

Oct. 27, 1964

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PERCUSSION DRILLING APPARATUS

3,154,153

Filed July 19, 1961

2 Sheets-Sheet 1

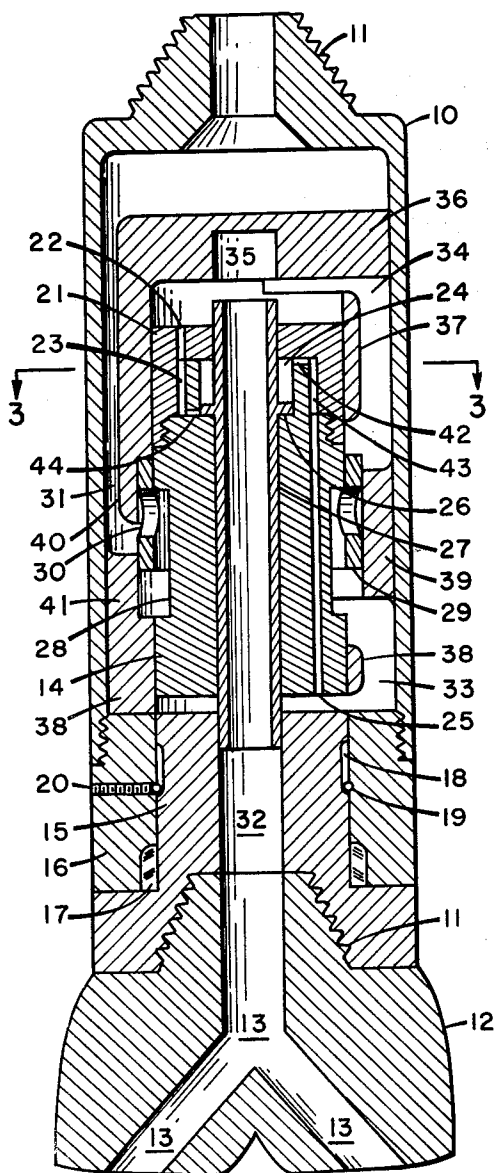


FIG. 1

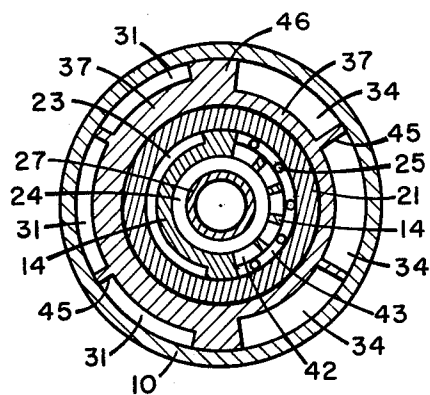


FIG. 3

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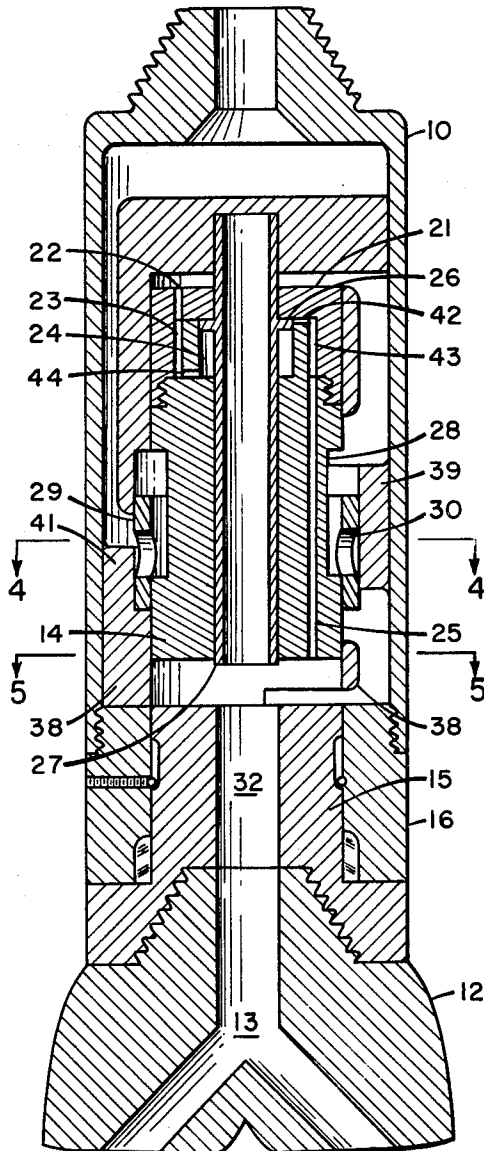


