Aug. 27, 1963 J. C. STALL ET AL 3,101,796

FLUID-DRIVEN PERCUSSION MOTOR

Filed Nov. 14, 1960 3 Sheets-Sheet 1

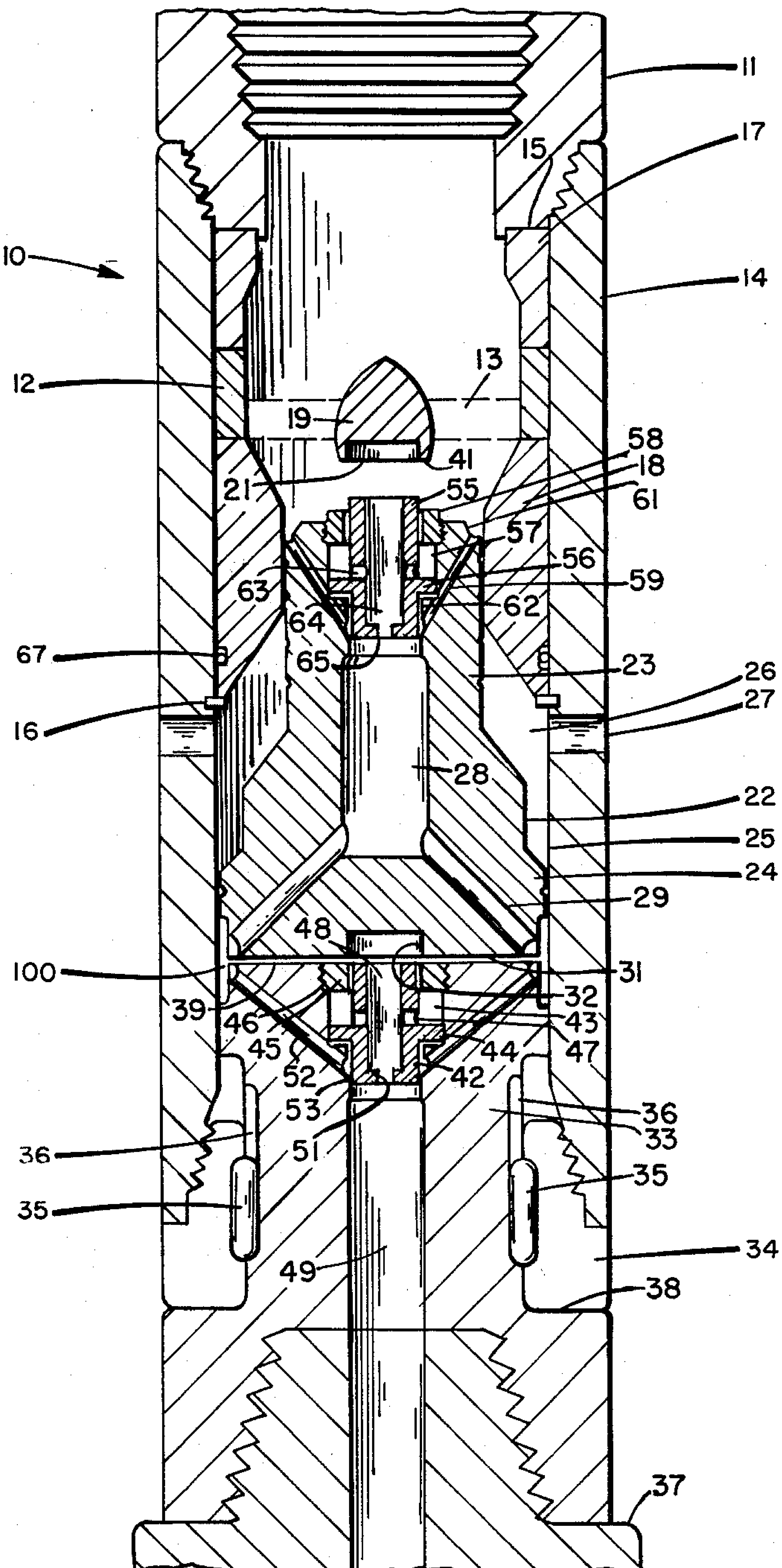

FIG. 1

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FLUID-DRIVEN PERCUSSION MOTOR

