United States Patent

Chenoweth

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[45] Mar. 14, 1972

[54] SUBSURFACE FLUID PRESSURE REDUCTION DRILLING APPARATUS

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[73] Assignee: Baker Oil Tools, Inc., Commerce, Calif.

[22] Filed: Apr. 12, 1971

[21] Appl. No.: 132,992

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 12,614, Feb. 19, 1970.

[52] U.S. Cl. 175/56, 91/47, 137/119, 175/92, 175/234, 175/243

[51] Int. Cl. E21b 5/00

[58] Field of Search 175/56, 92, 232, 234, 235, 175/241, 242, 243, 321; 166/224, 226; 137/119; 91/47-51

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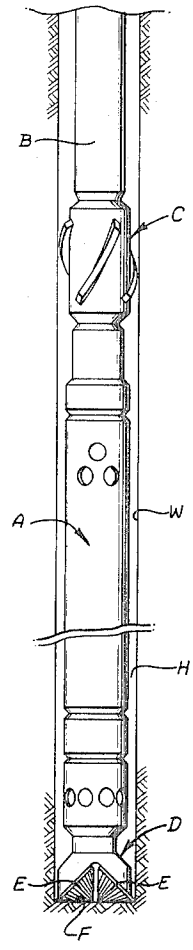
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[57] ABSTRACT

A pulse generator adapted to be connected to a drill pipe string at its upper end and a drill bit at its lower end, the pulse generator providing an external working shock passageway between its exterior and the wall of the bore hole being drilled and an internal counterbalance shock passageway, a shuttle valve in the path of drilling fluid flowing into the generator from the drill pipe string alternately closing the inlets to the shock passageways to alternately generate a negative pressure pulse wave in each passageway and reduce the hydrostatic pressure in the external passage, which includes the bore hole region in which the bit is operating, for the purpose of increasing the drilling rate of the bit in the formation.

18 Claims, 12 Drawing Figures



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SHEET 1 OF 4

FIG. 1.

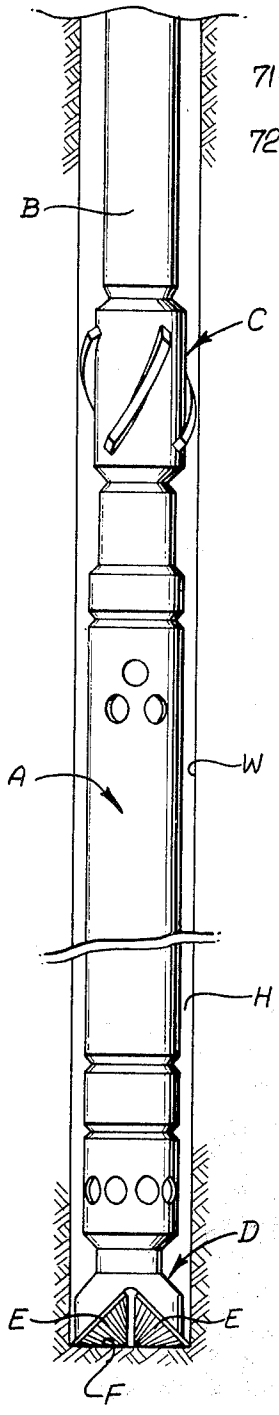


FIG. 6.

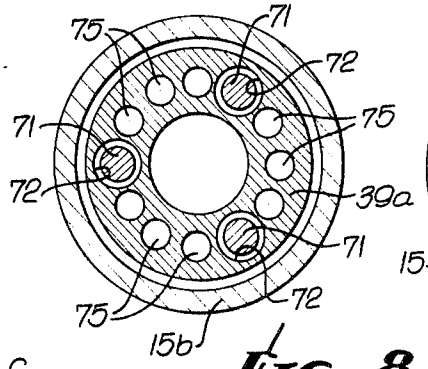


FIG. 3.

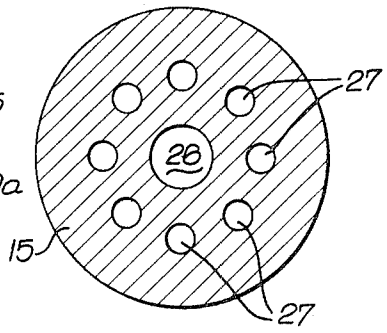


FIG. 8.

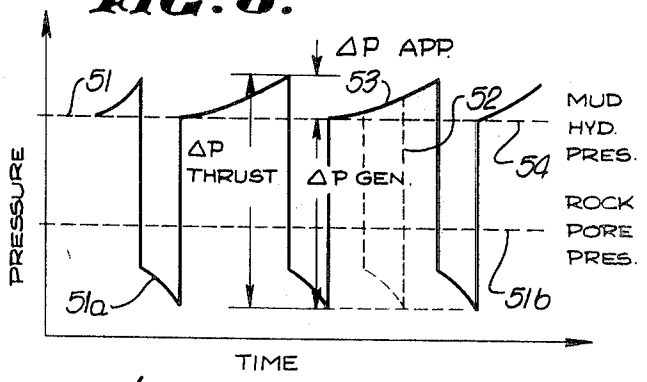
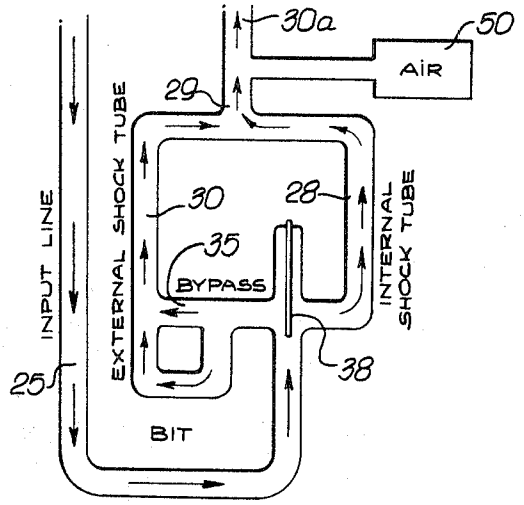


FIG. 7.



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FIG. 2a.

