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APPARATUS FOR SEALING CHAMBERS IN A PERFORATING TOOL

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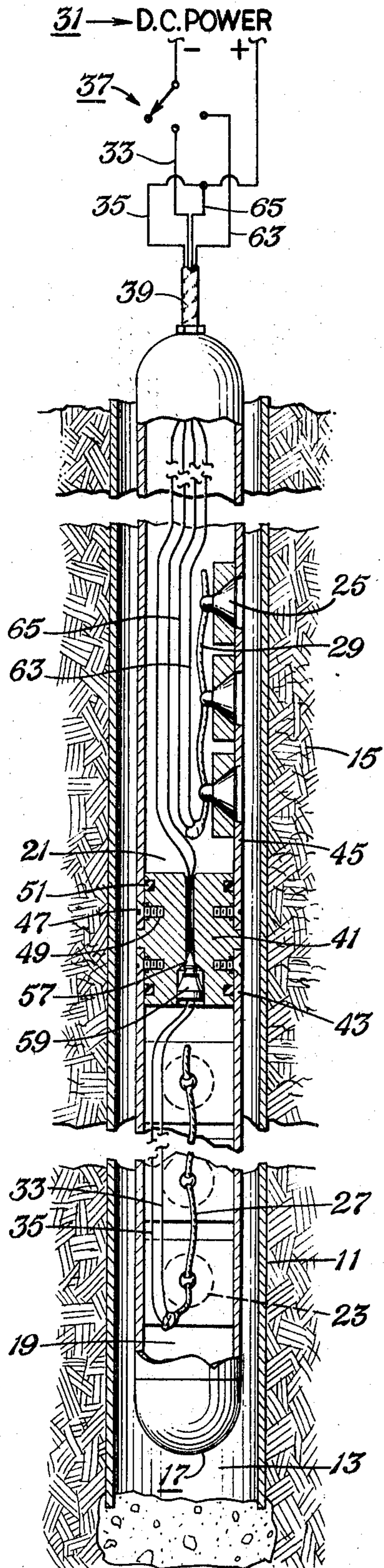


