May 17, 1960 S. A. COLGATE 2,936,743

INTERNAL COMBUSTION APPARATUS

Filed Nov. 19, 1956 5 Sheets-Sheet 1

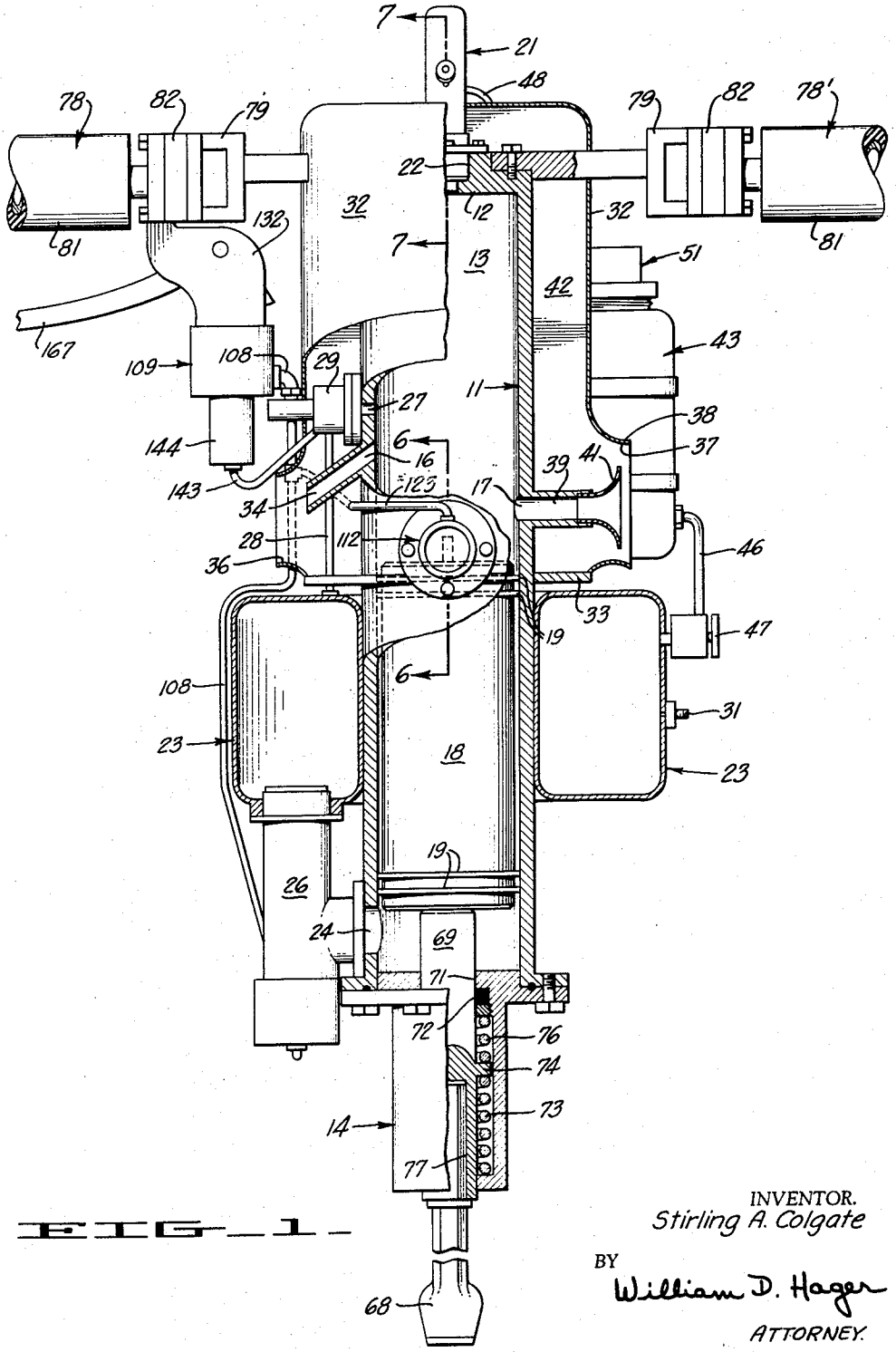


FIG. 1

INVENTOR.
Stirling A. Colgate

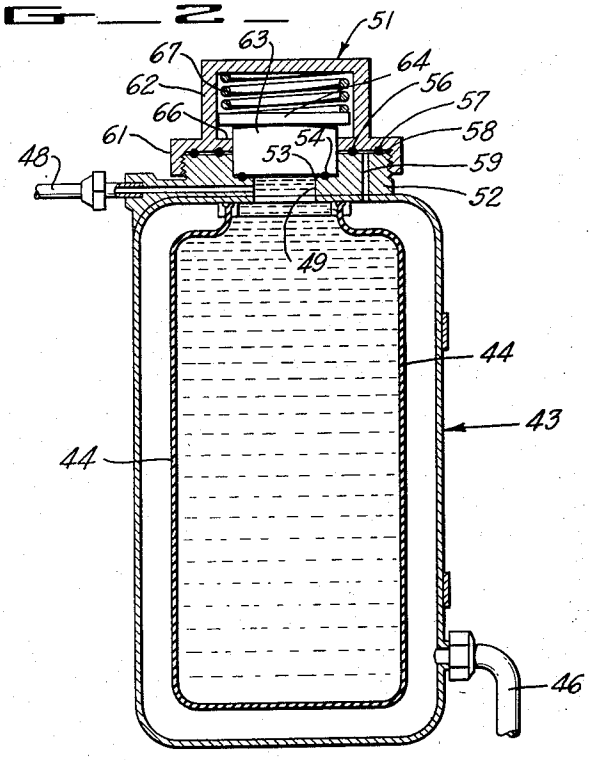
BY
William D. Hager
ATTORNEY.

May 17, 1960 S. A. COLGATE 2,936,743

INTERNAL COMBUSTION APPARATUS

Filed Nov. 19, 1956 5 Sheets-Sheet 2

FIG. 2



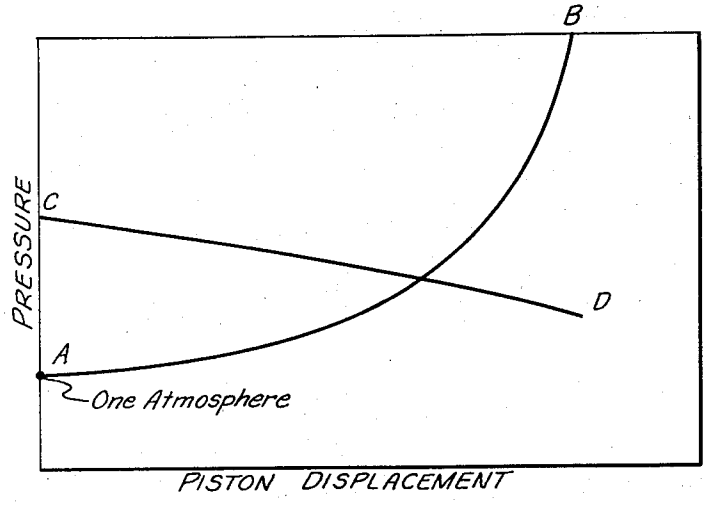


FIG. 3

INVENTOR.
Stirling A. Colgate

BY

William D. Hager
ATTORNEY.