FIG. 2

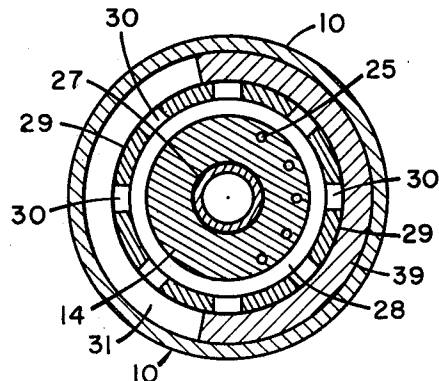


FIG. 4

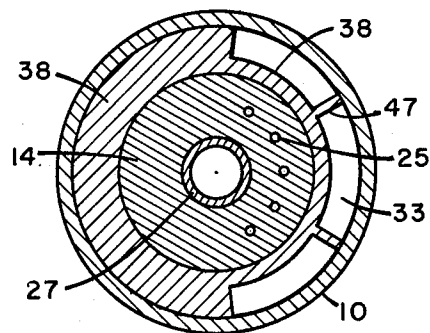


FIG. 5

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PERCUSSION DRILLING APPARATUS

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Filed July 19, 1961, Ser. No. 125,218
5 Claims. (Cl. 173-73)

This invention concerns a fluid-actuated device used to apply percussive blows to a rotary drill bit while drilling hard materials such as geologic formations. More particularly, the invention relates to valve designs for percussion motors which enable the pressure of the motive fluid to be applied to the motor hammer for a greater portion of the distance travelled by the hammer.

A substantial increase in drilling rate can be obtained if percussive blows are applied to a rotary drill bit. This technique has been used to great advantage in drilling shot holes for seismic exploration and quarrying operations as well as in drilling oil and gas wells. The percussive energy is usually obtained from a motor in the drill string immediately above the bit. Power fluid pumped down the drill pipe drives the motor and is exhausted through the bit to remove drilled material from the vicinity of the bit. Basically, these percussion motors contain a hammer element which is reciprocated by the power fluid, striking an anvil which transmits the energy to the bit. It has been found that a minimum or threshold quantity of energy must be delivered to the bit to stress the rock beyond its elastic limit and produce chips, i.e., drill. Limitations on the size of the apparatus which can be run in a well have made it difficult to design a tool which will operate efficiently and deliver adequate energy to the bit. Complex valve systems have been devised to increase the power delivered to the bit by the percussion motor. In general, these have been unsatisfactory because they are difficult to manufacture and, owing to space limitations, they cannot be designed to withstand rugged use for long periods of time. Mechanical elements of the intricate apparatus frequently fail after brief periods of operation.

Many of the prior art tools have used a differential area hammer. In these tools high-pressure gas is applied to opposed, unequal areas of the hammer, causing it to move in the direction responsive to the pressure on the larger area. The net force applied to the hammer is proportional to the differential area. It is therefore advantageous to make the differential area as great as possible, considering the limitations on overall size of the tool. This is illustrated in the following relationship for determining the kinetic energy of the hammer during its downstroke.

$$K.E. = (PA + W)S$$

where:

P=Differential pressure across the hammer

A=Net area of hammer subjected to the differential pressure

W=Weight of hammer

S=Distance travelled by hammer with the differential pressure across the hammer

This relationship shows that kinetic energy per blow of the hammer can be increased either by applying the force (PA+W) over a greater distance S or by increasing the force component (PA+W). Also, the total energy delivered by the hammer can be increased by increasing A while maintaining the other variables constant, thereby increasing the frequency of the hammer blows without decreasing the energy per blow. Owing to the limitations on space, and the desire to recover the maximum potential energy from the power fluid, the above relation-

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ship suggests application of the differential pressure across the entire area of the hammer through as great a distance as possible.

It is an object of our invention to produce a gas-operated percussion tool with a hammer element having top and bottom end surfaces of equal area. It is a further object to provide means for exhausting gas from alternate ends of the percussion hammer while simultaneously applying gas pressure to the opposite end. Another object is to provide a valve system which maintains the pressure differential across the hammer for a greater portion of the distance travelled by the hammer.

These and other objects are accomplished by the apparatus described herein.