Fig. 1

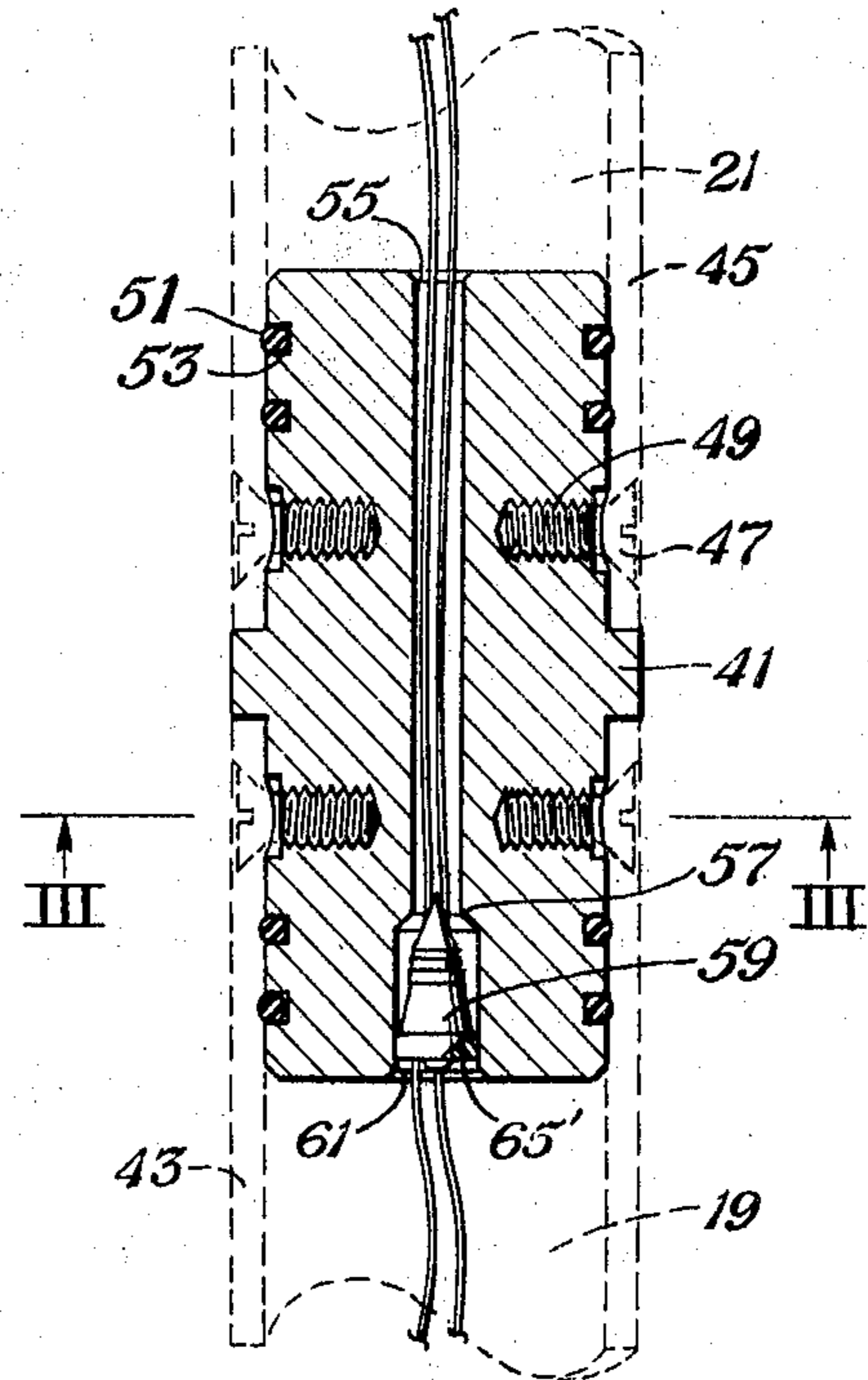


Fig. 2

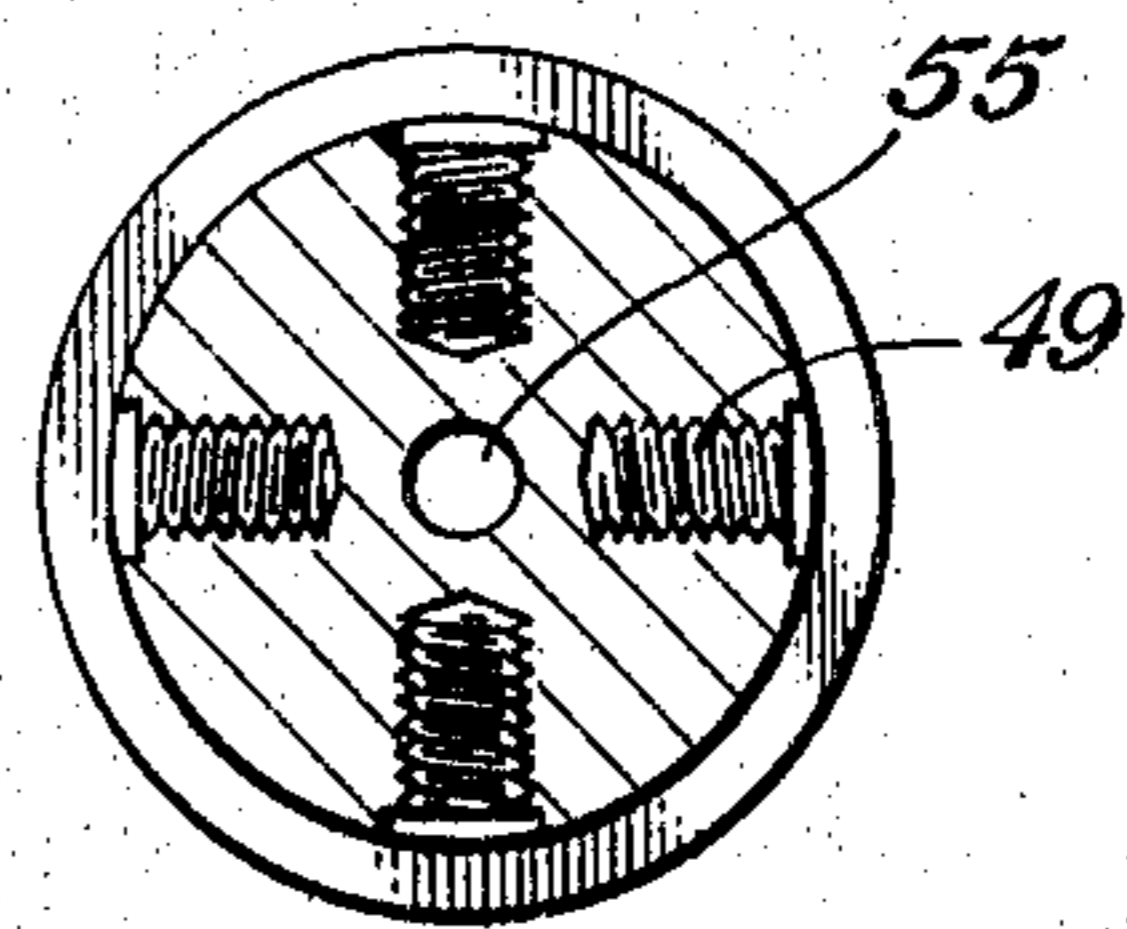


Fig. 3

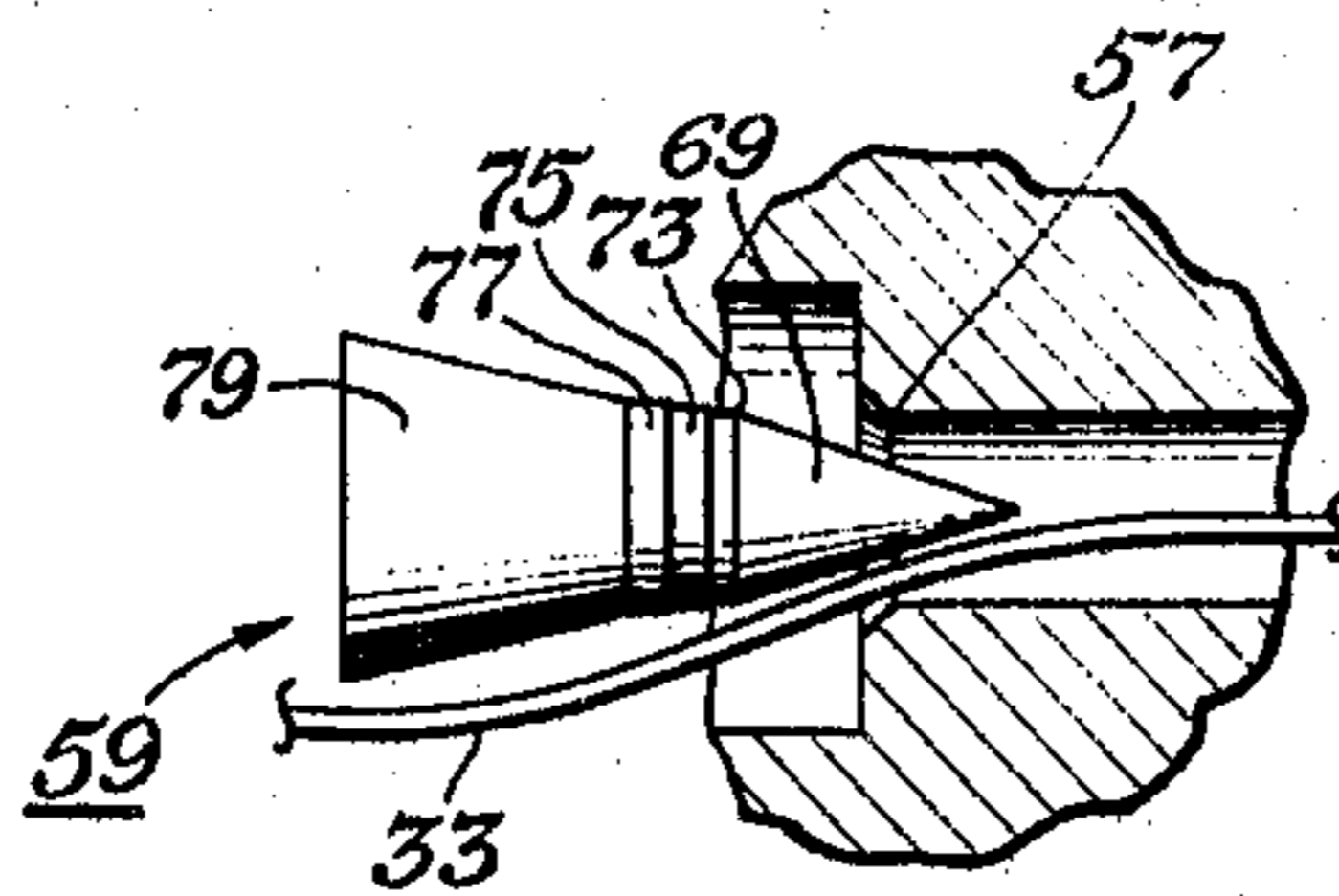


Fig. 4

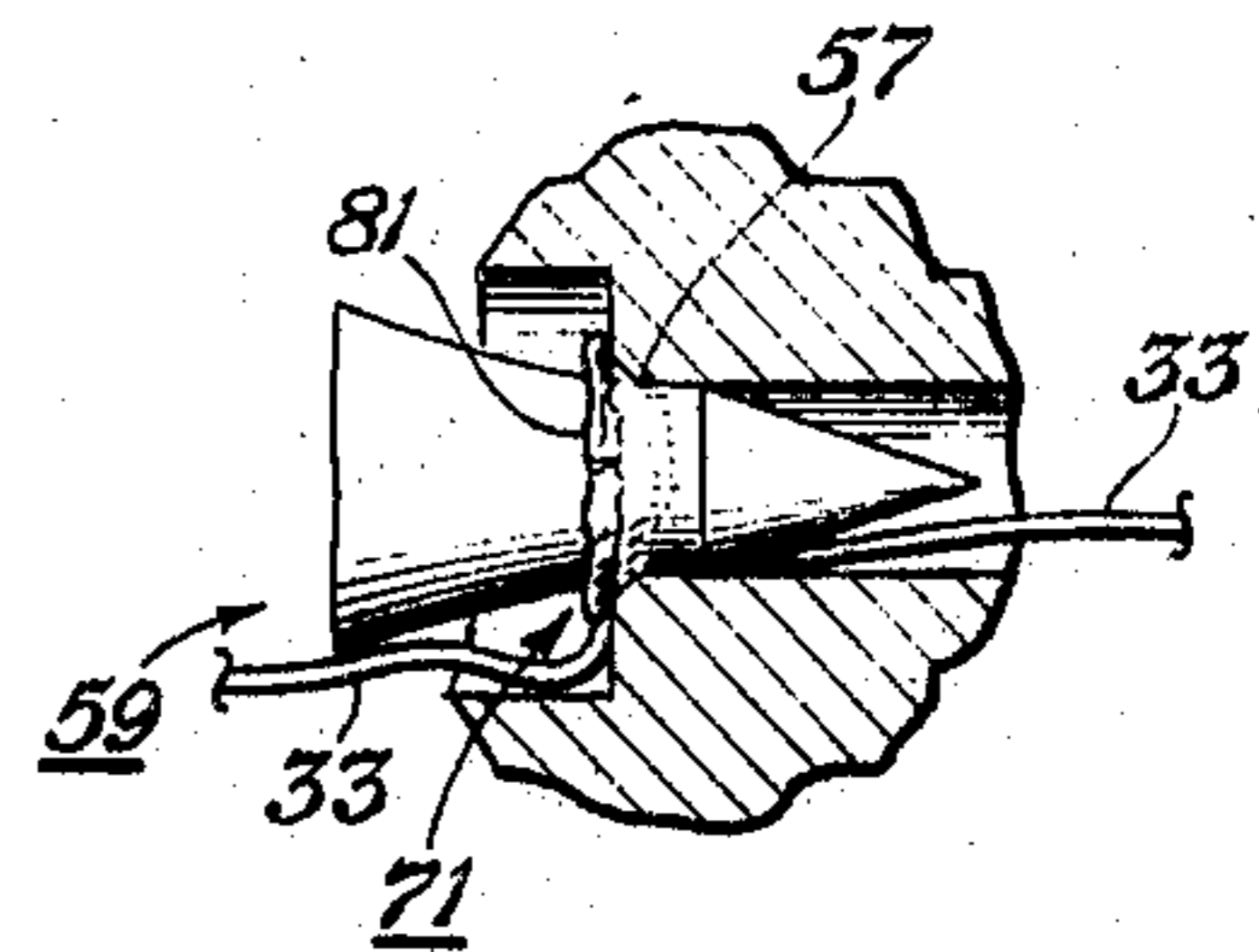


Fig. 5

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**APPARATUS FOR SEALING CHAMBERS IN A PERFORATING TOOL**

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13 Claims

**ABSTRACT OF THE DISCLOSURE**

This specification discloses apparatus for isolating a chamber in a perforating tool having a plurality of chambers and conductor means that connects an explosive charge in one of the chambers to a firing means, characterized by:

- (a) providing a sealing partition means between the chamber with the explosive charge and an adjacent chamber and having, connecting the chambers, a passageway through which the conductor means pass;
- (b) providing a seat in the passageway;
- (c) inserting a sealing projectile adjacent the seat and between the seat and the explosive charge; and
- (d) detonating the explosive charge to drive the sealing projectile into the seat.

This specification also discloses a specific construction of apparatus in which retaining means is provided behind the projectile and in which a preferred projectile comprises:

- (a) a cone-shaped guide portion no larger in diameter than the seat in the partition means;
- (b) a frustum base portion larger in diameter than the seat to prevent the projectile from passing completely through the seat; and
- (c) a plurality of successively larger cylindrical portions connecting the cone-shaped guide portion with the frustum base portion.

**BACKGROUND OF THE INVENTION**

**Field of the invention**

This invention relates to perforating tools. More particularly, it relates to perforating tools such as are employed in establishing communication through casing between a well bore and subterranean formations.