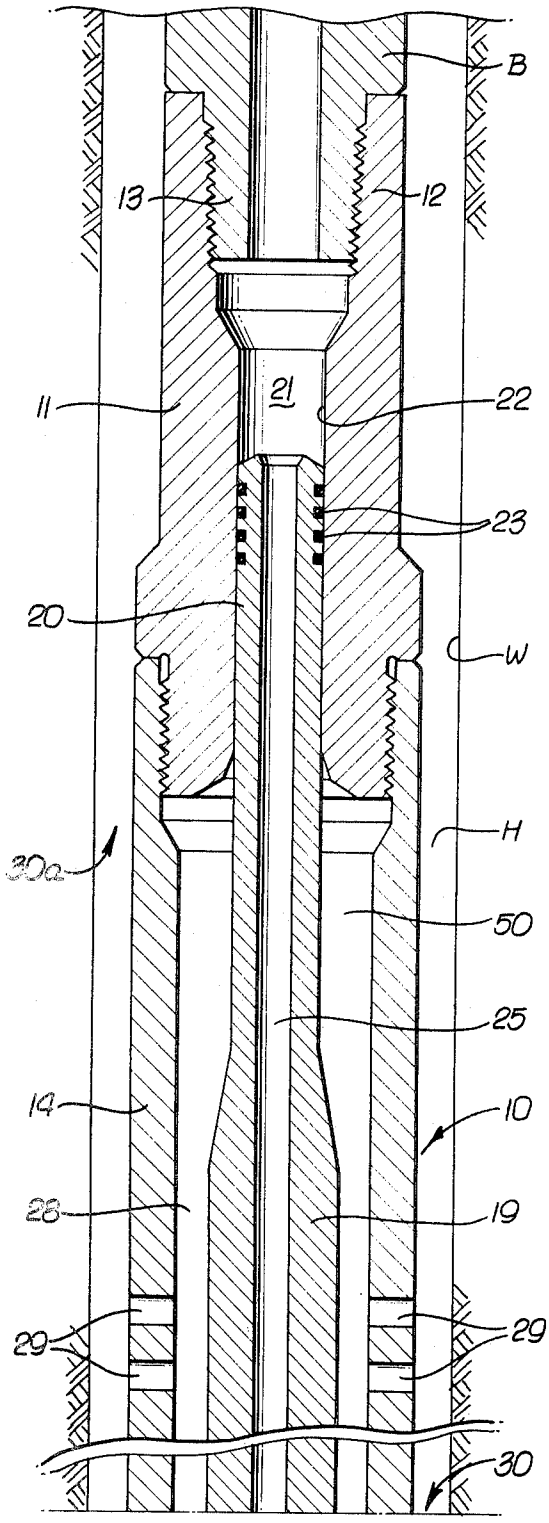
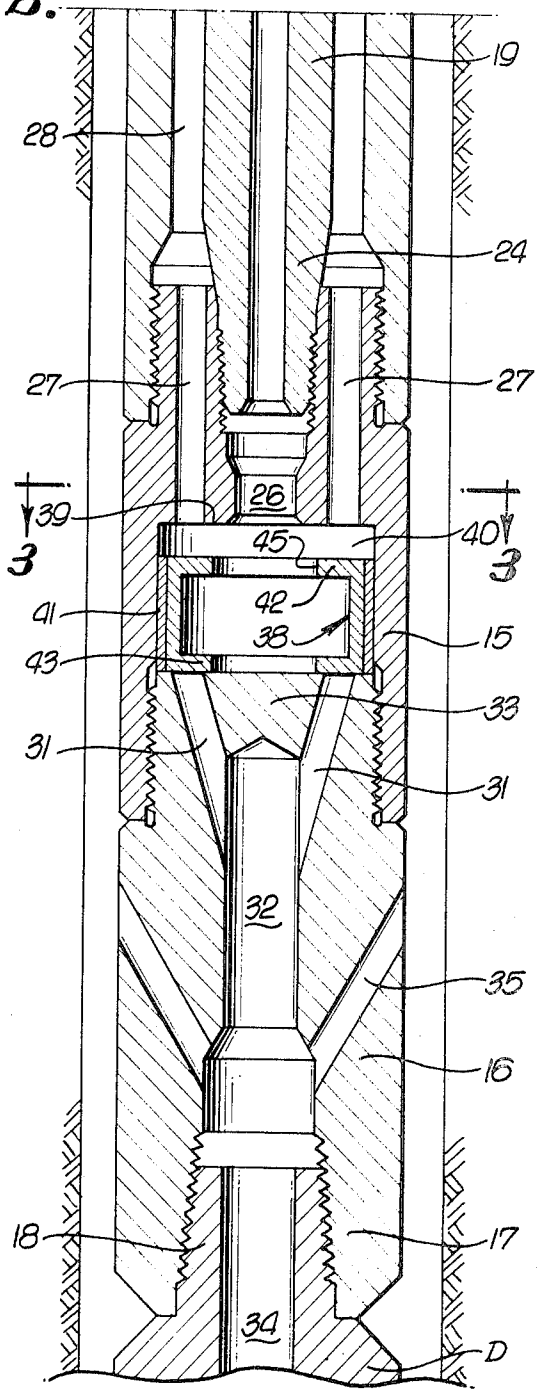


FIG. 2b.



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FIG. 5.

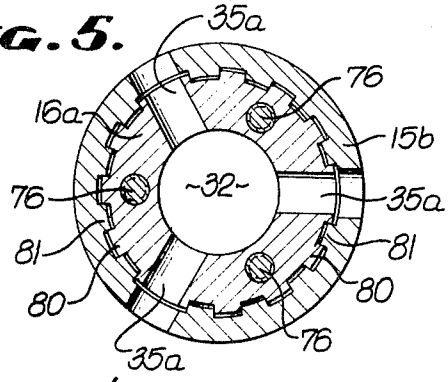


FIG. 4a.

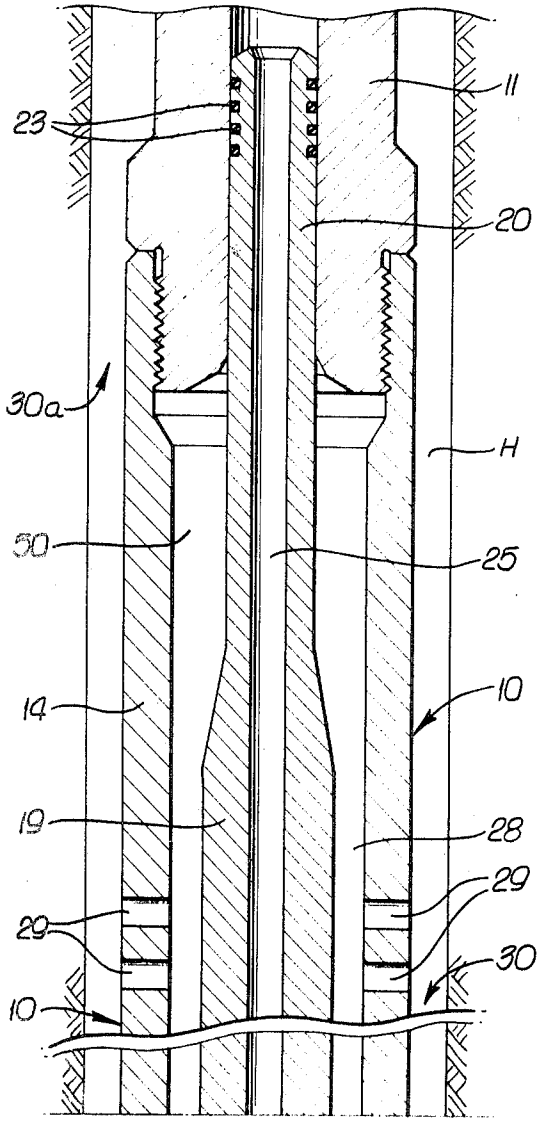
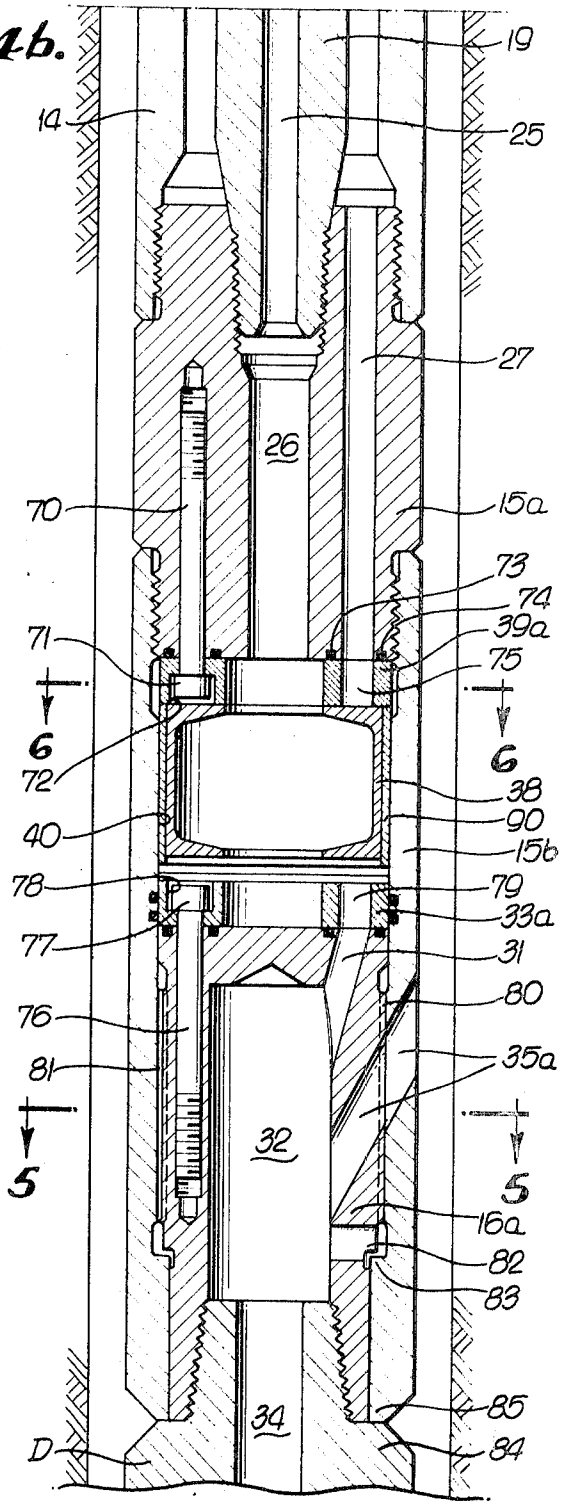


