

April 4, 1950

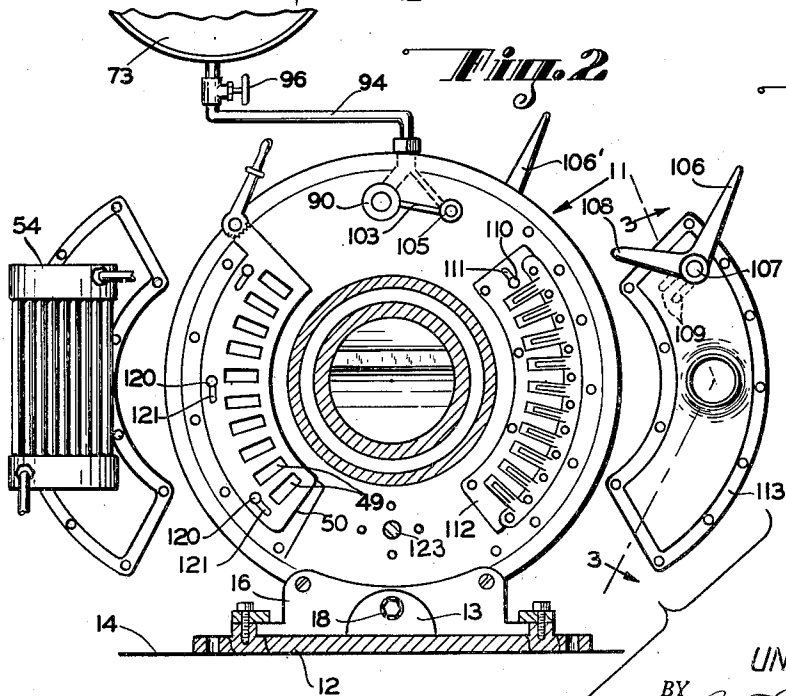
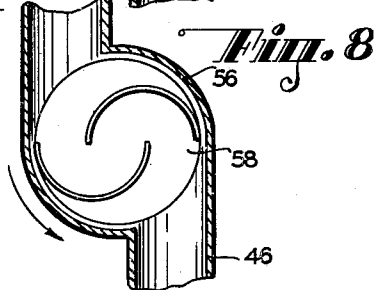
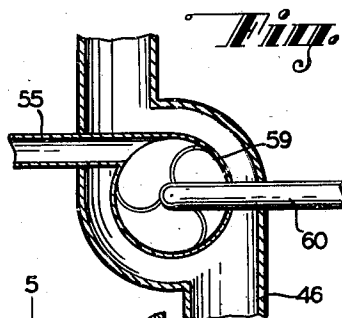
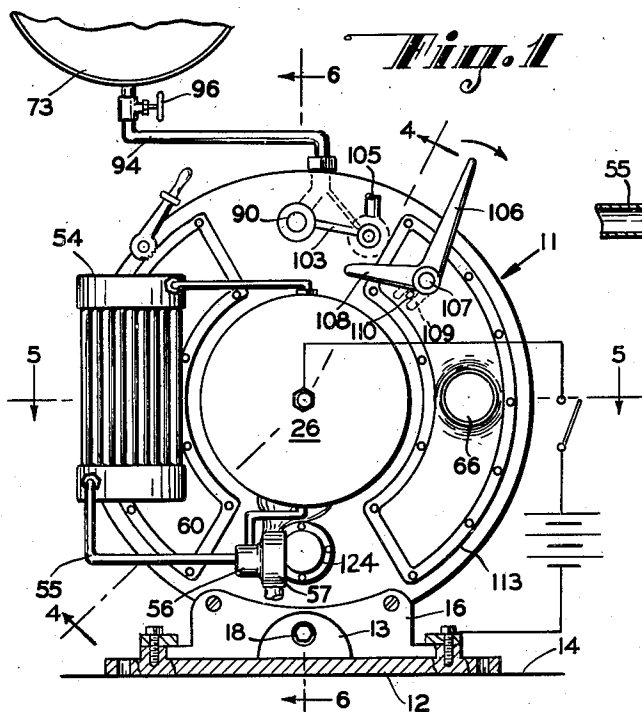
U. EKBLOM

2,503,152

FREE PISTON PUMP ENGINE

Filed July 3, 1946

5 Sheets-Sheet 1



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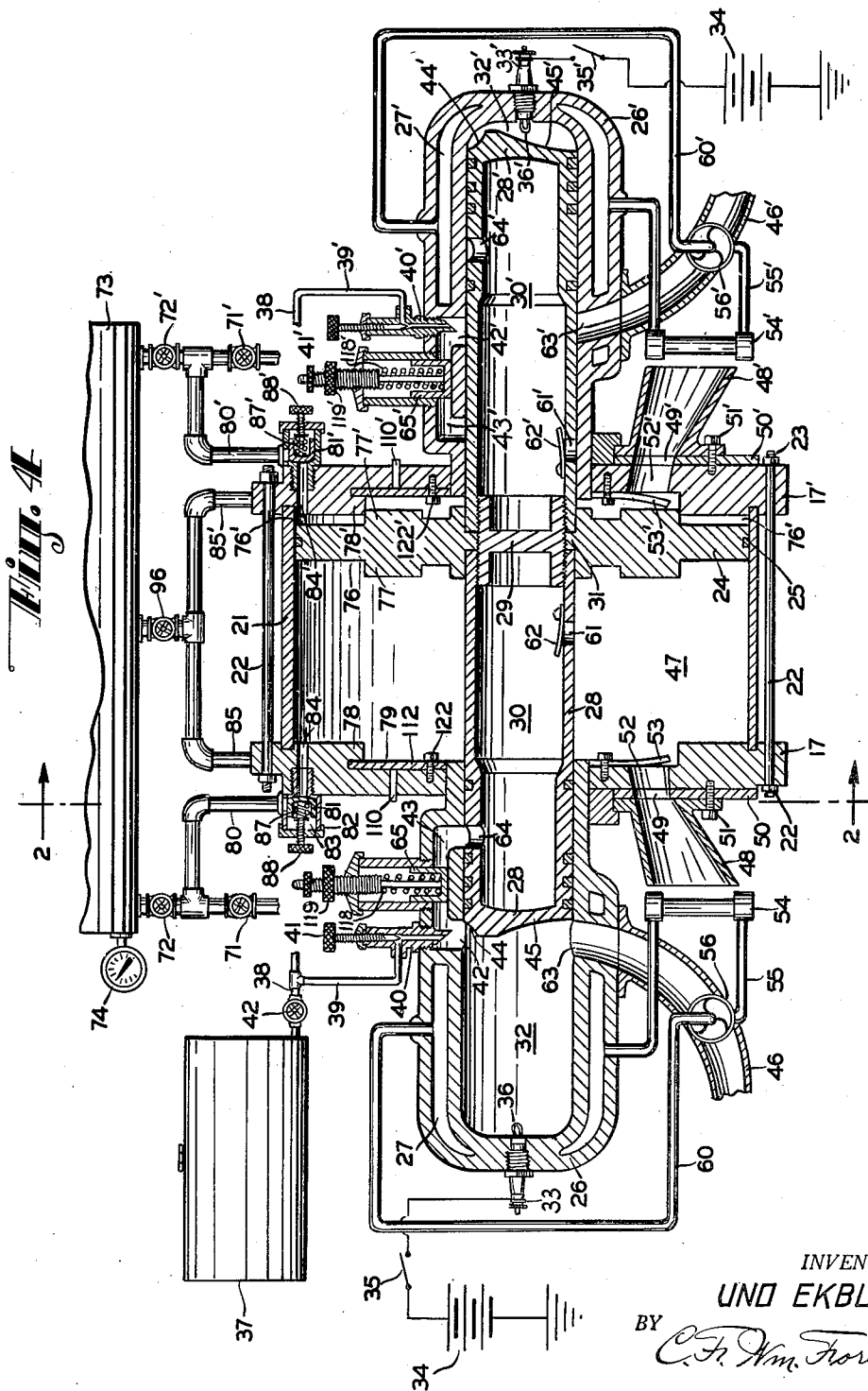
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2,503,152

