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Inventor(s)	Austin, II; David et al.

PERFORATING JET SHAPING SYSTEMS AND METHODS

Abstract

The present disclosure relates to a shaped charge. The shaped charge includes an explosive component and a liner member coupled to the explosive component. The explosive component and the liner member emit a perforating jet based on ignition of the explosive component. The liner member has a planar symmetric portion that is planar symmetric along an axial length of the planar symmetric portion relative to planes perpendicular to a direction of the emitted perforating jet.

Inventors: **Austin, II; David (Rosharon, TX), Fuller; John (Rosharon, TX)**

Applicant: **Schlumberger Technology Corporation** (Sugar Land, TX)

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Background/Summary

BACKGROUND

[0001] The present disclosure generally relates to systems and methods for shaping perforating jets.

[0002] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present techniques, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admission of prior art.

[0003] Exploring, drilling, and completing hydrocarbon and other wells are generally complicated, time consuming and ultimately very expensive endeavors. As a result, over the years, well architecture has become more sophisticated where appropriate in order to help enhance access to underground hydrocarbon reserves. For example, as opposed to wells of limited depth, it is not uncommon to find hydrocarbon wells exceeding 30,000 feet in depth. Furthermore, as opposed to remaining entirely vertical, today's hydrocarbon wells often include deviated or horizontal sections aimed at targeting particular underground reserves.

[0004] While such well depths and architecture may increase the likelihood of accessing underground hydrocarbon reservoirs, other challenges are presented in terms of well management and the maximization of hydrocarbon recovery from such wells. For example, during the life of a well, a variety of well access applications may be performed within the well with a host of different tools or measurement devices. However, providing downhole access to wells of such challenging architecture may require more than simply dropping a wireline into the well with the applicable tool located at the end thereof. Indeed, a variety of isolating, perforating, and stimulating applications may be employed in conjunction with completions operations.

[0005] In the case of perforating, different zones of the well may be outfitted with packers and other hardware, in part for sake of zonal isolation. Thus, wireline or other conveyance may be directed to a given zone and a perforating gun employed to create perforation tunnels through the well casing. Specifically, shaped charges housed within a steel gun may be detonated to form perforations or tunnels into the surrounding formation, ultimately enhancing recovery therefrom.

[0006] The profile, depth, and other characteristics of the perforations are dependent upon a variety of factors in addition to the material structure through which each perforation penetrates. That is, the jet formed by the detonation of a given shaped charge may pierce a steel casing, cement, and a variety of different types of rock that make up the surrounding formation. However, characteristics of different components of the shaped charge itself may determine the characteristics of the jet, and ultimately the depth, profile, and overall effectiveness of each given perforation as described herein.

[0007] Among other components, a shaped charge generally includes a case, explosive pellet material, and a liner member. Thus, detonation of the explosive within the case may be utilized to direct the liner away from the gun and toward the well wall as a means by which to form the noted jet. Therefore, the characteristics of the jet are largely dependent upon the behavior of the liner and other shaped charge components upon detonation. For example, a solid copper or zinc liner may be utilized to generate a jet of considerable stretch with a head or tip that travels at 5-10 times the rate of speed as compared to the speed at the tail. Depending on the casing thickness, formation type, and other such well-dependent characteristics, this type of liner is generally of notable effectiveness in terms of achieving substantial depth of penetration.

BRIEF DESCRIPTION

[0008] A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

[0009] In one embodiment, the present disclosure is directed to a shaped charge. The shaped charge includes an explosive component and a liner member coupled to the explosive component. The explosive component and the liner member emit a perforating jet based on ignition of the explosive component. The liner member has a planar symmetric portion that is planar symmetric along an axial length of the planar symmetric portion relative to planes perpendicular to a direction of the emitted perforating jet.

[0010] In one embodiment, the present disclosure is directed to a shaped charge. The shaped charge includes an explosive component. The shaped charge also includes a liner member coupled to the explosive component. The explosive component and the liner member are configured to emit a perforating jet based on ignition of the explosive component. Further, the shaped charge includes an external confinement feature that imparts a planar symmetry to the shaped charge.

[0011] In one embodiment, the present disclosure is directed to a method. The method includes providing a shaped charge. The method also includes inducing a planar symmetry in or near a liner member associated with the shaped charge. Further, the method includes assembling the shaped charged having the planar symmetry.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0013] FIG. **1** shows a perforation operation, in accordance with aspects of the present disclosure;

[0014] FIG. **2** shows a diagram illustrating a perforation being made with a perforation gun, in accordance with aspects of the present disclosure;

[0015] FIG. **3** shows a diagram illustrating a perforation and a tunnel made with a shaped charge, in accordance with aspects of the present disclosure;

[0016] FIG. **4** shows a cross-sectional view of an embodiment of a shaped charge, in accordance with aspects of the present disclosure;

[0017] FIG. **5**A shows a diagram of the shaped charge of FIG. **4** forming a first type of jet, in accordance with aspects of the present disclosure;

[0018] FIG. **5**B shows a diagram of the shaped charge of FIG. **4** forming a second type of jet, in accordance with aspects of the present disclosure;

