaped charge devices commonly known as capsule guns or perforators for use in a well bore to produce penetrations in earth formations.

So-called capsule type shaped charge perforators employed in oil well perforating typically are comprised of individual, fluid-tight, fragile, hollow containers linked to one another to form a chain-like assembly of containers. In each of the containers is a shaped charge adapted to develop a perforating jet for penetrating earth formations.

The容器s generally are provided with pin and socket type extensions loosely interconnected to afford some flexibility of the chain assembly. Thus, a long chain assembly of charges, when passed through a tubing, may faithfully follow whatever turns the tubing may take in the borehole without binding or sticking of the chain assembly in the tubing.

For many applications, the chain assembly is lowered beyond the end of a tubing to perforate a casing and, hence, the situation arises where the orientation of directions in which the shaped charges in the assembly will perforate becomes important to obtain the most effective penetration possible.

Another object of the present invention is to provide a new and improved capsule type perforator.

A further object of the present invention is to provide a new and improved capsule type perforator wherein an alternate direction of firing of shaped charges in an assembly are determined in a prescribed manner.

Another object of the present invention is to provide a new and improved shaped charge capsule container constructions providing a novel connecting arrangement.

Apparatus in accordance with the present invention includes shaped charge capsules having extensions which are slotted at their end for tongue and groove interconnection, thereby limiting relative pivotal movement of the capsules in an assembly to a single plane. Magnetic orienting apparatus having a resultant directional force of magnetic attraction lying in a plane extending longitudinally of the apparatus is aligned with the plane of pivotal movement of the capsule assembly to control the direction of firing of the capsules. The shaping of the tongue and groove connection provides for limited pivotal movement between adjacent capsules. Distinct coupling connections at the end of respective capsule extensions provide for a selected orientation of the capsules in an assembly. The distinct coupling connections may include different connecting pin sizes, different sizes of slots as well as different depths of slots.

The novel features of the present invention are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by way of illustration and example of certain embodiments when taken in conjunction with the accompanying drawings in which:

FIG. 1 is an elevational view of a shaped charge assembly embodying the features of the present invention;

FIG. 2 is a top view of portions of the shaped charge assembly in a well bore casing;

FIG. 3 is a view in partial cross section of an individual capsule device;

FIG. 4 is a top, cross-sectional view of a magnetic orienter for use with the present invention.

FIG. 5 is an enlarged view of a preferred capsule linkage embodying the present invention;

FIGS. 6 and 7 are top and front views respectively taken along lines 6-6 and 7-7 of FIG. 3;

FIGS. 8 and 9 are views taken along lines 8-8 and 9-9 of FIG. 6;

FIGS. 10 and 11 are views illustrating the interconnection of individual capsule devices in different positions as taken along line 10 of FIG. 1;

FIG. 12 is a view of a spacer for use with the assembly embodying the present invention;

FIGS. 13a, 14a and 15a are schematic illustrations employed in conjunction with FIGS. 13a, 14a and 15a;

FIG. 16 is a partial view of a tool assembly in accordance with the present invention.

Referring now to FIG. 1, a chain assembly 18 includes a number of typical shaped charge capsules 21, 21a, 21b and, in the drawings, the subscripts "a" and "b" are employed to distinguish separate capsules from one another. Since the capsules 21, 21a, 21b are identical, only one such capsule need be described.

Capsule 21 typically has forward and rearward portions 19 and 20 axially aligned relative to a transverse central axis 22 which is perpendicular to and intersects longitudinal axis 23 of the capsule (see also FIG. 2). The capsule also has differently arranged extensions "A" and "B" also aligned to be intersected by longitudinal axis 23, the extensions having slots 29 and 30 in their respective ends.