FREE PISTON PUMP ENGINE

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5 Sheets-Sheet 2



April 4, 1950

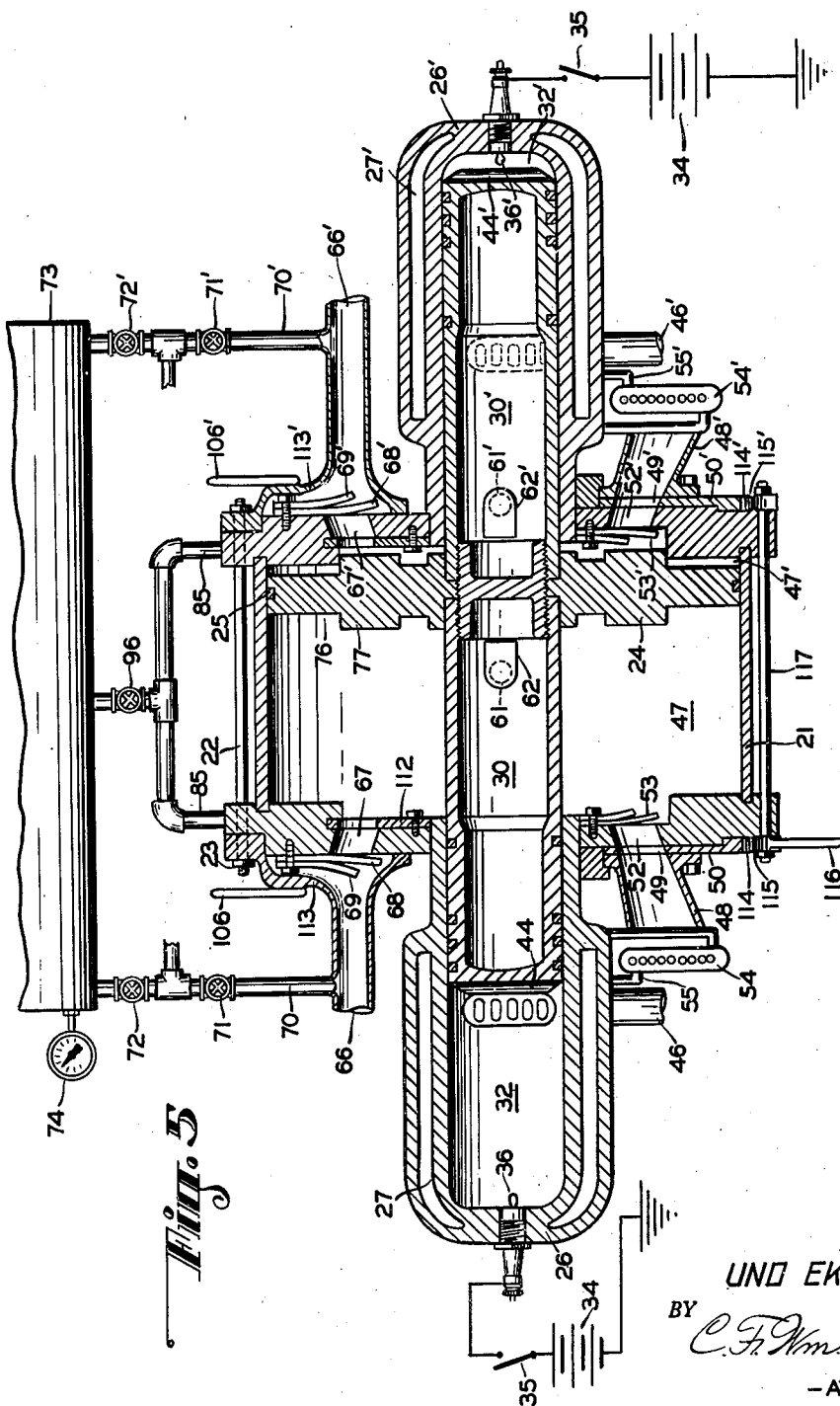
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2,503,152