[0019] FIG. **5**C shows a diagram of the shaped charge of FIG. **4** forming a third type of jet, in accordance with aspects of the present disclosure;

[0020] FIG. **6** shows a cross-sectional view of an embodiment of a shaped charge that includes a planar symmetry charge liner, in accordance with aspects of the present disclosure;

[0021] FIG. **7**A shows a perspective view of an embodiment of a first example of a planar symmetric confinement structure that imparts a planar symmetry to a shaped charge, in accordance with aspects of the present disclosure;

[0022] FIG. **7**B shows a perspective view of an embodiment of a shaped charge that includes the planar symmetric confinement of FIG. **7**A, in accordance with aspects of the present disclosure;

[0023] FIG. **8**A shows a perspective view of an embodiment of a first example of a planar symmetric confinement structure that imparts a planar symmetry to a shaped charge, in accordance with aspects of the present disclosure;

[0024] FIG. **8**B shows a perspective view of an embodiment of a shaped charge that includes the planar symmetric confinement of FIG. **8**A, in accordance with aspects of the present disclosure;

[0025] FIG. **9**A shows a perspective view of an embodiment of a first example of a planar symmetric confinement structure that imparts a planar symmetry to a shaped charge, in accordance with aspects of the present disclosure;

[0026] FIG. **9**B shows a perspective view of an embodiment of a shaped charge that includes the planar symmetric confinement of FIG. **9**A, in accordance with aspects of the present disclosure;

[0027] FIG. **10**A shows a perspective view of an embodiment of a first example of a planar symmetric confinement structure that imparts a planar symmetry to a shaped charge, in accordance with aspects of the present disclosure;

[0028] FIG. **10**B shows a perspective view of an embodiment of a shaped charge that includes the planar symmetric confinement of FIG. **10**A, in accordance with aspects of the present disclosure;

[0029] FIG. **11**A shows a perspective view of an embodiment of a first example of a planar symmetric confinement structure that imparts a planar symmetry to a shaped charge, in accordance with aspects of the present disclosure;

[0030] FIG. **11**B shows a perspective view of an embodiment of a shaped charge that includes the planar symmetric confinement of FIG. **11**A, in accordance with aspects of the present disclosure;

[0031] FIG. **12**A shows a cross-sectional view of planar symmetry confinement structure having a first type of thickness, in accordance with aspects of the present disclosure;

[0032] FIG. **12**B shows a cross-sectional view of planar symmetry confinement structure having a second type of thickness, in accordance with aspects of the present disclosure;

[0033] FIG. **12**C shows a cross-sectional view of planar symmetry confinement structure having a third type of thickness, in accordance with aspects of the present disclosure;

[0034] FIG. **13** shows a cross-sectional view of a perforating gun that includes a planar symmetry confinement structure, in accordance with aspects of the present disclosure; and

[0035] FIG. **14** shows a flow diagram of a method for assembling a shaped charge that includes a planar symmetry charge liner, in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

[0036] One or more specific embodiments will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0037] When introducing elements of various embodiments of the present disclosure, the articles “a,” “an,” and “the” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to “one embodiment” or “an embodiment” of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0038] As discussed above, shaped charges are used for a variety of oil and gas applications. In particular, the jet formed by the detonation of a given shaped charge may pierce a steel casing, cement, and a variety of different types of rock that make up the surrounding formation. The characteristics of the jet produced by a shaped charge are largely dependent upon the behavior of the liner and other shaped charge components upon detonation.

[0039] At least in some instances, it may be desirable to severe a control line behind a completion prior to cementing as part of a plug and abandon operation. To do so, it is advantageous to sever the intended target control line while minimizing unexpected damage to other parts of the completion. Conventional explosive intervention options, such explosive intervention options include axisymmetric shaped charges, short linear slot cutters, and radially symmetric circumferential cutters, are used to accomplish a task. However, each of these options have one or more shortcomings from irregular or unexpected performance, expensive or difficult manufacturing, or deployment.

[0040] It is presently recognized that altering the mass distributions of an explosive component, liner member, or both of an axisymmetric shaped charged design, may convert a shaped charge to an alternate symmetry that provides a fan-like cutting jet. For cutting control lines, it may be advantageous to adjust the mass distributions such that the resulting shaped charge has a planar symmetry, whereby mass is added or removed at poles 180 degrees apart. As a result, during jet collapse, the normally axially uniform fast-moving perforating jet is a slower fan-like geometry. The perforating jet having the fan-like geometry may act over a line spanning multiples degrees from the axis of symmetry (e.g., perpendicular to a perforating jet direction), thereby providing increased coverage as a cutter while still achieving velocities and densities inside the cutting fan. The perforating jet may perform comparable to linear slot cutters, but can also be retrofitted into existing hardware and manufacturing methods.