Filed Nov. 14, 1960 3 Sheets-Sheet 2

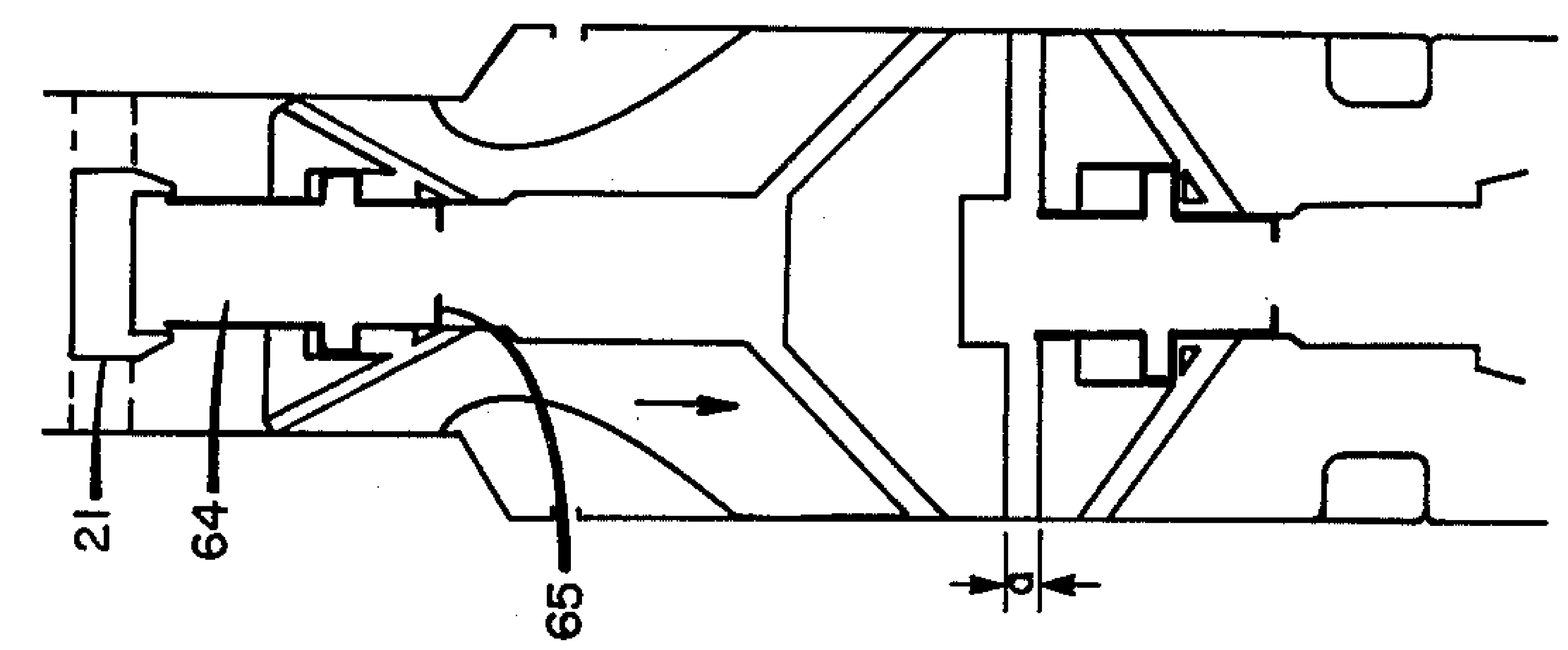

FIG-5

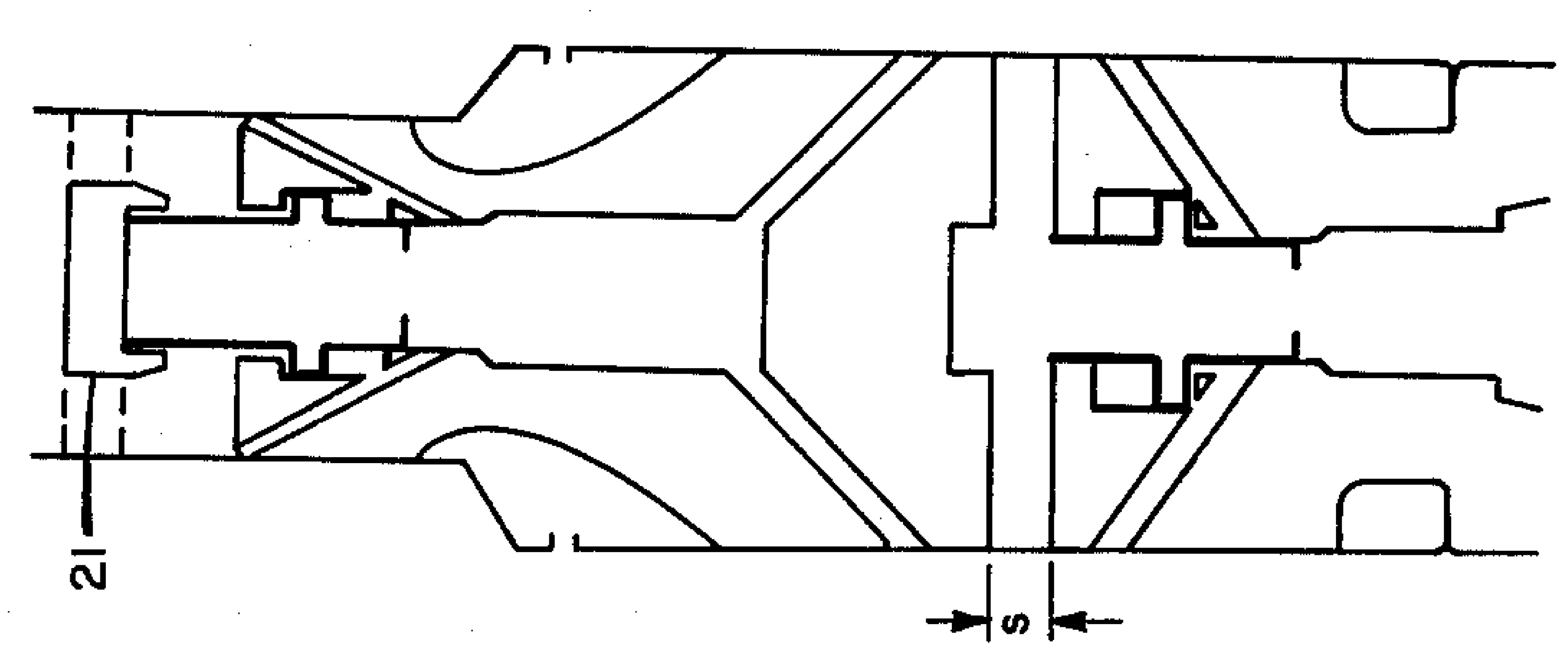

FIG-4

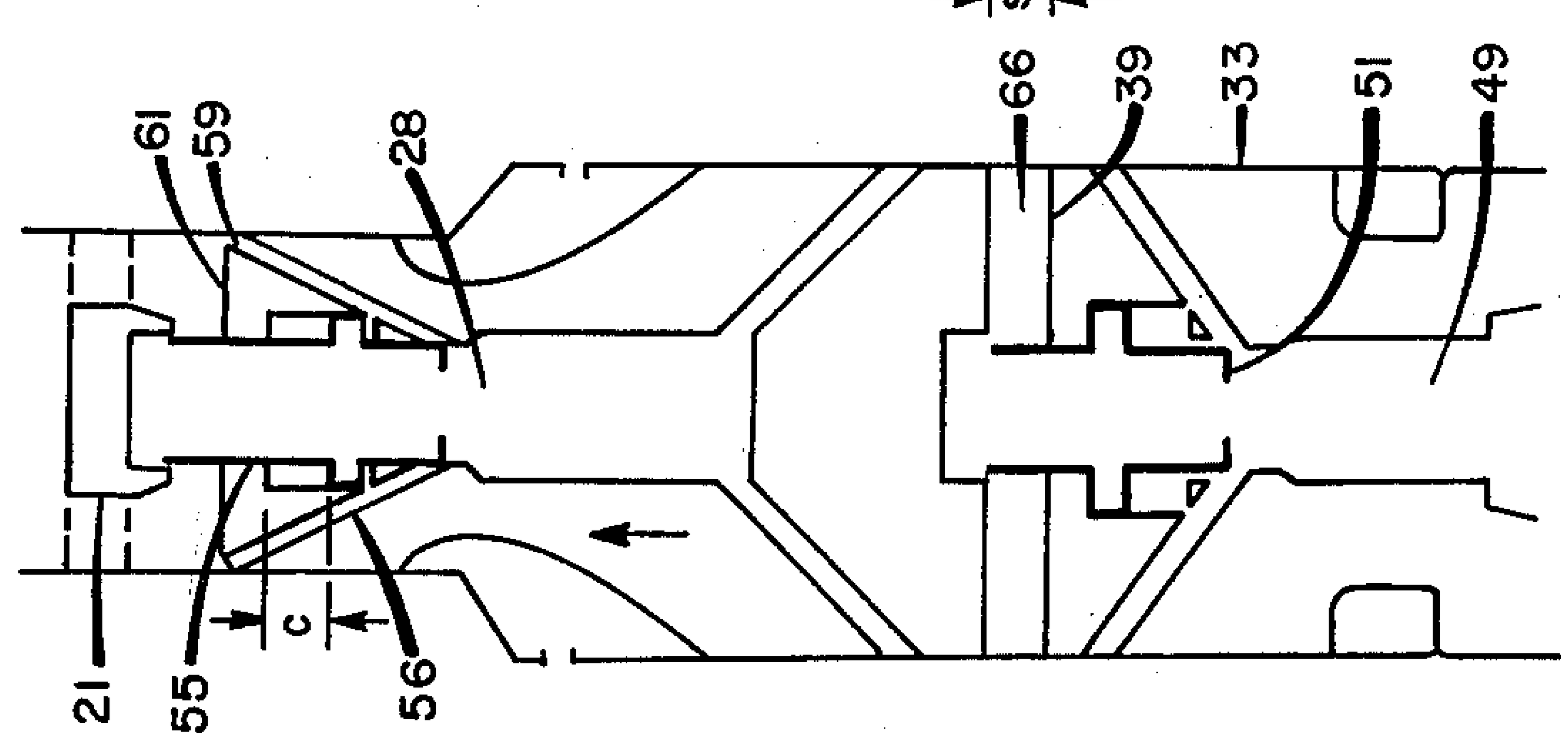

FIG-3

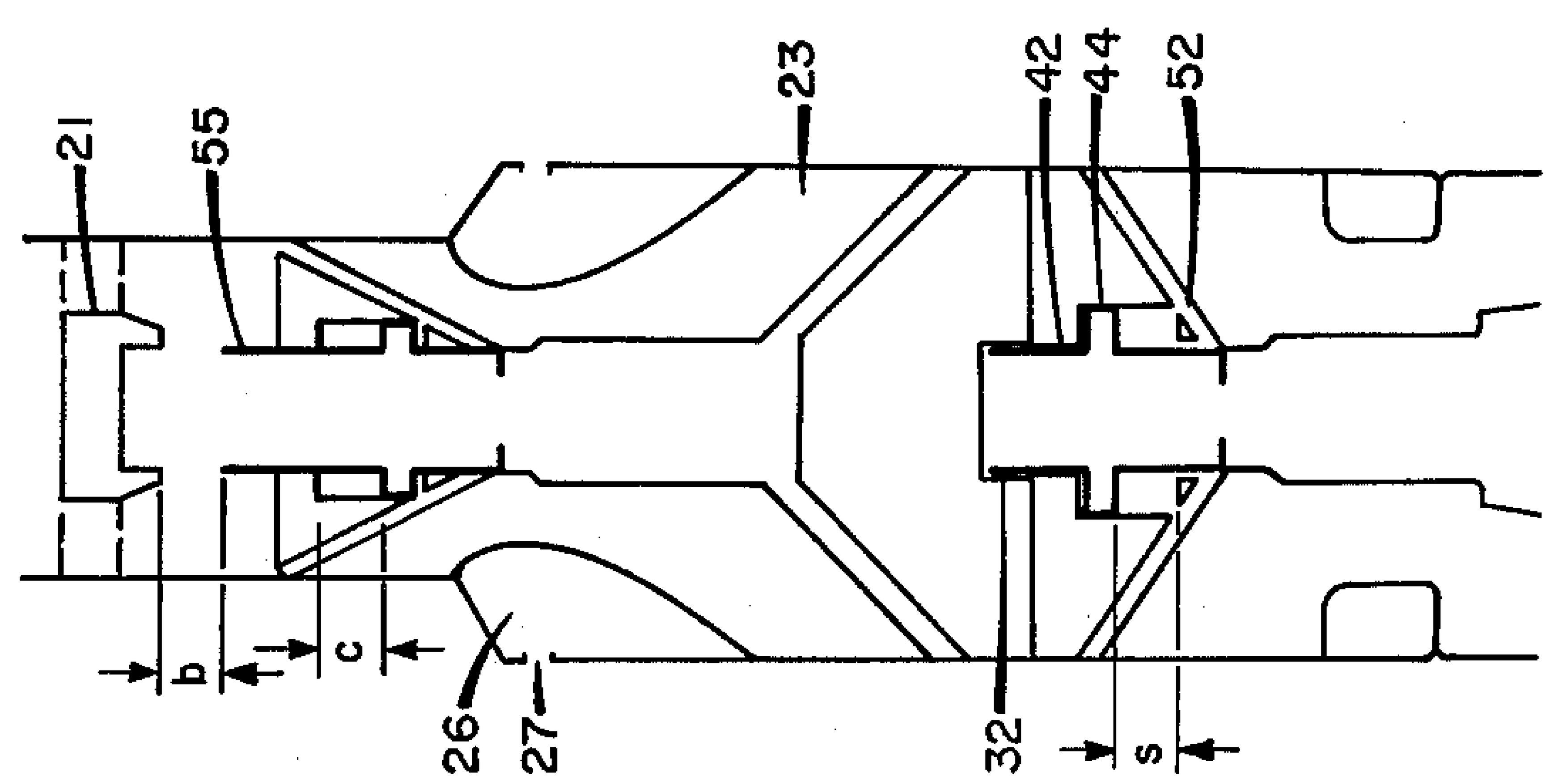

FIG-2