FIG. 4b.



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FIG. 9a.

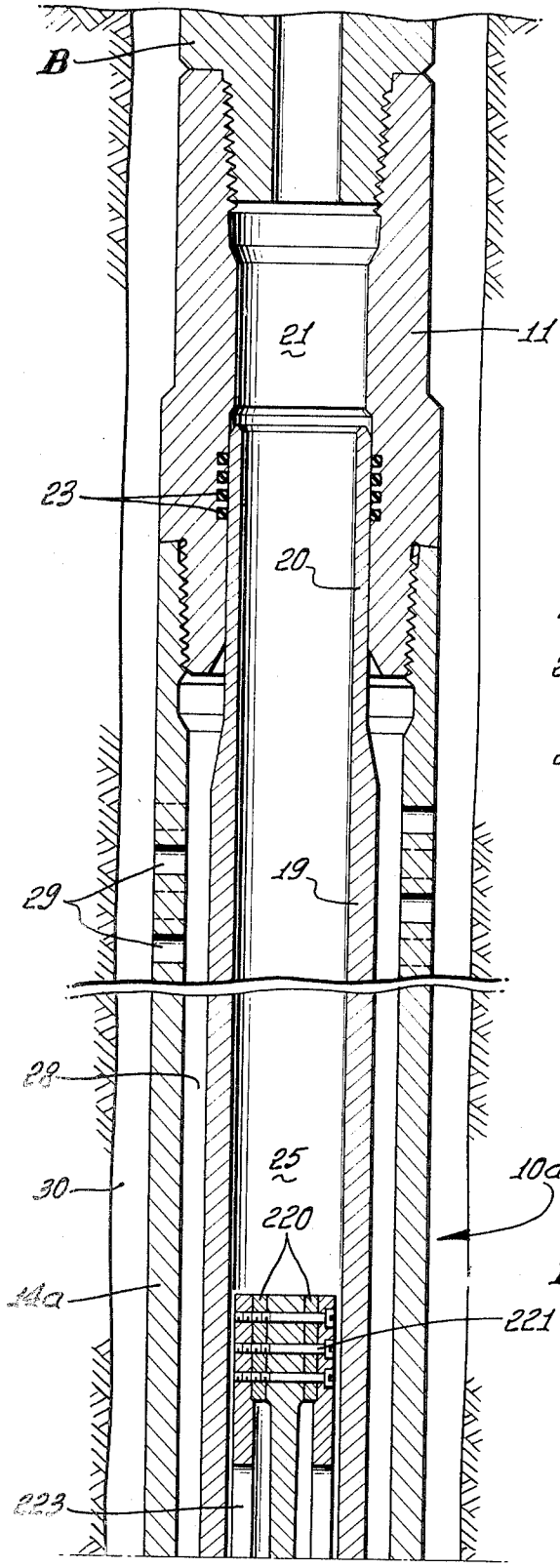
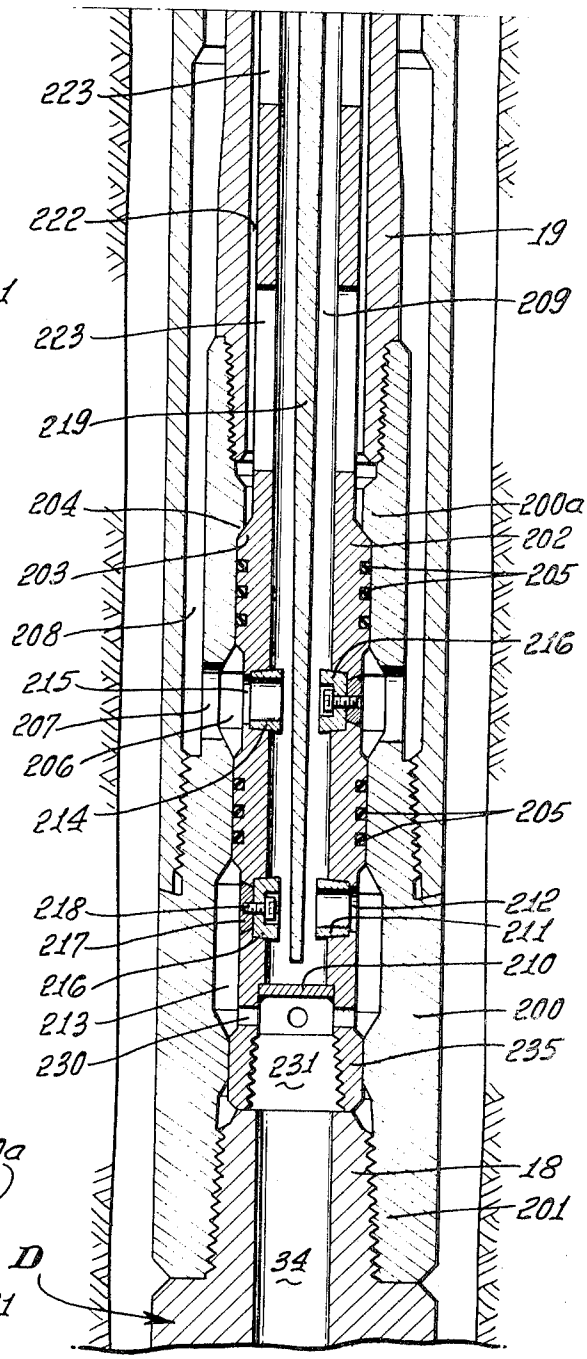


FIG. 9b.



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SUBSURFACE FLUID PRESSURE REDUCTION DRILLING APPARATUS

This application is a continuation-in-part of application Ser. No. 12,614, filed Feb. 19, 1970, for "Subsurface Fluid Pressure Reduction Drilling Apparatus."

The present invention relates to subsurface well bore apparatus, and more particularly to drilling apparatus capable of reducing the hydrostatic pressure of the fluid in the region of a bore hole being drilled by a bit.