[0041] Accordingly, the present disclosure relates to a planar symmetric liner member that forms a fan-line cutting jet when shot from an axisymmetric charge body, which may be advantageous for certain cutting or perforating jet applications (e.g., cutting or severing control lines). In general, the planar symmetric liner member includes two or more metal powders or metal powder mixtures, which may provide a region having a high average green density and a region having a low average green density (e.g., after pressing). In some embodiments, the planar symmetric liner member may include additional materials other than metal powders, such as machined metal parts, injection molded plastic parts, ceramic parts, powders, or a combination thereof. In such embodiments, the additional materials may become incorporated (e.g., via a compaction process) with the metal powders into a single piece liner. In some embodiments, the planar symmetric liner member may include features that are planar symmetric (e.g., the original liner member may not be planar symmetric but additional liner features include planar symmetry). For example, while the planar symmetric liner member in its entirety may be axisymmetric, the planar symmetric liner member may have additional volume at the apex, skirt, or other region(s) that are planar symmetric, doubly planar symmetric, or symmetric on another period and which intrude into the region either towards or away from the central axis. The disclosed planar symmetric liner member may be produced or otherwise manufactured using existing powder metal pressing methods to produce a single piece liner. The single piece liner may be pressed into otherwise conventionally manufactured charges requiring fewer parts and manufacturing operations with the result being a deep planar cutter for use against behind casing control lines. In this way, the planar symmetric liner member may be capable of producing a desired perforating jet that is otherwise unable to be produced using conventional shaped charges, while also capable of being manufactured using existing, less expensive techniques.

[0042] With reference to FIG. **1**, after a well **10** is drilled, a casing **12** is typically run in the well **10** and cemented to the well **10** in order to maintain well integrity. After the casing **12** has been cemented in the well **10**, one or more sections of the casing **12** that are adjacent to the formation zones of interest (e.g., target well zone **13**) may be perforated to allow fluid from the formation zones to flow into the well for production to the surface or to allow injection fluids to be applied into the formation zones. To perforate a casing section, a perforating gun string may be lowered into the well **10** to a desired depth (e.g., at target zone **13**), and one or more perforation guns **15** may be fired to create openings in the casing **12** and to extend perforations into the surrounding formation **16**. Production fluids in the perforated formation **16** can then flow through the perforations and the casing openings into the wellbore **11**.

[0043] Typically, perforating guns **15** (which include gun carriers and shaped charges mounted on or in the gun carriers or, alternatively, include sealed capsule charges) are lowered through tubing or other pipes to the desired formation interval on a line **17** (e.g., wireline, e-line, slickline, coiled tubing, and so forth). The charges carried in a perforating gun **15** may be phased to fire in multiple directions around the circumference of the wellbore **11**. Alternatively, the charges may be aligned in a straight line. When fired, the charges create perforating jets that form holes in the surrounding casing **12** as well as extend perforation tunnels into the surrounding formation **16**.

[0044] With reference to FIG. **1**, certain embodiments of the present disclosure include a perforation system comprising: (1) a perforating gun **15** (or gun string), wherein each gun may be a carrier gun (as shown) or a capsule gun (not shown); and (2) one or more improved shaped charges **20** loaded into the perforating gun **15** (or into each gun of the gun string), each charge having a liner member, as described herein; and (3) a conveyance mechanism **17** for deploying the perforating gun **15** (or gun string) into a wellbore **11** to align at least one of said shaped charges **20** within a target formation interval **13**, wherein the conveyance mechanism may be a wireline, tubing, or other conventional perforating deployment structure; among other components.

[0045] Examples of explosives (e.g., explosive component as described in FIG. **4**) that may be used in the various explosive components (e.g., charges, detonating cord, and boosters) include RDX (cyclotrimethylenetrinitramine or hexahydro-1,3,5-trinitro-1,3,5-triazine), HMX (cyclotetramethylenetetranitramine or 1,3,5,7-tetranitro-1,3,5,7-tetraazacyclooctane), TATB (triaminotrinitrobenzene), HNS (hexanitrostilbene), and others.

[0046] Referring to FIGS. **2** and **3**, the material from a collapsed liner of the shaped charge **20** (e.g., as described in more detail in FIG. **4**) forms a perforating jet **28** that shoots through the front of the shaped charge and penetrates the casing **12** and underlying formation **16** to form a perforated tunnel (or perforation tunnel) **40**. Around the surface region adjacent to the perforated tunnel **40**, a layer of residue **30** from the charge liner is deposited. The charge liner residue **30** includes “wall” residue **30**A deposited on the wall of the perforating tunnel **40** and “tip” residue **30**B deposited at the tip of the perforating tunnel **40**. As described in more detail with respect to FIG. **5**, adjusting properties of the shaped charge **20** (e.g., the geometry of the liner, the density of the liner, the mechanical strength of the liner, and so on) may adjust jet properties (e.g., jet velocity and/or jet shape) of the perforating jet **28**.

[0047] Referring now to FIG. **4**, a cross sectional view of an embodiment of a shaped charge **20** is shown. The shaped charge **20** includes a casing member **42** and an interior volume **44** that is defined by an explosive component **46** and a liner member **48**. The explosive component **46** is disposed between the casing member **42** and the liner member **48** such that the liner member **48** surrounds the interior volume **44**.