**Description of the prior art**

In producing hydrocarbon fluids from subterranean formations it is conventional practice, in completing a well in which casing has been set through the productive subterranean formation, to perforate the casing to effect communication between the well bore and the subterranean formation. Ordinarily, such communication employs the detonation of an explosive charge, either in jet perforating or in driving a bullet through the casing, cement sheath thereabout, and into the subterranean formation. The chambers housing the explosive charges for effecting perforations are conventionally relatively short; for example, on the order of a few feet or less. In many instances, therefore, it becomes necessary to employ a plurality of chambers to effect perforations over the desired interval, which may extend for a hundred feet or more. In such an arrangement, the explosive charges in the bottommost firing chamber will be detonated first, and the perforating proceed upward through successively higher firing chambers. It was early recognized that the later firing chambers must be isolated from the earlier firing chambers to prevent damage and ensure that subsequent chambers will fire in their turn. The damage oc-

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curred not only from the detonation itself, which often would prevent the firing or cause misfiring of the explosive charges in the subsequent chamber, but also from the invasion of the bore hole fluids, ordinarily at a relatively high pressure. The pressure is usually greater at greater depths.

In the prior art, the respective chambers were isolated during the assembly of the tool, including the firing chambers. To seal against the high temperatures and pressures with the conductors running through the sealing partition between the chambers created a difficult sealing problem, requiring expensive, elaborate and difficultly assemblable seals. Thus, prior art processes of sealing each chamber during assembly of the explosive charges, the explosive Primacord connecting the charges, and the conductors passing to the respective chambers, to effect an adequate seal; yet, ensure that the conductors would be operative to fire the charges in the respective chambers; was a very costly operation. Still further disadvantages attended the prior art seals since they were frequently unreliable and allowed some "blow-by" of the fluid during or after the detonation of the explosive charge in the chamber therebelow. This was particularly acute in wells deeper than about 9,000 feet, where the hydrostatic pressure on the fluids in the well bore became significant; for example, about 4,000 lbs. per sq. in. with salt water. Blow-by of hot detonation gases was disadvantageous, as would be expected, in that it could cause the explosive charges in the chamber immediately above to misfire or fire improperly.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a view partly in section and partly schematic of a down hole perforating tool employing one embodiment of the invention.

FIG. 2 is a longitudinal cross-section of a sealing partition employed in one embodiment of the invention.

FIG. 3 is a lateral cross-sectional view along the lines III—III of FIG. 2.

FIGS. 4 and 5 are side views, partly in section, showing the sealing projectile in place before and after detonation of an explosive charge in accord with one embodiment of the invention.

**DESCRIPTION OF PREFERRED EMBODIMENT**

It is a particular feature of the invention to provide an isolation means effecting isolation of a firing chamber with a seal that resists extremely high pressures, that eliminates difficulties sealing around conducting means, and that alleviates the other problems encountered in prior art devices; yet, to reduce labor costs to about 1/2 of that formerly required, to reduce materials costs for the seals to about 1/7 of the former cost, and to reduce manufacturing costs for the partition means to about 80% of that formerly required.

In accordance with one aspect of the invention, there is provided an improvement in a method of isolating a chamber in a tool being used to perforate a steel casing thereabout, the tool having conductor means leading into a plurality of chambers, the conductor means connecting an explosive charge in one chamber to a firing means. The improvement comprises:

- (a) Providing a sealing partition means in the tool between the chamber having the explosive charge and an adjacent chamber, having a passageway connecting the chambers, and having the conductor means passing through the passageway;
- (b) Providing a seat in the passageway;
- (c) Inserting a sealing projectile adjacent the seat and between the seat and the explosive charge; and

(d) Detonating the explosive charge to drive the sealing projectile into the seat and effect a seal to thereby isolate the chamber in which the explosive charge has been fired from the adjacent chamber.

In accordance with another aspect of the invention there is provided an improvement in a downhole tool for establishing communication through a casing from a well bore into a subterranean formation by detonating an explosive charge within one of a plurality of chambers in the tool. The improvement comprises:

(a) A partition means intermediate the one chamber containing the explosive charge and an adjacent chamber and sealingly connected to the walls thereof;

(b) A passageway passing through the partition means and communicating with both of the chambers;

(c) Conductor means within the passageway connecting the explosive charge with a firing means;

(d) A seat provided in the passageway; and

(e) A sealing projectile adjacent the seat and between the seat and the explosive charge.

The invention may be clearly understood by referring to the figures. FIG. 1 illustrates apparatus for establishing communication through a casing 11 from a well bore filled with fluid 13 into subterranean formation 15. Therein tool 17 has a plurality of chambers 19 and 21. In chamber 19, perforating means, including explosive charges 23, are set to perforate into the formation. In chamber 21 perforating means, including explosive charges 25, are also set to perforate into the formation. Explosive charges 23 are detonated by appropriate detonating means, such as Primacord 27. Similarly, second detonating means, such as Primacord 29, serves to detonate explosive charges 25.

As a firing means, a DC power source 31 may be connected by conductors 33 and 35 via a stepping switch 37 with Primacord 27 and explosive charge 23. Conductor means, such as conductors 33 and 35, are carried inside cable 39 which ordinarily has a tensile load bearing member in addition to the conductors. Cable 39 may have an exterior armored portion which will serve as a ground for the conductor means if desired.