A reduction in the hydrostatic head or pressure in a bore hole being drilled in a formation at the drilling region increases the drilling rate or efficiency of the bit. In the application of David V. Chenoweth and Talmadge L. Crowe, Ser. No. 12,591, filed Feb. 19, 1970, apparatus is disclosed in the nature of a pressure pulse generator that has a working shock passageway and a counterbalance shock passageway therein, the working shock passageway including the region in the bore hole at which drilling is taking place, and the counterbalance shock passageway being disposed within the generator itself, which is also true of a portion of the working shock passageway. A shuttle valve in the path of the drilling fluid flowing through the pulse generator alternately closes the passageways, causing the generation of negative pressure pulse waves therein, which, when passing through the external working shock passageway and its drilling region, effects a considerable reduction in the fluid pressure therein. In the prior application, the drilling region is isolated from the well bore thereabove so that the negative pulse pressure wave is confined to the immediate drilling region and has no effect on the drilling fluid in the well bore above the pack-off region and externally of the pressure pulse generator.

In the prior devices, both the external working shock passageway and the counterbalance shock passageway are located internally of the generator, which requires the cuttings and drilling fluid to pass through a circuitous path in the generator before discharging into the well bore above the location of the pack-off against the wall of the formation. This makes the generator apparatus relatively costly to manufacture, and susceptible to plugging by cuttings.

By virtue of the present invention, the counterbalance shock passageway is provided in the pressure pulse generator itself, but the working shock passageway is formed between the pulse generator and the wall of the surrounding well bore, eliminating the necessity for a pack-off against the wall of the well bore, as in the prior device. In addition, the cuttings produced by the drill bit attached to the lower end of the pulse generator need not travel through the pulse generator. Instead, they are circulated in a normal manner from the bottom of the well bore directly upwardly around the pulse generator and through the annulus surrounding the drill string.

Accordingly, an object of the present invention is to provide a pressure pulse generator of the character indicated which is much simpler than prior devices, less costly to manufacture, and easier to maintain in appropriate operating condition.

Another object of the invention is to provide an improved fluid pressure pulse generator apparatus used in connection with the drilling of a well bore that has a working shock passageway, including the drilling region in which the bit is operating, that is predominantly externally of the apparatus, being provided by the annulus between the exterior of the generator and the wall of the bore hole being drilled.

A further object of the invention is to provide a pressure pulse generator apparatus used in connection with the drilling of a bore hole, which is capable of reducing the hydrostatic pressure in the drilling region, and in which a pressure differential is created that imposes intermittent downwardly directed thrust on the apparatus and the drill bit connected thereto.

Another object of the invention is to provide a fluid pulse generator or oscillator used in the drilling of a bore hole, which is effective to reduce the hydrostatic pressure in the bore hole region in which the drilling operation is taking place, and which also utilizes a fluid pressure differential for

imposing a downward force on the lower portion of the apparatus and the drill bit connected thereto for penetrating the bit cutters into the bottom of the bore hole. It also produces a water hammer effect on the lower portion of the generator which is transmitted to the drill bit and its cutters to penetrate the latter into the bore hole. The rate of drilling is thereby increased by the combination of reducing the hydrostatic fluid pressure in the drilling region, providing a downwardly directed pressure differential on the apparatus and the drill bit, and imposing a downwardly directed water hammer or impact blow on the lower portion of the apparatus and the drill bit secured thereto.

This invention possesses many other advantages, and has other objects which may be made more clearly apparent from a consideration of several forms in which it may be embodied. Such forms are shown in the drawings accompanying and forming part of the present specification. These forms will now be described in detail for the purpose of illustrating the general principles of the invention; but it is to be understood that such detailed description is not to be taken in a limiting sense.

Referring to the drawings:

FIG. 1 is a side elevational view of an apparatus embodying the invention disposed in a bore hole being drilled;

FIGS. 2*a* and 2*b* together constitute a longitudinal section through the pulse generator portion of the apparatus illustrated in FIG. 1, FIG. 2*b* being a lower continuation of FIG. 2*a*;

FIG. 3 is a cross-section taken along the line 3—3 on FIG. 2*b*;

FIGS. 4*a* and 4*b* together constitute a longitudinal section through another embodiment of pulse generator that can form part of the combination of apparatus illustrated in FIG. 1, FIG. 4*b* being a lower continuation of FIG. 4*a*;

FIG. 5 is a cross-section taken along the line 5—5 on FIG. 4*b*;

FIG. 6 is a cross section taken along the line 6—6 on FIG. 4*b*;

FIG. 7 is a diagrammatic view of the hydraulic pulse generator systems illustrated in FIGS. 2*a*, 2*b* and FIGS. 4*a*, 4*b*;

FIG. 8 is a graph representing the pressure pattern developed in the bore hole by the pulse generator; and

FIGS. 9*a* and 9*b* are views corresponding to FIGS. 2*a* and 2*b* of another embodiment of the invention.

In the embodiment of the invention illustrated in FIGS. 1 to 3, a fluid pulse generator or shock oscillator A is provided, the upper end of which is adapted to be connected to the lower end of a drill string B, such as to its adjacent drill collar, or to the drill collar through an intervening stabilizer C. The lower end of the pulse generator is connected to a suitable drill bit D having cutters E adapted to operate upon the bottom F of a bore hole H being drilled, the drilling action taking place, in the specific example illustrated, through transmitting the drilling weight, rotation and torque of the drill string B through the pulse generator A to the drill bit D.

The pulse generator includes an outer housing structure 10 comprising an upper sub 11 having a threaded box 12 threadedly secured to the lower pin 13 of an adjacent drill collar section B thereabove, or to the stabilizer C. A central tubular housing section 14 is threadedly secured at its upper end to the top sub 11 and at its lower end to a valve housing or sub 15, which, in turn, is threadedly secured at its lower end to a mandrel 16 having a threaded box 17 for threadedly receiving the upper pin 18 of the rotary drill bit D, which may have any suitable type of cutters thereon, such as toothed roller cutters E.

Disposed centrally within the housing 10 and in laterally spaced relation thereto is a flow tube or inner shock tube 19, the upper end 20 of which is piloted within the top sub passage 21 and sealed against the sub wall 22 by seal rings 23. The lower end 24 of the flow tube is threadedly secured to the valve housing 15. Fluid can flow downwardly from the string of drill pipe B into the top sub passage 21 and the central or

input passage 25 through the inner shock tube 19, and then into a central passage 26 in the valve housing, the fluid in the valve housing, when permitted to do so, passing upwardly through longitudinal passages 27 in the housing and into the annular space 28 between the inner tube 19 and the outer housing 10, which annular space may be referred to as an internal or counterbalance shock annulus or passageway, as described hereinbelow. Fluid flowing upwardly through this passageway can pass through discharge ports 29 in the upper portion of the housing section 14 into the bore hole annulus 30 surrounding the apparatus.

The fluid, when permitted to do so, can also pass from the interior of the valve housing 15 downwardly through a plurality of ports 31 in the mandrel 16 into a central passage 32 through the mandrel below a valve seat or end wall 33 of the mandrel, the fluid flowing downwardly from this central passage into the drill bit passage 34 for discharge through its bit nozzles or orifices (not shown) toward the bottom F of the well bore, to clean the cutters E and to circulate the cuttings produced thereby laterally outwardly of the bit and thence upwardly through the annulus 30 between the apparatus and wall W of the bore hole, the cuttings and drilling fluid continuing upwardly through the annulus surrounding the drill string to the top of the bore hole. Some of the fluid passing downwardly through the passage 32 can flow through a plurality of by-pass ports 35 in the mandrel to its exterior, in order to insure an appropriate volume of fluid flow upwardly through the annulus 30 and an appropriate velocity of fluid flowing through the apparatus and upwardly around the pulse generator A.

The annular space 30 between the exterior of the housing 10 and the wall W of the bore hole H constitutes an external shock tube annulus or passageway, which is the working passageway of the apparatus, such working passageway extending from the bottom F of the bore hole up to the discharge ports 29, where the upwardly flowing fluid through the external passageway commingles with the fluid discharged from the internal passageway 28 through the ports 29, the fluid from both passageways flowing upwardly through the annulus surrounding the tubular drilling string B to the top of the bore hole.