FREE PISTON PUMP ENGINE

Filed July 3, 1946

5 Sheets-Sheet 3



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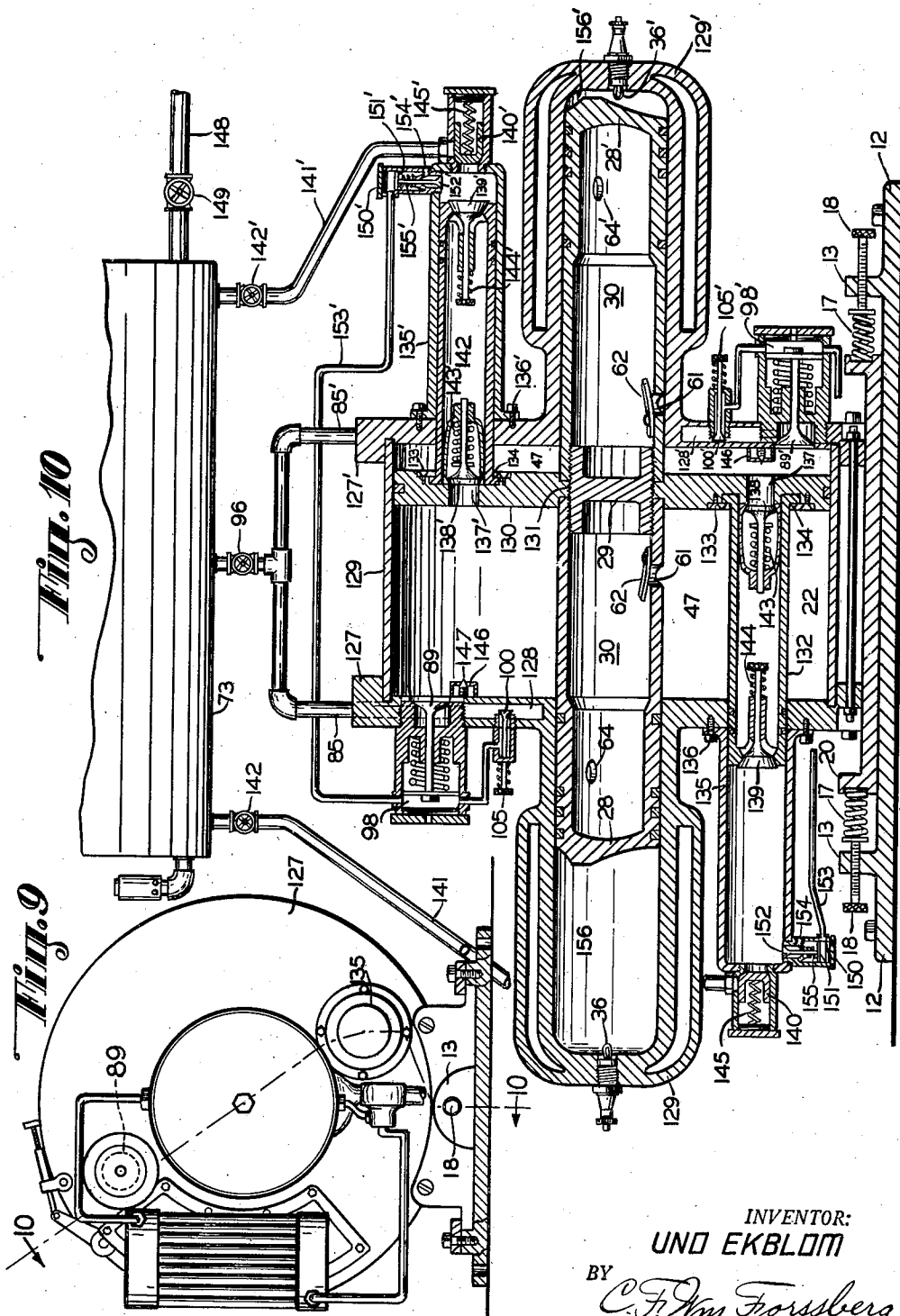
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2,503,152

FREE PISTON PUMP ENGINE

Filed July 3, 1946

5 Sheets-Sheet 5



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UNITED STATES PATENT OFFICE

2,503,152

FREE PISTON PUMP ENGINE

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Application July 3, 1946, Serial No. 681,397

8 Claims. (Cl. 230-56)

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This invention relates to a free piston or oscillatory type of internal combustion engine which may be classified with Diesel engines and is advantageously combined directly with a piston pump, generator and/or other power transmitting or transforming means.

The main object of my invention is to provide an internal combustion engine of the free piston type which is of such efficient design by elimination of piston rods, crossheads, cranks and shafts that the major portion of the frictional losses present in conventional engines is absent.

An equally important object is to have such an engine which when combined with a piston pump designed to cooperate therewith will form with the latter such a light weight and compact power plant that it is particularly adapted for pneumatic or jet propulsion on airplanes and ships where such operation has heretofore never been feasible.

Another object is to combine the engine with a special pneumatic pump in order to obtain the full power of the engine in the form of a supply of compressed air or suction, by directly combining the air pump piston with the engine piston without any intervening members, such as shafting, bearings, pulleys, gears, piston rods, cranks, crossheads, chains or bolts.

A further object is to include starting means for the engine and pump apparatus capable of controlling the running speed of the apparatus as a whole.

It is also an object herein to include special valve and piston equipment for producing high compression of the air supplied by the engine and pump combination comprising the invention.

In addition, it is an important object to have a free piston engine which by virtue of its simple construction and light form is capable of very high speeds of operation and adjustable compression, with consequent great power output and capacity with respect to any given size of engine.

An ancillary object is to have a free piston engine of the indicated type in which the power output may be represented by the compressed air, suction, stored water or other fluid, or by electric current if electric generation equipment replaces or accompanies the pump piston in actual service.

An object connected with the starting equipment is to have auxiliary pumping means formed by projections upon the pump piston and corresponding recesses in the pump cylinder without the addition of any parts although constituting independently effective operating means aside

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from the regular operation of the pump piston as such.

It is likewise an object of the invention to so mount the engine slidably upon a proper stationary base that all vibration tends to be neutralized during operation at any speed.

Other objects and the advantages of the arrangement, construction and practical application of my invention to the art will appear in further detail as this specification proceeds.

In order to disclose the invention in clearly comprehensible manner, the same is illustrated in certain non-limiting forms in the accompanying drawings forming part hereof, and in which

Fig. 1 is an end elevation of an internal combustion engine made according to certain principles of the present invention and embodying the salient features thereof in a practical form;

Fig. 2 is a cross section of the same engine taken on line 2-2 in Fig. 4, the view being partly exploded to show a radiator and manifolds shifted from their proper positions to disclose detail;

Fig. 3 is a section of a manifold of Fig. 2 taken on line 3-3;

Fig. 4 is a diagrammatic longitudinal section of the same apparatus of Fig. 1, taken obliquely on line 4-4, approximately;

Fig. 5 is a horizontal longitudinal view in section taken on line 5-5 in said Fig. 1;

Fig. 6 is a vertical longitudinal section taken on line 6-6 in the same Fig. 1;

Fig. 7, as well as Fig. 8 are enlarged detail sections of an exhaust driven rotary water pump of Figs. 1 and 4;

Fig. 9 is a longitudinal section of a modification of the engine of Figs. 1 and 6, and

Fig. 10 is an end view of the same modification.

Finally, Fig. 11 is an enlarged section of a detail of Fig. 10.

Throughout the views, the same references indicate the same or like parts.

It is a self-evident fact that in order for internal combustion engines to be suitable for aeroplanes, they must necessarily be very light and efficient, to some extent this goal has been attained when using such engines to drive propellers and thereby pull or push the aircraft through the atmosphere mechanically. On the other hand, it has been found that jets of gas projected rearwardly from aircraft are capable of producing high flying speeds without any of the intricate mechanism usually forming the power plant on conventional aircraft, and it is thus a promising means of propulsion.

Instead of using propellers, therefore, or even

highly heated gases for the jets to drive aircraft, it is now proposed to drive such craft with compressed air and even to drive ships in the water by such jets by providing a special free piston internal combustion engine combined with an air pump. The resulting combination is such an extremely light and efficient unit that the power of the same is converted into an output of compressed air of such volume and force that the air can be used directly in cool condition to produce the driving jets of the aircraft equipped with the unit operating according to the well known rocket principle but without heat or flame.

Hence, referring again to the drawings, and with the foregoing objects in view, a free piston engine, generally indicated at 11 is provided with a base plate 12 (Figs. 1, 2 and 6 and 10) having a pair of upright end lugs 13, 13' and preferably bolted to the floor 14. Upon this base plate is slidably mounted a plate 15 having lugs 16, 16' secured to the two engine end plates 17, 17', while in the lugs 13 of the base plate a pair of oppositely directed adjusting screws 18, 18' are inserted which at their inner ends engage against shock absorbing springs 19, 19'. At their other ends, these screws engage against ends 20, 20' of plate 15 to absorb shocks and vibration of the engine while plate 15 slides upon base plate 12 during operation produced by such vibration. If the springs require to be compressed or released to accurately cushion the vibrations of the engine, the screws 18 are easily adjusted accordingly.