In general, our invention consists of a gas-operated percussion drilling tool having an equal-area hammer which reciprocates within a housing as gas circulates through the hammer and discharges through a bit below the percussion tool. By equal-area, we mean a hammer having top and bottom surfaces of the same area. Also, we provide a quick-acting, sliding valve at the gas inlet which increases substantially the distance travelled by the hammer under the influence of differential pressure and decreases the distance it must travel by momentum at the expense of kinetic energy. Additionally, we have devised a moving finger valve which delays the opening and closing of the exhaust ports at the ends of the hammer, thereby further increasing the distance through which the differential pressure is applied to the hammer.

FIGURE 1 is a cross-sectional view of the percussion tool at a time when the hammer is being raised.

FIGURE 2 shows the elements of the percussion tool during the downstroke of the hammer.

FIGURE 3 shows the annular passageways in the tool along line 3-3 of FIGURE 1.

FIGURE 4 is a similar view showing the passageways in the tool along line 4-4 of FIGURE 2.

FIGURE 5 is a cross-sectional view, taken along line 5-5 in FIGURE 2, showing the arrangement of the elements at the lower end of the tool.

The percussion tool has a housing 10 with tool joint connections 11 at the top and bottom in order that the tool may be installed in a drill string between the pipe and a bit. Hammer 14 is arranged for reciprocation in the housing to deliver percussive blows to anvil 15 which is rigidly connected to drill bit 12. Splined connection 17 between anvil 15 and adapter 16 transmits rotary motion from the drill pipe and housing to the bit while permitting limited longitudinal movement of the anvil-bit assembly in response to impact blows by the hammer. Finger valve 27 is arranged for longitudinal movement along the axis of the hammer. Flange 26 on the finger valve limits its movement within the confines of cylinder 24. Fluid pressure above the hammer is transmitted to the lower side of flange 26 by way of upper port 22, annular passageway 23 and ports 44 through the wall of cylinder 24 in the upper end of the hammer. Fluid pressure below the hammer is transmitted similarly to the upper side of flange 26 by way of lower port 25 and slots 42. In this structure, the finger valve is positioned within the hammer in response to the differential pressure across the hammer. Exhaust passageway 32 in the anvil receives the lower end of finger valve 27 in a fluid-sealing engagement. Finger valve seat 35 in upper head 36 receives the upper end of the finger valve to stop the exhaustion of fluid from the chamber above the hammer.

Slide valve 29 surrounds the hammer. Ports 30 in the valve admit power fluid from inlet passageway 31 to annular recess 28 in the hammer. The slide valve is arranged for longitudinal movement in response to the differential pressure between upper fluid conduit 34 and lower fluid conduit 33.

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Upper and lower guide members, 37 and 38, respectively, keep the hammer in axial alignment to prevent wobbling and damage as well as providing a hammer seal. Guide members 39, 40 and 41 hold the slide valve in proper alignment.

The operation of the percussion motor will be described with reference to the figures. A fluid under pressure is circulated down the drill pipe and enters the upper end of housing 10. The fluid flows through inlet passageway 31 to ports 30 in the slide valve then to annular recess 28 in the hammer. In the position shown in FIGURE 1, the fluid above the hammer is vented through finger valve 27, exhaust passageway 32 and bit courses 13, whereas the lower end of the finger valve prevents the flow of fluid from below the hammer into exhaust passageway 32. Thus, the differential pressure across the hammer and slide valve 29 holds the latter in its upper position and lifts the hammer toward upper head 36. Additionally, the differential pressure acting on flange 26 in cylinder 24 holds the finger valve in its lower position whereby the lower end of the valve will prevent the escape of pressure fluid from below the hammer until the hammer is near upper head 36. As the hammer approaches the top of its stroke, the upper end of annular recess 28 in the hammer clears the top edge of slide valve 29, permitting high-pressure fluid to enter upper fluid conduit 34. Very soon thereafter the lower end of the finger valve is withdrawn from exhaust passageway 32 and the lower end of annular recess 28 enters the slide valve. It will be seen that the high-pressure fluid below the hammer rapidly exhausts to a low-pressure level. Simultaneously, the pressure above the hammer starts to increase, causing the slide valve to move quickly to its lower position and the finger valve to rise to its upper position with the upper end extending into valve seat 35. The rapid reversal of the differential pressure across the hammer decelerates the hammer and ultimately reverses its direction of travel.