May 17, 1960 S. A. COLGATE 2,936,743

INTERNAL COMBUSTION APPARATUS

Filed Nov. 19, 1956 5 Sheets-Sheet 3

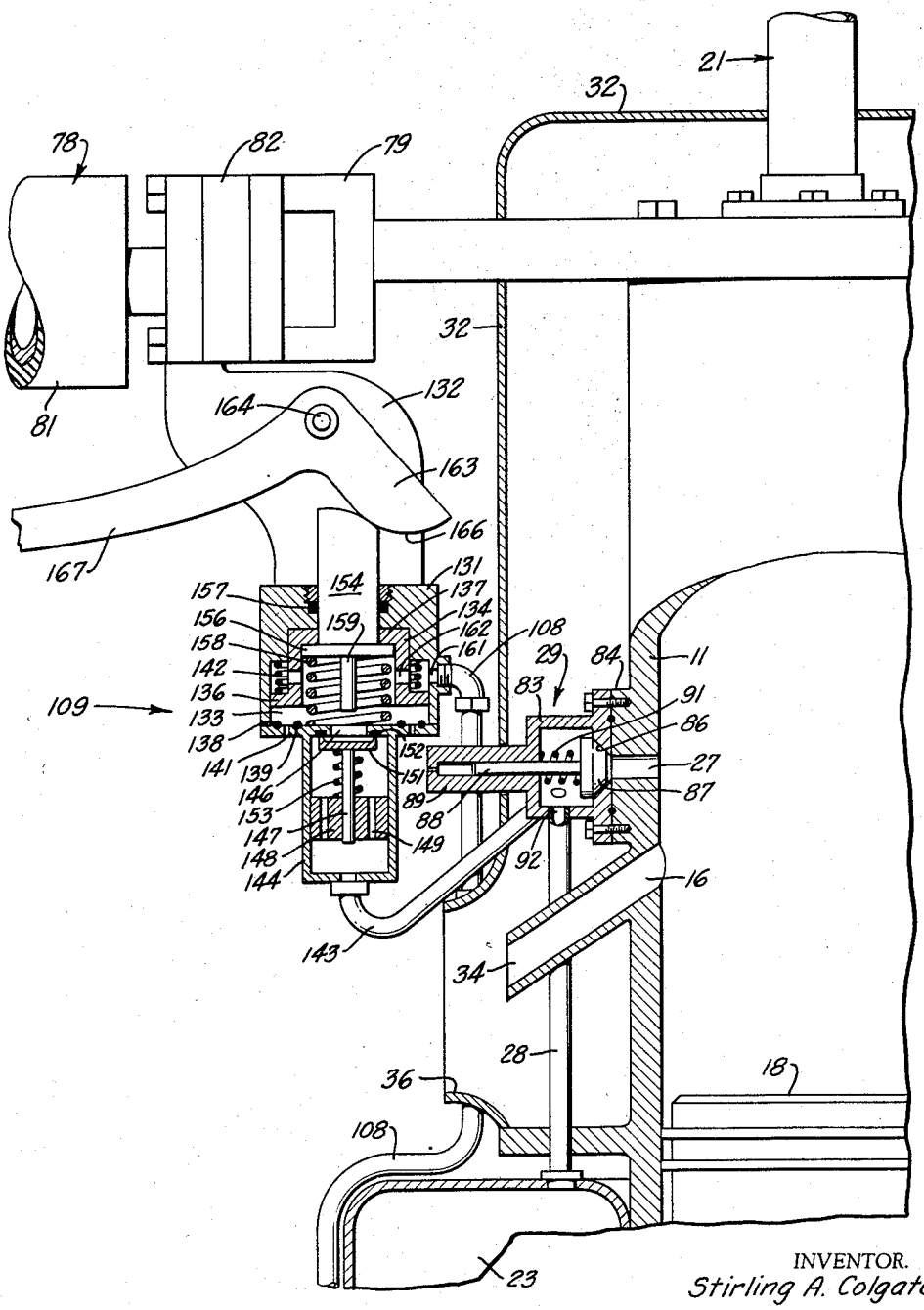


FIG. 4

INVENTOR.
Stirling A. Colgate

BY
William D. Hager
ATTORNEY.

May 17, 1960 S. A. COLGATE 2,936,743

INTERNAL COMBUSTION APPARATUS

Filed Nov. 19, 1956 5 Sheets-Sheet 4

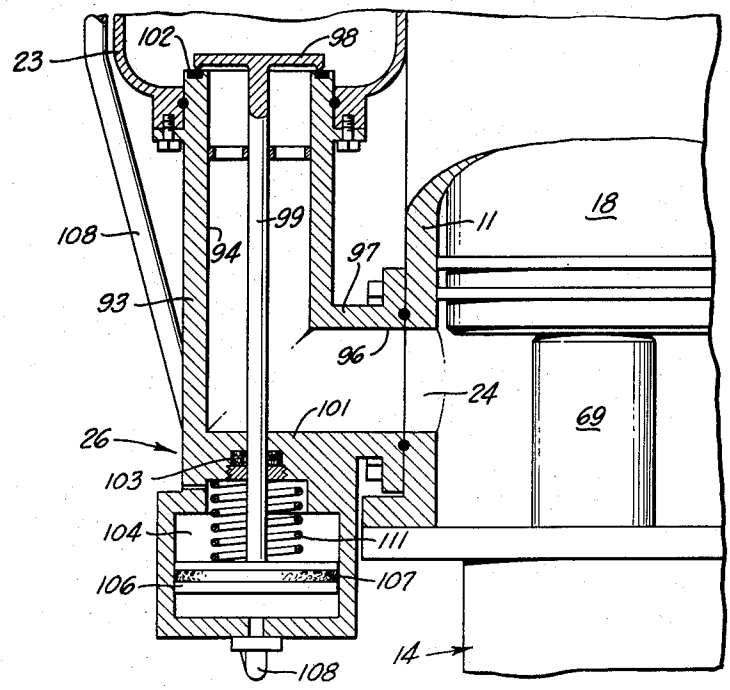


FIG. 5

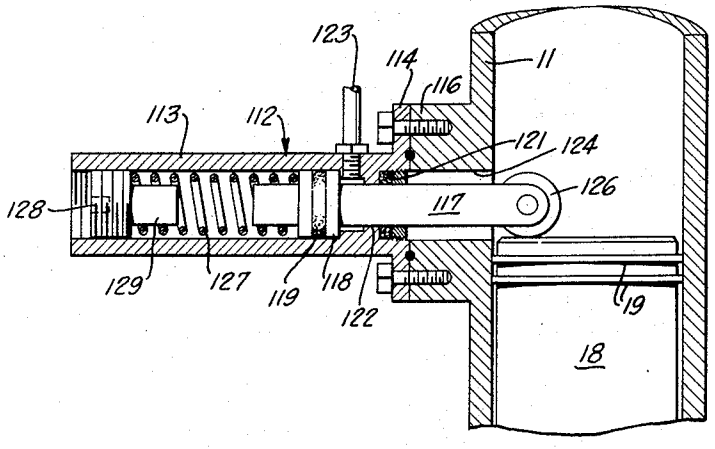


FIG. 6

INVENTOR.
Stirling A. Colgate

BY

William D. Hager
ATTORNEY.