The flow of fluid from the interior of the valve housing or sub 15 into the internal shock passageway 28, or downwardly through the ports 31 in the mandrel into its central passage 32, and then through the by-pass ports 35 and the drill bit D into the external shock tube passageway 30 is dependent upon the seating of a shuttle valve 38 in the valve housing 15 against the upper end 39 of the valve housing cavity 40, closing the upper passages 27, or its downward seating against the valve seat 33 provided by the upper end of the mandrel 16 to close the mandrel ports 31. The shuttle valve 38 has a cylindrical rim portion 41, with inwardly directed upper and lower flanges 42, 43 extended therefrom of an extent such that the upper flange 42 will engage the upper valve seat 39 and close the upper passages 27 upon upward movement of the shuttle valve, and the lower flange 43 will engage the lower valve seat 33 and close the lower ports. Within the flanges and the cylindrical rim, the shuttle valve has an open passage 45 to permit downward flow of fluid therethrough and into the mandrel ports 31 when the shuttle valve is in its upward position closing the upper passages 27.

The pulse generator A is elongate, for example, having a length of about 18 feet from the location of the pulse generator valve 38 to the discharge ports 29. Assuming the shuttle valve to be in its downward position closing the mandrel ports 31, and that fluid pumped down through the drilling string B and the flow tube 19 is then passing upwardly through the passages 27 and the inner shock passageway 28 to the discharge ports 29, the upward shifting of the shuttle valve 38 into engagement with the upper valve seat 39 to close the passages 27 will cause a negative pressure pulse wave to be generated in the internal shock tube annulus or passageway 28 that will travel upwardly to the region of the discharge ports 29 and then downwardly back to the shuttle valve. During this period of time, which is of very short duration, measured in a fraction of a second, fluid is flowing through the shuttle valve and through the open mandrel ports 31 into the central passage 32, flowing downwardly through the drill bit D to commingle with the cuttings and carry them in a direction upwardly of the apparatus, at the same time that fluid is also flowing upwardly from the central passage 32 through the by-pass ports 35 into the external shock passageway 30.

Assuming the shuttle valve 38 shifts downwardly against the lower valve seat 33 to close the mandrel ports 31, a negative pressure pulse wave is generated in the external shock tube passageway 30, which wave travels down through the ports 31, central passageway 32 and the bit D, as well as through the by-pass ports 35, and then upwardly through the external shock passageway 30 to the discharge ports 29, then travelling downwardly through the path just mentioned back to the shuttle valve. When it reaches the shuttle valve, the pressure in the external shock tube passageway 30 exceeds the pressure of the fluid flowing downwardly through the fluid passage 25 and shifts the shuttle valve upwardly against the upper valve seat 39 to close the passageway 28 and open the mandrel ports 31, fluid then flowing from the central tube 19 downwardly through the shuttle valve 38 and through the mandrel 16 and bit D, as well as through the by-pass ports 35, into the external shock passageway 30, to carry the cuttings upwardly therethrough. As soon as the shuttle valve 38 engages the upper valve seat 39, a negative pressure pulse wave is generated in the internal shock passageway 28, which travels up to the discharge ports 29 and then downwardly to the shuttle valve, where its pressure exceeds the pressure in the inlet passage 26 and the fluid pressure below the shuttle valve, shifting the latter downwardly into engagement with the lower valve seat 33, whereupon the cycle of operation repeats itself, the shuttle valve being shifted by the pressure pulse wave generated in the passages between its upper and lower positions.

In the operation of the apparatus, the pulse generator A is threadedly secured to the lower end of the drill string B, or to the stabilizer C, a drill bit D being secured to the mandrel 16 of the pulse generator. The apparatus is lowered in the bore hole until the bit D engages the bottom F of the latter, fluid being circulated down through the drill string and into the input passage 25. Assuming the shuttle valve 38 to be in its upper position, the fluid is passing downwardly through the mandrel passages 31, 32 and the drill bit D, and also upwardly through the by-pass passages 35 into the external shock passageway 30. Circulating fluid will shift the shuttle valve 38 downwardly against the valve seat 33 to close the mandrel ports 31 and cause a negative pressure pulse wave to be generated by the fluid in the external shock passageway 31, which travels down through the mandrel 16 and drill bit D and into the bore hole region where the drill bit is operating, and also up through the external passageway 30 to the discharge ports 29, whereupon, as stated above, the negative shock pulse returns through the annulus and through the bit and mandrel to the shuttle valve 38. The negative pressure created in the external passageway is substantially lower than the hydrostatic head of fluid in the well bore at the drilling region. When the negative pulse wave returns to the shuttle valve 38, the pressure in the external passageway 30 and in the mandrel and bit passages 32, 34 rises suddenly to a value exceeding the hydrostatic head of fluid and the circulating pressure in the inlet passage 25, 26, creating a pressure differential that shifts the shuttle valve 38 upwardly against its upper seat 39 to close off the upper passages 27 and the internal shock passageway 28 against flow of fluid from the inlet passage 25, 26, the fluid column in the internal compensating passageway 28 still having a certain velocity, a negative pressure pulse wave being generated therein that travels upwardly to the discharge ports 29 and then downwardly back to the shuttle valve 38, where the pressure increases above that of the circulating pressure of the fluid passing through the shuttle valve and into the lower passages 31, 32, 34, thus shifting the shuttle valve back to its

lower position closing the lower passages 32, 34. A negative pressure pulse wave is then generated in the mandrel and the external shock passageway 30.

The foregoing cycle of operation is repeated, with the shuttle valve 38 alternately opening and closing the shock passageways, being shifted by the travelling waves between upper and lower positions, and effecting intermittent generation of negative fluid pressures and then positive fluid pressures in each shock passageway. When one passageway is closed by the shuttle valve, the other one is open so that fluid is always being circulated in the well bore to carry the cuttings upwardly around the apparatus and through the annulus surrounding the drill string B to the top of the bore hole. During such circulating action, the drilling string B, pulse generator A and drilling bit D are being rotated, with appropriate drilling weight being applied by the drill collars on the drill bit to penetrate its cutters E into the formation, the fluid pressure in the external shock passageway 30, which includes the drilling region, being intermittently decreased considerably below the pressure of the circulating fluid, which relieves the formation being drilled of the hydrostatic pressure, causing the formation to maintain a relatively brittle state, as compared to a ductile state which is incident to the subjecting of certain formations to high pressures. As a result, the drill bit D produces cuttings of larger particle size, the bit drilling the bore hole H at a much greater rate and with a higher degree of efficiency.

It is to be noted that the annular space 50 between the discharge ports 29 and the top sub 11 is a dead space. This space is capable of acting as a surge damper, since air will be trapped therein when the apparatus is lowered into the fluid in the well bore, such air becoming compressed at the upper end of the dead space. In addition, formation gas in the drilling mud will also move into this space through the discharge ports 29, such gas separating from the liquid and provide an additional compressed gaseous medium at the top of the surge damper annular space 50. This trapped gas will prevent oscillator pulsations from the internal and external passages 28, 30 from reaching the upper annular space surrounding the drill collars B, so that the oscillator pulsations are essentially confined to the external shock passageway 30 and the internal shock passageway 28.

In lieu of the trapped compressible gas in the surge damper annular space 50, such space could be extended to the length of the internal shock passageway 28, becoming a quarter wave stub, to provide pulsation cancellation at the discharge ports 29. However, this may not be desirable since the pulse generator A must then be made considerably longer.