Capsule 21 includes a hollow container 28 (FIG. 3) constructed of a fragile material such as aluminum which receives a shaped charge explosive 24 provided with a liner 25 in a conventional manner and a closure cap 26 (shown in dashed lines) received over the open end of container 28 which thereby provides a fluid-tight enclosure of the explosive 24. The explosive 24 is arranged to be detonated from the forward portion 20 of the capsule to develop a perforating jet emanating from the forward portion 19 along a jet axis which coincides with the central axis 22 of the capsule. To detonate the explosive 24, a detonating cord means 27 is received in the rearward portion 20 of the capsule 21 and extends lengthwise of the capsule (see FIG. 1) in a conventional manner.

The chain assembly 18 is formed by assembling like extensions of adjacent capsules to one another in a tongue and groove fashion. For example, as shown in FIG. 1, extension B of capsule 21 interfits with extension B of capsule 21a and a pin connection 32 serves to pivotally couple the extensions to one another. Extension A of capsule 21 interfits with extension A of capsule 21a and a pin connection 32a, similar to pin connection 32, pivotally couples extensions A and Aa to one another. The axes of the pin connections 32 and 32a are arranged parallel to one another in the extensions A and B, so that the capsules 21, 21a, 21b can pivot relative to one another in only a single alignment (see FIG. 2) in which all of the longitudinal axes of the capsules lie, as will be more fully explained hereinafter.

A cylindrical, magnetic orienting device 34 (FIG. 4) is connected (as shown in FIG. 16) to the upper end of the chain assembly 18 to magnetically clamp to a casing 35 in a well bore (or a tubing as the case may be), the device 34 having a resultant force of magnetic attraction which lies in a plane extending longitudinally of device 34 and operates in a single direction as shown by the arrow 36 (FIG. 2). Thus, when the assembly 18 and device 34 are lowered through a tubing string (not shown) by means of the conventional cable and winch assembly (not shown), the assembly 18, upon entering the string of casing 35 below the tubing, is
positioned relative to the casing 35 of means of the magnetic orienting device 34. The magnetic orienting device 34 may, for example, be comprised of a number of permanent magnets 37 secured to a nonmagnetic housing shell 38, so that the outwardly facing pole pieces of the magnets 37 produce a resultant force of magnetic attraction operating in the single direction. The alignment plane "P" of chain assembly 18 may then be disposed so as to bisect the air gap between pole pieces of the magnets 37 and, therefore, be aligned with the resultant force of magnetic attraction.

The perforating axes 22 of the chain assembly 18 are positioned relative to the alignment plane "P" by a pre-operational alignment of the magnetic device 34 with respect to the capsules 21 in the assembly 18. For example, as shown in FIG. 2, the capsule assembly 18 may have a typical arrangement, as illustrated by capsules 21 and 21b, such that the transverse axes 32 and 22b (and also the perforating axes) of the adjacent containers are angularly disposed at 120° to one another and respectively intersect the corresponding central axes 23 and 23b of each capsule. With a 120° phasing, the transverse axes 22 and 22b of the capsules 21 and 21b may be disposed at positive and negative angles of 60° relative to the alignment plane "P." It should be noted that the alignment plane "P" intersects the central longitudinal axes 23, 23b, as well as the generatrix of contact resulting from the force of magnetic attraction between the magnetic device 34 and casing 35. As was noted above, the capsules can pivot only in the alignment plane "P" so that the 60° phasing of the axes 22 relative to the alignment plane "P" is always maintained.