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FLUID-DRIVEN PERCUSSION MOTOR

Filed Nov. 14, 1960 3 Sheets-Sheet 3

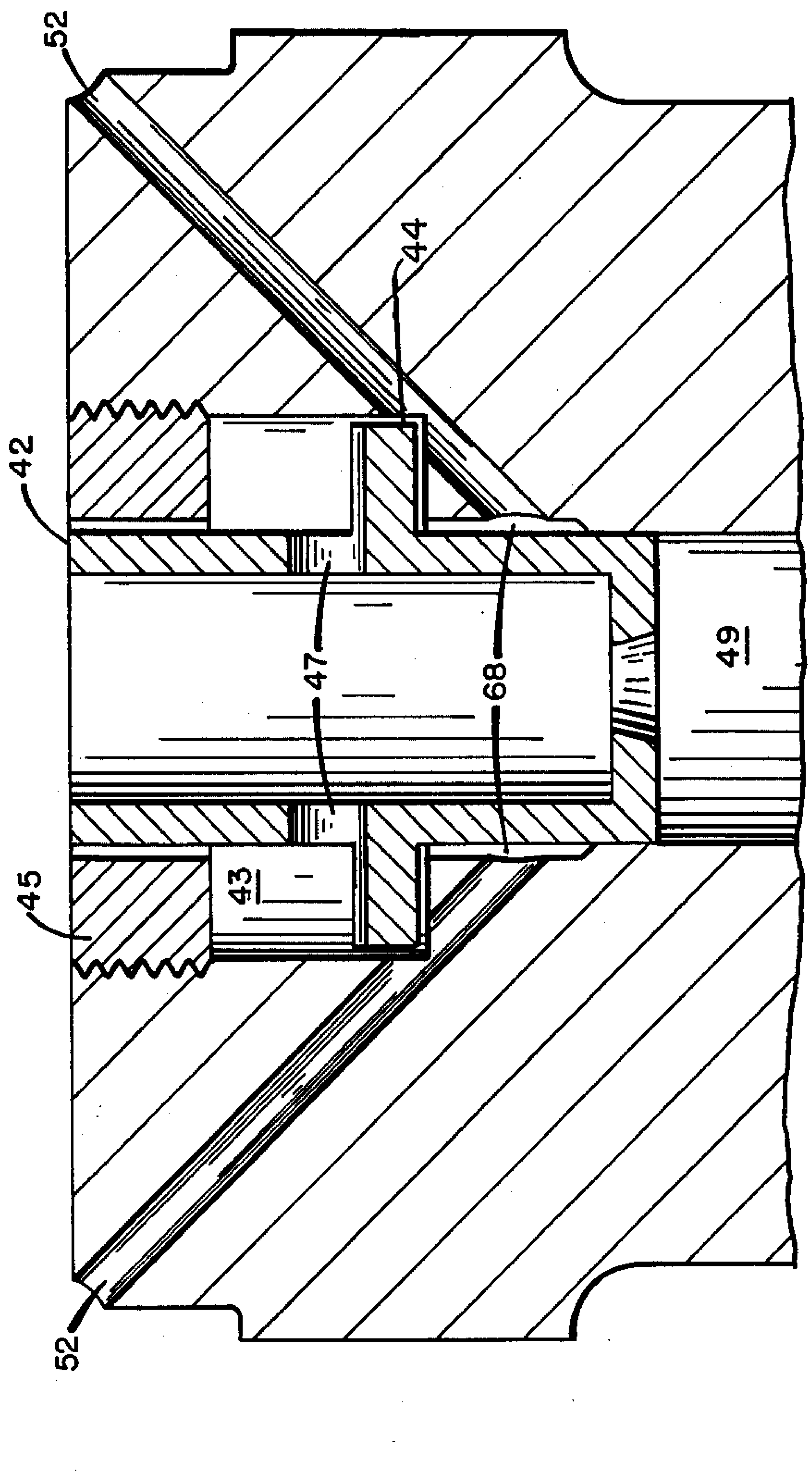

FIG. 6

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FLUID-DRIVEN PERCUSSION MOTOR

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This invention relates to a fluid-actuated percussion motor. More particularly, this invention relates to a fluid-actuated percussion motor adapted to be incorporated in a rotary drilling apparatus for applying percussion to the drill bit.