[0048] The liner member **48** may be formed of packed, powered metals and, in at least in some instances, non-metallic materials. The metals of the liner member **48** may include metals having a density of approximately 6 or greater grams per cubic centimeter (g/cc), 7 or greater g/cc, 8 or greater g/cc, 9 or greater g/cc, 10 or greater g/cc, 11 or greater g/cc, 12 or greater g/cc, or 13 or greater g/cc, and so on. In some embodiments, the metals of the liner member **48** may include metals having a density less than approximately 6 g/cc (e.g., aluminum, beryllium, titanium, and so on). For example, the liner member **48** may include copper (e.g., having a density of approximately 8.9 g/cc) and/or lead (e.g., having a density of approximately 11.3 g/cc). In some embodiments, the liner member **48** may include tungsten (e.g., having a density of approximately 19.3 g/cc). In some embodiments, the liner member **48** may include a mixture of metals, which may provide a desired density. For example, the liner member **48** may include approximately 50 weight percent (wt %) or greater, approximately 60 wt % or greater, approximately 70 wt % or greater, approximately 80 wt % or greater, or approximately 90 wt % or greater of a first metal (e.g., tungsten). Further, the liner member **48** may include a remaining wt % of a second metal (e.g., copper or lead), such as approximately 10 wt % or less, 20 wt % or less, 30 wt % or less, and so on.

[0049] As mentioned above, the liner member **48** may also include non-metallic materials, such as nitrides, carbides, oxides, diamond, ceramic materials, or a combination thereof. For example, the liner member **48** may include relatively low-density materials (e.g., as compared to the metals), such as SiC, Si.sub.3N.sub.4, SiO.sub.2, B.sub.4C, B.sub.4N, ZnO, TiC, Li.sub.3N, TiO.sub.2, Mg.sub.3N.sub.2, and other relatively low density non-metallic materials. In some embodiments, the liner member **48** may include a polymer material, such as fluorinated polymers (e.g., polytetraflouroethylene). In some embodiments, the liner member **48** may include metal-polymer composite mixtures. In such embodiments, the liner member **48** may include a first weight percent (wt %) (e.g., first amount) of one or more metals and a second wt % of one or more non-metallic materials. For example, the liner member **48** may include approximately 50 wt % or greater, 60 wt % or greater, 70 wt % or greater, 80 wt % or greater, 90 wt % or greater of one or more metals. As such, the liner member **48** may include approximately 50 wt % or less, 40 wt % or less, 30 wt % or less, 20 wt % or less, or 10 wt % or less of one or more non-metallic materials.

[0050] Referring specifically now to FIGS. **5**A, **5**B, and **5**C (e.g., collectively FIGS. **5**A-**5**C), side cross-sectional views of a different types of shaped charges **20***a*, **20***b*, and **20***c* in use during perforating applications are shown. That is, in each case, a charge **20***a*, **20***b*, and **20***c* has been loaded into a perforating gun (not shown), and utilized in a perforating application in a well **10**. The charges **20***a*, **20***b*, and **20***c* may be made up of generally the same features described with respect to FIG. **1**. For example, the charges **20***a*, **20***b*, and **20***c* may include the same type of casing **12** and explosive component **46**. However, in each case, a different type of liner member **48***a*, **48***b*, and **48***c* may be used to provide a different type of charge **20***a*, **20***b*, and **20***c* for a different type of perforating application.

[0051] With reference to FIG. **5**A in particular, a deep penetrating jet shaped charge **20***a* is shown. Upon detonation, a deep penetrating jet **28***a* is formed and directed at the casing **12** that defines the well **10**. Ultimately, this forms a perforation tunnel **40***a* that penetrates through the casing member **42**, cement **49**, and into the adjacent formation **16** so as to aid in hydrocarbon recovery therefrom. In the embodiment shown, the liner member **48***a* that is used to form the jet **28***a* and achieve such penetration may be a comparatively thin but high-density tungsten-based liner member **48***a* so as to form a thinner and longer jet **28***a*. The end result, depending largely on the particular characteristics of the casing **12**, may be a perforation tunnel **40***a* of between approximately 30 and approximately 40 inches deep with a diameter of between approximately 0.3 inches and approximately 0.4 inches.

[0052] Of course, as depicted in the embodiment of FIG. **5**B, a different type of liner member **48***b* may be utilized to obtain a different type of charge **20***b* and performance during perforation. More specifically, in the embodiment of FIG. **5**B, a side cross-sectional view of wide jet shaped charge **20***b* is shown. In this case, the liner member **48***b* is of a comparatively thicker dimensions and lower density, perhaps with a lower percentage of tungsten. Thus, a comparatively thicker or wider jet **28***b* may be formed. The end result, again depending on characteristics of the casing **12** and other physical factors, may be a shorter perforation tunnel **40***b* that is closer to a threshold distance (e.g., 60-90 cm deep but with a wider diameter (e.g. between about 1 cm and about 1.3 cm).

[0053] Referring now to FIG. **5**C, a side cross-sectional view of a combination jet shaped charge **20***c* is shown. In this case, the liner member **48***c* may be of a thickness, density, materials and other characteristics similar to either of the deep penetrating **48***a* or wide **48***b* liner member types described above. However, the combination liner member **48***c* of FIG. **5**C is of a uniquely tailored non-uniform morphology. Thus, a combination jet **28***c* may ultimately be formed such that the perforation tunnel **40***c* which is formed is also of a uniquely tailored morphology.