Referring now to FIGS. 5-7, which relate to capsule 21, a completely foolproof arrangement is disclosed for insuring the correct interconnection of adjacent capsules to alternate the direction of firing. Extensions "A" and "B" are substantially square in cross section and the ends of the extensions respectively have rectangular slots or grooves 29 and 30. Slot 29 in extension "A" forms inner and outer lugs 40 and 41, respectively, which have flat facing surfaces 42, 43 lying in parallel planes which are disposed at an angle of 90° relative to the transverse axis 22. Inner surface 42 is disposed at an angle of 60° relative to the plane containing the intersecting transverse axis 22 and longitudinal axis 23, the axis 23 bisecting the surface 42. Slot 20, in a like manner, forms inner and outer lugs 50 and 51, respectively, which have flat facing surfaces 52, 53 lying in planes which are disposed at an angle of 90° relative to transverse axis 22. Inner surface 52 is likewise disposed at an angle of 60° relative to the plane containing the intersecting transverse axis 22 and longitudinal axis 23, the axis 23 bisecting the surface 52. Hence, the extensions "A" and "B" are offset or displaced from axis 23 and relative to one another so that the flat facing surfaces 42 and 52 of each inner lug 40 and 50 lie in the common alignment plane "P" and the alignment plane "P" is disposed at an angle of 60° relative to the plane containing transverse axis 22 and longitudinal axis 23. Slot 29 in extension "A" has a width W and is disposed in the extension so that inner lug 40 has a thickness slightly less than width W. Outer lug 41 has a protuberance 44 which makes the outer lug thick enough to prevent the outer lug 41 from fitting in a slot 29a of a subjacent extension "A." It will therefore be appreciated that like extensions "A" of adjacent capsules can be tongued and groove connected in only one way, i.e. only the inner lug 40 can be received by a slot 29b while the inner lug 40b of a subjacent extension "A" is received by the slot 29b.

In the remaining extension "B," slot 30 has a width W and is disposed so that the inner lug 50 has a thickness slightly less than the width W. Outer lug 51 has a protuberance 54 which makes the outer lug thick enough to prevent the outer lug 51 from fitting in a slot 30a of a subjacent extension "B." It will therefore be appreciated that like extensions "B" of adjacent capsules can be tongued and groove connected in only one way, i.e. only the inner lug 50 can be received by a slot 30b while the inner lug 50a of a subjacent extension "B" is received by a slot 30b.

Width W of slot 30 is made less than width W of slot 29, so that the different widths w and W (and corresponding lesser and greater thicknesses of inner lugs 50 and 40) prevent the occurrence of an incorrect connection of the extensions on the capsules and, hence, only like extensions can be fitted together. In each of the extensions A and B, pin openings 45 and 55 are provided, the pin openings having axes arranged parallel to one another and perpendicular to and intersecting the alignment plane "P." Hence, it will be appreciated that an assembly of capsules can be made by pin coupling individual capsules to one another. Since the inner surfaces 42 and 52 of inner lugs 40 and 50 are aligned in the alignment plane "P," the longitudinal axis 23 of capsules in a freely suspended assembly will coincide to provide a uniform arrangement for the various capsules in the assembly. In the assembly of capsules, the transverse axes 22 will alternate uniformly throughout the assembly plane "P" by virtue of the connections of like extensions.

Referring now to FIGS. 8-11, another aspect of the present invention, as embodied in the inner and outer lug arrangement, will now be explained. A typical inner lug 40, as shown in FIG. 8, has a pointed extremity 46 formed between converging inclined or sloping surfaces 47 and 48 having an included angle therebetween of 120°. A typical slot 29 has a bottom surface formed between converging sloping surfaces 49 and 58 disposed perpendicular to one another. The hole 45 for the pin connection is typically intermediate of the length of the slot. A typical outer lug 41 has a curved extremity 60. As shown in FIG. 10, when the extensions A and B of subjacent capsules are pin connected to one another, the extremity 46 of an inner lug 40 and surfaces 47, 48 of slot 29 are disposed slightly relative to the bottom wall surfaces 49a, 58a of slot 29a by virtue of the angular relations between the respective surfaces 47, 48 and 49a, 58a. Likewise, the extremity 46a of inner lug 40a and surfaces 47a, 48a of slot 29a are disposed slightly relative to the bottom wall surfaces 49 and 58 of slot 29. Thus, the adjacent capsules can pivot relative to one another about pin connection 32 until, for example, the respective surfaces 24, 47a, 47a, 49a, 49a, 58, 49a are in contact as shown in FIG. 11. Because of the tongue and groove arrangement between a pair of connected capsules, adjacent surfaces on both capsules provide for two distinct contact relationships between the extensions, thereby to limit relative pivotal movement of the capsules. The limited pivotal movement, of course, provides limited flexibility in the plane "P" for ease of manipulating the assembly into the well bore while, at the same time, kinking of the assembly is prevented.