In rotary percussion drilling as it has been recently practiced using compressible fluids such as natural gas or air, the problem of producing rapid, sharp, percussive blows to the bit by the use of a reciprocating hammer has been overcome. However, actuation of reciprocating motors by a liquid such as the drilling mud used in rotary drilling is much more difficult, and no successful solution has been attained. A liquid is a relatively noncompressible fluid. A problem in liquid-actuated motors not present in compressible fluid-actuated motors is in the removal of the fluid from beneath the hammer on the downstroke so that the hammer can strike the bit (or an anvil attached above the bit) with a hard, sharp blow. When the hammer is damped by liquid, there is no impact which will assist the bit in chipping the rock. When impact is attained, more rapid drilling results.

It is, therefore, an object of this invention to provide an improved percussion motor. It is a more specific object of this invention to provide a liquid-actuated percussion motor which will be effective with either compressible fluids such as a gas or noncompressible fluids such as water or drilling mud adapted to be incorporated in the lower end of a drill pipe and capable of producing rapid, vertical oscillations of the bit which will increase the drilling rate. It is still a more specific object of this invention to provide hydraulically-actuated valves and to provide improved hydraulic valve timing means inherent in the device for use in a rotary percussion drill using a substantially noncompressible drilling fluid. We believe that the valve timing is a significant part of the device; therefore, this should be included. Other objects of this invention will become apparent from the following description.

In this description, reference will be made to the accompanying drawings wherein: FIGURE 1 is a cross-sectional view of a preferred embodiment of our percussion motor in which the moving parts are shown near the end of the power stroke of the hammer; FIGURE 2 is a schematic drawing in which the elements of the percussion motor shown in FIGURE 1 are drawn in position to start the hammer on the upstroke; FIGURE 3 is a similar schematic view in which the elements are in a position attained just prior to the end of the return or upstroke; FIGURE 4 is a similar schematic view showing the elements in their position when the hammer is at the end of its upstroke; and FIGURE 5 is a similar schematic view showing the position of the elements at an intermediate position on the downstroke when the top valve is just at point of opening. FIGURE 6 is an enlarged cross section of a suitable valve.

This invention may be described in brief as a percussion drilling apparatus in which a unique motor, actuated usually by a liquid drilling fluid (though gas may be used), is located adjacent the bit at the lower end of a drill pipe. In its more specific aspects, this invention may be described generally as a liquid- or gas-actuated free piston type percussion motor in which motion of

the piston or hammer is controlled by novel pressure-actuated inlet and exhaust valves.

Referring now to FIGURE 1 for a more detailed description of a preferred embodiment of this invention, a percussion motor 10 is shown connected to the lower end of a drill pipe 11. Upper valve spider 12 having a multiplicity of liquid passages 13 adjacent the periphery is held in position in the motor casing 14 between the upper shoulder 15 on the lower end of the drill pipe and an expansion ring 16 by an upper spacer sleeve 17 and the upper motor cylinder 18. The spider has a central axial valve member 19 with a top valve closure 21 in the lower end. The step piston 22 (or hammer)has a reduced diameter portion 23 operating in the upper motor cylinder 18 and a lower major portion or piston 24 operating in the major cylinder 25. A cavity 26 is formed between the step piston 22, the upper motor cylinder 18, and the major cylinder 25. This cavity is connected by a conduit 27 to a low-pressure zone, specifically a zone having a pressure desirably substantially lower than the pressure of the power fluid driving the motor. Typically, this conduit 27 is merely one or more holes through the wall of the housing 14 located at the upper end of the major cylinder 25 so that this cavity 26 is connected to the annular space surrounding the drill pipe which is at a substantially lower pressure than the pressure of the power fluid within the drill pipe. A ring seal 67 is employed to prevent leakage back of the upper motor cylinder 18. Incidentally, the construction shown in just one of several ways in which a smaller diameter can be achieved in the housing of the tool adjacent the upper part 23 of step piston 22. There is a fluid passage 28 in piston 22, preferably concentrically located, which is connected at the lower end to the ports 29. These ports carry the power fluid from the fluid passage to the periphery of the hammer at the lower striking face 31 so that the power fluid is available for lifting the hammer and so that space is provided in the bottom center of the hammer for a bottom valve closure 32.

An anvil 33 is loosely supported in the lower end of the motor housing, for example, by a split nut 34. Keys or drive pins 35 are placed in the elongated grooves 36 to provide means for rotating the anvil with the drilling pipe and motor housing and particularly to provide loose or lost motion longitudinally between the motor housing and the anvil so that any desired static downward pressure may be applied to the anvil 33 and the bit 37 without restricting the downward movement of the anvil and bit when struck by hammer 24. Downward static pressure is applied to the anvil 33 and bit 37 through a shoulder 38 on the lower end of split nut 34. When this shoulder is in contact with the anvil, and hammer 22 is in contact with the anvil, the spacing between the top of upper sleeve valve 55 and the lower tip 41 of top valve closure 21 is substantially equal to the length of the hammer stroke, which is typically in the range of about ¼ inch to 1 inch. In our preferred design, the length of the hammer stroke (which is actually controlled by the stroke of the bottom valve 42) is about ½ inch.