Between the end plates 17, 17' is clamped the cylindrical wall member or tube 21, the plates and said wall member being retained in position in assembly by the rods 22 threaded at the ends and held in place by nuts 23, 23'. The members just described define a cylinder within which a plate piston 24 having a piston ring 25 is adapted to reciprocate in a manner which will be set forth presently. On the other hand, upon the two external end plates 17, 17' is fixed a pair of opposite cylinders 26, 26' provided with water jackets 27, 27' and being internally of considerably smaller diameter than cylinder 21. Within cylinder 26, 26' are slidably mounted hollow pistons 28, 28' which are secured in line upon piston core 29 which serves as a partition between interior piston chambers 30, 30'. The inner ends of pistons 28, 28' clamp the internal flange 31 of plate piston 24 between them so that for the purpose of the invention, pistons 28, 28', 24 and core 29 form a reciprocating piston unit in end cylinders 26, 26' and intermediate cylinder 21, respectively. The larger intermediate cylinder serves for compressing or supplying air for the engine as well as for outside use, and the smaller end cylinders contain the internal combustion chambers 32, 32', as will also be explained later on.

In the ends of the combustion chambers are provided hot wire ignition plugs 33, 33' connected to one or more sources 34, 34' of current controlled by switches 35, 35' (Figs. 4 and 5) by which to supply current to the plugs for heating the hot wires 36, 36' thereof, at will for starting the engine. As particularly shown in Fig. 4, a fuel tank 37 supplies liquid fuel such as oil or other combustible fluid by way of fuel line 38 and branch lines 39, 39' to injector nozzles 40, 40' controlling the amount of fuel drawn into the end cylinder chambers by pistons 28, 28' by means of manually adjustable needle valves 41, 41', while the flow of fuel to fuel line 38 is

controlled by manual cutoff valve 42. The fuel nozzles terminate at an inclined angle in the side wall recesses 43, 43' in end cylinders 26, 26' which are alternately cut off from communication with chambers 32, 32' by the end pistons 28, 28', the upper end portions 44, 44' being curved to direct the fuel into the respective cylinder chambers from the ends of said pistons. In similar fashion, the ends of the latter are curved also at their lower portions 45, 45' to facilitate smooth flow of exhaust gases from the chambers into exhaust pipes 46, 46', of which more later.

The cylinder chambers just described are supplied with air from the larger adjacent intermediate pump chambers 47, 47' on both sides of piston 24 via the internal chambers 30, 31 of pistons 28, 28', while the mentioned piston 24 draws in air to be compressed into chamber 47 through intake manifold 48, and inlet slots 49 in semirotary valve plate 50 held slidably against end plate 17 by screws 51 and through corresponding intake slots 52 in said plate 17 past leaf spring valves 53. In chamber 47' the corresponding parts have corresponding prime references and operate in similar fashion. Adjacent to the larger ends of intake members 48, 48' are fixed radiators 54, 54' connected by pipes 55, 55' to the cylinder water jackets 27, 27' and to rotary pumps 56, 56' driven by the associated exhaust operated motors 57, 57' (Figs. 1, 7 and 8) having their rotors 58, 59 actuated by the gases issuing from exhaust pipes 46, 46' to circulate cooling water through pipes 55, 60, 55', 60', radiators 54, 54' and water jackets 27, 27', the radiators being cooled by the incoming air rushing past them into the intake funnels 48, 48' during operation.

The air compressed in intermediate chambers 47, 47' is primarily fed to the interior piston chambers 30, 30' to a limited extent through piston apertures 61, 61' past internal leaf spring valves 62, 62' and thence through piston outlet ports 64, 64' into cylinder passages 63, 63' controlled, respectively, by pressure responsive valves 65, 65'; the compressed air thereafter passing not only the latter valves but fuel nozzles 40, 40' and entering cylinder chambers 32, 32' through ports 42, 42' already referred to above. During operation, the air pump piston 24 obviously furnishes more compressed air than can possibly be used for forming the explosive mixture in the internal combustion cylinders, the excess of this air being the main product of the apparatus as a whole when designed to furnish compressed air. The main bulk of the air thus delivered issues from cylinder chambers 47, 47' through main supply pipes 66, 66' by way of end ports 67, 67' past leaf spring valves 68, 68' limited in outward movement by stop members 69, 69', the air supplied being useful for any purpose already well established for compressed air. In the present case, however, the air is of such ample volume as to be particularly suitable for jet propulsion of boats and aeroplanes or for driving pneumatic tools and other devices without heat.

While the pressure is produced in supply pipes 66, 66', some of the air will pass upward through pipes 70, 70' and control valves 71, 71' as well as check valves 72, 72' into storage tank 73 used for storing starting air for the engine. This, of course is only a temporary drain on the compressed air supply which is quickly replenished when the engine has run a short time, and as soon as the pressure rises in the tank as may

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be read on gage 74, (Figs. 4 and 5), no further charge enters the tank. If for any reason the pressure should rise too high for the tank, because the air supply in pipes 66, 66' has a high pressure, the safety valve 75 will allow the excess to escape and thus preserve the tank intact, as seen in Fig. 6.

An additional source of compressed air for the tank is provided in end recess chambers 76, 76' resulting from the mutual interfitting of piston shoulders 77, 77' within end plate shoulders 78, 78' in recesses 79, 79' at the ends of the strokes of intermediate pump piston 24. When viewing Fig. 4, it will be seen that with the piston moving toward the left, shoulders 77 and 78 begin to overlap or engage, so that recess chamber 76 quickly acquires a high compression of the air trapped in said chamber and thereby provides an air cushion which effectively prevents the piston from striking end plate 17. In similar fashion, when the piston returns to the right to occupy the position shown in said Fig. 4, the shoulders 77' and 78' meet and trap air in recess chamber 76' so as to form another air cushion on the right side of piston 24 to softly stop it for the return movement toward the left, etc. Each of end plates 17, 17' is provided with an escape valve 81 slidable in a valve casing 82 having its interior chamber 83 communicating with the cylinder recess chamber 76 just described by a passage 84, the valve chamber also communicating through branch pipe 80 and valve 72 with tank 73. The valve 81 is urged toward passage 84 to close the same by a compression spring 87 which may be manually regulated for degree of pressure by manual screw 88, so that only when the air cushion in the recess chamber 76 attains a predetermined high compression will the valve open and admit air to tank 73. In similar fashion, the end plate 17' has corresponding parts with prime references. It is understood, of course, that the air cushion at both ends is not allowed to collapse by letting the air into the tank as the pressure rises in chambers 76, 76' but only the excess above a certain high pressure, and at the same time the main pump piston 24 is softly stopped at both ends of its strokes so as to prevent mechanical contact of the piston with the end plates.