Referring now to FIG. 12, an elongated spacer 69 is illustrated, which is comprised of an elongated bar piece having extensions "A" and "B," formed in the above-described manner. The spacer 69 is employed when a longer spacing is desired between capsules.

To better understand the present invention, other embodiments of the present invention are presented in FIGS. 13-15. In FIG. 13a, a schematically illustrated capsule 21 (as viewed from a rearward portion 20) has a transverse axis 22 (which corresponds to a firing axis of a shaped charge in the capsule) lying in an alignment plane "P" which is perpendicular to the plane "P," of the sheet of drawings. The plane "P" intersects a longitudinal axis 23 of the capsule which also lies in the plane "P," of the drawing. FIG. 13b schematically illustrates the arrangement of
axes 22 and 23 with respect to planes P and P in ease of comprehension. Capsule 21 has elongated radial extensions 70 and 80 aligned along axes 23 which are therefore diametrically disposed on the capsule. For purposes of explanation, the extensions 70 and 80 may be considered as substantially square in cross section and the ends of the extensions 70 and 80, respectively, have rectangular slots or grooves 71 and 81. Slot 71 in extension 70 for instance is aligned along axis 22' which have flat facing surfaces 74, 75 lying in parallel planes which are perpendicular to the plane P 2. Slot 81, in a like manner, forms inner and outer lugs 82, 83, respectively, which have flat facing surfaces 84, 85 lying in parallel planes which are perpendicular to the plane P. The extensions 70 and 80 are, further, offset or displaced from axis 22' with respect to one another, so that the flat surfaces 74, 84 of each inner lug 72, 82 lie in the common alignment plane "P." The depth and width of slots 71 and 81 are made identical. The length and width of the inner lugs 72 and 82 are sized so that adjacent capsules 21 may be tongue and groove connected. However, the outer lugs 73 and 83 are sized with the lengths of slots 71 and 81, so that only the inner lugs 72, 82 can be fitted in the respective slots.

Thus, with this arrangement, it will be appreciated that when extensions 70 and 80 of separate capsules are interfit and provided with a pin connection, shaped charges in the capsules would fire in plane "P" in only one direction away from the longitudinal axis 23', as shown by the arrow 89 in FIG. 13b. Since the extensions 70 and 80 have a symmetry when rotated about transverse axis 22' of the capsule 21', the like extensions 89 of adjacent capsules may be interfit (rather than the extensions 70, 80) without disturbing the one-way firing system.

It will be particularly noted that the thickness of the outer lugs 73 and 83 of capsule 21' prevents rotation of the capsule about axis 23 to face in a direction opposite to arrow 89. Hence, assuming the outer lugs 73 and 83 to be sized in thickness similar to that of the inner lugs 72 and 82, the direction in which the containers face could be alternated; however, this would raise the possibility of misalignment in assembly, since the extensions could be stepped endwise with respect to a common, longitudinal axis. If such a misalignment occurred, the charges would not be symmetrically disposed about a common center axis extending longitudinally of an assembly of containers (which would normally coincide with the longitudinal axis 23' of the capsules), or the direction of firing of the capsules could be alternated in an undesirable manner.

Referring now to FIGS. 14a and 14b, when the transverse axis 22' of a capsule 21' is rotated relative to the plane "P" on which the flat surfaces 74 and 84 of the inner lugs 72 and 82 lie, it is possible to have either one or two directions of firing, as shown schematically by arrows 89' and 89''. If the angle of an axis 22' of the capsule 21' with respect to the plane "P" is, say 60° and projections 70 and 80 of adjacent containers 21' are connected, the axes 22'' of the capsules would be aligned in a longitudinal plane disposed at an angle of 60° from the plane "P" so as to perforate in the direction of arrow 89'. On the other hand, if like extensions 70 of adjacent capsules are connected, the included angle between the axes 22'' of the capsules would be 120°, each of the axes 22'' being respectively disposed at positive and negative angles of 60° with respect to the plane "P." Thus, the capsules would perforate in the direction of arrows 89' and 89''. It will therefore be appreciated that the perforations made with the arrangement of FIG. 14a may be at random locations depending upon the particular make-up of the connections in an assembly.