Ordinarily, tool 17 is introduced into the well through a lubricator to maintain the well pressure, especially after perforating. Cable 39, suspending tool 17, is lowered over a sheave and is lowered into and withdrawn from the well in response to winching means. Additionally, depth measuring means may be employed in connection with cable 39 and its supporting sheave to position tool 17 in order to effect perforations at exactly the desired depth in the subterranean formation 15. The lubricator, sheave, winching means and depth measuring means are well known, and do not form any part of this invention and, hence, need not be described herein.

Partition means 41 is interposed between chamber 19 and chamber 21. Partition means 41 is sealingly connected with wall 43 of chamber 19 and with wall 45 of chamber 21. The connection may be effected by any means; such as, threaded bolts 47 having countersunk, recessed heads and passing through the respective walls and into the partition means having an aperture 49 tapped with matching threads, shown in greater detail in FIG. 2. The sealing may be effected by any means, such as O-rings 51 mounted in grooves 53 and interposed between partition means 41 and the walls 43 and 45 of the respective chambers 19 and 21.

Passageway 55 penetrates longitudinally through partition means 41. The conductor means passing through passageway 55 connects explosive charges 23 with the firing means. Seat 57 is formed in the passageway. Ordinarily, seat 57 is formed by reaming to a particular dimension for a depth; for example, about 1 inch; into passageway 55. If desirable, seat 57 may be coated by a hard coating, such as silicon carbide or Stellite.

Sealing projectile 59 is positioned adjacent seat 57 such that it is between seat 57 and explosive charges 23 (FIG. 1).

It has been found advantageous to employ a retaining means such as enlarged portion 61 to maintain sealing projectile 59 adjacent seat 57 and to help maintain it aligned therewith.

As can be seen in FIG. 3 threaded apertures 49 do not penetrate through the sidewall of the partition means to passageway 55; hence, there is no problem of communication of fluids between the well bore and passageway 55 except by way of chamber 19 following detonation of explosive charges 23.

In operation, the components are assembled in tool 17 as described hereinbefore. Thereafter, tool 17 is lowered, via cable 39 into well bore 13 to the depth interval to be perforated. Stepping switch 37 is stepped onto conductor 33. This detonates Primacord 27, also detonating explosive charges 23 in chamber 19. The detonation of the explosive charges 23 and Primacord 27 simultaneously perforates through casing 11 into subterranean formation 15, and drives sealing projectile 59 deeply into seat 57 to isolate firing chamber 19. Thereafter, the gases liberated by detonation of explosive charges 23 are dispelled through openings in chamber 19 into well bore 13.

Sealing projectile 59, in being driven into seat 57, severs conductor 33 and seals against seat 57. In this way, misfiring of explosive charges 25 in chamber 21 is prevented, either by damage from the detonation gases or from subsequent invasion of fluids from the pressurized well bore 13 into chamber 21.

Stepping switch 37 can be stepped onto conductor 63, which, via its connection with DC power source through conductor 65, detonates Primacord 29; in turn, (1) detonating explosive charges 25, (2) isolating chamber 21 by driving its sealing projectile into its seat, and (3) perforating into the formation.

Thus, it can be seen that any number of chambers may be fired successively to effect perforation over the desired interval by employing this embodiment of the invention.

It has been found preferable to employ a back up material 65 (FIG. 2) in retaining means 61 and interposed between sealing projectile 59 and explosive charges 23. Back up material 65 functions to help retain sealing projectile 59 in place adjacent seat 57 and aligned therewith before the detonation of charges 23; helps ensure that a maximum pressure is applied to the frustum base portion of sealing projectile 59 to drive it deeply into seat 57; and disintegrates to fill any voids that might occur, block "blow-by" of any detonation gases, and effect complete sealing. Back up material 65 is composed of short asbestos fiber formed into a disc. The asbestos fiber withstands high temperature and yet disintegrates readily because of its short fiber to fulfill the desired functions. Because it is asbestos, it may be pressed into retaining means 61 without harming conductors that pass therethrough.

Sealing projectile 59 may be of any shape that will form a seal with seat 57. For example, sealing projectile 59 can be in the form of a sphere or a cone. A cone having three sections differing in degree of taper, or slope, from the adjacent section can be employed as the sealing projectile.

It has been found, however, that dramatically improved results are obtained when sealing projectile 59 has a shape illustrated in FIG. 4. Therein, cone-shaped nose portion 69 aids in assembly and alignment, automatically dispersing conductors such as conductor 33 around the sealing projectile. Cone-shaped nose portion 69 need not be completed to its apex but can be frusto-conical. Its maximum diameter will be no larger than the diameter of seat 57. Preferably, cone-shaped nose portion has a slope with respect to its longitudinal axis of between 10 and 30 degrees.