When the engine is to be started, a further valve equipment is called into play, also associated with the end recess chambers just described, or rather with the end plates in the projecting shoulder portions 78, 78' of said plates which form the outer sides of said chambers. Thus, in each end plate is an inwardly opened valve 89 (Fig. 6) seated in the inner end of valve casing 90 within which is a valve chamber 91 communicating by passage 92 with a longer passage 93 in the end plate, which is connected in turn to branch pipe 94 and through control valve 96 with tank 73. It may be noted at this point that check valves 71, 71' serve to prevent escape of pressure fluid from the tank toward supply pipes 66, 66' (Figs. 4 and 5), so that the only normal escape for the air in the tank is through the control valve 96 and branch pipes 94, 94' toward valves 89, 89' in the end plates. The valve stem 95 of valve 89 is in each case provided with a disk piston 97 in rear valve chamber 98 and urged outwardly by a spring 99 to effect normal closure of the valve. Below the latter is a smaller valve 100 opening into the previously mentioned passage 93 in the end plate 17, extending through a valve casing 101 whose interior valve chamber

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102 is connected to the rear portion of valve chamber 98 by pipe 103. Externally the valve casing 101 supports a spring 104 which bears against the underside of stem head 105 of valve 100, tending to close said valve when the head is not depressed by external means. The corresponding parts associated with the other end plate 17' have the same references mentioned but primed.

Upon both ends the engine carries the starting levers 106, 106' (Figs. 1, 2 and 3) pivoted at 107, for example so as to be rockable to register the ends 108 into position on stem head 105, and in the case of valve 100', upon its stem head 105' to depress the valve 100 or 100', as the case may be, and thereby let pressure fluid from the tank through passage 93 enter the rear valve chamber 98 and thereby cause disk piston 97 to shift inwardly to open valve 89 and in this manner allow the pressure fluid in passage 93 to enter directly into pump chamber 47. It should be stated that when one of the starting levers is operated to open one of the valves 100, the other is shifted in the opposite direction for the moment to avoid opening the other corresponding valve until the pump piston 24 has made a stroke, and then the other lever is shifted to operate its adjacent valve 100' while the first starting lever is shifted the opposite way to avoid its valve 100, until the piston makes its return stroke during the starting of the engine.

However, at the same time lever 106 is operated, its fork 109 which is mounted on the pivot shaft 107 of said lever is likewise shifted with the latter, the fork being located in a position to engage upon both sides of a pin 110 movable in a slot 111 in end plate 17 and directly connected to a crescent-shaped valve plate 112 slidable upon the inside of said end plate. Thus when lever 106 opens valve 100, its associated fork will also shift plate 112 to close passages 67 so that pressure fluid entering the chamber 47 from the tank past valve 89 will not escape but serve the intended purpose of driving piston 24 toward the right through its first stroke into the position shown in Fig. 6. Assuming that the piston is first located at the left when lever 106 is operated, the air entering by valve 89 immediately acts on piston 24 to drive it toward end plate 17' as already indicated, causing it to compress air between the same and end plate 17' at least to a limited extent and which is forced to enter partly into piston chamber 30' through port 61' past valve 62' until said port is cut off from chamber 47' by the end plate during rightward travel of the piston. Of course, the piston chamber 30 initially receives a charge of compressed air from chamber 47 through port 61, but in any case, for starting the engine it is first necessary that valve 96 is open to release the air from tank 73 into end plate chambers or passages 93, 93'. If electric switches 35, 35' are closed, current from sources 34, 34' (which may be a single current source, if desired) will immediately begin heating hot wires 36, 36' in the cylinder ends and then maintain said wires red hot to be effective to ignite the combustible mixtures of air and fuel in said cylinders for starting.

When the piston 24 has thus been driven toward the right by the first charge of pressure fluid from tank 73 to occupy the position of Fig. 6, it is instantly ready for a return stroke toward the left end plate 17, involving a reversal of the operation of the valve equipment, but meanwhile, springs 99 and 104 have effected closure of valves 89 and 100, respectively. At this moment, if the

first starting lever 106 is returned to initial position, which allows valve 100 to close, and instead, lever 106' is shifted to open valve 100' at the right and thereby cause pressure fluid to pass through chamber 102' in valve housing 101' and through pipe 103' into valve chamber 98' to drive valve piston 97' and its associated valve 89' to open position and allow pressure fluid to enter piston chamber 47' past valve 89', thereby driving piston 24 back again toward left end plate 17. While piston 24 is first being driven toward the right as already described, the inlet port 61 will be uncovered as it leaves said end plate 17 thus allowing pressure fluid to enter piston chamber 30 from cylinder chamber 47, later to be supplied to cylinder 32 at the end of the stroke through piston outlet 64, passage 42, past fuel nozzle 40, and while taking up fuel from the latter enters cylinder chamber 32.

When the piston is then powerfully driven toward plate 17 just mentioned by the compressed air from tank 73 past valves 89' and 100' entering chamber 47', the air and fuel mixture in cylinder chamber 32 will be compressed, the piston port 61 being then closed by travel of piston 24 toward the left end plate. The mixture in chamber 32 is quickly and fully compressed and also ignited by hot wire 36, and then drives 28 toward the right by the resulting explosion in chamber 32, piston 24 associated with said piston 28 simultaneously compressing the air in cylinder chamber 47', while end piston 28' compresses the air and fuel mixture in cylinder chamber 32' which has just been supplied from piston chamber 30' past nozzle 40' by way of cylinder port 42'. As wire 36' is also heated, the compressed fuel and air mixture in cylinder chamber 32' ignites and drives the piston 28' toward the left. The starting levers are jockeyed back and forth once or twice in alternation, and need not be used further, but as ignition begins to occur by mere compression, switches 35, 35 may be opened to allow hot wires 36, 36' to cease glowing. At the same time, valves 89, 89' are no longer necessary for supplying air from the storage tank to cylinder chambers 32 and 32', and remain closed, the air thereafter being compressed in chambers 47, 47' feeding in sufficiently into piston chambers 30, 30' and by ports 42, 42' leaving said chambers and being transferred to cylinder chambers 32, 32' with fuel from nozzles 40, 40' during transfer, so that a constant supply of combustible fuel mixture is thus provided the cylinder chambers at the ends which are compressed and exploded by the compression. This results in a continuous oscillation of the composite piston 28, 24, 28' which very quickly gains in frequency and speed so as to oscillate at a high rate of oscillations per minute, which rate, however can be nicely controlled. It has been shown that the air introduced into the main cylinder chambers 47, 47' enters through slots or passages 52, 52' in end plates 17, 17' from intake members 48, 48' through slots 49 in valve plates 50, 50' (Figs. 2, 4 and 5), and due to the fact that the latter plates are slidably held against the end plates so as to be movable in limited manner, their slots 49 can be caused to register more or less or not at all with slots 52, 52' in said end plates, the result being that the incoming air is strictly limited to the amount which may pass through the plate slots thus controlled. Upon the valve plates 50, 50' are gear segments 114, 114' meshing with corresponding gear segments 115, 115' upon manual regulating lever 116, in one case and on a con-

necting shaft 117 in the latter case, this shaft interconnecting the two gear segments 115, 115' so that when lever 116 is partly rotated with its segment 114, the shaft 117 and segment 115' and its meshing segment 114' will also be similarly partly rotated. This partial rotation causes an arcuate sliding movement of valve plates 50, 50' between intake members 48, 48' and end plates 17, 17', with corresponding opening or closing of slots 52, 52' in the latter plates according to the degree in which slots 49, 49 in valve plates 50, 50' register therewith. Naturally, when only a small amount of air is allowed to enter the cylinder chambers 47, 47', the amount available to enter piston chambers 30, 30' and thereafter to issue therefrom past the fuel nozzles 40, 40' and into said cylinder chambers by way of passages 64, 43 and 42 is limited, with the result that only a moderate speed and rate of oscillation of piston 24 as driven by pistons 28, 28' is possible.