Flow of fluid (liquid or gas) through the motor is governed by the two sleeve valves, the lower of which 42 (outlet valve) is mounted slidably in the anvil 33 and the upper of which 55 (inlet valve) is similarly mounted in the piston or hammer 22. These valves are novel in design, and form the heart of the improvement we have made in this motor. Each such valve is of a partially balanced type; that is, the main controlled flow of fluid is largely transverse to the valve motion, and fluid pressures are nearly balanced so that a small force is sufficient to move the valve. Each valve has a main hollow cylindrical section, preferably with a constricted portion, and possesses an external cylindrical piston section closely fitting in a valve cylinder. Ports at or near the top surface of the piston section give fluid communication between the inside and outside of the main cylindrical section. The stroke of the lower (outlet) sleeve valve 42 is controlled by the length of the lower valve cylinder 43; that is, the stroke of the lower valve is equal to the length of the valve cylinder 43 less the length of the lower valve piston 44. Upward motion of this lower valve is stopped by a bushing 45 which is removably connected as by threads 46 to the upper end of the anvil 33. The top of this valve is flush or below the top of anvil 33 when the valve is in the bottom position.

A valve port 47 through the wall of the valve at the level of the valve piston provides fluid communication between the cylinder 43 above the piston 44 and the central fluid passageway 48 which leads to the exhaust passage 49 via a fluid constriction 51 within the central passageway of the valve. Due to this constriction (and due to the weight of the valve), when the motor is operating and fluid is flowing downwardly through the motor, the lower valve is held in its lower or bottom position, as shown. The valve is lifted hydraulically when the hammer striking face 31 and the upper anvil face 39 come together and shut off the flow of fluid through the central fluid passageway 48. With fluid blocked from passageway 48, high pressure fluid in annulus space 100 is applied through ports 52 to the lower face of valve piston 44. The lower end of port 52 is closed by the lower end of valve 42 at this time. Fluid is exhausted from annulus space 43 above the valve piston 44 to the lower pressure in passageway 48 through ports 47, permitting rapid motion of valve 42. However (see FIGURE 6), upward motion of the sleeve valve uncovers the lower end of ports 52. More properly, such motion first uncovers the lower end of grooves 68 which extend from the lower end of the valve cylinder 43 in the wall of exhaust passage 49 through and below the lower end of ports 52. These grooves are roughly the same diameter as ports 52 and have a length of around 80 percent to 90 percent of the valve travel. The length of the valve from the bottom of piston 44 to the lower end of the valve should be about equal to the valve travel.

As soon as the valve uncovers the lower end of grooves 68, the upward force on the valve decreases markedly but is still a positive quantity which results in the valve rapidly moving upward its total travel. However, the decrease in force results in very little possibility of breakage or jamming, and has been a very important factor in getting long motor life. In other words, the valve decreases in speed near the end of its stroke.

Other fluid passages can be used. The important fact is to have easy communication (low fluid impedance) from ports 52 to the lower part of valve cylinder 43. There is, of course, considerably greater fluid impedance from space 100 to the top of passage 49 through ports 52 (even when valve 42 is in top position) than that through passage 48. Accordingly, little fluid leaks into passage 49 when valve 42 is in top position, and the pressure on face 31 at such times approaches that on the upper face of piston 22. When the hammer strikes the anvil, there is an instantaneous impact or water hammer which produces a sharp pressure rise in annular space 100 and initiates at maximum acceleration the lift of the lower valve 42 into closure 32 to stop flow through passage 48. Closing the liquid outlet through passageway 48 at the bottom of the hammer stroke reverses the motion of the hammer 22.

It may be seen from this description that the flow of fluid from the space between the hammer striking face 31 and the upper anvil face 39 is unobstructed as the hammer descends and that the closing of valve 42 occurs after the faces 31 and 39 collide. This condition is important, as it permits the transfer of energy from the hammer to the anvil without fluid damping. The upper end of valve 42 in its downmost conditions may be even with the top of anvil face 39 or it may be spaced in a lower position to provide for closing after the hammer strikes the anvil.

There is an upper (inlet) sleeve valve 55 in the top end of step piston 22 constructed and operated substantially identically to the bottom valve 42. This upper valve has a valve piston 56 operating in the upper cylinder 57 below the threaded bushing 58 in the top of the step piston. The upper end of valve 55 extends for a substantial distance above the top of step piston 22 to prevent contact of the top of the piston 22 and the lower surfaces 41 of the closure 21. Upper valve actuating fluid ports 59 extend from the upper face 61 of the piston down to a clearance 62 between valve 55 and the surrounding part of passage 28 which leads to the bottom end of the top valve cylinder 57.

As discussed above, port 59 connects to the lower end of valve cylinder 57 for a more direct communication of pressure fluid from port 59 to the lower face of valve piston 56. (Actually, the valve and associated piston are constructed as shown in FIGURE 6 except for protrusion of the top of the valve.) Due to upward motion of hammer 22, when the upper end of valve 55 approaches the lower tip 41 of valve closure 21, fluid flow through passage 64 decreases, and the pressure within this passage goes down. Full pressure is still exerted against the lower face of piston 56 via port 59. Accordingly, valve 55 rises into closure 21 and stops flow into passage 64. The last part of the stroke is cushioned by movement of the valve into the closure, and by liquid in the upper end of the cylinder 57 exhausting into the central fluid passage 64 of valve 55. Means such as a constriction 65 in the valve below ports 63, and the weight of the valve tend to hold the upper valve in its bottom position, as shown in FIGURE 1, when power fluid is flowing through the fluid passages 64 and 28 within the step piston.

As shown in FIGURE 1, the hammer or step piston and the valves are all shown in their positions at the bottom end of the power stroke, i.e., at the time at which the hammer 23 strikes the anvil 33 to produce a percussive blow on the bit. The operation of the valves to make the hammer or piston oscillate will now be described in greater detail by reference to FIGURES 2–5, inclusive.

