The pipe cutting capacity of a explosive pipe cutter may be improved by mixing the explosive material with powdered metal to increase the explosive gas density or directing colliding shock fronts from opposite axial directions against a disc of metal having a shock impedance substantially corresponding to the shock impedance capacity of the explosive material.
DOWNHOLE SEVERING TOOL

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the Priority Date Benefit of Provisional Application No. 61/342,160 filed Apr. 9, 2010.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention
[0003] The present invention relates to the earthing arts. In particular, the present invention describes a method and apparatus for severing a downhole tool such as tubing, drill pipe or casing.

[0004] 2. Description of Related Art
[0005] Commercial systems have been around for years to sever pipe at a selected point that becomes stuck downhole. The simplest system detonates a large mass of explosive lowered to a desired point on a wireline to rupture and thereby separate the free, upper end of the pipe string from the stuck, lower end. A better system such as described by U.S. Pat. No. 7,530,397 to W. T. Bell detonates a cylindrical column of explosive simultaneously from both ends to create a shock wave that will then detonate the entire length of the tool. The present invention, however, utilizes a series of detonators at the ends of the column, with the front or tip speed of the radial gas jet approximately equal to 25% of the detonation speed.

SUMMARY OF THE INVENTION

[0006] There are a few variations on the colliding shock wave concept. One variation, described by U.S. Pat. No. 7,104,326 to A. F. Grattan et al., uses a centrally located radial shaped charge to pre-cut the pipe before the explosive shock waves collide. Another variation, such as described by U.S. Pat. No. 4,378,844 to J. D. Parrish et al., places a metal disc at the center of the collision point with the idea that the metal will liquefy and form a high-pressure radial cutting jet.

[0007] FIG. 2 is a prior art representation of a cylindrical explosive after detonation with opposing detonation fronts progressing toward collision.

[0008] FIG. 3 is a prior art representation of a completely detonated cylindrical explosive with colliding detonation fronts producing a planar jet of radially expanding explosive gases.

[0009] FIG. 4 is a prior art representation of a completely detonated cylindrical explosive with colliding detonation fronts producing a planar jet of radially expanding explosive gases.

[0010] FIG. 5 represents an undetonated cylindrical column of explosive having detonators at each end configured to fire substantially and an explosive composing of a mixture of explosive and metal powder.

[0011] FIG. 6 represents an undetonated cylindrical column of explosive having detonators at each end configured to fire substantially simultaneously. The column is assembled with a powdered metal disc at the center having a shock impedance matching the shock impedance of the explosive column.

[0012] FIG. 7 represents a completely detonated cylindrical explosive with detonation fronts colliding against a powdered metal disc as represented by FIG. 6 to produce a planar jet of radially expanding gases comprising the powdered metallic material.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013] The conventional understanding of the physical mechanism that explosively severs pipe is graphically illustrated by FIGS. 1-3. FIG. 1 shows a column of explosive such as RDX, HNS, PYX, TATB, PETN or HMX. The column may be of any material solid or a plurality of pressed pellets or wafers that are continuously aligned face-to-face in a column as disclosed by U.S. Pat. No. 7,550,357 to W. T. Bell. At opposite ends of the explosive column are respective detonators 12. This FIG. 1 assembly is mounted in an environmental protective casement, not shown, with the detonators 12 fused by prescribed length detonation cord or electrically wired EPI's, EBI's or SCBs for simultaneous ignition.

[0014] Referring to FIG. 2, simultaneous ignition of the detonators 12 produces a pair of simultaneously advancing shock fronts 16 ahead of expanding gas cells 14. Upon collision of the two shock fronts 16, a localized pressure is produced that may be two to five times greater than the detonation pressure, depending on the simultaneous timing precision of the ignition and resulting collision. As shown by FIG. 3, the high pressure spike generated by the collision of shock fronts 16 spreads the expanding explosion gases radially in a narrow focusing plane 18. This radial plane of dense, high pressure gas is transmitted through the tool's housing and wellbore fluid to impinge against the inside pipe wall to sever it.