May 17, 1960 S. A. COLGATE 2,936,743

INTERNAL COMBUSTION APPARATUS

Filed Nov. 19, 1956 5 Sheets-Sheet 5

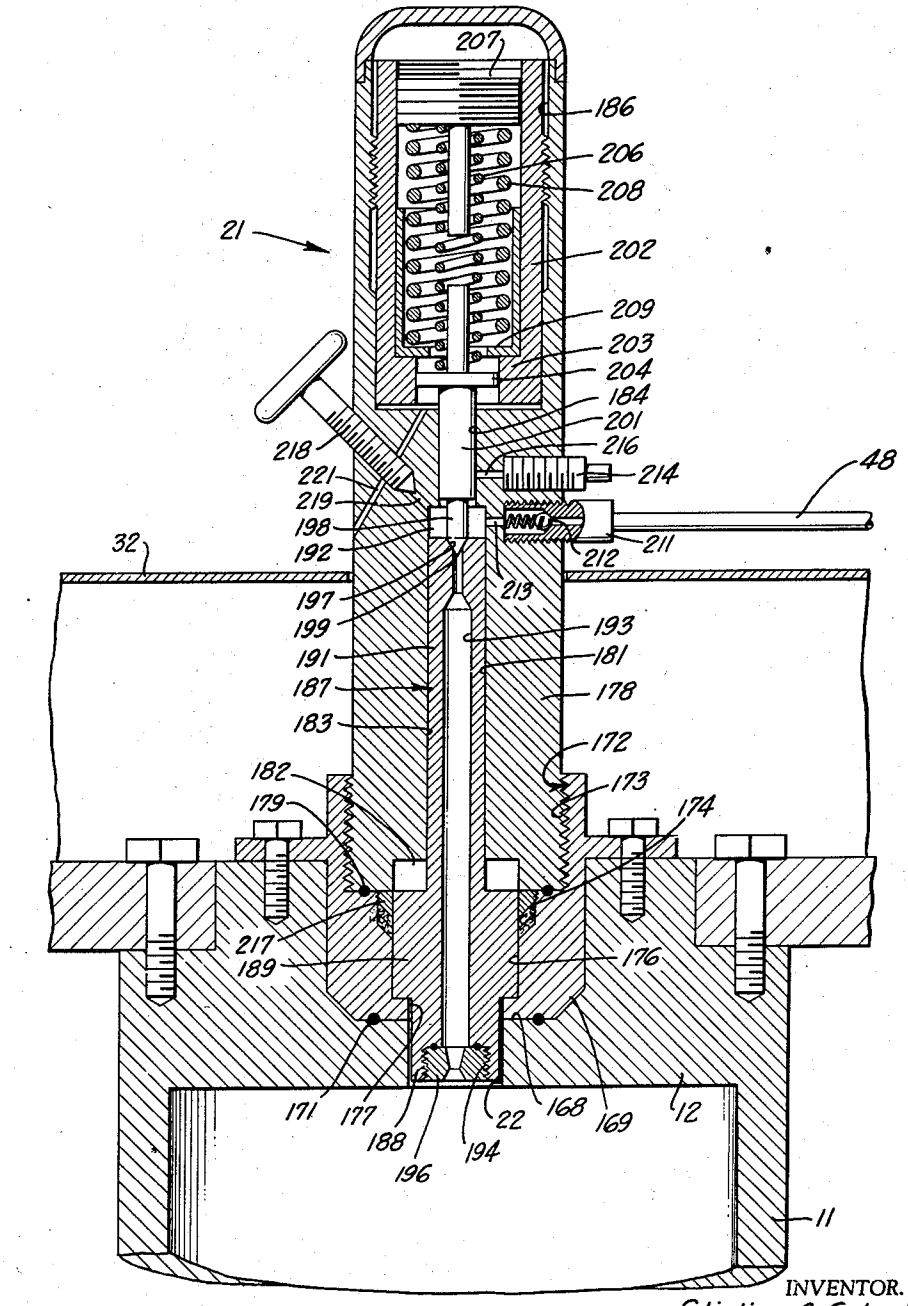


FIG. 7

INVENTOR.
Stirling A. Colgate

BY
William D. Hager
ATTORNEY.

United States Patent Office 2,936,743 Patented May 17, 1960

2,936,743

INTERNAL COMBUSTION APPARATUS

Stirling A. Colgate, Livermore, Calif.

Application November 19, 1956, Serial No. 623,034

22 Claims. (Cl. 123—7)

The present invention relates to internal combustion engines and more particularly to a free piston two cycle engine of the class adapted to drive power hammers, power chisels, and like tools.

Power equipment for imparting reciprocatory motion to a tool, which apparatus is known to the art as a power hammer and more popularly as a "jackhammer," is generally operated by means of compressed air delivered to the hammer by a conduit which connects with a remotely situated compressor. The compressor associated with these tools is necessarily bulky, costly, and heavy, and hinders movement of the hammer both as a given work progresses and between work sites. The thick relatively stiff conduit connecting the compressor with the hammer impedes an operator by entanglement and by adding to the weight which must be dragged along with the tool. It will further be found that use of a compressor situated remotely from the hammer results in a low degree of thermodynamic efficiency which factor is adversely reflected in fuel consumption. Such inefficiency results in that a large proportion of the power required to drive the compressor goes to heat the driving air, which thermal energy is dissipated rather than being delivered to the tool in the form of reciprocatory motion.

Some of the above described disadvantages of the compressor driven hammer were overcome by the introduction of the internal combustion hammer of which examples are disclosed in U.S. Patent No. 2,101,608, Internal Combustion Device, issued to E. R. Boddinghouse, December 7, 1937; and U.S. Patent No. 2,163,336, Spark Timer for Hammers, issued to C. L. Charles, June 20, 1939. Such hammers comprise a cylinder enclosing a spring returned piston and are provided with carburetion means, ignition means, and exhaust means. A tool mount is provided in position to be struck by the underside of the piston at the end of each working stroke thereof, thus imparting the desired reciprocatory motion to a tool. Hammers of this class eliminate the need for an external compressor and the heavy air conduit characteristic of compressor driven hammers is replaced with a relatively light cable connecting with a near battery and ignition coil.

Nevertheless, internal combustion hammers as heretofore constructed are subject to certain disadvantages. Notably, the spring which serves to return the piston to firing position is subjected to severe cycling. Such hammers may operate at a rate exceeding 1500 strokes per minute which inevitably results in frequent breakage of the spring. The cost and inconvenience of replacing the springs has mitigated, to a large extent, the basic advantages of internal combustion hammers. It has further been found that the remote ignition coil and connecting cable, while less of a hindrance than a compressor and airhose, is still a source of annoyance to the operator. A primary disadvantage of prior forms of internal combustion hammer is the requirement that the piston in such hammers be manually depressed in

order to start the tool. In practice this has resulted in a tendency to leave the hammer operating at all times during the usual intermittent use, which operation accelerates depreciation of the tool and increases fuel consumption. The thermodynamic efficiency of prior internal combustion hammers considerably exceeds that of air operated devices but falls short of the potentially available efficiency.

This invention provides an internal combustion power source, of the class adapted to drive power hammers, which overcomes the above described disadvantages of prior equipment. Specifically the invention is a free piston engine having no return spring subject to fracture, no connection with remotely situated equipment, fingertip starting, and which operates on a diesel cycle by means of a structure through which the highest thermodynamic efficiencies are attained. The above described characteristics, as well as certain further advantages features to be hereinafter pointed out, are achieved by a construction in which piston return is accomplished by a pressurized gas cushion which cushion is compressed by the working stroke of the piston.

Reference is made to my co-pending application Serial Number 16,381, filed March 21, 1960, and entitled Diesel Fuel Injector.

It is thus an object of this invention to provide an improved free piston internal combustion power source.

It is an object of this invention to provide a free piston internal combustion engine in which piston return is effected by means free from fatigue induced breakage.

It is an object of this invention to provide a free piston internal combustion device, having novel piston return means, in which the maximum thermodynamic efficiencies obtain.

A further object of this invention is to provide an improved free piston internal combustion engine having piston return means characterized by uniform pressure on the piston whereby vibration is reduced.

Still a further object of this invention is to provide a free piston internal combustion power source operating on the diesel principle which may be readily started by manipulation of a control member.

It is an important object of this invention to provide improved means for imparting a reciprocatory motion to hammers, chisels, drills, and the like.

Still another object of this invention is to provide an improved power hammer which may be readily started and stopped during intermittent use, which may be more economically operated, which may be operated in any position, and which is free from connection with remotely situated equipment.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in conjunction with the accompanying drawing, in which:

Figure 1 is a side elevational view of a power hammer constructed in accordance with the present invention, with portions of the structure broken away and shown in section for clarity of illustration.

Figure 2 is a vertical sectional view through a fuel bottle forming part of the present invention.

Figure 3 is a graphical presentation of pressure changes experienced by certain portions of the apparatus in the course of operation.

Figure 4 is an enlarged fragmentary detail view of an upper portion of the power hammer of Figure 1.

Figure 5 is an enlarged fragmentary detail view of a lower portion of the power hammer of Figure 1.

Figure 6 is an enlarged cross sectional view taken substantially on the line of 6—6 of Figure 1.

Figure 7 is an enlarged cross sectional view taken substantially on the line of 7—7 of Figure 1.