During the operation of the engine as above outlined, the exhaust gases leaving the cylinders 26, 26' by way of ports 63, 63' in chambers 32, 32' pass out through pipes 46, 46' already mentioned to drive exhaust fans or turbines 57 which in turn drive water pumps 56, the drive rotors 58 being directly connected to pump rotors 59 and circulate cooling water through cylinder jackets 27, 27'. One feature which also contributes to the smoothness of operation is the tension present in valves 65, 65' (Fig. 4) the springs 118, 118' being adjustable by manual adjusting screws 119, 119', the degree of pressure exerted by the spring on the valve in each case determining the pressure of the air from piston chambers 30, 30' which will be sufficient to open said valves and pass onward through ports 42, 42' into cylinder chambers 32, 32'. The density of the air and fuel mixture is thus largely determined by the mentioned valves and the adjustment of said springs 118, 118'.

While crescent valve plates 50 and 112 are somewhat similar, their functions are rather different, plates 50, 50' determining the amount of air which is initially permitted to enter the engine cylinders, while plates 112, 112' serve temporarily to close first one cylinder chamber 47 and then the other 47' during starting, but they are partly rotary in slidable manner against end plates 17, 17' with plates 50, 50' held slidably by bolts 120, 120, etc., (Fig. 2) in plate slots 121, 121, while plates 112, 112' are similarly held captive to plate 17, 17' upon the internal sides thereof by bolts 122, 122' (Fig. 4).

On the other hand, it is quite obvious that the piston 24 and its associated pistons 28, 28' should not be permitted to rotate during operation, but instead means must be included to ensure that piston ports 64, 64', for example will always register with cylinder ports 43, 43' at the ends of the piston strokes. For this purpose piston 24 is provided with aligned rods 123, 123' (Fig. 6) secured rigidly to the piston and sliding in sleeves 124, 124' fixed on end plates 17, 17', thus causing the piston to oscillate or reciprocate from one end position to the other without the least tendency to turn or rotate about its longitudinal axis. Furthermore, definite use is made of the movement of rods 123, 123' to produce electric currents by surrounding the sleeves in which they slide with coils 125, 125', the rods being of steel or other magnetic alloy such as that known as Alnico so that currents are induced in the coils, the leads 126, 126' of the latter being brought to accumulators or other electrical devices, or even to the hot wires 36, 36' at starting and thereby eliminate

other current sources. It is evident that the guide rods mentioned may be enlarged and the coils likewise, to such size and proportions that their capacity to produce electric currents forms the main purpose and product of the engine as a whole, the air compressed being then merely intended to suffice for supplying the engine with combustible mixture for its operation.

From the foregoing it may be noted that when the engine has been started by proper manipulation of the starting valves and is running so as to attain its proper speed to supply air or electric current or both, the engine will continue at a steady rate to supply compressed air or electric current by a high speed oscillation of its built up or composite piston without rotation of any shaft or flywheel nor sliding of a cross head or movement of any crank. It is also clear that by merely controlling the amount of air supplied to the engine, its speed and the resulting output are directly controlled and determined within a wide range of possible speeds and output volumes, as desired and as conditions require.

It is also readily seen that the invention is susceptible of modification even further so at one extreme, it delivers compressed air at high pressure and for this purpose, the guide rods may be replaced by other means as will now be discussed more fully. As may be noted in Figs. 9 and 10, the base equipment is the same as before stated, while the end plates 127, 127' differ somewhat from plates 17, 17', but are connected with their internal passages 128, 128' communicating by pipes 85, 85' and valve 96 with tank 73, the latter being in this case used for storing the high pressure air. The end plates are of course secured together by tie rods 22 and have the tubular cylinder wall 21 clamped between them to form with the same a slidable cylinder unit on base 12 while being directly supported on base plate 20 fixed to said end plates. The latter may have either secured thereto by bolts, or actually cast integral therewith a pair of cylinders 129, 129' in all respects similar to cylinders 26, 26' and hence, their cooling jackets and other appurtenances which may be assumed as associated with said cylinders are superfluous to show fully and discuss here. The pistons 28, 28' as well as intermediate block 29 have the novel pump piston 130 mounted thereon with its internal flange 131 clamped between said pistons 28, 28', but piston 130 is substantially flat and has upon each side a pair of hollow pistons 132, 132' secured thereto by screws or bolts 133, 133', only one upon each side appearing in the section of Fig. 10. These pistons are actually held by rings 134, 134' which are retained by said screws, this construction making for a certain adjustability that is desirable in this engine, the pistons extending slidably through the end plates into cylinders 135, 135' secured externally upon said end plates by screws 136, 136'.

It is shown in Fig. 9 that the two cylinders 135, 135' are located in balanced opposite positions upon the end plates, the other cylinders being indicated in broken lines which are attached to the end plate 127'. On the other hand, in this engine there is no outlet plate like plate or member 113 present, nor internal plate 112 to control the air output, as instead, passages 137, 137' in piston 130 allow the air being compressed at each stroke of said piston to press open valves 138, 138', according to which side of the piston is compressing the air in chambers 47, 47' and thus cause the compressed air to be injected into

the hollow pistons 132, 132', as the case may be. The air injected in this manner is released by the end valves 139, 139' into cylinders 135, 135', whence these pistons force the air charge thus received out through valves 140, 140' into pipes 141, 141' and past valves 142, 142' into tank 73 for storage. The springs 143, 143' serve to hold valves 138, 138' closed until the compressed air is of sufficiently high pressure to form a proper charge to introduce into the hollow pistons and their cylinders for transfer up to the storage tank. Likewise, springs 144, 144' tend to close valves 139, 139' so that the ends of pistons 132, 132' will be unbroken to force out the air charge in cylinders 135, 135' as efficiently as possible past valve 140, 140' to the tank.