A diagrammatic arrangement of an equivalent circuit is disclosed in FIG. 7, in which the fluid flows down the input passage 25 to the shuttle valve 38, disclosed herein as a reed type of valve, which will control the flow of fluid from the input line alternately into the internal shock tube or passageway 28 and the external shock tube or passageway 30, the fluid from the opposite ends of both passageways flowing into the output annulus 30a surrounding the apparatus and above the discharge ports. In the external shock tube or passageway 30, the fluid can flow from the shuttle valve through the by-pass passage 35, or through the drill bit and well bore region in which the bit is operating. Assuming the shuttle valve 38 is shifted to the left, a negative pressure pulse wave will be generated in the external shock passageway 30, the pressure dropping from a value above the normal hydrostatic pressure 51 in the annulus to the pressure 51*a*, which may be lower than the formation or rock pressure 51*b*, as depicted in the diagram of FIG. 8, in which pressure is plotted against time. The duration of the negative pulse is the time that it takes it to travel from the shuttle valve 38 up to the discharge ports 29 and back down to the shuttle valve, which is the time 2L/C., where L is the length of the shock passageway and C is a constant. When the pulse returns to the shuttle valve, its pressure exceeds the pressure of the fluid flowing from the input line 25 into the internal shock passageway 28, shifting the shuttle valve in the opposite direction, or to the right, to close the inlet to the internal shock passageway, causing a negative pulse wave to be generated therein for a duration of 2L/C, as shown in broken lines 52 in FIG. 8. During that time, the fluid is flowing from the input line 25 through the external shock passageway 30 at the pressure indicated by the portion 53 of the full line disclosed in the diagram, which is greater than the normal drilling fluid annulus hydrostatic pressure 54. Return of the wave to the shuttle valve then reshifts it back to the left, and the foregoing cycle is repeated.

As shown in the equivalent circuit diagram (FIG. 7), a surge tank 50 is depicted that corresponds to the surge damper annular space, with a gas, which may be air only, or a combination of air and formation gas, dampening the oscillator pulsations.

In the form of invention illustrated in FIGS. 4*a* to 6, essentially the same oscillator is disclosed as in FIGS. 2*a* to 3. However, certain specific structural changes have been made to the shuttle valve and the upper and lower valve seats. The apparatus has been adapted to alternately generate the negative pressure pulses in the internal and external shock passageways, but a downward directed thrust or impact is imparted to the drill bit upon the shuttle valve closing the inlet to the external shock passageway.

As disclosed, the lower portion of the external housing 10 is threadedly secured to a valve housing section 15*a* that has a plurality of circumferentially spaced, longitudinal passages 27 therethrough disposed around the central passage 26 that communicates with the inlet passage 25 through the flow tube 19. A replaceable valve seat 39*a*, in the form of a wear plate, is secured to the valve housing section or sub 15*a* by a plurality of screws 70 threaded into the sub and with their heads 71 disposed in countersunk bores 72 in the plate, leakage of fluid between the lower end of the sub and the upper end of the wear plate being prevented by inner and outer gasket seals 73, 74 carried by the sub and engaging the upper face of the wear plate within and outside of the region of the ports 75 in the wear plate in alignment with the passages 27. The lower surface of the upper wear plate 39*a* forms a valve seat for the shuttle valve 38, which is reciprocable in the annular space 40 in the valve housing section 15*b* into and from engagement with a lower valve seat or wear plate 33*a* sealed against and secured to a bit mandrel 16*a*, to which the drilling bit D is threadedly secured, by longitudinal screws 76 threaded into the mandrel, with the screw heads 77 disposed within countersunk bores 78 in the lower valve seat plate, there being ports or passages 79 through the valve seat 33*a* communicating with the ports 31 in the bit mandrel, the fluid flowing downwardly into the central passage 32 through the mandrel and through the drill bit D, as described above in connection with the other form of the invention.

As illustrated, the bit mandrel 16*a* is slidably splined to the external housing section 15*b* by external splines 80 on the mandrel meshing with internal splines 81 in the housing. The mandrel has limited relative longitudinal movement in the housing section 15*b* by virtue of engagement of a limit shoulder 82 on the mandrel with a companion upwardly facing shoulder 83 on the housing, and by virtue of the shoulder 84 on the drill bit, when screwed into the mandrel 16*a*, moving upwardly into engagement with the end 85 of the housing. The spline connection effects transmission of the drilling torque derived from the drilling string B through the housing 10 to the mandrel 16*a* and drill bit D, the drilling weight being transmitted from the drill string through the housing 10 and to the drill bit D by engagement of the terminal portion 85 of the housing with the drill bit shoulder 84.

By-pass ports 35*a* are also provided from the central passage 32 through the mandrel to the external shock passageway 30, such ports extending through the mandrel in alignment with companion ports in the housing portion 15*b*.

The generation of the negative pulse waves in the external shock passageway 30 and internal shock passageway 28 is effected in the same manner as described in the other form of

the invention. However, when the negative pulse shock wave is generated in the external passageway **30**, a pressure differential exists between the fluid above the shuttle valve **38** and the fluid in the external shock passageway **30**, which exerts a downward force on the mandrel **16***a* and on the drill bit D, shifting the mandrel downwardly of the housing by a slight amount and forcing the cutters E against the formation. In addition, the sudden closing of the shuttle valve **38** against the lower valve seat **33***a* creates a water hammer effect in the drilling fluid in the flow tube **19** and the drill string B thereabove, thereby imparting an impact blow against the lower valve seat **33***a*, mandrel **16***a* and drill bit D to strike the cutters E against the formation. There is thus produced a combination of the normal rotary drilling effort on the cutters E, and additional forces incident to the pressure differential and the shock force of the water hammer action against the mandrel **16***a* and drill bit D. The drilling effectiveness of the cutters is thereby increased, in addition to the increase in the drilling effectiveness caused by reduction of the pressure in the bore hole region in which the bit is operating, which forms part of the external shock passageway **30**. The pressure differential and the water hammer action is acting over the mandrel over the full cross-sectional area of the lower valve seat **33***a* affixed by the screws **76** to the mandrel **16***a*, both the pressure force and the water hammer thrust being very substantial in view of the relatively large cross-sectional area across the lower valve seat and mandrel **16***a*. The space between the mandrel shoulder **82** and the housing shoulder **83** is such that the mandrel shoulder ordinarily does not engage the housing shoulder upon subjecting the mandrel **16***a* to the combination of the water hammer thrust and differential pressure thrust. However, if a soft formation is encountered, or in the event that the drill bit is picked off bottom, then the shoulder **82** will engage the housing shoulder **83** to limit the extent of downward shifting of the mandrel within the housing.

Preferably, a wear sleeve **90** is provided in the housing section **15***b*, along which the periphery of the shuttle valve **38** is slidable. In the event of excessive wear occurring on the sleeve **90**, or in the event that the valve plates **33***a*, **39***a* become worn, as a result of the impacting action of the shuttle valve member **38** thereagainst, all of these parts are readily replaceable. With respect to the valve plates, all that need be done is to remove the screws **70**, **76** and either recondition or replace the plates, which are reassembled by reinserting the screws therethrough and threadedly securing them in the adjoining sub **15***a* or mandrel **16***a*.

It is to be noted that in both forms of the invention, the annulus **30** surrounding the pulse generator and extending upwardly from the bottom F of the bore hole is essentially the same as the annulus usually present in connection with the rotary drilling of a bore hole in the formation; that is to say, there are no restrictions present, as in the above-identified patent application, in which a pack-off is provided between the pulse generator and the wall of the bore hole. The cuttings produced by the drill bit are circulated by the drilling fluid from the bottom of the bore hole directly into the annular space **30** surrounding the apparatus for continued upward passage through the bore hole surrounding the drilling string B and to the top of the hole.