Referring now to the drawing, and more particularly to Figure 1 thereof, there is shown an elongate cylinder 11 having a thick closure 12 at the uppermost extremity, the upper portion of the cylinder being a combustion chamber 13. A hollow cylindrical anvil housing 14 is secured coaxially to the lower end of cylinder 11, the top end of the anvil housing being inserted a short distance into the cylinder to form a bottom closure therefor. An exhaust vent 16 is transpierced through the wall of cylinder 11 a substantial distance downward from top closure 12 and an air intake port 17 is situated in the opposing side of cylinder 11 a slight distance downward from vent 16. A free piston 18, having coaxial piston rings 19 adjacent each end, is fitted within cylinder 11 to reciprocate therein. A fuel injector 21, to be hereinafter described in more detail, is mounted in an axial bore 22 in cylinder top closure 12.

The above described assembly constitutes the basic elements of a two cycle free piston internal combustion engine. Assuming piston 18 to have been driven upward within cylinder 11 compressing and heating the air in the upper portion of the cylinder, the injection of combustible fuel in the upper end of the cylinder will result in the piston being driven downward with considerable force. Considering now the means by which the piston is returned upward following each such working stroke, an annular pressure vessel 23 is secured coaxially to the lower portion of cylinder 11. The interior of vessel 23 is communicated with the lower end of cylinder 11 through a bore 24 in the cylinder wall and a control valve 26, which control valve will hereinafter be described in more detail. Thus downward motion of the piston 18 will compress the air in the portion of the cylinder beneath the piston and the air so compressed will be stored in vessel 23. Such compressed air will act to return the piston 18 upward in a manner generally similar to the action of the springs heretofore utilized for such purposes.

Certain thermodynamic factors have been found to govern the design of the vessel 23. Notably the volume of the vessel should be large in relation to the piston deplacement, preferably at least five times such piston displacement. Thus as the piston descends, the combined volumes of the lower cylinder chamber and vessel change by only a small amount, for example twenty percent or less. As a consequence of the small change in volume of the compressed air cushion, a relatively small degree of adiabatic heating of the air cushion will occur as the cushion is compressed. Any heating of the air cushion results in the loss of heat through the walls of the cylinder and vessel. Such heat loss is, of course, a loss of potentially usable power and will weaken the force with which the piston is returned and complicate cooling and lubrication of the engine. By making the volume of vessel 23 large, heating of the cushion air, and thus the above described deleterious effects, are minimized.

Referring now to Figure 3, there is shown a graphical representation of the pressure changes undergone by the combustion chamber and by the air cushion as the piston rises. The compression of air in the combustion chamber as the piston rises is represented by curve AB. As may be seen, the pressure starts at atmospheric and rises to a much higher level to produce the temperature needed for fuel ignition. The area under curve AB is proportional to the work which must be applied to the piston by the air cushion in order to drive the piston upward and effect the needed compression. Thus the area under a curve CD, representing pressure in the air cushion as the piston rises, must at least equal the area under the curve AB. Were the volume of vessel 23 small, the curve CD would necessarily pass between the same range of pressures as curve AB, resulting in the deleterious heating described above. By making the vessel

23 large, the curve CD becomes relatively flat as shown in Figure 2 and while the area under the two curves is equated, little adiabatic heating will result. With reference to Figure 3, it will be noted that the net work which must be done by the piston is represented by the area between the curves and to the right of the intersection thereof; therefore the further area located between the curves and to the left of the intersection point, which further area is indicative of the net work done on the piston, must be at least equal to the first area.

It will now be observed that in order for the area under the relatively flat curve CD to equal the area under curve AB, the pressure of the air cushion, in its most expanded state, must exceed atmospheric pressure. A typical value for the mean air cushion pressure will be found to be around 40 lbs./in.^{2}. Thus means must be provided for maintaining the pressure in vessel 23 at this value. Since in practice there will always be some leakage of cushion pressure, principally past the piston 18, the means for charging vessel 23 to the requisite pressure must be continually operative.

The invention provides self charging of the air cushion by a one way connection between the vessel 23 and combustion chamber 13 of cylinder 11. A typical diesel exhaust pressure in apparatus of this class is 40 lbs./in.^{2}. Thus, referring again to Figure 1, a port 27 in the wall of cylinder 11, a small distance above the exhaust vent 16 will experience a momentary pressure greater than 40 lbs./in.^{2} once each cycle. To transfer such pressure to vessel 23, a conduit 28 connects the vessel with port 26 through a check valve 29. To provide the requisite base pressure to vessel 23 prior to the first operation of the hammer, and in the event pressure has been released from the vessel, a fitting 31, housing a check valve, is transpierced through the wall of the vessel through which fitting a hand pump or compressor may be used to charge the vessel.

Considering now further components of the hammer, a cylindrical hood 32 surrounds the upper portion of cylinder 11 in spaced relationship therefrom, the hood being closed across the top to form a cooling air passage around the upper portion of the cylinder. The bottom margin of hood 32 is secured to a flange 33 which projects coaxially from cylinder 11 at a level a small distance below air intake port 17. An exhaust tubulation 34 continuous with cylinder exhaust vent 16 projects outwardly and downwardly from cylinder 11 to channel exhaust gases from combustion chamber 13. Such exhaust gases are expelled through an opening 36 in hood 32, the opening being of greater diameter than tubulation 34. The portion of hood 32 surrounding opening 36 is formed to project outwardly from the body of the hood a distance beyond the termination of tubulation 34. Thus the tubulation 34 in conjunction with opening 36 in hood 32 forms an educator, the effect of the exhaust gases expelled through the opening being to pump air from the region between the hood and cylinder 11.

To admit air into hood 32, and into air intake port 17, a second opening 37 with an outwardly projecting rim 38 is formed in hood 32 over the intake port. A second tubulation 39 projects radially outward from the cylinder 11 coaxially with the intake port 17 and is provided with a flared termination 41, which termination is of lesser diameter than opening 37 and which is situated a small distance inward from the opening. Thus as exhaust gases pump air from within hood 32, cool air is drawn in through opening 37 a portion of the cool air being passed around the upper end of cylinder 11 and a portion being intercepted by the flared end of tubulation 39 which latter portion enters combustion chamber 13 to scavenge the cylinder. It will be found, using the described construction, that the exhaust gas expelled through opening 36 will draw one hundred times its volume through opening 37 which is adequate to maintain a low cylinder head temperature. To insure maximum cooling, vertical fins 42 are disposed between hood

32 and cylinder 11 to channel cooling air upwardly over the top of the cylinder.

To provide fuel to injector 21, a curved fuel bottle 43 is mounted against hood 32, the bottle being of a construction suitable for holding high pressures, see Figure 2. Within bottle 43, fuel is contained within a flexible liner 44 of Butyl or other oil resistant rubber. In order to pressurize the fuel a conduit 46 connects the space between liner 44 and the wall of bottle 43 with pressure vessel 23 through a shut off valve 47. A conduit 48 connects the interior of liner 44 with injector 21, the effect of the high pressure within bottle 43 being to force fuel upward through the feed conduit, and to permit the delivery of a consistently air-free fuel supply to the injector.

To provide for the filling of fuel bottle 43, an opening 49 is provided which opening must be provided with a special closure 51 to prevent ejection of the pressurized contents of the bottle when the cap is removed. An externally threaded annular base 52 is secured to the top of bottle 43 coaxial with the opening 49, the base having a stepped upper surface forming an interior shelf 53 upon which a circular seal 54 is seated. A second seal 56 and third seal 57 of greater diameter are seated upon the upper step 58 of base 52 and plurality of channels 59, leading from the space between liner 44 and the bottle wall, open between the two seals. The closure cap 51 is a stepped cylinder having a bottom section 61 seating coaxially around base 52 by means of internal threads which engage those of the base. The stepped portion of cap 51 thus seats against seals 56 and 57 sealing channels 59. The upper and narrower sections 62 of cap 51 contains a slidable coaxial plug 63 having a flange 64 at the upper end which overlaps an inwardly directed lip 66 at the lower end of section 62 to limit downward travel of the plug. A compression spring 67 is disposed within cylinder section 62 bearing against plug 63 to cause the plug to bear against seal 54, and thus hold opening 49 closed, as the cap is unscrewed to the point where the pressure in bottle 43 is released through channels 59. Opening of the fuel bottle 43 should of course be preceded by the closing of shut off valve 47 to avoid releasing pressure from within vessel 23.