In similar fashion, springs 145, 145' are sufficiently powerful to close valves 140, 140' when the pressure in end cylinders 135, 135' is not materially greater than in the pressure feed pipes 141, 141' leading to the storage tank just mentioned. The operation of the end pistons 28, 28' with their internal chambers 30, 30', inlet ports 61, 61' and outlet ports 64, 64' is the same as already described, but the inner sides or faces of end plates 127, 127' and both of the working faces of piston 130 are substantially flat, except for the hollow pistons 28, 28' projecting axially therefrom into the end plate cylinders. The mentioned piston 130 is braked at the end of each stroke by the air compressed between said piston and the end plate for the moment adjacent thereto, but the amount of air thus caught against the end plates in chambers 47, 47' is that actually caught ahead of the valve structures 146, 146' in valve inlet passages 137, 137', respectively, when these valves begin to project into the same. The amount of such air which it is intended to serve as an air cushion is regulated by the manually set needle valve member or screw 147 in valve 146, and 147' in 146', by which to allow a predetermined leakage of compressed air from inlet chambers 137, 137' through side apertures 156, (see Fig. 11) into the pump chambers 47, 47' past the needle valve members 147, 147' and thereby brake or cushion piston 130 as it approaches the end plates so as to prevent the latter piston from striking said plates. This cushioning effect is the same at each end of the piston stroke and in no case does it represent lost power, but rather accumulated energy which is immediately returned to the piston to send the same in the opposite direction. However, in this connection it may be noted that valve springs 143, 143' are of course sufficiently powerful to prevent unintended opening of valves 138, 138' to any further extent than to let pass the main bulk of the compressed air from cylinder chambers 47, 47', after which these valves close and allow the residue to remain as just described, in order to cushion the piston strokes. Naturally, the leakage valves could be arranged to cooperate with and project into blind chambers, if so desired. The apparatus is thus arranged to operate at the highest possible efficiency without actual contact of piston 130 with either end plate at any time, the pump delivering the air compressed to the hollow pistons and the latter further compressing the air to a higher degree and delivering the high pressure air thus resulting to the storage tank.

In the form of the apparatus shown in Figs. 9 and 10, the starting valves 100, 100' are included on the end plates and communicate with the plate chambers 128, 128' and are connected by mem-

tioned pipes 103, 103' to rear piston valve chambers 98, 98' in order to allow compressed air from storage tank 73 to pass said starting valves from said plate chambers into rear valve chambers 98, 98' when valve heads 105, 105' are alternately pressed manually inward to open valves 100, 100'. In this engine, it is hardly necessary to have manual levers similar to 116, as shown at the bottom of Fig. 5, for example, to operate said valves, as mere manipulation of heads 105, 105' by the fingers will suffice to cause operation of piston valves 89, 89' and thereby permit the compressed air to enter main pump cylinder chambers 47, 47' alternately to start piston 130 to reciprocate.

When the latter piston begins to operate regularly, and assuming that the hot wires 36, 36' are supplied with heating current and the engine otherwise provided with water cooling, etc., as already described in connection with the engine of the former figures, the compressed air produced by reciprocation of the main pump piston 130 is partly directed through ports 61, 61' and piston chambers 30, 30' to end cylinder chambers 145, 145' and there exploded or fired to drive pistons 28, 28' in much the same manner as already set forth in the foregoing description of Figs. 1 through 8. The main bulk of the compressed air is of course not delivered to the outside through any delivery pipes such as 66, 66', but is, as already intimated, instead alternately forced past valves 138, 139 in hollow piston 132 and valves 138', 139' in piston 132' into pipes 141, 141' and past check valves 142, 142' into storage tank 73 whence compressed air under high pressure may be supplied to the outside through pipe 148 by way of control valve 149 for running pneumatic motors and other devices.

When starting the engine, there are certain features somewhat different from the starting of the engine of former Figs. 1 to 8, as now the air first compressed in cylinders 135, 135' is not used but must be disposed of before the apparatus can attain proper operation. For this purpose, valve casings 150, 150' are connected to the interiors of cylinders 135, 135' at the inner ends of said casings, while in the latter are valve pistons 151, 151' integral with valves 152, 152' which are opened by the air pressure exerted on pistons 151, 151' when starting valves 100, 100' are opened by depression of their outside heads 105, 105', as the air entering rear valve chambers 98, 98' not only shifts valve pistons 97, 97' to effect opening of valves 89, 89', but some of this compressed air also, passes down pipe 153 and across in upper pipe 153' into valve casings 150, 150' and shifts valves 152, 152' to open positions by pressing upon valve pistons 151, 151', allowing first the air compressed in auxiliary cylinder 135 to escape through casing 150 past valve 152 and out to the atmosphere through side port 154 in said casing, and then air in casing 150' from cylinder 135' past the valve 152' and out through the side port in said casing 150' at 154'. As soon as the engine has begun to run without manipulating the starting valves 100, 100' and no longer requires encouragement from the hot wires to explode the combustible charges in cylinders 129, 129', the relief valves 152, 152' will be automatically closed by their springs 155, 155', the other valves 89, 89' and 100, 100' also being closed by their springs, so that control of the running of the apparatus passes to manual lever 116 operating the crescent-shaped valve plates 50, 50' directly controlling the intake of air into the chambers 47,

47'. The main principles of both forms of my invention are the same, and modification refers mainly to means for obtaining the desired product, compressed air of moderate pressure, or compressed air of moderate pressure and also electric current, or electric current alone, or high pressure compressed air, etc. The machine is likewise capable of fine regulation, even while running, and is especially capable of running at very high speeds with very high frequency of reciprocation of the composite piston, resulting in unusually high efficiency for minimum of weight of engine. It is evident also that the invention in its practical embodiments is capable of wide use and applications in various lines of work.

The apparatus described may be made of any metal, alloy or combination of metals, as found desirable, and other variations and modifications than those shown or suggested may be resorted to, and parts may be used without others within the scope of the appended claims.

Having now fully described my invention, I claim:

1. A free piston internal combustion engine, including in combination, a pump casing having a cylinder casing connected directly to each end thereof, a pump piston reciprocable in said pump casing and having a further piston member connected to each end thereof and extending into the end cylinder casings, ignition means associated with the latter for initially igniting explosive charges of fuel and air in starting the engine or operating, inlet ports for admitting air into the ends of the pump casing independently of said end cylinder casings and manually controlled valve means for controlling the ingress of the air into said pump cylinder casing, internal valve means within said pump cylinder casing preventing escape of air from the interior past said manually controlled valve means, exhaust pipes leading from the end cylinder casings independently of said pump casing, valve controlled fuel supply means connected to the end cylinder casings, means for supplying predetermined amounts of compressed air from the pump cylinder casing to the interior of the end cylinder casings, said last mentioned means including a partition dividing an internal chamber in one end piston member from an internal chamber in the other end piston member, an air inlet port in each end piston member spaced a limited distance from the partition and having an internal valve means for preventing escape of air from the internal chamber in the piston member involved, the air inlet ports in the end piston members being periodically exposed to the interior of the pump piston casing to receive a charge of compressed air from the same, and a further port in each end piston member spaced a short distance from the outer end thereof and periodically connected to the interior of its end cylinder casing upon movement of the pump piston and its associated end piston members to operated end positions therein, there being valve controlled ports in the pump cylinder casing for conducting the main bulk of the compressed air from said pump cylinder casing to a storage tank or an air supply line.