To be foolproof, the directions of the axes 22'' of adjacent capsules 21' along the assembly (FIG. 14a) in a foolproof manner, pin connections 76 and 86 of different diameters may be provided for the respective extensions 70 and 80. In this manner, the axes 23'' of adjacent capsules may be disposed at positive and negative angles of 60° with respect to plane "P" by alignment of correct pin sizes. While pin connections 76 and 86 having different diameters afford an almost foolproof method of connection, it is still possible to make an incorrect connection by using a small pin in an incorrectly sized hole. It is therefore desirable to have flat facing surfaces 74, 75 lying in parallel planes which are perpendicular to the plane P. Slot 81, in a like manner, forms inner and outer lugs 82, 83, respectively, which have flat facing surfaces 84, 85 lying in parallel planes which are perpendicular to the plane P.

Referring now to FIGS. 15a and 15b, the above possibility of making an incorrect pin connection, as referred to in relation to FIG. 14a, may be obviated by the provision in the extension 80 of capsule 21', of a slot 81a with a different depth from the depth of slot 71. Pin connections 77 and 87 are centrally located with respect to a given slot depth. In this manner, a shallower slot 81a and correspondingly shorter inner lug 82a of adjacent capsules may be reliably matched. With this arrangement, the axes 22'' of adjacent capsules may be reliably and regularly alternated at positive and negative angles of 60° relative to plane "P." Thus, the assembly of capsules with regularly alternating directions of firing can be made foolproof.

It will be appreciated, from the foregoing, that the present invention incorporates many complementary features. For example, the tongue and groove connection permits alignment of the individual capsules relative to an alignment plane and bending of an assembly only in the alignment plane. The shaping of the tongue and grooves in a connection provides for limited relative pivotal movement between adjacent capsules. By providing distinct coupling connections at each end of the capsules, a preferred orientation of the capsules in an assembly can be obtained using identical capsules. The distinct coupling connections may, for example, include different sized pin connections, different sized slot and tongue widths, as well as different sized slot and tongue lengths.

While a particular embodiment of the present invention has been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A perforating assembly for use in a case well bore including: a plurality of shaped charge capsules wherein each capsule has opposite longitudinally extending connecting portions; and magnetic longitudinal extending connecting portions, said first connecting portion of each capsule having a bifurcated end thereby forming a first slot defined by surfaces between lug portions, said second connecting portion of each capsule having a bifurcated end thereby forming a second slot defined by surfaces between lug portions, said first and second connecting portions of each capsule being disposed relative to a first longitudinal plane passing therethrough so that said first and second slots lie to either side of said first plane with a surface of each slot substantially coextensive with said first plane, said slots being sized relative to said connecting portions of said connecting portions for close fitting coupling of connecting portions of said capsules to maintain alignment of said slot surfaces; and means pivotally connecting connecting portions of said capsules to one another for forming an articulated assembly of interconnected capsules; and the central orienting apparatus coupled to said articulated assembly and having a resulting force of magnetic attraction along a second plane extending lengthwise of said assembly, said second plane having a fixed alignment relative to said first plane so that said articulated assembly may be oriented in a cased well bore.

2. The apparatus of claim 1 wherein said capsules respectively include explosive means for developing a perforating jet along a perforating axis, said explosive
means and said perforating axis being disposed at an angle relative to first plane through the connecting portions of a capsule so that a perforating jet, when formed, is at angle with respect to said first plane.

3. The apparatus of claim 1 wherein said slots having inclined bottom wall surfaces forming a V shaped section and said lug portions receivable in said slots having inclined end surfaces forming a V shaped end section, the included angle between said inclined bottom wall surfaces of said slot being greater than the included angle between said inclined end surfaces of said lug portions, said lug portions being positioned in said slots so that engagement of an inclined end surface of a lug portion with an inclined bottom wall surface of a slot limits relative pivot movement between coupled capsules.