As the hammer starts its downward movement, the components are in the positions shown in FIGURE 2. The hammer is driven downward until it contacts the upper face of the anvil and delivers its kinetic energy. Immediately preceding the contact of the hammer with the anvil, the lower edge of the annular recess clears the lower end of the slide valve and the upper edge of the recess enters the slide valve. Also, the upper end of the finger valve is withdrawn from valve seat 35 immediately preceding the impact of the hammer with the anvil. This sequence of events produces a quick reversal in the differential pressure, causing the slide valve to rise and the finger valve to drop, thereby starting another cycle in the operation of the percussion tool.

Referring now to FIGURE 3 for a description of the fluid conduits at the upper end of the hammer, it can be seen that fluid pressure in cylinder 24 above flange 26 is equalized with that below the hammer by way of slots 42 in the upper end of the hammer, annular passageway 43 between the cylinder wall and upper head 21 of the hammer, and lower ports 25. Fluid pressure above the hammer equalizes with that below the flange through upper ports 22, annular passageway 23 and ports 44 in the cylinder wall. Ribs 45 centralize and stabilize upper guide member 37 in housing 10. Ribs 46 provide a pressure seal between inlet passageway 31 and upper fluid conduit 34.

FIGURE 4 illustrates particularly the structure of the slide valve. In this embodiment there are several ports 30 spaced radially about the valve member. Power fluid flows from passageway 31 into annular recess 28 by way of those ports in the slide valve adjacent the inlet passageway. Guide member 39 prevents the flow of fluid from the recess through the remaining ports. Thus, power fluid can flow from the recess only by passing under one end of the slide valve. This arrangement permits operation of the slide valve at any radial position of the hammer and valve.

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The ports are desirably about midway between the ends of the valve members. The width of slide valve guide member 39, i.e., the longitudinal separation between upper fluid conduit 34 and lower fluid conduit 33, should be slightly greater than the distance spanned by slide valve ports 30 as the valve member moves between its upper and lower positions. This will prevent the flow of power fluid from the annular recess into the upper and lower conduits by way of the ports. The length of the sleeve valve may be approximately equal to the width of the annular recess in the hammer. This will prevent the simultaneous flow of power fluid to the upper and lower conduits, a condition which might cause the percussion motor to stall. The width of the annular recess is preferably approximately equal to the distance between the upper and lower conduits.

The position of lower guide member 38 can be seen in FIGURE 5. Ribs 47 provide support across lower fluid conduit 33 between the guide and housing 10.

The connection between adapter 16 and anvil 15 has mating splines 17 in the adapter and anvil to transmit rotary motion from the drill stem and housing 10 to the drill bit. Longitudinal movement produced when the hammer strikes the anvil is permitted by the wide groove 18 which passes over the retainer balls 19. Set screw 20 may be used to close the opening where the balls were inserted.

Various methods may be used in the assembly of this tool. For example, guide members 37, 38, 39, 40 and 41, as well as upper head 36, may be stacked on adapter 16 with suitable spacer elements whereby they will be held in place by housing 10 when it is connected to the adapter.

From the foregoing description of the operation of the tool, it will be understood that the hammer moves in response to the inlet pressure of the power fluid on one end and the exhaust pressure on the other end. This feature enables the hammer to operate at high velocity delivering energy to the bit equal to that obtained with more massive hammers in lower velocity tools.

To obtain the maximum benefit from the slide valve in the power fluid inlet, the valve should operate at a velocity substantially greater than that of the hammer. Using the corresponding designations given previously in the relationship for kinetic energy of the hammer and:

V = Velocity

g = Acceleration due to gravity

$$V^2 = 2 \left(\frac{PA}{W} + 1 \right) gS$$

When, P , g and S do not vary, it will be seen that:

$$V \propto A/W$$

Thus, the velocity of the slide valve may be increased either by increasing the net area of the valve member or by decreasing its weight. Our slide valve combines both possibilities. One end of the valve member is subjected to inlet pressure while the opposite end is exposed to exhaust pressure. The entire cross-sectional area of the member is therefore subjected to the differential pressure. Also, weight of the valve member is quite small in relation to the weight of the hammer. The length of the slide valve is desirably slightly less than the width of the annular recess in the hammer. The width of the recess may be less than twice the length of the hammer stroke. To avoid damage to the tool, the hammer stroke is usually less than one inch. Thus, the ratio A/W for the slide valve may be from 10 to 100 times that of the hammer. Therefore, the slide valve will shift to its alternate position at a velocity from 10 to 100 times that of the hammer, disregarding the effect of friction. This fast operation will insure the repositioning of the valve member in advance of the hammer. Owing to friction effects and fluid leakage between the motor components, it is desirable for the slide valve to have a theoretical

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velocity at least twice, and preferably ten times, that of the hammer.