[0015] This description of prior art explosive pipe cutters does not consider the density of the radially expanding high speed gases that occurs after the shock front collision. There is conservation of axial momentum upon collision with no net axial component. This, in turn, produces the high-speed radial jet of gases that can generate high pressures (upward of one million psi) to cut pipe (having a strength normally of less than 100,000 psi) upon impact much like the jet of a shaped charge penetrates steel. The particle speed, U, of the radial jet is equal to the particle speed of the explosive gas in the column, with the front or tip speed of the radial gas jet approximately equal to 25% of the detonation speed [Cooper,
Paul W. Kurowski, Stanley R.: Introduction to the Technology of Explosives, Wiley VCH, Inc. 1996.] and the remaining jet having progressively reduced speed as the particle flow of the gas from the trailing column is diverted radially from the column axis (see FIG. 4). The radial expansion of the jet reduces the density of gases. In this description, as with a shaped charge, jet velocity is not particularly relevant provided the resulting jet pressure impacting the pipe is much higher than the strength of the pipe being cut. The parameter that determines cutting ability in this description is jet density. The greater the density of the jet gas, which is related directly to the explosive density, the deeper the cut. To improve the cutting capacity of such explosive pipe cutters, the present invention, therefore, proposes a radial jet having a greater cutting pressure than conventional devices.

[0019] With this more complete view of the physics contributing to explosive pipe cutting, explosive gas density is seen as an important factor. By increasing gas density we can improve cutting ability. However, there are relatively small differences in density of the various common explosives, with less than 10 percent difference between the RDX and HMX, for example. Disclosed herein are two methods of increasing radial jet density delivered by a severing tool, and thereby increasing its cutting ability.

[0020] Metalized Explosive. Metals, such as aluminum, have been added to explosives by the prior art to increase the time duration of the explosive event through a reaction (i.e., burning) of the metal by the explosive gases. See U.S. Pat. No. 6,651,564 to Tite, et al. For this application, however, explosive density $\rho_e$, is increased by mixing powered metals with the base explosive as represented by the explosive column 20 of FIG. 5. This explosive/powdered metal mixture 20 increases the density of the mixture to a magnitude greater than that of the explosive alone and thereby increases the density of the radial gases that are produced when the shock fronts 16 collide. Metals that react with the explosive gases and those that are non-reactive are candidates, including powders of one or more of the following: aluminum, copper, lead, tin, bismuth, tungsten, iron, lithium, sulfur, tantalum, zirconium, boron, niobium, titanium, cesium, zinc, magnesium, selenium, tellurium, manganese, nickel, molybdenum, and palladium. Powders of these elements may be used in mixed combination with the explosive either singularly or in blended combination.

[0021] As an example, a 50/50 weight mixture (86/14 volume mixture) of HMX and lead powder would increase the overall explosive density from 1.75 g/cc to about 3.1 g/cc. In the case of lead with its melting temperature, the explosive gases would contain higher density (in gaseous or liquid state) lead in addition to the HMX gaseous products. The resulting radial jet would have a higher density, generating higher cutting pressure. A greater percentage of lead would increase the mixture density more, but would simultaneously reduce the explosive’s overall detonation speed. A 55/45 weight mixture (86/14 volume mixture) of HMX and copper powder would increase the explosive density to about 2.8 g/cc, as another example of this approach.

[0022] Centralized Metal Disc. An alternative embodiment of this invention creates a metal radial jet by inserting one or more metal discs 22 at the center of the explosive column as represented by FIG. 6. As the opposing shock fronts 16 of FIG. 7 converge on the metallic disc 22, some of the explosive energy is converted into a radial jet 26 composed of high density liquid metal 24 that would cut pipe. This approach was broadly described by U.S. Pat. No. 4,378,844 to D. D. Parrish et al. The analytical mathematics of two equal colliding liquid streams that corresponds to one stream impacting a solid wall is well known and is described by the Earle H. Kennard study of Irrotational Flow of Frictionless Fluids, Mostly of Invariable Density published by the David Taylor Model Basin, Washington, D.C., February 1967, for example. [0023] However, Parrish et al did not recognize and certainly did not disclose the dynamic consequence of shock impedance, which is the product of the at-rest density of the material times the speed of propagation of the shock wave in that material. The shock impedance of the lead disc described by Parrish as an example, is greater than that of the impinging explosive. Considering the lead example described by Parrish et al, the shock impedance (density times shock speed) of a solid metal disc (density=11.3 g/cc, shock speed=2.0-2.8 km/sec) is 1.5-2.5 times that of the explosive (density=1.75 g/cc; detonation speed=8 km/sec), causing strong reflected energy to be propagated back through the explosive thereby reducing the magnitude of transmitted energy. This action results in a weakened collision of shock fronts 16 at the center of the disc and a reduced energy imparted to the radial jet 26.

[0024] An improved alternative to the same idea would be to make a metal disc that has substantially the same shock impedance of the impinging explosive. One way to match the shock impedances is to form the disc of compressed metal powder rather than as a solid article. As an example, a compressed powder lead disc with 25% porosity would approximate the shock impedance of HMX, as would a powdered copper disc of about 35%. With the matching shock impedances at the interface between the explosive and the disc, the explosive pressure shock is transmitted directly to the metal disc, with a collision that produces the desired high density metallic radial jet (see FIGS. 6 and 7).