The form of invention illustrated in FIGS. **9***a* and **9***b* is generally the same as the other embodiments disclosed. The outer housing structure **10***a* includes a top sub **11** threadedly secured to the lower end of the drill pipe string B, the upper end of a central housing section **14***a* being threadedly attached to the sub, its lower end being threadedly attached to a bottom sub **200** that has a threaded box **201** adapted to receive the threaded pin **18** of the drill bit D for drilling the bore hole.

An inner shock tube **19** has its upper end **20** piloted within the passage **21** of the top sub **11**, leakage around the exterior of the shock tube being prevented by the seal rings **23** in the top sub engaging the periphery of the upper portion of the inner shock tube. The lower end of the inner shock tube is threadedly secured to an extension **200***a* of the bottom sub **200**, projecting upwardly into the central housing section or outer shock tube **14***a* and in spaced relation thereto. An elongate valve housing **202** is disposed in the bottom sub **200** and its upward extension **200***a*, this valve housing also projecting upwardly within the inner shock tube **19** to a substantial extent. The valve housing is retained within the bottom sub **200** and inner shock tube **19** by an upwardly facing shoulder **203** thereon engaging a downwardly facing shoulder **204** in the sub extension, downward movement of the valve housing **202** being prevented by engagement of the upper en of the drill bit pin **18** with the lower end of the valve housing, as disclosed in FIG. **9***b*. The valve housing carries upper and lower seal rings **205** sealingly engaging the inner wall of the bottom sub **200** on opposite sides of a circumferential internal groove **206** in the sub extension communicating with ports **207** that open into the annular space **208** between the sub extension **200***a* and the outer shock tube **14***a*.

The valve housing **202** has a central passage **209** therethrough, the lower portion of which is closed by a suitable plate or other closure member **210** welded, or otherwise attached, to the valve housing, this closure member being disposed below a lower radially disposed valve seat **211** secured within a lateral passage **212** through the valve body below the lower seals **205**, this valve passage communicating with a circumferential internal groove **213** in the bottom sub **200**. An upper generally radial valve seat **214**, 180° displaced with respect to the lower valve seat **211**, is fixed to the valve body or housing in a passage **215** between the upper and lower seal rings **205** opening into the internal groove **206**. Opposite each valve seat is disposed a limit plug **216** clamped to the valve housing by a suitable clamp plate **217** and a screw **218** extending through the plug and threaded into the clamp plate, the plugs **216** having a purpose described hereinbelow.

Fluid is capable of flowing alternately through the upper valve seat **214** and the lower valve seat **211**, as determined by a vane or reed form of shuttle valve **219** mounted within the valve body **202**. The upper portion of this reed valve is secured centrally within the valve body passage **209** by spacers **220** on opposite sides of the upper end of the reed and screws **221** extending through the upper end of the valve body, spacers and reed valve. The reed valve **219** tapers in a downward direction, terminating just below the lower valve seat **211**. Fluid flowing downwardly through the input passage **25** can flow into the annulus **222** surrounding the upper portion of the valve housing **202** and through side ports **223** in the latter to the interior **209** of the valve housing, such fluid being limited to flowing alternately through the upper valve seat **214** and the lower valve seat **211**, the fluid alternately shifting the vane **219** into engagement with the upper valve seat and the lower valve seat, the vane also alternately engaging the lower plug **216** or the upper plug **216**, which lend support to the vane.

As described in connection with the other forms of the invention, the annular space **30** between the exterior of the housing **10***a* and the wall of the bore hole constitutes an external shock tube annulus or passageway, which extends from the bottom of the bore hole up to the discharge ports **29** that forms the junction with the internal shock passageway **28**, the fluid from both passageways flowing upwardly through the annulus surrounding the tubular drill string B to the top of the bore hole.

When the shuttle valve **219** engages the lower valve seat **211**, the upper valve seat **214** is open and fluid can flow therethrough into the internal or counterbalancing shock passage **28** up to the junction ports **29**, flowing outwardly therethrough and upwardly around the apparatus and the drill pipe string. The shifting of the vane **219** into engagement with the upper valve seat **214** closes the lower end of the internal shock passageway **28**, causing a negative pressure pulse wave to be generated therein that travels upwardly to the region of the junction ports **29**, and then downwardly back to the reed valve **219**. During this time, fluid is flowing through the lower

valve seat 211 into the circumferential groove 213 and then through ports 230 in the lower end of the valve body 202 into a central passage 231 therein that communicates with the central passage 34 through the drill bit D, the fluid commingling with the cuttings and carrying them in a direction upwardly of the apparatus. It is to be noted that, at this time, all of the fluid is passing through the drill bit D, rather than some of it being caused to flow through a by-pass 35 of 35*a*, as disclosed in FIGS. 2*b* and 4*b*.

Assuming the reed valve 219 to have shifted against the lower valve seat 211 to close the lower passage 212, a negative pressure pulse wave is generated in the external shock tube passageway 30 which travels down through the drill bit D and then upwardly through the external shock passageway to the discharge and junction ports 29, then travelling reversely through this path back to the reed valve 219. When it reaches the latter, the pressure in the external shock tube passageway exceeds the pressure of the fluid flowing downwardly through the input passage 25 and the central valve body passage 209, shifting the reed valve away from the lower valve seat 211 and against the upper valve seat 214 to close the internal or counterbalance shock passageway 28, the fluid then flowing through the lower valve seat 211 and through the drill bit D, as described above. As soon as the reed valve 219 engages the upper valve seat 214, a negative pressure pulse is generated in the internal shock passageway 28 which travels up to the discharge ports 19 and then downwardly to the reed valve, where its pressure exceeds the pressure in the inlet passage 209, shifting the reed valve into engagement with the lower valve seat 211 again, whereupon the foregoing cycle of operation repeats itself. The reed valve 219 is shifted by the pressure pulse wave generated in the passageways 28, 30 laterally in opposite directions and alternately against the lower valve seat 211 and upper valve seat 214.

The form of invention illustrated in FIGS. 9*a* and 9*b* is simpler and more economical to manufacture than the other forms of invention disclosed. All of the wear in the apparatus is confined essentially to the valve housing 202 and the reed valve 219, which can be replaced readily by disconnecting the bit D, a suitable tool being inserted into the lower threaded box 235 of the valve assembly to enable it to be pulled out of the bottom sub 200 and inner shock tube 19, whereupon a replacement or repaired assembly can be substituted in its place, the threading of the pin 18 of the drill bit D into the bottom sub box 235 again retaining the valve assembly in place. All of the fluid passing through the lower valve seat 211 discharges through the drill bit D, insuring an adequate supply of flushing fluid for cleaning the cuttings from the bottom of the hole, as well as cleaning and cooling the cutters of the drill bit. In all other respects, the apparatus illustrated in FIGS. 9*a* and 9*b* operates in the same manner as described above in connection with the other forms of the invention.

I claim:

1. In pressure reduction apparatus for drilling a bore hole in a formation: a pulse generator adapted to be connected in a tubular drilling string and adapted to be connected at its lower end to a drill bit that drills the bore hole, said generator having a fluid passage adapted to receive fluid pumped from the drilling string, said generator having a first shock passageway therewithin having an inlet to receive fluid from said passage and having an outlet above said inlet for discharging fluid from said first shock passageway to the exterior of said generator, a second shock passageway adapted to receive fluid from said passage and including the region in the bore hole at which the drill bit is cutting the formation and further including the bore hole annulus surrounding the generator and extending upwardly from said region to said outlet, and a shuttle valve device in the paths of fluid flow through said passage and passageways shiftable by the fluid in the passageways alternately between a first position closing the inlet to said first passageway and opening the inlet to said second passageway and a second position opening the inlet to said first passageway and closing the inlet to said second passageway, whereby closing of each inlet generates a negative fluid pressure pulse wave travelling through its associated passageway between said shuttle valve device and the location of said outlet.