4. The apparatus of claim 3 wherein the included angle between said inclined bottom wall surfaces of said slot is 100° and the included angle between said inclined end surfaces of said lug portions is 90°.

5. The apparatus of claim 1 wherein said pivotal coupling means are pivot pins, each of said first and second coupling portions having aligned openings with an axis disposed perpendicular to said first plane and with different diameters, said pivot pins being sized to said openings.

6. The apparatus of claim 1 wherein said first slots are greater in depth than said second slots.

7. The apparatus of claim 1 wherein said first connecting portions have first means forming a first type of interfitting configuration and said second connecting portions have second means forming a second type of interfitting configuration, said first means permitting interconnection of only first connecting portions, said second means permitting interconnection of only second connecting portions.

8. The apparatus of claim 1 wherein said assembly includes at least one spacer member comprising an elongated expendable member having first and second connecting portions corresponding in configuration to the respective configurations of said first and second connecting portions of each capsule.

9. A perforating assembly for use in a cased well bore including: a plurality of shaped charge capsules wherein each capsule has oppositely disposed first and second, longitudinally extending connecting portions, said first connecting portion of each capsule having a bifurcated end thereby forming a first slot defined by surfaces between first lug portions, said second connecting portion of each capsule having a bifurcated end thereby forming a second slot defined by surfaces between second lug portions, said first and second connecting portions of each capsule being disposed relative to a first longitudinal plane passing therethrough so that said first and second slots lie to either side of said first plane with a surface of each slot substantially coextensive with said first plane, said first slots being sized relative to a first lug portion of said first connecting portions for close fitting coupling of first connection portions of said capsules and said second slots being sized relative to a second lug portion of said second connecting portions for close fitting coupling of second connecting portions of said capsules to maintain alignment of said slot surfaces, said first slots having a width which is less than the width of said second slots; and means pivotally coupling connecting portions of said capsules to one another for forming an articulated assembly of interconnected capsules; and magnetic orienting apparatus coupled to said articulated assembly and having a resultant force of magnetic attraction along a second plane extending lengthwise of said assembly, said second plane having a fixed alignment relative to said first plane so that said articulated assembly may be oriented in a cased well bore.

10. For use in a well bore with apparatus which includes: a plurality of pivotally-interconnected shaped charge capsules and orienting apparatus for orienting said interconnected capsules in a well bore, the improvement comprising a shaped charge capsule having oppositely disposed first and second longitudinally extending connecting portions, said first connecting portion of said capsule having a bifurcated end thereby forming a first slot defined by surfaces between lug portions, said second connecting portion of said capsule having a bifurcated end thereby forming a second slot defined by surfaces between lug portions, said first and second connecting portions of said capsule being disposed relative to a longitudinal plane passing therethrough so that said first and second slots lie to either side of said longitudinal plane with a surface of each slot substantially coextensive with said first plane, said slots being sized relative to lug portions of said connecting portions for close fitting coupling of connecting portions of other capsules to said capsule to maintain alignment of said slot surfaces; said capsule having means for pivotal coupling of said capsule to connection portions of other capsules so that said capsule when coupled to other capsules forms an articulated assembly of interconnected capsules.

11. The capsule of claim 10 wherein said connecting portions have first means forming a first type of interfitting configuration and said second connecting portions have second means forming a second type of interfitting configurations, said first means permitting interconnection of only first connecting portions, said second means permitting interconnection of only second connecting portions.

12. The capsule of claim 10 wherein said first slots have a width which is less than the width of said second slots.

References Cited in the file of this patent

UNITED STATES PATENTS

96,025 Morse Oct. 19, 1869
2,664,156 Allen Dec. 29, 1953
2,756,677 Mccullough July 31, 1956
2,796,023 Abendroth June 18, 1957
2,799,224 Long July 16, 1957
2,927,534 Le Bus Mar. 8, 1960
2,981,185 Caldwell Apr. 25, 1961