[0054] Accordingly, FIGS. **5**A-**5**C show that altering physical properties (e.g., density) of the liner member **48** adjusts the shape of the resulting jet **28**. That is, by altering the explosive component **46**, the liner member **48**, and/or mass distributions of an axisymmetric shaped charged design, the charge may be converted to an alternate symmetry. It is presently recognized that for cutting control lines, it may be advantageous to use a shaped charge having a planar symmetry, whereby mass is added or removed at pole 180 degrees apart. As a result, during jet collapse, the normally axially uniform fast-moving jet is converted to a slower fan-like geometry that cuts the line spanning multiple degrees from the axis of symmetry serves to provide increase coverage of the cutter while still achieving velocities and densities inside the cutting fan, which are comparable to linear slot cutters, but which can utilize existing hardware and manufacturing methods.

[0055] As described herein, it is presently recognized that it may be advantageous to form a liner member **48** that has a planar symmetry (e.g., a planar symmetry liner member). As referred to herein, an object having an “axial symmetry” refers to an object that is symmetrical about a principle longitudinal axis (e.g., the axis **52** described herein). As referred to herein, a “longitudinal axis” refers to an axis whereby an object is identical through one or more rotations around the object (e.g., one or more 45° rotations, one or more 60° rotations, one or more 90° rotations, or one or more 180° rotations). In addition, as referred to herein , a “principle longitudinal axis” refers to an axis having the highest number of rotations around the object while still appearing identical. For example, a cone may undergo an infinite number of rotations if rotated about the central longitudinal axis along its height. As referred to herein, an object having a “planar symmetry” refers to an object that is symmetrical at all planes perpendicular to the principle longitudinal axis at all points of intersection of the object along the principle longitudinal axis.

[0056] The disclosed planar symmetric liner member **48** may provide a jet having a fan-like geometry. Such a jet may span multiples degrees from the axis of symmetry (e.g., of the shaped charge), thereby providing increased coverage as a cutter while still achieving velocities and densities inside the cutting fan, which are comparable to linear slot cutters. In some embodiments, the planar symmetric liner member **48** may be formed by adjust the mass distributions of the liner member **48** and/or explosive component **46**.

[0057] As shown in FIG. **6**, the planar symmetry charge liner **50** includes a planar symmetric portion **52** and an axial symmetric portion **54**. illustrated, the axial symmetric portion **54** includes a skirt section **53** that extends toward the planar symmetric portion **52** from an apex **56** of the axial symmetric portion **54** along a longitudinal axis **55**, and the planar symmetric portion **52** has a generally cylindrical shape (e.g., located at an axial end of the skirt section **53**, for example, away from the apex **56**). The apex **56** and the skirt section **53**, and the planar symmetric portion **52**, generally define the interior volume **44** (e.g., inner volume) of the planar symmetry charge liner **50** as described herein.

[0058] In some embodiments, the planar symmetric portion **52** includes a mixture of metals and non-metallic materials. For example, the planar symmetric portion **52** may be a green compact formed of a powder including one or more metals and one or more non-metallic materials. Additionally or alternatively, the planar symmetric portion **52** may include a mixture of metals and non-metallic materials. In some embodiments, the planar symmetric portion **52** may be formed of relatively denser materials than the axial symmetric portion **54**. In some embodiments, the planar symmetric portion **52** may be formed using machined metal parts, injected molded plastic parts, ceramic parts, metallic or non-metallic powders, or a combination thereof. However, in some embodiments, the planar symmetric portion **52** and the axial symmetric portion **54** may be formed of the same material.

[0059] As illustrated, the planar symmetric portion **52** is in contact with the axial symmetric portion **54**. In particular, the planar symmetric portion **52** and the axial symmetric portion **54** form an outer surface **60** that extends from the apex **56** of the axial symmetric portion **54** to an axial end of the planar symmetric portion **52**. The planar symmetric portion **52** is generally symmetric about the axis **55**. That is, the planar symmetric portion **52** is symmetric through one or more rotations about the axis **55**. Further, as described herein, the planar symmetric portion **52** includes a planar symmetry. For example, cross sections of the planar symmetric portion **52** are substantially identical at all planes **62** (e.g., mirror planes, horizontal mirror planes) that are perpendicular to the axis **55** along a length of the planar symmetric portion **52**. However, the axial symmetric portion **54** does not include the same planar symmetry properties as the planar symmetric portion **52** (i.e., cross sections of the axial symmetric portion **54** are not substantially identical at all planes perpendicular to the axis along a length of the axial symmetric portion **54**).

[0060] As discussed herein, utilizing a planar symmetry charge liner **50** (e.g., by adjusting the distribution of mass of the explosive component **46** may produce fan-like cutting jet. It is presently recognized that a “fan-like cutting jet” may be useful for selectively cutting certain downhole components (i.e., a control line), while avoiding other components. In some embodiments, the planar symmetry of the shaped charge **20** may be achieved by adding a confinement feature that is external to the liner member **48** and the explosive component **46**, or the planar symmetry charge liner **50**. Examples of such a confinement feature are generally described with reference to FIGS. **7**A, **7**B, **8**A, **8**B, **9**A, **9**B, **10**A, **10**B, **11**A, and **11**B (e.g., collectively FIGS. **7-11**).