2. In apparatus as defined in claim 1; said pulse generator including a mandrel connectable to the drill bit and slidably coupled to an adjacent pulse generator portion for the transmission of torque from said adjacent portion through said mandrel to the drill bit, said mandrel having the inlet to said second passageway, said shuttle valve device engaging said mandrel to close said mandrel inlet and provide a pressure differential in said generator above said shuttle valve exerting a downward force on said mandrel and drill bit upon generation of each negative fluid pressure pulse wave travelling through said second passageway.

3. In apparatus as defined in claim 1; said pulse generator including a mandrel connectable to the drill bit and slidably coupled to an adjacent pulse generator portion for the transmission of torque from said adjacent portion through said mandrel to the drill bit, said mandrel having the inlet to said second passageway, said shuttle valve device engaging said mandrel to close said mandrel inlet and provide a pressure differential in said generator above said shuttle valve exerting a downward force on said mandrel and drill bit upon generation of each negative fluid pressure pulse wave travelling through said second passageway, said shuttle valve device being movable downwardly into engagement with said mandrel to close said mandrel inlet.

4. In apparatus as defined in claim 1; said shuttle valve device being movable upwardly to close the inlet to said first passageway and downwardly to close the inlet to said second passageway.

5. In pressure reduction apparatus for drilling a bore hole in a formation: a pulse generator comprising an outer housing structure connectable at its upper portion to a tubular drilling string and at its lower portion to a drill bit that drills the bore hole, a flow passageway within said structure extending downwardly from the upper portion of said structure, said flow passageway being adapted to receive fluid pumped down the drilling string, said flow passageway providing a first shock passageway with said housing structure extending upwardly from the lower end of said flow passageway, said housing structure having a discharge outlet from the first shock passageway longitudinally spaced above the lower end of said flow passageway, a second shock passageway adapted to receive fluid from the lower end of said flow passageway and including the region in the bore hole at which the drill bit is cutting the formation and further including the bore hole annulus surrounding said housing structure and extending upwardly from said region to said discharge outlet, and a shuttle valve device in the paths of fluid flow from said flow passageway to said first and second shock passageways shiftable by the fluid in said passageways alternately between a first position closing the inlet to said first passageway and opening the inlet to said second passageway and a second position opening the inlet to said first passageway and closing the inlet to said second passageway, whereby closing of each inlet generates a negative fluid pressure pulse wave travelling through its associated passageway between said shuttle valve device and said discharge outlet.

6. In apparatus as defined in claim 5; said pulse generator including a mandrel connectable to the drill bit and slidably coupled to said housing structure for the transmission of torque from said housing structure through said mandrel to the drill bit, said mandrel having the inlet to said second passageway, said shuttle valve device engaging said mandrel to close said mandrel inlet to provide a pressure differential in said generator above said shuttle valve device exerting a downward force on said mandrel and drill bit upon generation of each negative fluid pressure pulse wave travelling through said second passageway.

7. In apparatus as defined in claim 1; said generator having another passage forming part of said second passageway for

conducting fluid to the drill bit for discharge therefrom into the bore hole, said generator having a fluid bypass from said another passage to the exterior of said generator.

8. In apparatus as defined in claim 1; said pulse generator including a mandrel connectable to the drill bit and slidably coupled to an adjacent pulse generator portion for the transmission of torque from said adjacent portion through said mandrel to the drill bit, said mandrel having the inlet to said second passageway, said shuttle valve device engaging said mandrel to close said mandrel inlet and provide a pressure differential in said generator above said shuttle valve exerting a downward force on said mandrel and drill bit upon generation of each negative fluid pressure pulse wave travelling through said second passageway, said mandrel having a passage forming part of said second passageway for conducting fluid to the drill bit for discharge therefrom into the bore hole, said mandrel and adjacent pulse generator portion having a fluid bypass from said mandrel passage to the bore hole externally of said mandrel and adjacent portion.

9. In pressure reduction apparatus for drilling a bore hole in a formation: a pulse generator adapted to be connected in a tubular drilling string and adapted to be connected at its lower end to a drill bit that drills the bore hole, said generator having a fluid inlet passage adapted to receive fluid pumped from the drilling string, a first shock passageway adapted to receive fluid from said inlet passage, a second shock passageway adapted to receive fluid from said inlet passage and including the region in the bore hole at which the drill bit is cutting the formation, and a shuttle valve device in the paths of fluid flow through said passage and passageways shiftable by the fluid in the passageways alternately between a first position closing the inlet to said first passageway and opening the inlet to said second passageway and a second position opening the inlet to said first passageway and closing the inlet to said second passageway, whereby closing of each inlet generates a negative fluid pressure pulse wave travelling through its associated passageway between said shuttle valve device and an end of said associated passageway located a substantial distance from said inlet, said pulse generator including a mandrel connectable to the drill bit and slidably coupled to an adjacent pulse generator portion for the transmission of torque from said adjacent portion through said mandrel to the drill bit, said mandrel having the inlet to said second passageway, said shuttle valve device engaging said mandrel to close said mandrel inlet to provide a pressure differential in said generator above said shuttle valve device exerting a downward force on said mandrel and drill bit upon generation of each negative fluid pressure pulse wave travelling through said second passageway.

10. In apparatus as defined in claim 9; said shuttle valve device moving downwardly into engagement with said mandrel to close said mandrel inlet.

11. In apparatus as defined in claim 9; said mandrel having a passage forming part of said second passageway for conducting fluid to the drill bit for discharge therefrom into the bore hole, said mandrel and adjacent pulse generator portion having a fluid bypass from said mandrel passage to the bore hole externally of said mandrel and adjacent portion.

12. In apparatus as defined in claim 1; said generator having a surge damper region above said outlet communicating with said first passageway.

13. In apparatus as defined in claim 5; said flow passageway and housing structure providing a surge damper annular space therebetween above and communicating with said discharge outlet.

14. In apparatus as defined in claim 1; said generator having another passage forming part of said second passageway for conducting all of the fluid received by said second passageway from said fluid passage to the drill bit for discharge therefrom into the bore hole.

15. In apparatus as defined in claim 1; said shuttle valve device comprising a vane movable laterally of the axis of the apparatus alternately between said first position and second position.

16. In pressure reduction apparatus for drilling a bore hole in a formation: A pulse generator comprising an outer housing structure connectable at its upper portion to a tubular drilling string and at its lower portion to a drill bit that drills the bore hole, an inner tube within said structure extending downwardly from the upper portion of said structure and providing a flow passageway adapted to receive fluid pumped down the drilling string, a tubular valve body within said inner tube and having inlet passage means for the flow of fluid from said tube to the interior of said valve body, said inner tube being spaced inwardly from said housing structure to provide a first shock passageway with said housing structure, said valve body and housing structure having a first inlet establishing communication between the interior of said valve body and the lower portion of said first shock passageway, said housing structure having a discharge outlet from the first shock passageway longitudinally spaced above said first inlet, a second shock passageway including the region in the bore hole at which the drill bit is cutting the formation and further including the bore hole annulus surrounding said housing structure and extending upwardly from said region to said discharge outlet, said valve body having a second inlet communicating the interior of said valve body with said second shock passageway, and a shuttle valve device in said valve body shiftable by the fluid in said passageways alternately between a first position closing said first inlet and opening said second inlet and a second position opening said first inlet and closing said second inlet, whereby closing of each inlet generates a negative fluid pressure pulse wave travelling through its associated passageway between said shuttle valve device and said discharge outlet.

17. In apparatus as defined in claim 16; said shock valve device comprising an elongate vane in said tubular body shiftable alternately against said lateral passages to close the same.

18. In apparatus as defined in claim 16; said valve body and vane therein being removable as a unit through the lower end of said outer housing structure.

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