Referring specifically to FIGURE 2, the hammer face 31 and the anvil face come together, closing off passageways 48 and 49. The resulting pressure rise effective on the bottom face of bottom valve 44 moves it up rapidly into closure 32 a distance substantially equal to the length of the hammer stroke. (This assumes the depth of closure 32 exceeds the movement of valve 44.) Radial clearance between the upper end of this valve and closure 32 is small. This action stops flow of fluid through passageway 48 and confines the pressure fluid flowing through passage 28 to the annular area between hammer and anvil surrounding the valve 44 and thus raises the piston. It is to be noted that while pressure fluid is applied to both ends of the piston 23, the area of the major piston 24 exposed to this pressure fluid is substantially greater than the area of the minor portion 23 exposed to the same pressure, while cavity 26 is exposed via ports 27 to a low-pressure area. Accordingly, the piston raises until lower valve 42 no longer extends into closure 32.

As piston 23 rises, eventually the upper end of the top valve 55 enters the top valve closure 21, as shown in FIGURE 3. (Momentum of the piston carries it up the last small amount.) As this upper valve enters that closure, the pressure surrounding the valve which is substantially greater than the pressure within the fluid passage 28 acts through the ports 59 on the bottom face of valve piston 56, which rapidly raises valve 55 to its top position, as shown in FIGURE 4. As soon as the bottom of the hammer **23** clears the upper end of the lower valve **42**, fluid exhausts from the hammer and flows through the bottom valve. Due to the constriction **51** and due to the weight of the valve, the lower valve **42** is shifted rapidly (at least, more rapidly than the speed of piston **22**) to its lower position, allowing the power fluid in the annular space **66** to flow freely into the passage **49** so that the pressure acting on the top **61** starts the hammer **23** down, as shown in FIGURE 5. After the piston has moved down about two-thirds of its power stroke, the upper valve is withdrawn from the top valve closure. This permits the power fluid to flow through the upper valve fluid passage **64**. The weight of the valve and the flow of fluid through constriction **65** force the upper valve to its bottom position, as shown in FIGURE 1. The inertia of the hammer and the action of the pressure fluid on the upper end of the piston continue to force the piston down until it strikes the anvil, as shown in FIGURE 1. At that time, the lower valve **42** is again raised, and the motor goes through another cycle.

In spite of the fact that liquid-actuated percussion motors are inherently much more difficult to design successfully than gas-actuated percussion motors, due to the lack of compressibility of liquids compared to gas, this particular percussion motor has proved to be operable within wide design limits. For example, the dimensions of hammer **23** can be varied over a substantial range. Three successful motors have been built with hammer weights of 36, 24, and 105 pounds, respectively. In the second, the valves were larger and of greater mass than in the first. The third tool was sealed up dimensionlessly from the second. The sizes and locations of the ports **52** and **59** into the passages **28** and **49** were considerably different between the first and second tools, yet both operated well.

For simplicity of definition in the claims, the quantity b—S as shown in FIGURE 2 is designated "upstroke standoff" and the quantity S—c or a of FIGURES 2, 3, and 5 will be designated "downstroke standoff."

While the final design of the valve and associated ports looks straightforward, it should be pointed out that this hardly is the case. Four different basic valve structures were tried before one was found which was successful. One of the unsuccessful designs had over a dozen variations attempted without ultimate success. It is necessary that the valve move rapidly. It is highly desirable to cause each valve to snap from end to end of its travel and certainly travel faster than the velocity of the hammer at that time. It is accomplished by applying greater acceleration to the valve than to the hammer. This, in turn, requires that the maximum hydraulic force applied to the valve piston divided by its weight (i.e., a quantity proportional to valve acceleration) be at least equal to or preferably greater than the maximum hydraulic force applied to the hammer divided by its weight. The valve also must be damped near the end of the stroke so that it will not strike the stop at the end of its travel with enough intensity to cause the metal to peen. This occurs in the design shown by dash-pot action as the fluid on the downstream side of the valve piston is expelled into the main flow of fluid exhausting from the motor. This is also aided by a decrease in pressure in the valve piston cylinder when the ports such as **68** (FIGURE 6) are opened. Also, the design must be such that the valve is not subject to excessive wear, to the action of hydraulic transients (which are particularly bad for liquid-actuated devices), or to fatigue failure. Additionally, the valve design must be such that all parts are self-draining, so that any solid particles entrained in the drilling fluid cannot jam a working part and incapacitate the motor. This, the current valve design has accomplished in actual tests for drilling periods exceeding several hundred hours.

From the foregoing, it can be seen that various modifications can be made in the details of construction of

our percussion motor without departing from the spirit of the invention. This invention should, therefore, be construed not to be limited by the above description which has been directed specifically to a preferred embodiment, but should be construed to be limited only by the scope of the appended claims.

We claim:

1. A cylindrical sleeve valve comprising a hollow cylindrical member containing a constriction, a housing defining a cylindrical opening in which said valve is axially slidably disposed, said housing containing a conduit for flow of fluid therethrough and through said member, hydraulic means including a piston connected to said member for axially sliding said member, and closure means disposed in the path of fluid flow through said member and shaped to contain a part of said member whereby said valve may be slid to a position where said part is disposed in said closure means and said flow is shut off.

2. A cylindrical sleeve valve comprising a hollow cylindrical member containing a constriction and an annular piston disposed about and connected to said member, a housing defining a cylindrical opening radially close fitting said member and said piston but permitting limited axial motion thereof, said housing containing a conduit for flow of fluid therethrough and through said valve, said housing also containing a fluid passage for application of pressure to one side of said piston, means for draining fluid from said one side of said piston, said valve containing an orifice through the wall thereof adjacent said piston opposite said one side, and closure means disposed in the path of fluid flow through said valve and shaped to contain a part of said member whereby said valve may be slid to a position where said part is disposed in said closure means and said flow is shut off.