To transfer reciprocation of piston 18 to a chisel 68, or other tool, a cylindrical anvil 69 is slidably disposed within anvil housing 14. The upper end of anvil 69 projects upward into cylinder 11 a short distance through a bore 71 in the upper end of the housing an annular seal 72 being disposed in the bore to prevent the escape of air. A heavy compression spring 73 is disposed within anvil housing 14 coaxially around anvil 69, the upper end of the spring bearing against a flange 74 on the anvil. A second shorter spring 76 is disposed coaxially around the anvil between flange 74 and the top of anvil housing 14, to limit upward travel of the anvil. The upper end of the tool 68 is inserted in a coaxial bore 77 in the bottom end of the anvil.

Considering now means for grasping the hammer, two handles 78 and 78' are secured, in opposed radial positions, to the upper end of cylinder 11. Each such handle comprises a fork 79 connecting a cylindrical handgrip 81 with the cylinder head in the manner conventional for such hammers, a section of thermal insulation 82 being disposed between each such fork and handgrip.

Referring now to Figure 4, there will be described control means for starting and stopping the hammer, as well as the detailed structure of the check valve 29 which supplies combustion chamber pressure to vessel 23. Such check valve 29 comprises a housing 83 sealingly secured to a boss 84 on cylinder 12 which boss surrounds port 27 therein. Port 27 is continued through the adjacent wall of housing 83 and is flared at the end to form a valve seat 86 within the housing. Valve seat 86 is closed by a valve member 87 which is mounted at one end of a rod 88. The opposite end of rod 88 extends into a guide 89 projecting from housing 83 coaxially with respect to port 27, and a compression spring 91 is disposed coaxially around the rod to force valve member 87 into the valve seat 86. Conduit 28, connecting with vessel 23, opens into housing 83 by means of an aperture 92 therein.

To seal air compressed by downward motion of piston 18 in vessel 23, when it is desired to stop the hammer, and to release such compressed air from the vessel to drive the piston upward when it is desired to start the hammer, control valve 26 is mounted over the passage 24 from the cylinder to the vessel, see Figure 5. The valve 26 comprises a vertical cylindrical housing 93, the upper end of which is sealingly transpierced through an opening in the bottom of vessel 23. An interior passage 94 through the upper section of housing 93 connects with a passage 96 through a lateral projection 97 on the housing, which projection is sealingly secured to the rim of passage 24 in cylinder 11, thus passages 24, 94 and 96 provide a gas channel from the lower end of the cylinder to vessel 23. To seal the above described gas channel, a circular valve disc 98 is disposed coaxially over the upper end of housing 93, within vessel 23, the disc being secured to the end of a vertical rod 99 which passes downward through passage 94 and through a closure 101 at the bottom of passage 94 into the lower section of housing 93. To seal the valve against leakage, an annular resilient seal 102 is imbedded in the upper end of housing 93, coaxial with passage 94, to form a seat for disc 98, and an annular seal 103 is disposed in a recess in closure 101 around rod 99.

The lower section of housing 93 into which the lower portion of rod 99 projects defines a stepped gas tight chamber 104, the upper portion of the chamber being of smaller diameter than the lower portion, which lower portion should have a diameter at least one and one half times the diameter of the seal 102 on the top of housing 93. A piston 106 is secured coaxially to the lower extremity of rod 99 the piston being provided with a peripheral seal 107 to form a gas tight fit against the inner wall of chamber 104. To open the valve 26 when it is desired to start the hammer, compressed air from vessel 23 is fed into the lower end of chamber 103 through a conduit 108 by means of a hand valve 109 which hand valve will hereinafter be described in detail. Since the diameter of piston 106 exceeds that of seal 102, the piston, rod 99, and valve disc 98 will be lifted upward thus opening the passage from vessel 23 to cylinder 11, the upward motion of rod 99 being limited by the abutment of the piston 106 against the stepped portion of chamber 104. To close the control valve 26, when it is desired to stop the hammer, air is released from the lower end of chamber 104 through the conduit 108 and hand valve 109, and a compression spring 111 disposed coaxially around rod 99 between piston 106 and the upper end of chamber 104 returns the valve to closed position. It will be observed that port 24 in cylinder 11 and passages 94 and 96 should be sufficiently broad that air velocities through the channel remain subsonic. Such passages should preferably have a diameter at least one third that of the piston 18.

In order to insure that piston 18 is in proper position for starting when the hammer is stopped, a retractable latch mechanism 112 is provided to hold the piston at the bottom of cylinder 11 as the valve 26 is closed. The latch mechanism may best be seen in Figure 6, and comprises a cylindrical casing 113 having a terminal flange 114 sealingly secured to a boss 116 on the side of cylinder 11 at the level reached by the top edge of piston 18 when the piston rests on anvil 69, the casing being aligned in radial relationship to the cylinder. A thick latch shaft 117 is disposed within casing 113 to reciprocate therein, the latch being of smaller diameter than the bore of casing 113 and being provided with a flange 118 mounting an annular seal 119 which flange and seal

form a gas-tight piston within the casing. A second annular seal 121 is disposed against an inwardly directed lip 122 in the bore of casing 113 to form a gas-tight seal against the shank of latch shaft 117, the lip 122 and seal 121 being on the cylinder side of flange 118, so that a gas-tight region is formed within casing 113, between the two seals, into which compressed air from hand valve 109 may be admitted through a conduit 123 to retract the latch outward from the cylinder. The inner end of latch shaft 117 projects into a passage 124 in boss 116 which passage is continuous with the bore of casing 113 and which opens into cylinder 11, the latch shaft being of sufficient length to catch the edge of piston 18 when the flange 118 is abutted against lip 122. To reduce friction between the end of the latch shaft 117 and the piston top, a rotatable bearing 126 is mounted on the inward end of the shaft. A compression spring 127 is disposed within casing 113 between flange 118 and a stop element 128 which stop element is threadably mounted in the far end of the casing, the spring serving to urge shaft 117 into the cylinder. An axial projection 129 on the stop element 128 limits outward movement of the shaft 117 at a point where bearing 126 is withdrawn from the cylinder and is completely within passage 124.

In starting the hammer, it is desirable that control valve 26 open slightly before the latch mechanism 112 retracts, in order that pressure from vessel 23 will build up under the piston 18 prior to release of the piston. To accomplish the foregoing, the conduit 123 through which air is released from the latch mechanism should be of appreciably smaller diameter than conduit 108 through which air is released from the control valve.

Considering now the hand valve 109 by which means control valve 26 and latch mechanism 112 are actuated, and thus the means with which the hammer is started and stopped, there may be seen a vertical cylindrical housing 131 secured beneath hand grip 81, and adjacent hood 32, by means of a support 132 connecting with the hand grip base. Within housing 131 is a chamber 133 having three sections of progressively reduced diameter, the narrowest section being uppermost. A cylindrical sleeve 134 is coaxially fitted within the lower and intermediate sections of the chamber 133, the sleeve being equal in diameter to the intermediate section and of slightly less length than the combined lower and intermediate sections. The lower end of sleeve 134 is provided with a flange 136 extending outward to the wall of the lower section of chamber 133 and the upper end of the sleeve has an inwardly directed shoulder 137 having an inside diameter equal to the diameter of the upper section of chamber 133. A first annular seal 138 is disposed coaxially on the bottom of chamber 133, and a second seal 139, of slightly less diameter, is similarly disposed thereon. Apertures 141 transpierce the bottom of chamber 133 between the two seals 138 and 139 providing a means by which the chamber may be vented to atmosphere. The seals 138 and 139 and apertures 141 are so placed that flange 136 will seal the chamber upon descent of sleeve 134. To urge the sleeve 134 downward a compression spring 142 is disposed coaxially within the lower section of the chamber bearing against the upper surface of flange 136.