Next, there is a section 71 of at least two stepped cylindrical portions. First cylindrical portion 73, con-

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tiguous with the base of the cone-shaped nose portion 69, has a diameter substantially equal to the seat diameter. Thus, when sealing projectile 59 is driven into seat 57, first cylindrical portion 73 severs conductor 33, instead of merely compressing it and allowing blow-by through openings at the edge of the compressed conductor.

Second cylindrical portion 75 contiguous with first cylindrical portion 73 has a diameter slightly larger than the seat diameter. The diameter of the second cylindrical portion is at least 0.002 inch, preferably about 0.005 inch, larger than the seat diameter. The second cylindrical portion serves to make the projectile self aligning in order to get seal material all around the seat opening and somewhat cushion the impact of the projectile. The amount of metal larger than the seat must not be so great as to diminish the wall to wall contact penetration into the seat to less than about  $\frac{1}{8}$  inch. Although the maximum diameter will vary with the material of construction; ordinarily, the diameter of the second cylindrical portion will be no more than about 0.010 inch larger than the seat diameter.

It has been found that improved results are obtained by including a third cylindrical portion 77 contiguous with the second cylindrical portion which has a diameter similarly slightly larger than the diameter of the second cylindrical portion. Specifically, similarly as described with respect to the second cylindrical portion and the seat diameter, the diameter of the third cylindrical portion is, ordinarily, 0.002-0.010 inch, preferably about 0.005 inch, larger than the second cylindrical portion. The third cylindrical portion 77 improves the self aligning characteristics of the projectile and by the additional metal around its periphery further cushions the impact of the projectile into seat 57; yet, does not accumulate metal so rapidly as to prevent the projectile from being driven deeply into the seat for a better seal.

Ultimately, there is a frustum base portion 79, adjacent the last cylindrical portion, that has a minimum diameter substantially the same as the last cylindrical portion and sloping to a diameter at its base large enough to ensure that the projectile does not pass completely through the seat under the force of the explosive charge. Although the maximum diameter of the base will depend somewhat upon the material from which sealing projectile 59 is made and on the degree of slope, ordinarily, a maximum diameter of at least 50% more than the diameter of the seat is adequate to ensure that the sealing projectile does not pass completely through the seat. Preferably the frustum base portion has a slope of between 10 and 30 degrees with respect to its longitudinal axis.

FIG. 5 illustrates sealing projectile 59 after it has been driven deeply into seat 57 by the detonation of explosive charges 23. Conductor 33 is cleanly severed. Excess metal 81 is driven onto the reamed seat and into any small openings thereabout to effect a complete seal that is resistant to high temperature and high pressure.

Sealing projectile 59 may be constructed of any material that will resist the high temperature and high pressure; yet, be malleable enough to be driven deeply into the seat to effect a seal. Ideally, the material of which the sealing projectile is constructed should be lightweight such that it would have little inertia and will be moved into sealing position quickly when the explosive charge is detonated. It should have a uniform density so as to truly align itself and properly seat into seat 57. It should withstand temperature as high as 500 degrees Fahrenheit down hole plus instantaneous temperature as high as 1000 degrees Fahrenheit. It should be capable of shear and flow; i.e., not be frangible; should have less hardness than the seat but should have high enough density and resistance to shear and flow to keep from being forced completely through the seat. Specifically, soft, malleable metals; such as, brass, copper, and mild steel may be employed. Aluminum is particularly pre-

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ferred. Any other material having the desired properties can be employed.

A specific embodiment that has been found to work well in several different tools having different diameters was the following. A passageway  $\frac{5}{16}$  inch in diameter was drilled longitudinally through the partition means. A retaining means  $\frac{5}{8}$  inch in diameter was drilled 1 inch deep into the passageway before the seat was formed. A seat  $\frac{21}{64}$  inch was reamed 1 inch deeper into the passageway. A sealing projectile was fabricated of aluminum. It had a maximum diameter at the base of the frustum base portion of about  $\frac{9}{16}$  inch. The frustum base portion had a slope of about 13 degrees with respect to its longitudinal axis. The cone-shaped nose portion has a slope of about 15 degrees with respect to its longitudinal axis and had a maximum diameter of 0.328 inch. The first cylindrical portion had a diameter of 0.328 inch and a length of  $\frac{1}{32}$  inch. The second cylindrical portion had a diameter of 0.333 inch and a length of  $\frac{1}{16}$  inch. The third cylindrical portion had a diameter of 0.338 inch and a length of  $\frac{1}{16}$  inch. The overall length of the sealing projectile was  $1\frac{5}{32}$  inch, affording  $\frac{1}{2}$  inch each for the cone-shaped nose portion and the frustum base portion.