[0025] Although the invention disclosed herein has been described in terms of specified and presently preferred embodiments which are set forth in detail, it should be understood that this is by illustration only and that the invention is not necessarily limited thereto. Alternative embodiments and operating techniques will become apparent to those of ordinary skill in the art in view of the present disclosure. Accordingly, modifications of the invention are contemplated which may be made without departing from the spirit of the claimed invention.

1. An explosive cutting system comprising:
   a substantially cylindrical column of explosive/metal mixture including high explosive material mixed with one or more powdered metals, the explosive/metal mixture having a density greater than the high explosive material alone;
   an explosive detonator at opposite ends of said column; and
   means to initiate said detonators substantially simultaneously.

2. An explosive cutting system as described by claim 1 wherein said cylindrical column comprises a plurality of contiguously aligned pellets of explosive/metal mixture.

3. An explosive cutting system as described by claim 1 wherein said high explosive material is selected from the group comprising HMX, RDX, HNS, PXN, TATB and PETN.

4. An explosive cutting system as described by claim 1 wherein said metal is selected from the group comprising aluminum, copper, lead, tin, bismuth, tungsten, iron, lithium, sulfur, tantalum, zirconium, boron, niobium, titanium,
cesium, zinc, magnesium, selenium, tellurium, manganese, nickel, molybdenum, and palladium.

5. An explosive cutting system comprising:
   A substantially cylindrical column comprising a coaxial alignment of at least one metallic disc contiguous
   between adjacent cylinders of high explosive material, the shock impedance of said disc or discs being substan-
   tially the same as the shock impedance of said explosive; an explosive detonator at opposite ends of said column;
   and means to initiate said detonators substantially simultaneously.

6. An explosive cutting system as described by claim 5 wherein said column comprises a plurality of contiguous
   aligned pellets of high explosive material.

7. An explosive cutting system as described by claim 5 wherein said high explosive material is selected from
   the group comprising HMX, RDX, HNS, PYX, TATB and PETN.

8. An explosive cutting system as described by claim 5 wherein said metallic disc or discs comprises an integral
   compression of powdered material selected from the group comprising aluminum, copper, lead, tin, bismuth,
   tungsten, iron, lithium, sulfur, tantalum, zirconium, boron, niobium, titanium, cesium, zinc, magnesium, selenium, tellurium,
   manganese, nickel, molybdenum, and palladium.

9. A method of cutting pipe structures comprising the steps of substantially simultaneously detonating a column
   of explosive material to generate a pair of explosions for propagating a pair of colliding shock fronts transmitted
   along a substantially common axis to cause a radial expansion of explosion gas within a plane substantially normal
to said axis wherein said explosion gas is a mixture of high explosive gas and fluidized metal, with said explosion gas
   having an explosive density greater than the explosive density of said high explosive gas independent of said metal.

10. A method of cutting pipe structures as described by claim 9 wherein said explosive material is pressed into discs
    that are aligned face-to-face along said axis in a column that is detonated substantially simultaneously at opposite
    ends thereof to generate said pair of colliding shock fronts.

11. A method of cutting pipe structures as described by claim 9 wherein high explosive and powdered metal are
    mixed to form said explosive material with an explosive density greater than the explosive density of said high explosive
    gas independent of said metal.

12. A method of cutting pipe structures as described by claim 9 wherein said column of explosive material is posi-
    tioned contiguous adjacent opposite faces of said metallic disc or discs, said explosive material and said disc having
    substantially the same shock impedance.

13. A method of cutting pipe structures as described by claim 9 wherein said metal comprises an element selected
    from the group comprising aluminum, copper, lead, tin, bismuth, tungsten, iron, lithium, sulfur, tantalum, zirconium,
    boron, niobium, titanium, cesium, zinc, magnesium, selenium, tellurium, manganese, nickel, molybdenum, and palladium.

14. A method of cutting pipe structures as described by claim 9 wherein said explosive material comprises material
    selected from the group comprising HMX, RDX, HNS, PYX, TATB and PETN.

15. A method of cutting pipe structures as described by claim 9 wherein column of explosive material is substan-
    tially simultaneously detonated by detonating cords of prescribed length.

16. A method of cutting pipe structures as described by claim 9 wherein opposite ends of said column of explosive
    material are substantially simultaneously detonated by one or more detonators selected from the group comprising
    EBWs, EFIs, SCBs and hot-wire initiators.

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