To supply compressed air from vessel 23 to the interior of chamber 133, a conduit 143 connects the check valve housing 83 with a sub-housing 144 disposed coaxially on the underside of valve housing 131. An opening 146 in the center of housing 131 at the bottom of chamber 133 connects the chamber with the sub-housing 144. A vertical rod 147 is disposed within sub-housing 144, to be slidable along the axis thereof, by a guide member 148, the guide member being transpierced by air passages 149 to provide communication between the conduit 143 and chamber 133. A disc 151 is secured to the upper end of rod 147 and seats against an annular seal 152 mounted coaxially around the underside of opening 146, the disc thus serving to seal the opening and to seal the passage from vessel 23 to chamber 133. To urge the disc upward against seal 152, a compression spring 153 is disposed between the underside of the disc and guide member 148.

A vertical valve piston 154 is slidably mounted within the upper section of chamber 133, the upper end of the piston projecting a distance above housing 131 and the lower end of the piston being provided with a flange 156 which flange is equal in diameter to the inside diameter of sleeve 134. To prevent the escape of pressure, an annular seal 157 is set within the upper surface of housing 131 around the piston 154. To urge the piston upward, a compression spring 158 is disposed within chamber 133 between the bottom thereof and flange 156. An axial projection 159 extends downwardly from piston 154 to depress disc 151, and open opening 146, upon descent of the piston. Conduit 108 from control valve 26, into which conduit 123 from latch mechanism 112 connects, communicates with chamber 133 through an opening 161 in the lateral wall thereof.

In the rest position, when the hammer is stopped, conduit 143 which connects with the vessel 23 pressure is closed by the seating of disc 151 against opening 146. Conduit 103, from the control valve 26 and latch mechanism 112, is opened to atmosphere through apertures 141 in chamber 133. To start the hammer, piston 154 must be moved downward, such downward movement first allowing sleeve 134 to descend and seal the apertures 141. Further downward movement of the piston results in projection 159 depressing disc 151 allowing compressed air from vessel 23 to flow to the control valve 26 and latch 112. Passages 162 in the lateral walls of sleeve 134 allowing the compressed air to bear against flange 136 to insure no leakage to atmosphere will occur. The hammer is stopped by allowing piston 154 to rise, the first effect being that disc 151 reseals opening 146. It will be observed, however, that full vessel pressure has been locked within the valve and thus no stopping of the hammer will be effected by the closure of opening 146. To stop the hammer the trapped pressure must be vented to atmosphere by retraction of flange 136 from apertures 141. Owing to the pressure remaining within the valve, a substantial force is required to lift the flange 136 from the apertures 141. Such force is automatically supplied in that the pressure bears against the undersurface of piston 154. Provided the area of the underside of piston 154 exceeds the area between the seals 138 and 139, the piston will rise lifting sleeve 134 and venting the chamber to atmosphere. As the pressure is released, control valve 26 closes and latch mechanism 112 extends stopping the hammer.

To provide a convenient control for depressing and releasing the valve piston 154, a cam 163 is mounted to pivot about an axle 164, which axle is mounted on support 132 at a point which is above the piston and displaced a small distance outward therefrom. Cam 163 is provided with a curved surface 166 bearing against the upper end of piston 154, shaped so that the piston is depressed the requisite distance in approximately fifteen degrees travel of the cam. To facilitate hand rotation of the cam 163, an elongate control lever 167 extends outward from the cam beneath and generally parallel to hand grip 81.

Referring now to Figure 7, there will now be described the fuel injector 21. Injector 21 is mounted in a stepped coaxial bore 22 in closure 12 at the top of cylinder 11, the bore having an upper section, an intermediate step 168, and a lower section of reduced diameter. A cylindrical injector base member 169 is disposed within the upper section of bore 22, an annular seal 171 being disposed between the lower surface of the base and step 168 of bore 22. Base member 169 is pierced by an axial

bore 172 which bore is divided by three steps into four sections 173, 174, 176, and 177, of progressively reduced diameter, the lowermost section 177 conforming in diameter to the lower section of bore 22.

The lower end of an injector body 178 is threadably fitted within the upper section 173 of bore 172, an annular seal 179 being disposed between the two members. Injector body 178 is pierced by an axial bore 181, which bore has a lower chamber 182 conforming in diameter to section 176 of bore 172, and elongate intermediate chamber 183 of less diameter, a relatively narrow upper passage 184, and an expansive upper terminal chamber 186. A piston 187 is disposed within bore 181 of injector body 178, the piston having a lower extremity 188 slidably fitted within the lower section of bore 22, an enlarged intermediate section 189 conforming in diameter to section 176 of base member bore 172, and an elongate upper end 191 projecting upward into intermediate chamber 183 of injector body bore 181, the upper end 191 being equal in length to chamber 183 such that a fuel compression region 192 is formed in the upper portion of chamber 183. The piston 187 is provided with an axial passage 193 having an enlargement 194 at the lower end into which a fuel injection nozzle 196 is threadably fitted. Passage 193 has a constriction at the upper end which constriction is outwardly flared at the top to provide a needle valve seat 197 within fuel compression region 192.

Needle valve 198, having a tapered lower end 199 seating in valve seat 197, comprises the lower portion of a plunger 201 slidingly fitted within upper passage 184 of bore 181 and projecting upward into terminal chamber 186 thereof, the lower portion of the plunger being of less diameter than passage 184. A sleeve 202 is secured within chamber 186 in coaxial relationship therein by means of threads engaging like threads on the inside wall of the chamber. An inwardly directed rim 203 at the lower end of sleeve 202 forms a guide for flange 204 on the upper end of plunger 201. To urge plunger 201 downward against needle valve seat 197 a first compression spring 206 is disposed within chamber 186 between flange 204 and a stop element 207 threadably secured in the upper end of sleeve 202. To increase the spring tension against plunger 201 after limited upward travel thereof, for reasons which will hereinafter be explained, a second heavier compression spring 208 is disposed between stop element 207 and an annulus 209 which rests coaxially against the upper surface of rim 203, the annulus having an inside diameter smaller than the outside diameter of flange 204 so that the flange will bear against spring 208 as plunger 201 travels upward.

To supply fuel to the fuel compression region 192 conduit 48 from fuel bottle 43 connects by means of a fitting 211 and check valve 212 with a passage 213 communicating with region 192. To provide a means for purging air from the fuel compression region 192, as will hereinafter be described, conduit 48 also connects with a second fitting 214 and a passage 216 communicating with a midpoint in pasage 184.

Considering now the operation of the injector, as well as certain critcal parameters thereof, it will be seen that the rise of piston 18 in cylinder 11 causes a high pressure to be exerted against the underside of piston 187. To confine such pressure, an annular seal 217 is disposed coaxially in section 174 of base member bore 172. The effect of such pressure will be to cause piston 187 to rise and compress the fuel within region 192, the compression being very high by virtue of the area ratio of seal 217 to the upper surface of piston 187. A fuel pressure of 5000 lbs./in.^{2} will be found typical for an area ratio of 10:1. This high pressure pushes upward on the still smaller area of needle valve plunger 201. The needle valve 201 is held down by the force of first spring 206 which is selected to have a force constant just sufficient to counterbalance the desired fuel injection pressure, for example 5000 lbs./in.^{2}. When the fuel pressure reaches this value, the needle valve plunger 201 rises from the valve seat 197 allowing fuel to travel down passage 193 and enter cylinder 11 through nozzle 196. As fuel is injected, the piston 187 continues to rise so that needle valve plunger 201 must continue ahead of the piston to permit fuel injection. After a preselected travel of rod 201, determined by the quantity of fuel it is desired to inject, flange 204 engages second spring 208. Spring 208 has a force constant two times greater than spring 206 so that to continue further injection, the fuel pressure would have to be greater than the sum of the two springs, 15,000 lbs./in.^{2} for example, which is at least twice as high as could be reached in practice. Therefore fuel injection stops when flange 204 engages spring 208. The clearance between flange 204 and annulus 209 thus determines the quantity of fuel injected which clearance may be adjusted by rotation of sleeve 202. When the pressure is relieved in cylinder 11 as piston 18 descends, spring 206 pushes rod 201 downward and with it, piston 187, and the injector returns to the original condition.