[0061] FIGS. **7**A and **7**B show a planar symmetric confinement feature **70** (e.g., external confinement feature) that may be provided around the liner member **48** or planar symmetry charge liner **50**. To facilitate discussion of the planar symmetric confinement feature **70**, FIGS. **7**A and **7**B include axis **55**, axis **72**, and axis **74**. Axis **55** generally corresponds to the direction that a jet **28** is produced, and axis **72** and axis **74** are lateral axes. In general, the planar symmetric confinement feature **70** imparts a planar symmetry to the liner member **48** or planar symmetry charge liner **50** along the axis **55**. The planar symmetric confinement feature **70** has a plane **62** of symmetry that spans the axis **72** and the axis **74** along most of the axial length of the planar symmetric confinement feature **70** (e.g., along the axis **55**). In some embodiments, the planar symmetric confinement feature **70** may be used in conjunction with planar symmetry charge liner **50**.

[0062] In the illustrated embodiment, the planar symmetric confinement feature **70** includes two separable components, such as a first confinement portion **76** and a second confinement portion **78**. As shown in FIG. **7**B, the first confinement portion **76** and the second confinement portion **78** each couple to the outer surface **80** of the liner member **48**. As shown, the first confinement portion **76** and the second confinement portion **78** each are approximately the same size and are symmetrical about a plane that spans the axis **55** and the axis **74**. Such symmetry may cause the shaped charge to produce the fan-like cutting jet (e.g., a perforating jet **28**, that would extend along the axis **55**) as the explosive component **46** collapses inwards towards the interior volume **40**.

[0063] In some embodiments, the planar symmetric confinement feature **70** may be provided as a single component. To illustrate this, FIGS. **8**A and **8**B show a planar symmetric confinement feature **70** that may be provided around the liner member **48** or planar symmetry charge liner **50**. To facilitate discussion of the planar symmetric confinement feature **70**, FIGS. **8**A and **8**B include axis **55**, axis **72**, and axis **74**. Axis **55** generally corresponds to the direction that a jet **28** is produced, and axis **72** and axis **74** are lateral axes. In a generally similar manner as described in FIG. **7**A and **7**B, the planar symmetric confinement feature **70** imparts a planar symmetry to the liner member **48** along the axis **55**. Further, the planar symmetric confinement feature **70** has a plane **62** of symmetry that spans the axis **72** and the axis **74**.

[0064] As shown in the illustrated embodiment, the planar symmetric confinement feature **70** includes a coupling rim **90** on a first axial end **92** (e.g., along the axis **55**) of the planar symmetric confinement feature **70** that joins a first confinement portion **76** and a second confinement portion **78** (e.g., which may be disposed on opposite radial sides of the. Additionally or alternatively, the planar symmetric confinement feature **70** may include a coupling rim **90** on the second axial end **92** (e.g., along the axis **55**) of the planar symmetric confinement portion **70**. As shown, the coupling rim **90** is a circular portion of the planar symmetric confinement portion **70**. However, the coupling rim **90** may be any suitable shape, such as a rectangular shape, a hexagonal shape, an octagonal shape, and so on. In general, the first axial end **92** corresponds to an outer axial end of the shaped charge **20** that is downstream of the direction of travel of the perforating jet.

[0065] In any case, the planar symmetric confinement feature **70** includes a window **96** that generally runs between the first confinement portion **76** and the second confinement portion **78**. The window **96** also runs along the axis **74** of the planar symmetric confinement portion **70** from a first lateral end **98** to a second lateral end **100**. In some embodiments, the planar symmetric confinement feature **70** may be capable of surrounding the shaped charge **20**. For example, the planar symmetric confinement portion **70** could serve as a charge jacket or it could be designed to fit an existing charge jacket (e.g., relatively larger than an additional charge jacket).

[0066] As shown in FIGS. **8**A and **8**B, the window **96** is generally a linear or straight divide between the first confinement feature **76** and the second confinement feature **78**. Accordingly, the first confinement feature **76** and the second confinement feature **78** have a hemispherical shape. In some embodiments, the window **96** (e.g., a split in the mass of the planar symmetric confinement feature **70**) is not linear, such that the first confinement feature **76** and the second confinement feature **78** have a pie-slice shape. To illustrate this, FIGS. **9**A and **9**B show a planar symmetric confinement feature **70** that may be provided around the liner member **48**. To facilitate discussion of the planar symmetric confinement feature **70**, FIGS. **9**A and **9**B include axis **55**, axis **72**, and axis **74**. Axis **55** generally corresponds to the direction that a jet **28** is produced, and axis **72** and axis **74** are lateral axes. In a generally similar manner as described in FIG. **7**A and **7**B, the planar symmetric confinement feature **70** imparts a planar symmetry to the liner member **48** along the axis **55**.

[0067] As shown, the first confinement feature **76** and the second confinement feature **78** each generally extend along circular portions **110**, **112**, respectively, of the circular coupling rim **90**. The circular portions **110**, **112**, may be 120 degrees or less, 100 degrees or less, 90 degrees or less, 80 degrees or less, and so on. As shown, the circular portions **110**, **112** are substantially similar. However, in some embodiments, the circular portions **110**, **112** may be different.