2. A free piston internal combustion engine, including in combination, a pump casing having a cylinder casing connected directly to each end thereof, a pump piston reciprocable in said pump casing and having a further piston member connected to each end thereof and extending into

the end cylinder casings, ignition means associated with the latter for initially igniting explosive charges of fuel and air in starting the engine operating, inlet ports for admitting air into the ends of the pump casing independently of said end cylinder casings and manually controlled valve means for controlling the ingress of the air into said pump cylinder casing, internal valve means within said pump cylinder casing preventing escape of air from the interior past said manually controlled valve means, exhaust pipes leading from the end cylinder casings independently of said pump casing, valve controlled fuel supply means connected to the end cylinder casings, means for supplying predetermined amounts of compressed air from the pump cylinder casing to the interior of the end cylinder casings, said last mentioned means including an air inlet port in each end piston member spaced a short distance from the pump piston and leading to an internal chamber in each end piston member, an internal valve member in each chamber preventing escape of air from the same through the air inlet port thereof, a further air port in each end piston member spaced a limited distance from the outer end of the latter, a corresponding port in the wall of each end cylinder casing disposed in a position to register with the further air port in one extreme position of the piston members, a second port in the wall of each end cylinder casing connected to the corresponding port therein, a fuel nozzle disposed in association with each said second port, the second port in each case being closed by the respectively adjacent end piston member except in the extreme operated position of the latter, and valve means for controlling the flow of air from the internal chamber in each end piston member out through the further air port therein into the corresponding cylinder wall port past the valve means through the second port in the cylinder wall into the outer end of the end cylinder casing to form a fuel charge and scavenge exhaust gases from said casing, there being valve controlled ports in the pump cylinder casing for conducting the main bulk of the compressed air from said pump cylinder casing to a storage tank or an air supply line.

3. A free piston internal combustion engine, including in combination, a pump casing having a cylinder casing connected directly to each end thereof, a pump piston reciprocable in said pump casing and having a further piston member connected to each end thereof and extending into the end cylinder casings, ignition means associated with the latter for initially igniting explosive charges of fuel and air in starting the engine operating, inlet ports for admitting air into the ends of the pump casing independently of said end cylinder casings and manually controlled valve means for controlling the ingress of the air into said pump cylinder casing, internal valve means within said pump cylinder casing preventing escape of air from the interior past said manually controlled valve means, exhaust pipes leading from the end cylinder casings independently of said pump casing, valve controlled fuel supply means connected to the end cylinder casings, means for supplying predetermined amounts of compressed air from the pump cylinder casing to the interior of the end cylinder casings, each end plate having an auxiliary cylinder casing projecting therefrom and the pump piston having a hollow piston upon each side thereof projecting into the auxiliary cylinder

casing upon its side, valve means for passing compressed air from one side of the pump piston through the hollow piston on the other side into the auxiliary cylinder casing on said other side but preventing passage of air in the opposite direction through said piston, similar valve means for passing compressed air into the other hollow piston from the side of the pump piston opposite thereto and preventing return flow of air therethru, and end valves in said auxiliary cylinder casings connected to an air storage tank or compressed air supply line for feeding compressed air from said casings to said tank or line when a predetermined pressure of air is produced in said auxiliary cylinder casings, there being valve controlled ports in the pump cylinder casing for conducting the main bulk of the compressed air from said pump cylinder casing to a storage tank or an air supply line.

4. A free piston internal combustion engine, including in combination, a pump casing having a cylinder casing connected directly to each end thereof, a pump piston reciprocable in said pump casing and having a further piston member connected to each end thereof and extending into the end cylinder casings, ignition means associated with the latter for initially igniting explosive charges of fuel and air in starting the engine operating, inlet ports for admitting air into the ends of the pump casing independently of said end cylinder casings and manually controlled valve means for controlling the ingress of the air into said pump cylinder casing, internal valve means within said pump cylinder casing preventing escape of air from the interior past said manually controlled valve means, exhaust pipes leading from the end cylinder casings independently of said pump casing, valve controlled fuel supply means connected to the end cylinder casings, means for supplying predetermined amounts of compressed air from the pump cylinder casing to the interior of the end cylinder casings, a leakage valve structure secured in projecting position upon each side of the pump casing, a manually adjustable valve member mounted in each mentioned valve structure having a valve seat exposed to the interior of the pump cylinder casing at the point of greatest projection of the valve structure into the same, the valve member cooperating with the valve seat in each case, and each valve structure having at least one side port adjacent to the wall of the pump casing upon which it is located, and the pump piston having recesses upon the sides thereof into which the valve structures at the end of the piston strokes will fit and serve as cushioning means preventing the pump piston from striking the ends of the pump casing, there being valve controlled ports in the pump cylinder casing for conducting the main bulk of the compressed air from said pump cylinder casing to a storage tank or an air supply line.

5. A free piston internal combustion engine, including in combination, a pump casing having a cylinder casing connected directly to each end thereof, a pump piston reciprocable in said pump casing and having a further piston member connected to each end thereof and extending into the end cylinder casings, ignition means associated with the latter for initially igniting explosive charges of fuel and air in starting the engine operating, inlet ports for admitting air into the ends of the pump casing independently of said end cylinder casings and manually controlled valve

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means for controlling the ingress of the air into said pump cylinder casing, internal valve means within said pump cylinder casing preventing escape of air from the interior past said manually controlled valve means, exhaust pipes leading from the end cylinder casings independently of said pump casing, valve controlled fuel supply means connected to the end cylinder casings, means for supplying predetermined amounts of compressed air from the pump cylinder casing to the interior of the end cylinder casings, the manually controlled valve means including a slidable plate having at least one slot portion therein adapted in one position to register with the inlet ports at each end of the pump cylinder casing, the internal valve means controlling the same inlet ports and consist of leaf spring valve members, there being valve controlled ports in the pump cylinder casing for conducting the main bulk of the compressed air from said pump cylinder casing to a storage tank or an air supply line.

6. A free piston internal combustion engine, comprising a pump cylinder casing having a pump piston reciprocable therein, two end cylinder casings rigidly connected to said pump cylinder casing, two pistons connected to the pump piston and extending into said end cylinder casings, air inlet ports in the end walls of the pump casing, means for regulating the ingress of air through said ports, means preventing escape of air from the pump cylinder casing out from said ports, means for passing compressed air periodically from said pump cylinder casing into the end cylinder casings, means for exhausting spent gases from said end cylinder casings,

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means for delivering compressed air to the outside from both ends of the pump cylinder casing through air supply ports, means for preventing ingress of air into said pump cylinder casing through said air supply ports, an air storage tank, air pipes connecting the engine with the air tank, and valve means controlling supply of air from said tank to the interior of said pump cylinder casing for starting said engine.

7. A free piston engine according to claim 6, in which the pump cylinder casing has a pair of end plates spaced apart and supporting the end cylinder casings in axial alinement with the pump cylinder casings.

8. A free piston engine according to claim 6, in which the pump piston and the end cylinder pistons include an internal partition member, a pair of end pistons secured upon the ends thereof, and a disk piston member mounted upon the inner ends of said end pistons and having an internal flange portion extending in between said inner ends of the end pistons and thereby retaining said disk piston member in fixed relation to the latter pistons.

UNO EKBLOM.

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