Considering now how air is automatically purged from the fuel compression region 192, it will be seen that in the event air is present, a negligible back pressure will be experienced by piston 187 so that only spring 206 will resist upward movement of the piston. Since this force is relatively small, the piston 187 will move upwards and will continue to move up even after the flange 204 engages spring 208, since the combined springs exert a force of three units on the plunger 201 where the upward force on the piston is four units. Therefore the piston will rise until region 192 is vented through passage 216. The downward movement of piston 187, as piston 18 descends in cylinder 11, draws in a new charge of fuel through passage 213, and the action proceeds as previously described. To provide for manual purging of the fuel compression region 192, prior to starting the hammer, a bleed valve 218 is situated in injector body 178 and closes vent passages 219 and 221 connecting with region 192 and chamber 186 respectively.

As will be seen from study of the above described structure, the injector 21 possesses the advantages that the entire fuel injection system is disposed within the cylinder head, the fuel reaches the nozzle 196 only under full pressure thus eliminating dripping and resultant carbonization of the nozzle, the injection pressure and volume are easily controlled, and air is automatically purged from the system.

It will be observed that an alternate fuel injection system is possible in a hammer of the present design. Unlike conventional internal combustion engines, in which pre-ignition of the fuel is harmful inasmuch as the pistons cannot reverse their direction at an arbitrary time, fuel can be injected in the present invention as the piston is at the bottom of its stroke. Thus a simple mechanism might be provided to inject fuel into intake port 17 (see Figure 1) at any time following the release of exhaust from the combustion chamber 13.

Considering now the sequence of steps involved in operating the hammer, with reference again to Figure 1, the vessel 23 must first be charged to operating pressure, 40 lbs./in.^{2} for example, by a hand pump or other compressor connectable with fitting 31. Upward motion of control lever 167 will feed compressed air to control valve 26 and latch mechanism 112. As control valve 26 opens and latch 112 retracts, piston 18 will be driven upward in cylinder 11 compressing the air therein and triggering injector 21. Ignition of fuel in combustion chamber 13, brought about by the high compressive temperature therein, will drive the piston 18 downward where it will ultimately strike anvil 69 delivering a sharp blow to tool 68. As the top piston rings 19 clear port 27 during the downward portion of the piston 18, check

valve 29 opens, delivering a charge of compressed gas to vessel 23 to replenish any leakage of pressure which may have occurred. As the piston rings 19 clear exhaust vent 16, the exhaust gases are discharged and a new charge of air is sucked in through intake port 17. Owing to the high pressure bearing on the bottom of piston 18, the downward motion of the piston is reversed and the above described cycle of operations repeated.

Release of control lever 167 vents control valve 26 and latch 112 causing the valve to close and the latch to enter cylinder 11 and lock the piston 18 at the bottom of the stroke.

While the invention has been disclosed with respect to a single preferred embodiment, it will be apparent to those skilled in the art that numerous variations and modifications may be made within the spirit and scope of the invention and thus it is not intended to limit the invention except as defined in the following claims.

What is claimed is:

1. A free piston diesel engine comprising, in combination, a cyclinder having a first end defining a combustion chamber, a free piston reciprocable therein, means introducing fuel into said combustion chamber to drive said piston longitudinally within said cylinder, a vessel having a passage connecting with said cylinder at the opposite end thereof for receiving air compressed by motion of said piston within said cylinder, and a manually controlled valve disposed in said passage, said valve having an open position providing an unobstructed passage for air flow in each direction between said cylinder and said vessel whereby said compressed air acts to reverse said motion of said piston and return said piston and having a closed position whereby said compressed air is entrapped in said vessel for subsequent starting of said engine.

2. In a two cycle diesel power source, the combination comprising a tubular cylinder having a closure at each end, a first end portion of said cylinder being a combustion chamber and being pierced by an exhaust port and an air intake vent situated at respectively greater distances from the closure at said first end, a free piston reciprocable within said cylinder, a fuel injector disposed at said first end section of said cylinder, a pressure vessel connected with the second end of said cylinder receiving air compressed by travel of said piston in said cylinder, said pressure vessel having a volume substantially exceeding the maximum volume of said combustion chamber, and a manually actuated two position valve controlling gas flow between said pressure vessel and said cylinder, said valve having a first setting wherein said vessel communicates with said cylinder and air flow in each direction therebetween is permitted and having a second setting wherein said vessel is sealed.

3. In an internal combustion engine, the combination comprising a tubular cylinder having a combustion chamber at a first end thereof, a free piston reciprocably disposed within said cylinder, means introducing combustible fuel into said combustion chamber, a pressure vessel forming an enlargement of the second end of said cylinder for receiving gases compressed by motion of said piston within said cylinder, a conduit connecting said pressure vessel with the combustion chamber end of said cylinder for charging said vessel to pressures in excess of those generated by motion of said piston, and a check valve limiting gas flow through said conduit to a direction from said combustion chamber to said pressure vessel.

4. In an internal combustion engine, the combination comprising a tubular cylinder having a closure at each end, a first end section of said cylinder being a combustion chamber and being pierced by an exhaust vent and an intake port situated at progressively greater distances from the closure at said first end, a free piston reciprocable within said cylinder, means supplying combustible fuel to said combustion chamber, a pressure vessel having connection with the second end of said cylinder for receiving gases compressed by motion of said piston within said cylinder, a gas flow channel connecting said combustion chamber with said vessel, and a check valve restricting gas flow through said channel to a direction into said pressure vessel whereby said vessel will be charged to pressures in excess of those produced by motion of said piston within said cylinder which pressures serve to return said piston towards said first end of said combustion chamber.

5. An internal combustion engine substantially as described in claim 4 wherein said pressure vessel has a volume substantially exceeding the maximum volume of said combustion chamber.

6. An internal combustion power source comprising, in combination, a tubular cylinder closed at each extremity, a first end section of said cylinder defining a combustion chamber and being pierced by an exhaust vent and an intake port situated at progressively greater distances from the closure at said first end, a piston sealingly disposed within said cylinder and free to reciprocate therein, means introducing a combustible fuel charge into said combustion chamber, a pressure vessel having a volume substantially exceeding the maximum volume of said combustion chamber and having a first gas flow channel communicating with the second end of said cylinder, said pressure vessel further having a second gas flow channel communicating with said combustion chamber, a first valve controlling gas flow through said first channel and having an open position and a closed position, a second valve controlling gas flow through said second channel, said second valve being a check valve and serving to limit gas flow through said second channel to a direction from said combustion chamber to said vessel.

7. A two cycle internal combustion engine comprising, in combination, a tubular cylinder having a gas-tight closure at each end, a first end of said cylinder defining a combustion chamber and being pierced by an exhaust vent and an intake vent situated at progressively greater distances from the closure at said first end of said cylinder, a free piston reciprocable within said cylinder, means supplying a combustible fuel charge to said combustion chamber, a pressure vessel having a volume substantially exceeding the maximum volume of said combustion chamber and having a first gas flow channel communicating with the second end of said cylinder and having a second gas flow channel communicating with said combustion chamber, a valve disposed in said first channel and having a first setting wherein said vessel is sealed and having a second setting wherein said vessel is communicated with said cylinder, a check valve limiting gas flow through said second channel to a direction from said combustion chamber to said vessel, a latch retractably transpiercing the wall of said cylinder in position to lock said piston at said second end of said cylinder, and a manually operable control mechanism manipulating said first valve means between said first and second settings thereof and manipulating said latch to retracted position as said first valve is manipulated to said second setting thereof.

8. A two cycle diesel engine comprising, in combination, a tubular cylinder having a gas-tight closure at each end, a first end of said cylinder being a combustion chamber and having an exhaust vent and an air intake port situated at progressively greater distances from the closure at said first end of said cylinder, a free piston sealingly disposed within said cylinder and reciprocable therein, fuel supply means introducing diesel fuel into said combustion chamber, a pressure vessel having a volume exceeding the maximum volume of said combustion chamber, said vessel having a first gas passage opening into the second end of said cylinder and having a second gas flow passage communicating with said combustion chamber at a point between said closure at said first end thereof and said exhaust vent, a control valve selectively closing said first passage, and a check valve limiting gas flow

through said second passage to a direction away from said combustion chamber.