The moving finger valve should extend above the hammer a short distance, preferably about one-quarter to one-half inch, when flange 26 is at the lower end of cylinder 24. This will stop the exhaust of fluid through the finger valve near the end of the hammer upstroke and compress the fluid trapped above the hammer, thereby preventing the hammer from striking upper head 36. During the downstroke of the hammer, the finger valve should be almost flush with the lower face of the hammer. A slight extension, e.g., about one-eighth inch, may be desirable to provide a better fluid seal between lower fluid conduit 33 and exhaust passageway 32 at the start of the upstroke.

This tool may be used with either a liquid or a gaseous power fluid; however, gaseous fluids are preferred. The stresses produced by the sudden closure of the valves are less severe when a compressible fluid is used to drive the tool.

From the above it can be seen that we have provided a percussion drilling tool wherein the pressure of the power fluid is applied to the hammer throughout substantially the entire stroke. Although the description of the apparatus has been limited to our preferred embodiment, it should be understood that other mechanical designs are functional equivalents. In some circumstances, it may be desirable to use either the slide valve or the moving finger valve without the other. Either alone will improve the operating efficiency of the equal-area percussion tool; however, the optimum benefits are obtained when they are used in combination. Therefore, our invention should be limited only by the scope of our claims.

We claim:

1. A percussion drilling tool comprising

- (1) a hollow cylindrical housing,
- (2) an anvil containing an exhaust passageway, said anvil slidably constrained within said housing and so shaped relative thereto that axial torque may be transmitted therebetween, said anvil protruding from said housing and including coupling means for attaching a drill bit,
- (3) a hollow hammer adjacent said anvil, slidably constrained within and closely fitting said housing, said hammer being shaped to define an annular recess in the outer surface thereof,
- (4) a hollow finger valve slidably disposed in said hammer and longer than said hammer by approximately the length of stroke of said hammer, the end adjacent said anvil being of shape and alignment to seal said exhaust passageway,
- (5) means within said hammer and responsive to the difference in pressure on the ends of said hammer for moving said finger valve in the direction of the hammer end under greater pressure,
- (6) said housing defining a stationary inlet fluid passageway and separate, stationary upper and lower fluid conduits, the latter communicating at all times respectively with the upper and lower ends of said hammer, said upper and lower conduits terminating adjacent said annular recess and longitudinally separated by a distance approximately equal to the width thereof,

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(7) an annular slide valve mounted with limited axial movement in said housing and about said hammer and closely fitting said housing and said hammer, said valve being approximately the same width as that of said annular recess, the upper and lower ends of said slide valve being in constant fluid communication with said upper and lower fluid conduits respectively, said slide valve being interposed between said annular recess and said upper and lower fluid conduits but so arranged as to admit fluid continuously from said inlet fluid passageway to said annular recess, so that differences in fluid pressure between said upper and lower conduits controls the axial displacement of said slide valve in said limited axial movement and thus controls flow of fluid to said upper and lower fluid conduits, and

(8) a recessed upper head fixed to said housing above said hammer, the recess in said head being shaped and aligned to fit closely the upper end of said finger valve when said hammer is near the top of its stroke.

2. A percussion drilling tool in accordance with claim 1 in which said finger valve includes a flange attached thereto and said hammer is shaped to form a cylindrical chamber closely fitting said flange, said flange and said finger valve forming a piston in said cylindrical chamber, said hammer containing fluid passages connecting respectively the top of said hammer with the bottom of said cylindrical chamber and the bottom of said hammer with the top of said cylindrical chamber.

3. A percussion drilling tool in accordance with claim 1 in which the diameter of said hammer above said annular recess is substantially the same as the diameter of said hammer below said annular recess.

4. A percussion drilling tool in accordance with claim 1 in which said slide valve is mounted in a groove in said housing, said groove being substantially centered with respect to the position of said annular recess in said hammer at the mid-point of its stroke, said inlet fluid passageway terminating in said groove, said slide valve containing radial ports at least one of which is in constant fluid communication with said annular recess and said inlet fluid passageway.

5. A percussion drilling tool in accordance with claim 4 in which the minimum longitudinal separation between said upper and lower fluid conduits is slightly greater than the distance spanned by said radial ports in said slide valve as said slide valve moves between its upper and lower positions, the width of said annular recess is approximately equal to said minimum separation between said upper and lower fluid conduits, and the width of said slide valve is slightly less than the width of said annular recess in said hammer.

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