Thus, it can be seen that the invention provides a method of effecting a seal in situ, using the explosive force of the detonation of an explosive charge, to effect a seal that is resistant to high temperatures and to pressures in excess of 4,500 p.s.i. The seal alleviates difficulties with blow-by of fluid, either during the detonation or from the well bore fluids following the detonation, that could cause misfiring of the explosive charges in the remaining chambers. Yet, even with the improved results, the invention effects a cost reduction by cutting the labor costs on loading and assembling the gun in half, reducing the material cost for the seal itself to about  $\frac{1}{7}$  the former cost and reduces the manufacturing cost for the sub-assembly by about 20%.

Although the invention has been described with a high degree of particularity, it is understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. Apparatus for establishing communication through a casing from a well bore filled with fluid to a subterranean formation comprising:

- (a) a tool having a plurality of chambers;
- (b) perforating means in at least one chamber and employing an explosive charge to effect perforation of said casing;
- (c) a firing means;
- (d) a cable leading into said tool carrying conductor means that is connected with said explosive charge so as to ultimately effect detonation thereof when suitable current is impressed onto said conductor means;
- (e) partition means interposed between said one chamber having said explosive charge therein and an adjacent chamber and sealingly connected with the walls of said one chamber and said adjacent chamber;
- (f) a passageway penetrating longitudinally through said partition means and having said conductor means passing therethrough;
- (g) a seat formed in said passageway;
- (h) a sealing projectile adjacent said seat interposed between said seat and said explosive charge; said sealing projectile being adapted to sever said conductor means and be driven deeply into and sealed with said seat; and
- (i) retaining means for holding said projectile adjacent said seat.

2. The apparatus of claim 1 wherein said seat has a first diameter and said sealing projectile comprises a cone-shaped guide portion no larger in diameter than said seat first diameter, a first cylindrical portion contiguous with base of said cone-shaped guide portion and having a diameter substantially equal to said seat first diameter, a second cylindrical portion contiguous with said first cylindrical portion and having a diameter at least 0.002 inch larger than said seat first diameter, and a frustum base portion adjacent said last cylindrical portion and having a minimum diameter substantially the same as said last cylindrical portion and sloping to a diameter large enough to ensure that said projectile does not pass completely through said seat.

3. The apparatus of claim 2 wherein said second cylindrical portion has a diameter 0.02–0.010 inch larger than said seat first diameter.

4. The apparatus of claim 3 wherein said second cylindrical portion has a diameter of about 0.005 inch larger than said first cylindrical portion.

5. The apparatus of claim 2 wherein a third cylindrical portion is interposed between said second cylindrical portion and said frustum base portion of said sealing projectile contiguous with said second cylindrical portion and having a diameter .002–.010 inch larger than said second cylindrical portion.

6. The apparatus of claim 5 wherein said third cylindrical portion has a diameter about 0.005 inch larger than second cylindrical portion.

7. The apparatus of claim 2 wherein said cone-shaped guide portion has a slope in the range of 10–30 degrees with respect to its longitudinal axis.

8. The apparatus of claim 2 wherein said frustum base portion has a slope in the range of 10–30 degrees with respect to its longitudinal axis.

9. The apparatus of claim 1 wherein said retaining means includes back up material interposed between said sealing projectile and said explosive charge.

10. The apparatus of claim 9 wherein said back up material consists essentially of short fiber asbestos arranged in the form of a disc which can be inserted behind said sealing projectile in said retaining means and about said conductor means.

11. The apparatus of claim 1 wherein said seat con-

sists essentially of substantially uniformly cylindrical aperture formed in metal and concentric with said passageway.

12. The apparatus of claim 1 wherein said partition means comprises a steel cylindrical block having a central cylindrical portion of larger diameter adapted to abut ends of walls of chambers, having diametrically disposed threaded apertures on each side of said cylindrical portion and matching with countersunk apertures in said walls of said chamber and adapted to conformingly receive a stud bolt inserted through the apertures in said walls, and having at least one groove at each end of said partition means containing a ring seal to sealingly engage the respective walls of said chambers, said threaded apertures penetrating only into said steel and not into said passageway penetrating longitudinally through said partition means.

13. In a down hole tool for establishing communication through a casing from a well bore into a subterranean formation by denoting an explosive charge within one of a plurality of chambers in the tool, the improvement comprising:

- (a) a partition means intermediate said one chamber and an adjacent chamber and sealingly connected to the walls thereof;
- (b) a passageway passing through said partition means and communicating with both of said chambers;
- (c) conductor means within said passageway connecting said explosive charge with a firing means;
- (d) a seat provided in said passageway; and
- (e) a sealing projectile adjacent said seat and between said seat and said explosive charge.

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