[0068] As mentioned above, with respect to FIGS. **8**A, and **8**B, the first confinement feature **76** and the second confinement feature **78** may be coupled on either the first axial end **92** or the second axial end **94** of the planar symmetric confinement feature **70**. FIGS. **10**A and **10**B show a planar symmetric confinement feature **70** that may be provided around the liner member **48**. To facilitate discussion of the planar symmetric confinement feature **70**, FIGS. **10**A and **10**B include axis **55**, axis **72**, and axis **74**. Axis **55** generally corresponds to the direction that a jet **28** is produced, and axis **72** and axis **74** are lateral axes. In a generally similar manner as described in FIG. **10**A and **10**B, the planar symmetric confinement feature **70** imparts a planar symmetry to the liner member **48** along the axis **55**.

[0069] As shown, the first confinement feature **76** is coupled to the second confinement feature **78** at the second axial end **94** of the planar symmetric confinement feature **70**. For example, the planar symmetric confinement feature **70** includes a coupling rim **120**. The coupling rim **120** is generally a conical shape with a diameter that decreases along the axis **72** and the axis **74** as the coupling rim **120** extends along the axis **55** in a direction towards the second axial end **94**. For example, the coupling rim **120** may correspond to the second axial end **94** where the apex **56** resides.

[0070] It is presently recognized that the higher the density of the material being used and the thicker the tamping mass, the more effective it will be at fanning the jet **28**. To illustrate this, FIGS. **11**A and **11**B show a planar symmetric confinement feature **70** that may be provided around the liner member **48**. To facilitate discussion of the planar symmetric confinement feature **70**, FIGS. **11**A and **11**B include axis **55**, axis **72**, and axis **74**. Axis **55** generally corresponds to the direction that a jet **28** is produced, and axis **72** and axis **74** are lateral axes. In a generally similar manner as described in FIG. **7**A and **7**B, the planar symmetric confinement feature **70** imparts a planar symmetry to the liner member **48** along the axis **55**. In general, each of the examples show a planar symmetric confinement feature **70** that includes additional mass (e.g., due to the first confinement portion **76** and the second confinement portion **78**) that are at poles 180 degrees apart (e.g., opposing axial sides). As shown, the thickness **130** of the walls **132** of the planar symmetric confinement feature **70** is generally thicker than what was generally shown in FIGS. **7-10**. This is discussed in more detail below.

[0071] In some embodiments, the planar symmetric confinement feature **70** may have a varying thickness from the base of the charge case to its top. To illustrate this, FIGS. **12**A, **12**B, and **12**C (e.g., collectively FIGS. **12**A-C) show examples of the planar symmetric confinement feature **70** having varying thicknesses. To facilitate discussion of the planar symmetric confinement feature **70**, FIGS. **12**A, **12**B, and **12**C include axis **55**, axis **72**, and axis **74**. FIG. **12**A shows a uniformly thick version from the first axial end **92** to the second axial end **94**. That is, a wall **132***a* has a first thickness **130***a*, and a wall **132***b* has a second thickness **130***b* that is equal to the first thickness **130***a*. FIG. **12**B shows a thicker uniformly thick version from the first axial end **92** to the second axial end **94**. That is, the wall **132***a* has a first thickness **130***a*, and the wall **132***b* has a second thickness **130***b* that is equal to the first thickness **130***a*. Further, the thicknesses **130***a* and **130***b* show in FIG. **12**B are greater than the thicknesses **130** shown in FIG. **12**A. FIG. **12**C shows a non-uniformly thick version from the first axial end **92** to the second axial end **94**. That is, the wall **132***a* has a first thickness **130***a*, and the wall **132***b* has a second thickness **130***b* that is different than the first thickness **130***a*. In FIG. **12**C, the first thickness **130***a* is less than the second thickness **130***b*. However, in some embodiments, the first thickness **130***a* may be greater than the second thickness **130***b*. It should be noted that the techniques for variable thickness may also be applied to the liner member **48** and the explosive component **46** arrangement described in FIG. **6**.

[0072] In some embodiments, multiple tamping masses could be integrated into a single body and also serve other functions such as taking the place of the loading tube. To illustrate this, FIG. **13** shows a cross sectional view of a perforating gun **15** that includes a planar symmetric confinement feature **140** that houses multiple shaped charges **20**. To facilitate discussion of the planar symmetric confinement feature **140**, FIG. **13** include the axis **55**, the axis **72**, and the axis **74**. In a generally similar manner as described above, the planar symmetric confinement feature **140** may impart a planar symmetry to the shaped charges **20**, thereby resulting in a “fan-like cutting jet” upon ignition of the explosive component **46**. In the illustrated embodiment, the planar symmetric confinement feature **140** holds the explosive component **46** and the liner member **48** of five shaped charges **20**. However, in other embodiments, the planar symmetric confinement feature **140** may be sized to fit any number of shaped charges **20**, such as two, three, four, five, or more than five.