9. In a two cycle diesel engine substantially as described in claim 8, the further combination of a hood enclosing said first end of said cylinder in spaced relationship therefrom, said hood having a first opening in the vicinity of said exhaust vent and a second opening in the vicinity of said air intake port.

10. In a two cycle diesel engine substantially as described in claim 8, the further combination comprising a second cylinder, a second piston movable therein, said second piston being connected to actuate said control valve, a conduit delivering air from said pressure vessel to said second cylinder to drive said second piston, and a hand valve operating on said conduit, said hand valve having a setting wherein said conduit is closed and said second cylinder is vented to atmosphere.

11. In a two cycle diesel engine substantially as described in claim 8, the further combination comprising a latch shaft slidably transpierced through a radial bore in the wall of said cylinder to catch said piston at the bottom of a working stroke thereof, a tubular housing secured to said cylinder, a second piston slidable within said housing, said second piston being connected to retract said latch shaft from said cylinder, a conduit delivering compressed air from said pressure vessel to said housing to drive said piston therein, and a hand valve operating on said conduit, said hand valve having a setting wherein said conduit is closed and said housing is vented to atmosphere.

12. In apparatus for driving a reciprocatory tool, the combination comprising a tubular cylinder having gas-tight closure means at each extremity, a first end of said cylinder being a combustion chamber and having an exhaust opening and an intake opening situated at progressively greater distances from the closure at said first end of said cylinder, means supplying combustible fuel to said combustion chamber, a free piston disposed within said cylinder to reciprocate therein, a pressure vessel having a first passage communicating with the second end of said cylinder, said pressure vessel being of substantially greater volume than the maximum volume of said combustion chamber, said pressure vessel having a second passage communicating with said combustion chamber at a point between said exhaust opening therein and the closure at said first end of said cylinder, a check valve disposed in said second passage restricting gas flow therethrough to a direction from said cylinder to said vessel, a tool mounting axially transpierced through said second end of said cylinder in position to be struck by said piston as said piston reciprocates within said cylinder, yieldable spring means urging said tool mounting into said cylinder, and stop means limiting motion of said tool mounting into said cylinder.

13. In apparatus for driving a reciprocatory tool substantially as described in claim 12, the further combination of a manually controllable valve disposed in said first passage between said pressure vessel and said cylinder, said valve having a setting wherein said passage is open and a setting wherein said passage is closed.

14. In apparatus for driving a reciprocatory tool substantially as described in claim 12, the further combination of a control valve disposed in said first passage between said pressure vessel and said cylinder, a second cylinder, a second piston slidably fitted within said second cylinder and connected to actuate said control valve, a conduit connecting said second cylinder with said pressure vessel, and a hand valve controlling said conduit, said hand valve having a setting wherein said conduit is closed and said second cylinder is vented to atmosphere.

15. In apparatus for driving a reciprocatory tool substantially as described in claim 12, the further combination of a latch shaft slidably transpierced through a radial bore in the wall of said cylinder to catch said piston at the bottom of a working stroke thereof, and means retracting said latch from said cylinder as said valve is manipulated to open said passage.

16. In apparatus for driving a reciprocatory tool substantially as described in claim 12, the further combination comprising a latch shaft slidably transpierced through a radial bore in the wall of said cylinder to lock said piston at the second end thereof, a tubular housing secured to said cylinder, a second piston slidable within said housing and connected to retract said latch shaft from said cylinder, a conduit delivering compressed air from said pressure vessel to said housing to drive said second piston, and a hande valve operating on said conduit, said hand valve having a setting wherein said conduit is closed and said housing is vented to atmosphere.

17. A diesel operated power hammer comprising, in combination, a tubular cylinder having a gas-tight closure at each extremity, a first end section of said cylinder being a combustion chamber and having an exhaust vent and an air intake opening situated at progressively greater distances from the closure at said first end of said cylinder, means injecting combustible fuel into said combustion chamber, a free piston sealingly disposed in said cylinder to reciprocate therein, a pressure vessel having a volume substantially exceeding the maximum volume of said combustion chamber, said pressure vessel having a first passage connecting with the second end of section of said cylinder and having a second passage connecting with said combustion chamber at a point between said exhaust vent and the closure at said first end of said cylinder, a manually controllable valve disposed in said first passage and having a first setting wherein said passage is open and having a second setting wherein said passage is closed, a check valve limiting gas flow through said second passage to a direction away from said combustion chamber, an anvil axially transpierced through the closure at said second end of said cylinder in position to be struck by said piston, said anvil having provision for retaining a tool in axial relationship with respect to said cylinder, and stop means limiting motion of said anvil into said cylinder.

18. In a diesel operated power hammer substantially as described in claim 17, the further combination of a latch transpierced through the wall of said cylinder in radially retractable relationship thereto, said latch having an extremity projectable into said cylinder whereby said piston may be locked at said second end of said cylinder and means holding said latch in retracted position at such times as said manually controllable valve is at said first setting thereof.

19. In a diesel operated power hammer substantially as described in claim 17, the further combination of a hood surrounding said first end portion of said cylinder in spaced relationship therefrom, said hood having an opening in the region of said exhaust vent and having a second opening in the region of said air intake.

20. A diesel operated power hammer comprising, in combination a tubular cylinder having gas-tight closures at each extremity a first end portion of said cylinder being a combustion chamber and being pierced by an exhaust opening and an air intake opening situated at progressively greater distances from said closure at said first end of said cylinder, means injecting combustible fuel into said combustion chamber, an annular pressure vessel disposed coaxially around the second end portion of said cylinder and having a volume substantially exceeding the maximum volume of said combustion chamber, said pressure vessel having a first passage connecting with said second end portion of said cylinder and having a second passage connecting with said combustion chamber at a point a relatively small distance towards said first end thereof from said exhaust opening, a manually controllable valve disposed in said first passage and having a first setting wherein said passage is open and having a second setting wherein said passage is closed, a check valve disposed in said second passage and restricting gas

flow therethrough to a direction away from said combustion chamber, a manually controllable retractable latch radially transpierced through the wall of said cylinder, an anvil axially transpierced through said second end closure of said cylinder in position to be struck by said piston, said anvil having provision for retaining a tool projecting axially with respect to said cylinder, spring means urging said anvil inwardly of said cylinder, and stop means limiting motion of said anvil into said cylinder.

21. A diesel operated power hammer substantially as described in claim 20 and having the further combination of handle means projecting generally radially from said first end of said cylinder, and a control lever secured to one of said handles, said control lever being in operating relationship to said manually controllable valve and said manually controllable retractable latch.

22. In an internal combustion power source, the combination comprising a tubular cylinder having a closure at each end, said cylinder having an air intake port and an exhaust vent positioned at progressively greater distances from a first end of said cylinder, a free piston reciprocable within said cylinder, means introducing combustible fuel into said first end of said cylinder, and a

reservoir communicating with the second end of said cylinder and receiving air compressed by longitudinal movement of said piston within said cylinder whereby said longitudinal movement is reversed and said piston is returned by decompression of said air, said reservoir having a volume substantially exceeding the maximum volume between said piston and said first end of said cylinder.

References Cited in the file of this patent

UNITED STATES PATENTS

915,320	Trott	Mar. 16, 1909
1,361,648	Van Meter	Dec. 7, 1920
1,537,450	Babin	May 12, 1925
1,571,615	Babin	Feb. 2, 1926
1,995,459	Olsen	Mar. 26, 1935
2,055,580	Larsson et al.	Sept. 29, 1936
2,396,627	Wohlmeyer	Mar. 12, 1946
2,701,555	Huber	Feb. 8, 1955
2,730,082	Wampach	Jan. 10, 1956

FOREIGN PATENTS

476,411	Italy	Dec. 10, 1952