3. A cylindrical sleeve valve comprising a hollow cylindrical member containing a constriction and an annular piston disposed about and connected to said member, a housing defining a cylindrical opening radially close fitting said member and said piston but permitting limited axial motion thereof, said housing containing a conduit for flow of fluid therethrough and through said valve, said housing also containing a fluid passage for application of pressure to one side of said piston, said valve containing a fluid drain permitting fluid to be removed from the region opposite said one side of said piston, means closed by said member when said valve is in nearly full open position for permitting fluid to escape from said one side of said piston, and seating means disposed in the path of fluid flow through said valve and shaped to contain a part of said valve whereby said valve may be slid to a position where said part is disposed in said seating means and said flow is shut off.

4. A percussion motor comprising a cylindrical housing, means for supplying fluid under pressure to said housing to drive said motor, a cylindrical piston including portions of larger and of smaller diameter radially close-fitting portions of said housing, said housing and said piston forming a variable-volume chamber, a conduit connecting said chamber with a zone of pressure lower than that of said fluid entering said motor, a passage through said piston controlled by an inlet sleeve valve, an anvil slidably disposed in said housing adjacent and below said piston, a passage through said anvil controlled by an exhaust sleeve valve, and passages through at least part of said piston and at least part of said anvil for applying actuating pressure to said inlet and to said exhaust sleeve valves, respectively, whereby said inlet sleeve valve is maintained in open position during the major portion of upward travel of said piston and said exhaust sleeve valve is maintained in open position during the major portion of downward travel of said piston.

5. A percussion motor comprising a cylindrical housing, means for supplying fluid under pressure to said housing to drive said motor, a cylindrical piston including

portions of larger and of smaller diameter radially close-fitting portions of said housing, an opening through said housing between top and bottom of said piston, a fluid passage through said piston controlled by a top sleeve valve, an anvil slidably disposed in said housing adjacent and below said piston, a fluid passage through said anvil controlled by a bottom sleeve valve, and means actuated by fluid flow through said piston and said anvil, respectively, for holding said top sleeve valve open during the major portion of upward travel and closed during the major portion of downward travel of said piston, while holding said bottom sleeve valve open until said piston strikes said anvil and closed during the major portion of upward travel of said piston.

6. Apparatus in accordance with claim 5 in which said means for closing each of said sleeve valves actuates said valve during the closing thereof at a speed greater than that of said piston at the same time.

7. A percussion motor comprising a cylindrical housing, means for supplying fluid under pressure to said housing to drive said motor, a cylindrical hammer including portions of larger and of smaller diameter radially close-fitting portions of said housing, an opening through said housing between the ends of said piston, a passage through said piston controlled by a top sleeve valve, an anvil slidably disposed in said housing adjacent and below said piston, a passage through said anvil controlled by a bottom sleeve valve, each of said top and bottom sleeve valves being cylindrical and containing a piston portion, a conduit in said hammer connecting hydraulically the lower face of the piston portion of said top valve with the upper face of said hammer, a conduit in said anvil connecting hydraulically the lower face of the piston portion of said bottom valve with the upper face of said anvil, a vent in each sleeve valve connecting hydraulically the upper face of the piston portion to the corresponding passage, a port adjacent each sleeve valve and closed in lower position thereby, each said port hydraulically connecting the corresponding conduit with the corresponding passage, and a closure member above said top sleeve valve and connected to said housing, said closure member being so shaped with respect to said top sleeve valve as to close off flow of fluid through said top sleeve valve when it is in top position, a bottom portion of said piston being so shaped with respect to said bottom sleeve valve as to close off flow of fluid through said bottom sleeve valve when it is in top position.

8. Apparatus in accordance with claim 7 in which the ratio of total maximum hydraulic force applied to each valve divided by the weight thereof is at least equal to the maximum hydraulic force applied to said piston divided by the weight thereof.

9. Apparatus in accordance with claim 4 in which the upstroke standoff does not exceed the stroke and in which the downstroke standoff is always positive and not substantially greater than said stroke.

10. A fluid-operated free piston motor including a step cylinder having a minor bore and a subjacent major bore, a peripheral fluid inlet at the upper end of said minor

bore, a step piston hammer having its upper end in said minor bore and its larger end in said major bore, said cylinder and said hammer forming a variable-volume cavity in the upper end of said major bore, conduit means from said cavity through the wall of said cylinder, an axial fluid passage in the upper end of said hammer, an inclined port extending from the bottom of said fluid passage to an off-center fluid outlet in the bottom of said hammer, a top valve closure in said fluid inlet coaxial with said fluid passage in said hammer, a hollow top sleeve valve in said fluid passage adapted for limited longitudinal movement, upper means including a piston mounted in a cylinder and connected to said top valve to raise said top valve, a conduit extending from the upper end of said hammer to said cylinder and to a position in said fluid passage covered by said top sleeve valve in its lower position and uncovered by said top sleeve valve in its upper position, said top sleeve valve being raised by said upper means in contact with said closure whenever the pressure at said fluid inlet is greater than the pressure in said fluid passage, a bottom valve closure in the bottom center of said hammer, an anvil slidably connected to the lower end of said cylinder, said anvil being so constructed and arranged that said hammer strikes the top end of said anvil at the bottom of the power stroke, an axial exhaust port in said anvil, a bottom sleeve valve in said exhaust port adapted for limited longitudinal movement, lower means including a second piston mounted in a second cylinder and connected to said bottom valve to raise said bottom valve, and a conduit extending from the upper end of said anvil to said second cylinder and to a position in said exhaust port covered by said bottom valve in its lower position and uncovered by said bottom valve in its upper position, said bottom valve being raised by said lower means whenever the pressure at said top end of said anvil is greater than the pressure in said exhaust port.

11. A fluid-operated free piston motor as set out in claim 10 including a constriction in the fluid passage of each of said top sleeve valve and said bottom sleeve valve to produce a pressure drop in the fluid flowing downwardly therethrough and accelerate the opening of each of said valves.

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