[0073] In any case, as described herein, the disclosed techniques for forming the planar symmetric confinement feature **70** or **140** may provide a shaped charge capable of producing a fan-like cutting jet that advantageously may cut certain downhole components, while preventing damage to the components that would otherwise result from other perforating jets. FIG. **14** shows an example process **150** for forming the planar symmetric confinement feature **70** or **140** in accordance with the present disclosure. As shown, the process **150** includes, at block **152**, providing the shaped charge **20**. Further, the process **150** includes inducing, at block **154**, a planar symmetry on or near the liner member **48**. In some embodiments, inducing the planar symmetry may include altering the mass distribution of the liner member **48** and/or the explosive component **46** such that the shaped charge **20** includes a region having a planar symmetry. That is, as opposed to an axial symmetry, a portion may have a type of planar symmetry such that the object has a horizontal mirror plane. In some embodiments, inducing the planar symmetry may include coupling a planar symmetric confinement feature **70** to the shared charge **20**. For example, the planar symmetric confinement feature **70** may be coupled to the outer surface of the liner member **48** and/or the explosive component **46**. In some embodiments, the planar symmetric confinement feature **70** may be coupled to an exterior of the shaped charge **20**, as generally shown in FIG. **13**. In some embodiments, the planar symmetric confinement feature **70** may be formed of relatively dense, easy to machine (e.g., malleable) materials, such as lead, brass, zinc, and the like. It is presently recognized that it may be advantageous such that the material forming the planar symmetric confinement feature **70** has close to the same shock impedance as the casing **42**, such as steel or zinc. Further, the planar symmetric confinement feature **70** may be multilayered, which may be capable of dissipative to reflections. Further, drop-in parts may be used that may include combinations of metals and/or certain plastics, such as injection molded plastics. Referring back to the process **150**, at block **156**, the process includes assembling the shaped charge **20** such that the shaped charge **20** includes a region having a planar symmetry. In some embodiments, the process includes assembling a perforating gun **15** using the shaped charge.

[0074] Accordingly, the present disclosure relates to a planar symmetric confinement feature **70** or **140** that causes a perforating jet emitted by a shaped charge **20** to have a fan-like cutting jet. The

disclosed techniques may be retrofitted onto existing perforating guns **15**, without needing to manufacture a different type of explosive component **46** and/or liner member **48**.
[0075] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.
[0076] The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as “means for (perform)ing (a function) . . . ” or “step for (perform)ing (a function) . . . ”, it is intended that such elements are to be interpreted under 35 U.S.C. 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. 112(f).

Claims

1. A shaped charge, comprising: an explosive component; and a liner member coupled to the explosive component, wherein the explosive component and the liner member are configured to emit a perforating jet based on ignition of the explosive component, and wherein the liner member has a planar symmetric portion that is planar symmetric along an axial length of the planar symmetric portion relative to planes perpendicular to a direction of the emitted perforating jet.
2. The shaped charge of claim 1, wherein the emitted perforating jet comprises a fan-like shape.
3. The shaped charge of claim 1, wherein the liner member comprises additional mass at opposing axial sides of the liner member.
4. The shaped charge of claim 1, wherein the liner member comprises two or more metal powders or metal powder mixtures.
5. The shaped charge of claim 1, comprising an external confinement feature disposed external to the liner member, the explosive component, or both.
6. The shaped charge of claim 5, wherein the external confinement feature is formed of lead, brass, zinc, or a combination thereof.
7. The shaped charge of claim 5, wherein the external confinement feature comprises machined metal parts, injection molded plastic parts, ceramic parts, powders, or a combination thereof.
8. A shaped charge, comprising: an explosive component; a liner member coupled to the explosive component, wherein the explosive component and the liner member are configured to emit a perforating jet based on ignition of the explosive component; and an external confinement feature configured to impart a planar symmetry to the shaped charge.
9. The shaped charge of claim 8, wherein the external confinement feature comprises two separate portions coupled to an outer surface of the explosive component.
10. The shaped charge of claim 8, wherein the external confinement feature comprises two confinement portions coupled via a coupling rim.
11. The shaped charge of claim 10, wherein the coupling rim is disposed on a downstream portion of the shaped charge relative to a direction of travel of the perforating jet.
12. The shaped charge of claim 10, wherein the external confinement feature comprises a window that runs between the two confinement portions.
13. The shaped charge of claim 10, wherein the coupling rim comprises a conical shape.
14. The shaped charge of claim 8, wherein the external confinement feature comprises a variable thickness along an axial length of the external confinement feature.
15. The shaped charge of claim 8, wherein the external confinement feature is formed of lead, brass, zinc, or a combination thereof.
16. A method, comprising: providing a shaped charge; inducing a planar symmetry in or near a

liner member associated with the shaped charge; and assembling the shaped charged having the planar symmetry.

17. The method of claim 16, wherein inducing the planar symmetry comprises altering a mass distribution of the liner member and/or an explosive component of the shaped charge such that the shaped charge includes a region having the planar symmetry.

18. The method of claim 16, wherein inducing the planar symmetry comprises providing an external confinement feature that houses a plurality of shaped charges including the shaped charge.

19. The method of claim 18, wherein the external confinement feature is formed of lead, brass, zinc, or a combination thereof.

20. The method of claim 16, comprising assembling a perforating gun using the shaped charge.